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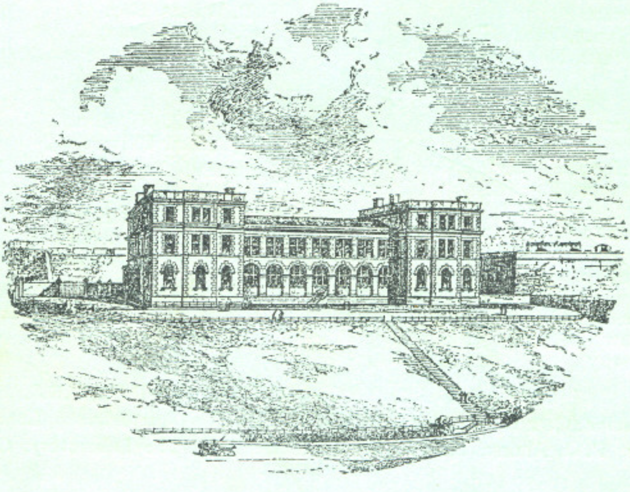

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Seals (*Halichoerus grypus*) of Cornwall Coasts.

By

G. A. Steven, B.Sc., F.R.S.E.

Assistant Naturalist at the Plymouth Laboratory.

(Report to the Ministry of Agriculture and Fisheries—30th September, 1935.)

With 6 Figures in the Text.

I. Introductory.

It has long been known that there is a considerable seal population on the North Cornwall coast. But precise information concerning the species present, the density of the population, and the positions of the rookeries has been almost entirely lacking. In order to obtain data on these points, a detailed survey of the North Cornwall coast was carried out during the fortnight August 7th–20th (1935) inclusive.

On this coast the seals live in caves. All the caves of any size or possible importance were visited and explored. With only a very few exceptions, direct landings from a boat could not be made in the caves. Because of the narrow and difficult openings of most of them and of the surf which was breaking in them even on what appeared to be "dead calm" days, it was usually unsafe for a dinghy to go right in and landing had to be made by swimming.

The method employed was to visit the various fishing ports and villages and hire a motor-boat and dinghy with and from which to explore the shores. The places at which boats were hired were St. Ives, Portreath, Newquay, Padstow, and Port Isaac. At all those places the advice and assistance of fishermen and others interested in the work were freely given and gratefully received. Without the friendly counsel and information which they were able to supply, the difficulties connected with the work would have been very greatly enhanced. At all times, such additional observations as were possible from the land were also made in order to supplement those carried out from the seaward side.

While engaged on this work I was accompanied by Midshipman G. P. Blake, R.N., of the Royal Naval College, Keyham, Devonport, who rendered invaluable assistance both ashore and afloat. Because of the danger involved, it was considered unwise for only one person at a time to enter the caves. Mr. Blake therefore accompanied me into every one of them: in fact, he was usually the first to set foot on their beaches and the last to leave.

The precaution was taken always to work difficult caves on a falling tide. Usually, on each day, from the time that the first cave was entered until operations ceased, we had to work clad only in bathing dress. As a consequence of these lengthy periods spent in a damp or wet garment and of extensive exposure alternately to the heat of the sun outside and the damp, dismal chilliness of the cave interiors, both Blake and myself became afflicted with a disorder of the skin which can best be described as resembling miliaria or " prickly heat " and which caused us considerable discomfort.

The interiors of the caves were all so dark, many of them in their inner recesses being in total darkness, that it was necessary to carry lamps in order to explore them. Two Lucas " Ever-ready " searchlight torches, No. 2223, were used. Ordinary pocket flash-lamps were also carried as additional (emergency) units. One of the chief difficulties to be overcome when, as was usual, direct landing could not be made, was the safe transit of the torches from the dinghy to the cave beach. It was found necessary to seal with electrician's insulating tape all apertures in the lamps through which water could enter them. The lamps were then placed in a tin box—a large biscuit tin—which was also sealed with rubber tape. By means of a line attached to it this box, with the torches safe inside, could sometimes be towed ashore behind a swimmer. When conditions made this method impracticable or impossible—e.g. a breaking surf which would buffet the box about too much—one of us entered the cave with a rope by means of which he later hauled ashore the box. In some instances, numerous wholly or partially submerged rocks were serious obstacles in the cave entrance. When these were encountered one of us landed on the nearest rock and the box was thrown to him. The other then swam to the next foothold farther in and in turn received the box, this process being repeated as necessary until the cave beach was reached. Not infrequently a combination of methods had to be used.

II. THE CAVES.

Although seals are to be observed from time to time all along the North Cornwall coast, caves which they can and do inhabit are not uniformly distributed along that shore. Where suitable caves do exist, therefore, the seals congregate into colonies (=rookeries). From thence they disperse in all directions to forage for food, residing for the time being in temporary or even semi-permanent resting-places—termed " seal lodges " in this report (defined below).

So far as seals are concerned, there are three types of cave in Cornwall. These are : (1) Caves in which seals can and do reside permanently and in which they can successfully bring forth their young. Such caves have beaches and/or rock ledges which lie or extend sufficiently far above high-water mark to ensure their not becoming submerged in any state of the tide or weather. For purposes of reference these caves may be termed *Seal Caves*. (2) Caves which the seals habitually visit, often in considerable numbers, but which cannot form for them a permanent home, and in which successful breeding must be difficult or impossible, as no beaches or adequate ledges remain uncovered during high tide. Such caves may be called *Seal Lodges*. (3) Caves in which seals are seldom or never found. Those which dry out completely to or beyond their mouths at low tide, or, for any other reason, are periodically or permanently easily accessible from either land or sea are, as a rule, avoided by the seals. Such caves are referred to as *Unused Caves*.

III. THE SURVEY.

Seals are common on the North Cornwall coast, but they are seldom seen along that county's southern shore. There is, however, at least one seal lodge on the south coast, situated at Prussia Cove (O.S. 146).* On the eastern side of this small cove, at about half-tide level, a small hole in the shelving rocks leads underground into a subterranean cavern of considerable size, the floor of which slopes quickly down under water. From this entrance the cave extends eastwards for some fifty or sixty yards† where another entrance connects directly with the sea through a deep, water-filled gully, too narrow to admit even a very small punt. Even at low tide the cave remained largely filled with water, so it had to be explored by swimming (Fig. 1).

From the main chamber a large recess branches off northwards (i.e. landwards) and ends in a gravelly beach on which, after the rest of the cave had been fully explored, a landing was made. Little light enters the cave, and this beach is in total darkness. As far as could be ascertained, it must be completely submerged at high tide. There are no large ledges in this cave, so it seems unlikely that it can be other than a more or less permanent seal lodge. Because of its relatively small size it cannot support a large population. Only one seal—a large grey—was found actually in the cave and none were observed outside or anywhere in the vicinity. Local fishermen state, however, that in their opinion not more than from six to ten seals lodge in the cave. This seems a reasonable figure.

Apart from this small colony at Prussia Cove, seals are seldom found in Mount's Bay. But immediately Land's End is reached seals become common. They are frequently encountered in considerable numbers

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* In this report the letters "O.S." followed by a number refer to the Ordnance Survey one-inch map of that number.

† Estimated distance.

among the Longships Rocks; and from thence all along the rocky shore northward to St. Ives Head some seals are generally to be found. Within this area, however, their most favoured haunts are the Carrack Rocks (about 3½ miles west of St. Ives; O.S. 146) and their vicinity. But although this part of the shore is much frequented by seals, presumably for feeding purposes, caves are few, insignificant, and mainly unused.

Beyond St. Ives Bay, the shores of which are mostly sand, the next rocks are found at Godrevy Point (O.S. 146). The shores of this headland and beyond to Navax Point, Hell's Mouth, Deadman's Cove, and eastwards to Portreath, are other favourite haunts of the seals. But although there are numerous caves, large and small, at Hell's Mouth—all of which were entered and fully explored*—none of them can serve for permanent residential and breeding purposes. Several are well fitted to act as seal lodges and apparently are much used as such, though no seals were present in any of them at the time of our visit.

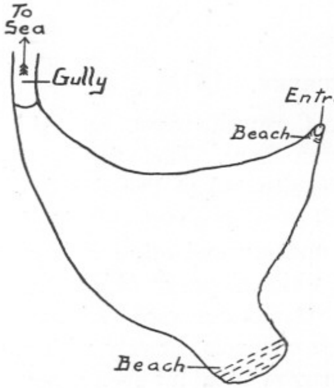

FIG. 1.—Cave at Prussia Cove.

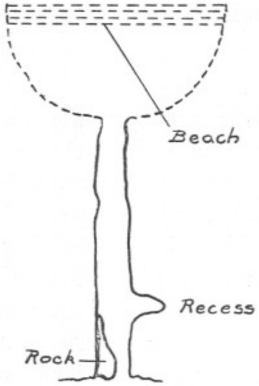

FIG. 2.—Cave at Portreath. Boundaries of cave proper undetermined (dotted lines).

The first seal cave proper is situated in the tip of the headland—known as Tregea Hill—on the south side of Portreath Bay, about one half-mile from Portreath harbour (O.S. 143 and 146). This cave extends in through the rock in the form of a long straight tunnel which opens out into a large cavern with an extensive gravel beach. The mouth of this cave is largely blocked by a big rock which leaves a very narrow channel through which a small dinghy can only just be coaxed to pass, and that only in the most favourable weather conditions. When it is too rough to take a dinghy through—as on all our three visits—landing may often still be made on the obstructing rock. From this rock a small part of the cave

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* These caves received special attention because, before we explored them, we believed them to be important breeding places.

beach is discernible in the distance, but in order to land thereon it is necessary to swim through the intervening deep water—about 70 or 80 yards estimated distance (Fig. 2).

When, after a previous unsuccessful attempt, this cave was first entered (by landing on the rock) two seals could be dimly discerned lying on the beach inside. Twenty-four seals were later driven out of this cave and counted as they passed through the narrow channel at the entrance. In addition, eleven others had previously been seen outside, making a total of thirty-five seals counted in or near this cave—all Grey Seals, *Halichoerus grypus*. On the same day that this cave was visited one other seal was passed at Godrevy Point and from sixteen to twenty seals were reported to me as having been seen in the vicinity of the Carrack Rocks. All these must have their main base at Portreath although, as explained above, probably occupying suitable lodges elsewhere (e.g. the Hell's Mouth caves) from time to time. As far as can be judged, the Portreath cave is capable of housing a colony of anything up to 150 seals. Having regard to the fact that up to about 100 have actually been seen at one time in its immediate vicinity (*vide* letter in *Western Morning News and Mercury*, 7th December, 1932) it seems fairly certain that the strength of this colony exceeds 100 seals with a maximum of not more than 150 animals.

About midway between Portreath and Porthtowan are two other seal caves which, however, at the time of our visit, were empty. An explanation of this was supplied by Mr. Landry, of Factory Farm, Porthtowan, whose land borders that part of the shore in which these caves are situated. Both caves can be reached without very much difficulty from the land at low tide.* During the summer months these caves are visited not infrequently by holiday-makers and the seals depart. But in late autumn, when they are no longer disturbed, some seals return to the caves to breed. At the present time they must be attached to neighbouring colonies.

From Porthtowan northwards to Kelsey Head, which lies about three miles south-west of Newquay, there are but few caves, mostly unused. In Kelsey Head, however, immediately inside the Chick Rock on its southern side, is a large seal cave (O.S. 143). Its mouth is narrow and difficult and an entrance can be effected only by landing on the steep rock on its northern side and climbing to the top of it—about 20 feet up. It is then possible to descend the inner side of this rock and enter the cave (Fig. 3). It is filled for most of its length by huge boulders over and amongst which it is exceedingly difficult to make one's way. At its inner end the cave expands slightly into a somewhat oval-shaped chamber in the bottom of which is a large pool. There is in this cave a good deal of accommodation at all states of the tide, the tips of many of the boulders

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* One can also be entered through a disused mine shaft.

rising above high-water mark and the sides of the cave being furnished with numerous ledges. Although no seals were found actually in this cave, at least thirteen were counted swimming about outside on the day that it was entered.

A short distance to the southward of the above seal cave is another much used by seals. Across its entrance is a large rock which was just awash at the time of our visit. Some distance inside this rock there is an excellent gravel beach; the whole floor of the cave, in fact, consists of fine gravel in which several newly made seal tracks were found. The seals had gone out before we were able to land. This cave, however, is simply a lodge; it possesses no high ledges and its floor must all be covered at high tide.

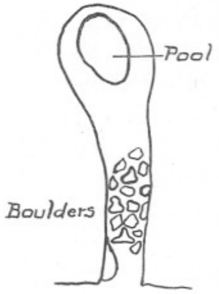

FIG. 3.—Cave at Kelsey Head.

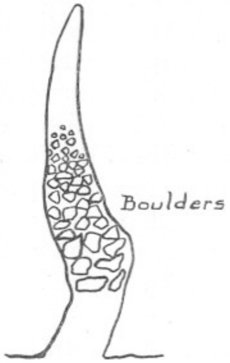

FIG. 4.—Cave at Trevose Head.

Other caves in this vicinity are unsuitable for general use by seals, though some may serve occasionally as unimportant lodges.

At Kelsey Head, then, we counted 13 seals—all *H. grypus*. Fishermen whom we consulted estimated the total population of this locality to be from 20 to 25 seals. It seems safe, therefore, to place the strength of the Kelsey Head colony at from 20 to 30 individuals.

Between Kelsey Head and Newquay there is another seal cave in the rocks at the tip of Pentire Point East. Like its neighbour at Kelsey Head, this cave also is filled with gigantic boulders the tops of many of which must remain permanently uncovered. There are also some ledges at the sides. This, however, is a relatively small cave and could accommodate only a small colony of seals. On the two occasions on which this cave was visited a few seals—all *H. grypus*—were seen. Three were counted on the first occasion when it was too rough to land and five on the second occasion when the cave was explored. No seals were found actually inside. From these numbers and from the nature of the cave I estimate the strength of this colony to be not less than ten and not more than twenty individuals. This agrees well with the estimate of local fishermen who, ignorant of the total at which I had arrived, placed the strength of this colony at "about a dozen seals."

Continuing north from Pentire Point East, the next seal cave (Fig. 4) is found at Trevose Head, opening from a small cove south of the lighthouse and directly under it (O.S. 136). Beyond the deep water which extends some distance into this cave there are exceedingly large boulders. Inside these boulders are smaller ones, while still farther in the cave narrows, all boulders are left behind, and an elongated pool several feet deep covers the cave floor. In this cave there are large crags and ledges at all heights, providing good accommodation for seals at all times. While making our way out of this cave, although no seals had previously been seen inside, we were surprised to find two large grey seals behind us, clambering over the boulders amongst which they must have been lying, hidden from the light of our torches. The rapid and successful progress of the seals over and amongst the very largest of those boulders which almost barred our way, was noteworthy. In addition to the two seals which followed us out of the cave, at least six others were counted swimming about outside. The number of seals seen at Trevose and the size and nature of the cave agree closely with what we found at Kelsey Head. These two colonies may, therefore, safely be considered to be of approximately the same size —twenty to thirty seals. Fishermen's independent estimates for the Trevose locality varied from twelve to twenty-five seals.

There is another large seal-frequented cave at Gunver Head (Fig. 5), about three miles east of Trevose. Deep water extends some way in and landing had to be made among some fairly large rocks well inside the cave entrance. These rocks give place successively to pebbles, gravel, and finally to fine sand. At its inner end the cave expands into a chamber of considerable size with a sandy floor. There are two entrances to this chamber, one of which was so small that one could crawl through it only with difficulty. The second entrance—which we did not notice at first or we should not have crawled through the first one !—is much larger. This is a very long cave and we found it difficult to be certain whether all the beach at the far end would be covered with water at high tide. Our general impression was that it would be. If this be so, then this cave can be only a seal lodge, as it possesses no ledges of any magnitude. On the other hand, one or more seals were seen near it on each of the three occasions on which it was visited. On our last visit, when the cave was explored, four seals (the largest number) were counted outside, though none were found inside. It is just possible, therefore, that this is a true seal cave and that it may accommodate a residential colony of not more than from ten to fifteen seals.

From Gunver Head to Pentargon there are, here and there, several unused caves and one or two which may perhaps be used occasionally as lodges.

At Pentargon, near Boscastle (O.S. 136), there is what appears to be a seal cave. On our visit, three seals were seen in its vicinity but none inside the cave itself. This colony, therefore, if it exist at all, can scarcely exceed ten individuals.

Just beyond Pentargon Cove are the Beeny High Cliffs in which there are numerous small unused caves. But just inside the rocks called Beeny Sisters at the place known as Fire Beacon Point, there are three exceedingly large residental caves (Fig. 6). Although it was found impossible fully to explore these caves, they appeared to be the largest of any we had seen. Their openings are all close together and not unduly large. The northernmost cave—i.e. the nearest one to the Beeny Sisters—consists of a long and narrow, but high, corridor extending inwards for a long way and curving towards the right. Its width, which remains fairly uniform for as far in as we were able to penetrate—an estimated distance of from 80 to 120 yards—was just sufficient to allow of the free passage of a dinghy. Eventually, however, the passage narrowed and we could proceed no farther. As far as we went in, and beyond for as far as we could see—this distance being limited by the curve of the cave—there was deep water. By the light of our torches we could see numerous seals swimming about in the water inside of us, while others could be seen and heard plunging from high ledges. It was impossible further to explore and examine this cave. To do so it would have been necessary to swim farther in. This was considered too risky as, once beyond reach of light from the dinghy, the swimmer would have been in total darkness and might have found it

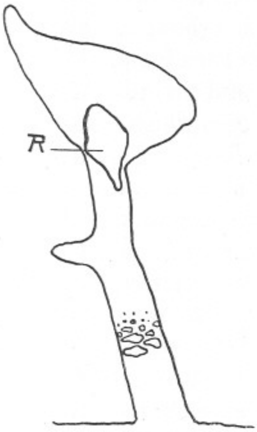

FIG. 5.—Cave at Gunver Head.
R=large column of rock.

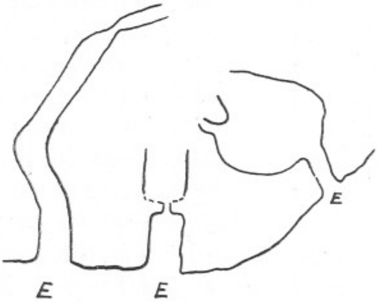

FIG. 6.—Caves at Fire Beacon Point.
E=entrance to caves.

difficult or even impossible to find his way back. Nevertheless, we were able to satisfy ourselves that this great cave is well provided with ledges at all heights and houses many seals.

A little farther along, in the direction away from Beeny Sisters, there is another cave which was also entered for a short distance. Further progress was completely barred by a sudden constriction of the cave to a narrow slit, too narrow even to swim through in the conditions prevailing at the times of our visits. This narrow part continues for only a short way and through it the cave could be seen to open out again beyond. Still farther along, but around a small bend in the cliff, is a third large cave which runs into the rocks roughly at right angles to the other two. The entrance is narrow but quickly opens out into a large, pitch-dark subterranean cavern in which there is room to row about quite freely. From this cavern two extensions continue inwards, but because of the low roof of the one and the narrowness of the other it was impossible to enter them. For reasons similar to those mentioned above, it was also considered undesirable to swim into them in the hope of finding a beach. They appeared, however, to continue towards—and almost certainly join up with—the two other caves already described. No live seals were seen in this cave but some could be heard in the distance, the sounds coming from somewhere near where we judged cave number one to be. A dead seal, a small grey, was picked up, however, and taken on board for examination.

Along the base of Beeny High Cliffs, inside of and extending northwards from the Beeny Sisters, is a fairly extensive beach consisting largely of massive boulders. A landing was made on this beach and all the caves in the cliffs behind fully explored. None of them are suitable for either seal caves or seal lodges.

Beyond this beach, still proceeding northwards, is a small bay having on its northern side, and close to the shore, an islet called Beeny Island or Gull Rock. Hard by this island, to northward, in the small headland called Buckator (O.S. 136), are three* large caves which previously I had thought to be important seal caves. All three were entered and fully explored. They proved to be all seal lodges only. The floors of all of them must be fully covered at high tide, and they are all devoid of ledge accommodation.

It can now be stated definitely, therefore, that the seal colony, well known to fishermen to be situated somewhere near Beeny Sisters—on which seals are often seen basking in the sunshine—is situated in the caves at Fire Beacon Point and not, as many of them had supposed, in the caves hard by Beeny Island. The latter caves are, however, evidently

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* What, on a previous visit, I took to be the submerged opening of a fourth cave was found to be only a large recess in the cliff base.

much used as lodges. It is possible at low tide to discern their beaches from outside. Seals are therefore much more likely to be observed in them than in the impenetrable caverns at Fire Beacon Point, which are their true residences. It is thus easy to understand how the Buckator caves came to be considered more important than they really are.

As explained above, it was found impossible fully to explore the caves at Fire Beacon Point, or even to count the seals which were seen in them. As far as could be made out, at least a dozen different individuals came within range of our torches. How many more were in the caves at that time is not known. When we emerged from the caves, however, a large number of seals had appeared outside. Although an exact count was difficult to obtain, the number arrived at was twenty-six individuals. That is to say, approximately thirty-eight live seals were counted in addition to one dead one. From these numbers and the nature of the caves—as far as this could be ascertained—I arrived at the conclusion that the seal colony at Fire Beacon Point is of approximately the same numerical strength as that at Portreath—i.e. one hundred to one hundred and fifty seals. Three fishermen, with long experience of this part of the coast, and all unaware of the figure at which I had arrived, separately and independently gave "about 150 seals" as their estimate of the number having their headquarters in that area. It would appear, therefore, that this figure is reasonably reliable.

There are no seal caves farther north than Fire Beacon Point.

IV. Total Number of Seals.

North Coast. It can now be stated that the seal colonies on the North Cornwall Coast are situated at Portreath (Porthtowan), Kelsey Head, Pentire Point, Trevose Head, Gunver Head (?), Pentargon (?), and Fire Beacon Point, in Beeny High Cliffs. As far as can be ascertained the numerical strengths of these several colonies are as follows :—

Portreath	100	to	150	seals	
Kelsey Head	20	,,	30	,,	
Pentire Point East . .	10	,,	20	,,	
Trevose Head	20	,,	30	,,	
Gunver Head	10	,,	15	,,	(?)
Pentargon	5	,,	10	,,	(?)
Fire Beacon Point . .	100	,,	150	,,	
Total .	265	,,	405	,,	

Allowing a fairly generous margin for errors and omissions it can safely be stated that the total seal population of the North Cornwall coast is not less than about 300 and probably not more than 500 individuals. Although difficult to measure accurately, North Cornwall may be considered to have a total coastline—including bays, coves, inlets, etc., but excluding estuaries—of approximately 100 miles. The density of the seal population on this coast, then, amounts on an average to from 3 to 5 seals per mile for every mile of shoreline. Although these numbers fall far short of an estimate of 2000* seals put forward by the Fishery Officer to the Cornwall Sea Fisheries Committee, they are surprisingly large. They denote a seal population from three to five times as dense as that on the South Wales coast, for example, where Lockley estimates the number to average only about one seal to every mile of shoreline.*

If, to the present population of, say, 500 seals, be added the 177 seals which were shot last year,† the total seal population at the beginning of 1934 must have been roughly 700 animals or approximately 7 individuals to every mile of coast. There can be no doubt, therefore, that several years of organised shooting with an annual "bag" of this magnitude‡ would quickly reduce the North Cornwall population to an insignificant number.

It has not been possible in this survey to collect any data which will indicate whether—apart from interference by man—the seal population of Cornwall is increasing, decreasing, or static. Nor is any light thrown on the highly important possibility of an influx of seals from other localities at certain times—e.g. during the herring-fishing season.

South Coast. There are but few seals on the south coast. Only the small colony at Prussia Cove was visited. There may possibly be one or more additional small colonies in the vicinity of Lizard Point, but this locality was not investigated. No estimate of the number of seals on Cornwall's southern shore can therefore be given, but it certainly is very small.

V. Species of Seal.

At all points where residential caves were found, and elsewhere along the shore where seals were sighted, they were viewed from close range with binoculars. Every seal seen was, without exception, a Grey Seal—*Halichoerus grypus*. Not a single Brown Seal, *Phoca vitulina,* was encountered. There can be little doubt, therefore, that the Brown Seal, if present at all, is very rare around those shores. It would seem that recent references to this species of seal in Cornwall must, almost certainly, have been due to faulty identification.

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* Unpublished data. See also addendum on p. 506.

† Cornwall Sea Fisheries Committee. Fishery Officer's Report, 1934.

‡ But becoming proportionately smaller, of course, as seals became fewer.

VI. Breeding.

Seals of all sizes and (presumably) of all ages from about one year old upwards were seen. But no seal pups were observed. The breeding season evidently had not yet begun.

VII. Log.

Wednesday, 7/8/35.

Proceeded to Boscastle. Failed to obtain suitable boat for cave work. Visited Pentargon Cove by land. One seal—large grey—observed. Proceeded to Port Isaac and arranged with Mr. S. Thomas for hire of motor-boat and dinghy on the following day if weather suitable.

Thursday, 8/8/35.

At Port Isaac.

Out in *Boy Jack*. Too rough to land anywhere. Two seals—grey—seen at Pentargon and four near Beeny Sisters. Proceeded to Padstow and arranged with Mr. Orchard for hire of boat *Tamar* and punt on the following day.

Friday, 9/8/35.

At Padstow.

Out in *Tamar*. Too rough to land anywhere. One seal—grey—seen at Gunver Head and one at Trevose Head. None elsewhere. Proceeded to Newquay and arranged with Mr. J. Harris for hire of boat *Fairy* and punt on the following day if not too rough to go out.

Saturday, 10/8/35.

At Newquay.

Out in *Fairy*. Could not land anywhere. Three grey seals seen at Pentire Point East and ten at Kelsey Head. None elsewhere.

Proceeded to Portreath and arranged with Mr. E. H. Hicks for hire of his punt on the following day if fine.

Sunday, 11/8/35.

At Portreath.

Out in punt to Ralph's Cupboard and vicinity but too rough to land. Three seals—grey—seen at tip of headland called Tregea Hill (O.S. 143 and 146). Walked along cliffs to Ralph's Cupboard where seals are reported often to lie on a small beach visible from the land but accessible only from the sea. One seal seen. Seven seals, all grey, seen near cave in tip of Tregea Hill headland.

Monday, 12/8/35.

At Portreath.

Too rough to go out. With assistance of Messrs. G. Davy and E. H. Hicks attempted to dig up bones of seals shot last year and buried in the sand of Portreath Beach. Skulls wanted for examination. Failed to find the skeletons. Public Health officer from Redruth arrived to hold up operations—which, however, had already ceased owing to failure to locate exact positions of burials.

Weather became hopelessly rough in afternoon so returned to Plymouth.

Tuesday, 13/8/35.

At Plymouth.

Wednesday, 14/8/35.

At Plymouth.

Telephoned to Port Isaac to inquire concerning weather conditions on North Coast. Received report that sea was calming down. Proceeded to St. Ives, and arranged with Mr. R. Ninnes for hire of boat *Ada* and punt on the following day, if fine.

Thursday, 15/8/35.

At St. Ives.

Out in *Ada*. Shores explored, caves entered, and seal colony at Portreath located ; 36 seals seen—all grey. On coming ashore proceeded to Porthtowan. Interview Mr. Landry, of Factory Farm, concerning the caves under his land (*vide* p. 497 of this report).

Proceeded to Port Isaac.

Friday, 16/8/35.

At Port Isaac.

Too rough to land anywhere so did not go out. Telephoned to Padstow. Coastguard thought landing possible at Trevose and vicinity.

Proceeded to Padstow. Out with Mr. Orchard. Couldn't land anywhere. One seal—grey—seen at Gunver Head and one at Trevose. None elsewhere.

On return, proceeded to Prussia Cove as sea smooth on south coast.

Saturday, 17/8/35.

At Prussia Cove.

Explored cave. One seal—grey—seen at eastern entrance. Telephoned to Port Isaac. Received report of improving conditions there. Explored shore—from landward—from Cape Cornwall to Mussel Point (O.S. 146). One seal seen at Gurnard's Head—very large.

In evening, carried on to Port Isaac.

Sunday, 18/8/35.

At Port Isaac.

Out with Mr. J. Lark in boat *Shamrock*. Shores explored ; caves entered ; and seal colony located at Fire Beacon Point (*vide* p. 500 of this report).

In evening, proceeded to Padstow.

Monday, 19/8/35.

At Padstow.

Out with Mr. W. England in boat *Celia*. Shores explored, caves entered, and seal colonies located at Gunver Head and Trevose (*vide* p. 499 of this report).

Tuesday, 20/8/35.

Proceeded to Portreath in early morning in order to re-enter seal cave there *at high water* in order to verify previous conclusion that large beach left uncovered. Conclusion found correct.

Returned Newquay.

Out with Mr. J. Arthur in boat *Charlie*. Shores explored, caves entered, and seal colonies at Kelsey Head and Pentire Point East located (*vide* p. 497 of this report).

Returned Plymouth at night.

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ADDENDUM.

Since this paper went to press I have been informed by Lockley (see p. 503) that the seal concentrations on the islands off-shore are not included in his estimate of one seal to every mile of shoreline on the South Wales coast. If these island populations be taken into account Lockley's figure for South Wales is approximately doubled. On the Pembrokeshire coast, where the seals are most numerous, Lockley finds the density of population to be about the same as that of North Cornwall.

Observations on the Distribution of Plankton Animal Indicators made on Col. E. T. Peel's yacht "St. George" in the Mouth of the English Channel, July, 1935.

By

F. S. Russell,

Naturalist at the Plymouth Laboratory.

With 6 Figures in the Text.

The possible value of *Sagitta elegans* and *S. setosa* together with certain other plankton animals as indicators of water movements at the mouth of the English Channel has been discussed in a previous report (Russell, 1935, b). To confirm the belief there outlined it was necessary that a cruise should be made to see whether the boundaries of the different water masses could be easily indicated by plankton observations alone. Through the great kindness of Col. E. T. Peel, who offered to put his yacht *St. George* at my disposal, an opportunity arose to make this test in July, 1935.

From the data presented in the previous report it was surmised that a body of water characterised by the presence of *S. elegans*, without *S. setosa*, would be found at the mouth of the Channel. The first aim of the cruise was to find this water. A line of stations was taken across the Channel between the Lizard and Ushant. No pure *S. elegans* water was found, although it was evident that a body of water of characteristic plankton content was entering the Channel past Ushant. Just north of Ushant and under the island itself indications were found of a slight admixture of *elegans* water. (While in the previous report this water was called "western" water it will here for convenience be called *elegans* water.) The cruise was continued in a south-westerly direction from Ushant, when two stations were taken at ten-mile intervals. The course was then changed to the north-west and within twenty miles the *elegans* water was found. This *elegans* water was followed up in a northerly direction until in the northern half of the Channel mouth we passed into water characterised by the presence of *S. setosa*. Having demonstrated the existence of *elegans* water the programme was then changed. It was thought that, rather than continue to follow the *elegans* boundary, it would be more valuable at this stage to find whether the distribution of plankton animals could be used to give any indication of the water movements in the region of the Land's End—Scillies passage. Stations were therefore taken in that area and then westward of the Scillies until the *elegans* water was once more found. The observations were then completed by a cruise round to the north coast of Cornwall as far as St. Ives. The general results of the cruise have shown that certain plankton animals can undoubtedly be used as valuable aids in understanding the hydrography of these regions.

It is a great pleasure to record my deep gratitude to Col. Peel for his generosity in enabling this programme to be carried out. His great interest in the work and his kind hospitality have combined to leave pleasant memories for me of a cruise which has produced results of great scientific value. My thanks are also due especially to Captain H. W. Smart and the crew of the *St. George* for their invaluable help so willingly rendered, and also to Col. W. Mackenzie and Major J. S. Paterson for much practical assistance.

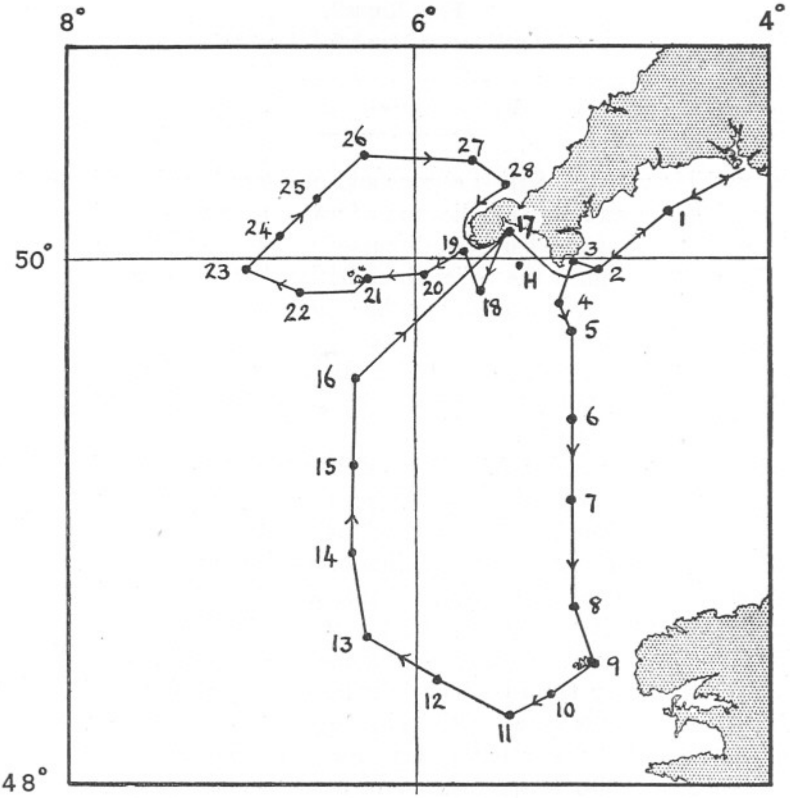

FIG. 1.—Chart showing cruise of *St. George* and positions of Stations.

Twenty-eight stations were taken between July 23rd and 27th. Their positions are given in Figure 1 and details of the log in Table I (p. 521). Two types of net were used for collecting, a one-metre stramin net and a coarse international standard silk net (58 meshes to one inch, without the coarse netting in front). The two nets were towed together at each open sea station for ten minutes with 40 fathoms of rope out. As large samples of plankton were required to get a true idea of the general *facies* of the catches it was thought that in a preliminary survey deep horizontal hauls would be of more value than vertical hauls. In addition to the open sea stations, four stations (3, 9, 17 and 21) were made while at anchor by streaming the silk net in the tide. While of value in showing the composition of the plankton these catches are not comparable quantitatively with those of the open sea stations. In the charts giving the numbers of animals caught the presence of any species has therefore been indicated at the anchorage stations by a plus sign. I am also greatly indebted to Mr. C. F. Hickling who made two plankton collections for me from a Newlyn fishing vessel off Mounts Bay on the nights of July 26th and 27th marked H in Fig. 1).

General Results.

Full counts were made of all the animals from samples of each catch. Instead of publishing the full tables it is thought that a clearer picture can be presented by plotting on separate charts (Figs. 2, 3 and 4) the numbers of the more important species discussed in this report. Detailed examination of the catches shows that we have here to deal with three distinct bodies of water, *elegans* water, Biscay water, and Channel water. The first and last can for convenience further be subdivided into southern and northern *elegans* waters, and coastal and offshore Channel waters. The observations concerning these bodies of water will be discussed in detail below.

S. elegans Water.

Southern.

The southern *elegans* water extending from Stations 12 to 15 inclusive was characterised by the presence of the following species: *Sagitta elegans*, the hyperiid amphipod *Themisto gracilipes*, young of the pteropod Clione,* late larval stages of Euphausians, the medusa Aglantha, and the copepod Metridia (probably all *M. lucens*). The numbers of the first four indicators are shown in Figure 2 and those of the two last species in

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* The usual species found at the mouth of the Channel is *Clione limacina*. On showing the present specimens to Dr. M. V. Lebour, however, she expressed the opinion that they were not *C. limacina*. A number of specimens were therefore sent to Madame A. Pruvot-Fol and I am grateful to her for the following information. They were not *C. limacina*, but unfortunately they were too young to make certain identification possible. They were very probably the young of *Clionina longicauda* (Souleyet), a common Atlantic species.

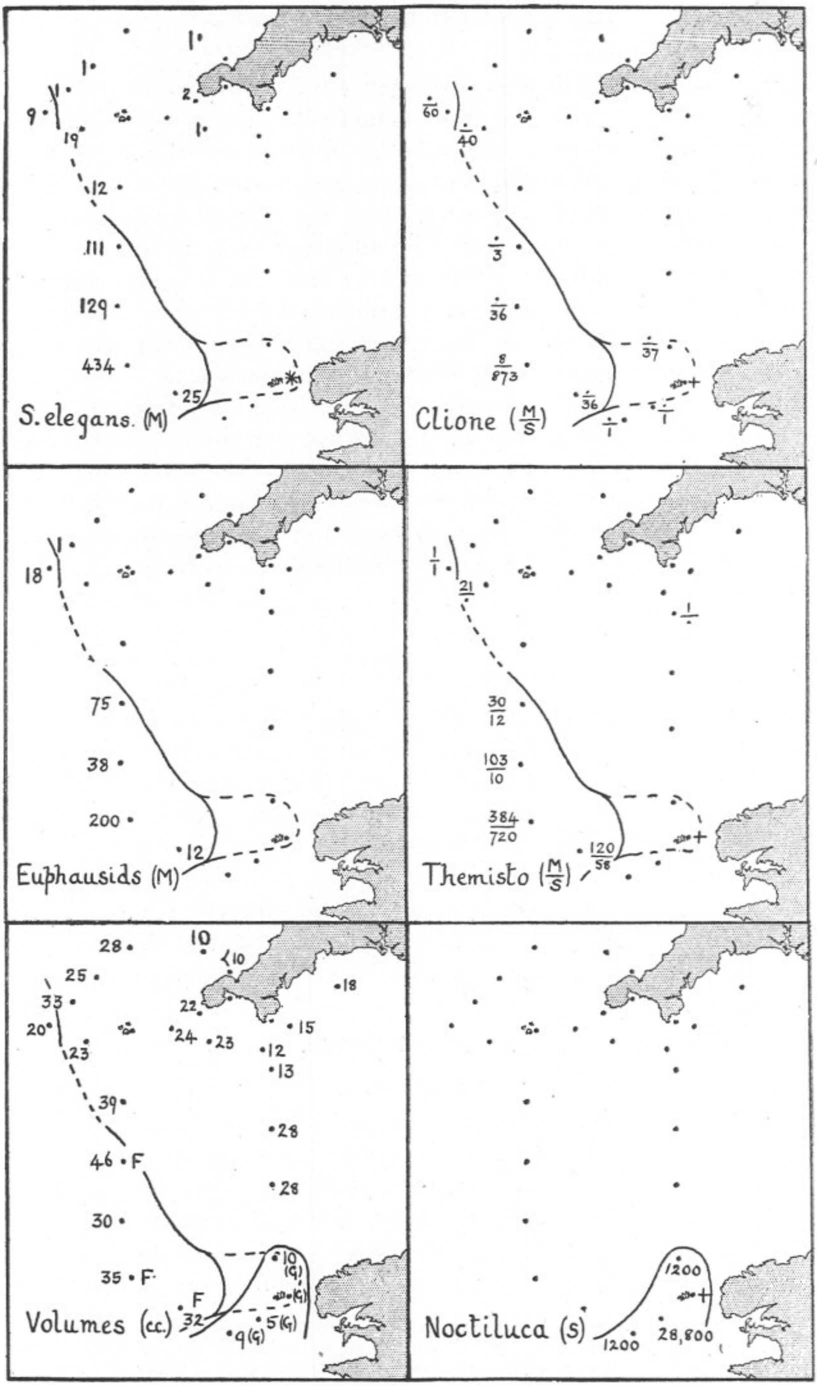

FIG. 2.—Numbers of *S. elegans*, and Euphausian larvæ in metre-net catches; of young Clione and *Themisto gracilipes* in metre net and silk net catches; volumes in c.c. of catches in silk net; and numbers of Noctiluca in silk net catches. (M.=metre net; S.=silk net.)

Figure 4. Some of these indicators were found in addition at the Stations 8 to 12, but observations given below on the characteristics of the Biscay water which predominated at these stations show that the presence of *elegans* water indicators can only have been due to a mixture of a small amount of that water.

The *elegans* water was further characterised by the richness of the catches. The settled volumes (after 24 hours) of the silk net catches from all the open sea stations are given in Figure 2. At Stations 12, 13 and 15 the fatty nature (marked F on chart in Fig. 2) of these catches was especially noticeable from the masses of fat floating at the surface of the fluid in the storage jars after standing for a month in the laboratory. At no other station was the presence of fat noticeable. The richness of the plankton is exemplified by the great increase in the numbers of Pseudocalanus (plus Paracalanus) as shown in Figure 4. The numbers of *Calanus finmarchicus* were also high in this region. A further characteristic was that the *S. elegans* population consisted to a high degree of large mature specimens. In addition there were at Stations 14 and 15 a few specimens of the siphonophore Stephanomia and at Station 15 one individual of the copepod *Rhincalanus nasutus*.

The catches were also characterised by the purely oceanic nature of their constituents and the small number of component species. This is well shown by the following figures giving the numbers of different types counted in the plankton: Station 1, 29; Station 4, 35; Station 6, 17; Station 7, 24; Station 18, 31; Station 20, 33; and Station 25, 27; giving an average of 28, while corresponding figures in *elegans* water were Station 12, 11; Station 13, 14; and Station 14, 12.

The occurrence of the above indicators, together with the nature of the plankton, affords definite indication that the boundary of this southern region of the *elegans* water lay probably somewhat as indicated by the unbroken line shown on the Charts in Figure 2. The mixture of a small quantity of this water with that lying to the south-east near Ushant is indicated by a broken line.

Northern.

It has been mentioned above that in the second half of the cruise collections were made to the west of the Scillies until the *elegans* water was once more found. This was at Station 23. This water was characterised by the same plankton animals as the southern water, but differed in that Stephanomia was here very much more abundant. The *S. elegans* population had a higher proportion of young stages. It is unfortunate that no station was taken on a direct line between Stations 16 and 23, but it is evident from the fact that the boundary of the *elegans* water was found to lie between Stations 15 and 16 in the south, and between

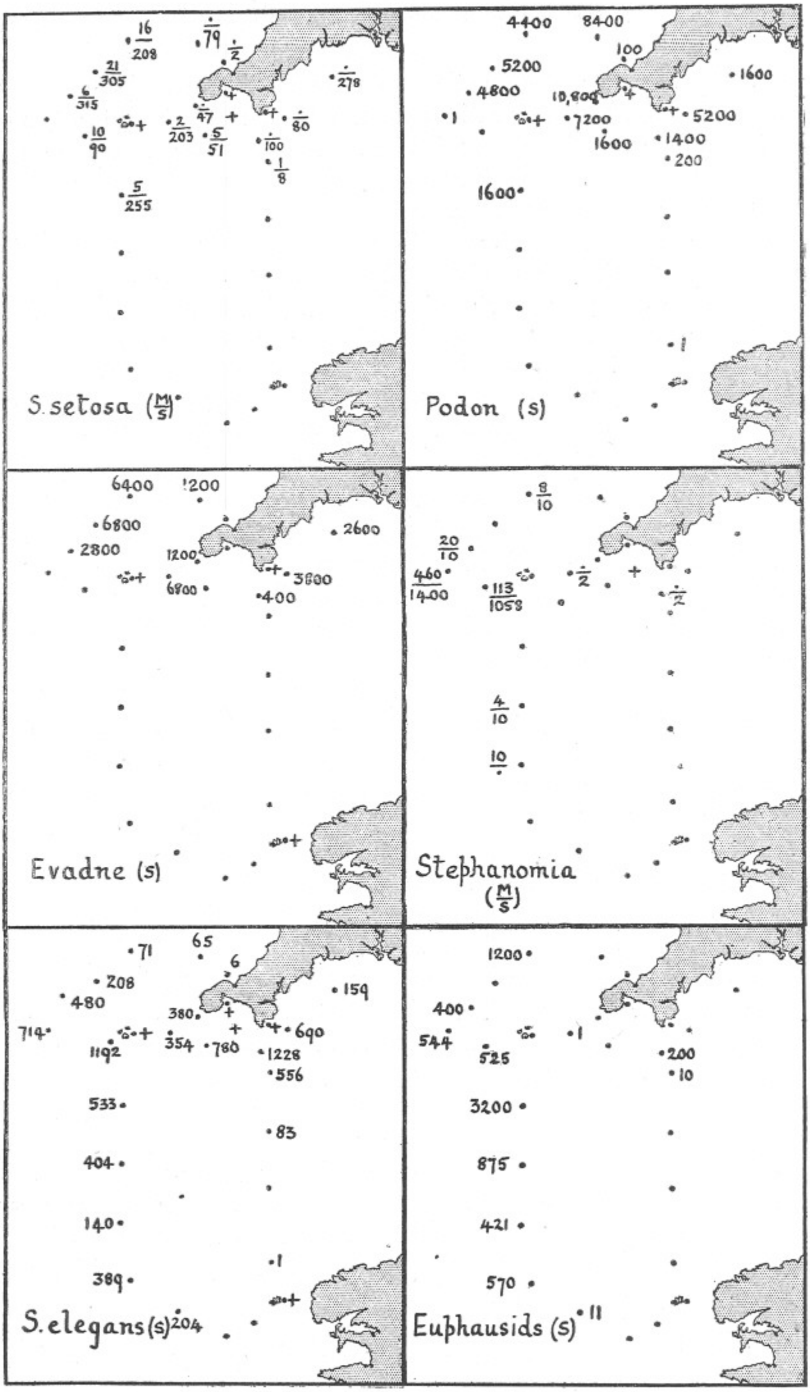

FIG. 3.—Numbers of *S. setosa* and Stephanomia nectophores in metre net and silk net catches; and of Podon, Evadne, *S. elegans* and Euphausian larvæ in silk net catches. (M.=metre net; S.=silk net.)

Stations 23 and 22 and 24 in the north, that the whole western boundary of the *elegans* water can be completed probably as indicated by the dotted line in Figure 2.

THE BISCAY WATER.

Water with a distinct planktonic content was indicated at Stations 8, 9, 10 and 11. It is here called Biscay water and is probably the water called " south-western " in the previous report. All the catches at these stations were characterised by the presence of green flocculent matter containing diatoms and dinoflagellates. Noctiluca was abundant in this water (see Fig. 2). Zooplankton was, relative to the other waters, almost entirely absent, and in spite of the flocculent nature of the catches the volumes were extremely low (see Figure 2, where these green flocculent catches are indicated by the letter G). The presence of a number of large Aglantha at Station 8 and of large *S. elegans* in the silk net collection at the anchorage under Ushant (Station 9) indicates that there had been a mixture here with *elegans* water ; but as the volumes of the plankton were so very low this could only have been slight. The transition from this Biscay water into the *elegans* water from Stations 11 to 12 was very striking.

CHANNEL WATER.

Offshore.

This water, probably only completely typified by the collections at Station 7, is characterised by the absence of all indicators, including on this occasion *S. setosa.* The contents of the metre net hauls at Stations 6 and 7 were practically negligible in marked contrast to those in the *elegans* water (see Fig. 5, p. 516).

Coastal.

This coastal subdivision of the Channel water here includes all those stations taken in the Scillies—Land's End—Cornish Coast area north of a line drawn east and west between Stations 5 and 6. The water was characterised by the presence of *S. setosa.* The cladoceran crustacea Podon and Evadne were also confined to the same area (Fig. 3). But this water also contained a considerable population of the indicators of *elegans* water, especially *S. elegans* and Aglantha. It was, however, a noticeable feature that all the individuals were small and immature. This is shown very clearly by a comparison of the metre net catches of *S. elegans* (Fig. 2) with those of the silk net (Fig. 3). *S. elegans* is practically absent from the metre net collections in this area, all the small individuals having passed through the meshes of the stramin. At all stations where Sagitta occurred a number of specimens were measured to the nearest half-millimetre. The results of these measurements, reduced to millimetre intervals, are

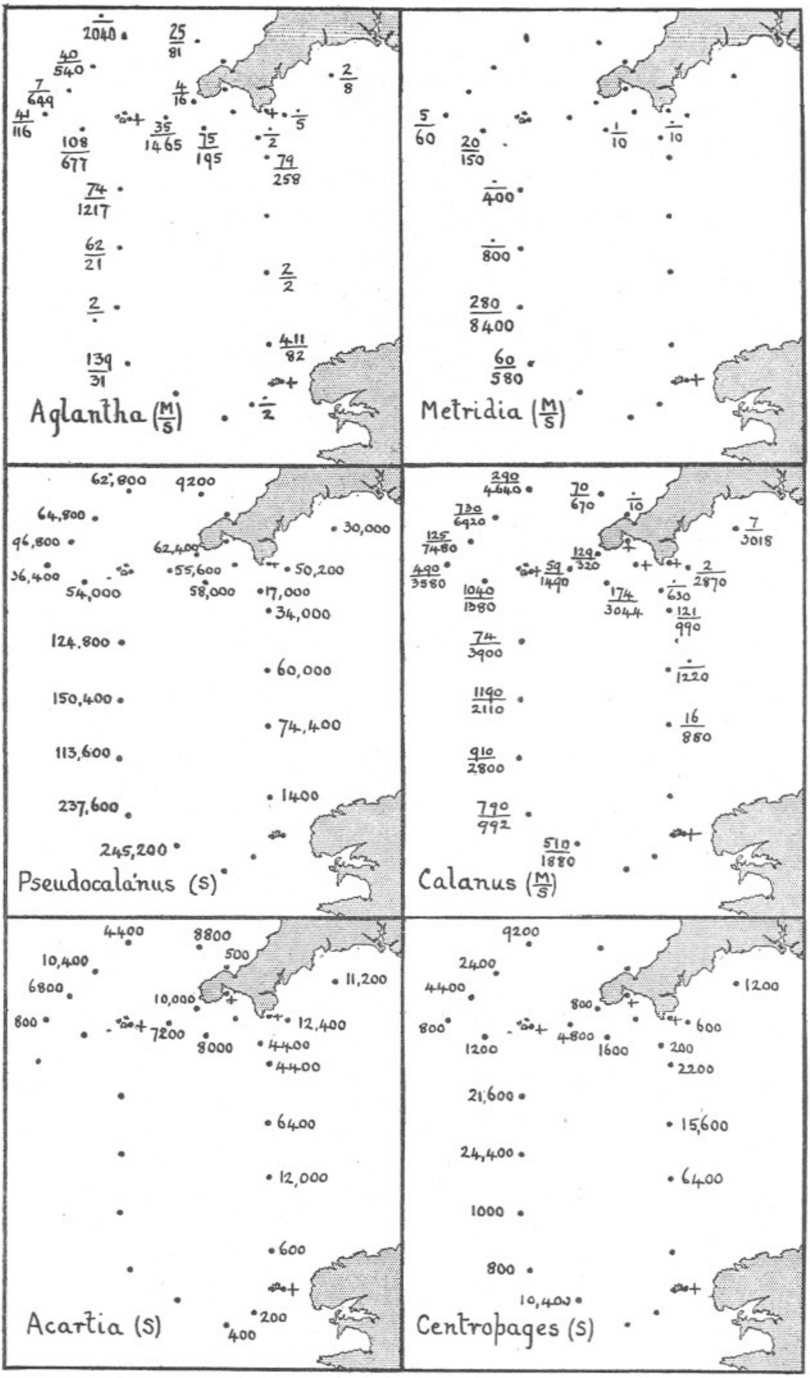

FIG. 4.—Numbers of Aglantha, Metridia and Calanus in metre net and silk net catches; and of Pseudocalanus (plus Paracalanus), Acartia and Centropages in silk net catches. (M.=metre net; S.=silk net.)

given in Tables II–V (pp. 521–522). A study of the size distribution of *S. elegans* is of value as indicating whence the individuals found in this coastal Channel water have been derived. If in Table II we compare the sizes of *S. elegans* at Stations 15 and 16 we notice at Station 16 a complete absence of large mature specimens and indeed all individuals above 9 mm. in length; there is also at Station 16 a much higher proportion of the youngest stages of 5 mm. and under than at Station 15. Between these two stations we passed from *elegans* water to water containing *S. setosa*. A comparison of Stations 23 and 24 shows the same story, namely a disappearance of large *elegans* and increased proportion of very small on passing from *elegans* to *setosa* water. It is known that the youngest individuals of Sagitta can live much nearer the surface in the daytime than the older individuals; and that they migrate right to the surface at dusk, and tend to leave the surface much later than their elders (Russell, 1931). The small Sagitta are therefore in the surface layers for a considerable period of time and can become separated from the older individuals by a movement of the surface waters. It follows, therefore, that the change in the size composition of the *elegans* population on passing into the *setosa* water can be explained by a drift of surface waters in a north-westerly direction, probably due to wind action. The absence of mature *elegans* in the *setosa* water precludes any possibility of suggesting that there has been an actual mass mixing of *elegans* water with the coastal Channel water. This explanation of the occurrence of *elegans* water indicators in coastal Channel water by surface drift receives further confirmation in that the same tendency for a preponderance of youngest stages in the coastal water was noticed for other animals, e.g. Calanus and Aglantha. It has been clearly shown by Nicholls (1933) that the youngest stages of Calanus live in the surface layers, and it is most probable that the same would be found true of Aglantha.

Further examination of Table II shows also that as one proceeds further east from Stations 16 and 24 there is a slight tendency for an increase in the numbers of larger *S. elegans* from which the direction of flow of the water might be inferred. A comparison of the proportions of *elegans* to *setosa* in the Sagitta population might also throw light on the nature of the water movements in this region. Actually the proportions of these two species did show rather consistent differences. The area in which *setosa* composed 40% or more of the Sagitta population is indicated in Figure 6 (dotted area); the supposed boundary between this area and that in which *elegans* were the more abundant is shown by a dotted line. The indications are that *setosa* water extended as a tongue from the north through the Scillies–Land's End passage. While too much stress cannot be laid on this single observation, it indicates the possibility that a number of closely spaced collections made at frequent intervals

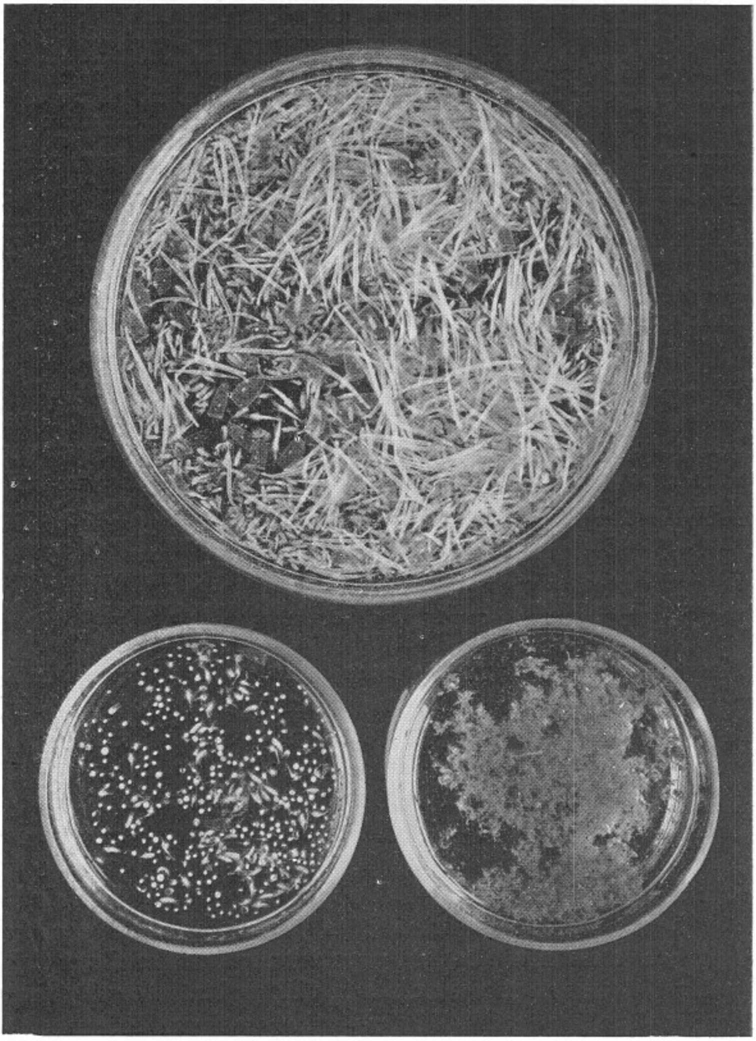

Photo D. P. Wilson

FIG. 5.—Actual catches of 10-minute hauls with the one-metre stramin net at St. 13—*elegans* water (above); St. 11—Biscay water (bottom right); and St. 7—Channel water (bottom left).

might prove of great value in helping to show the complex water movements in this small area. In elucidating the results obtained by such collections it should not be forgotten that the actual numbers of the two species are of little significance unless their size is also taken into consideration. The very youngest stages will naturally be more numerous than older stages on which the rate of mortality has had its effect.

Discussion.

The above results have proved without doubt that a number of plankton animals can be used to aid the hydrographer in a study of the water movements in the region of the Channel mouth. Indeed, apart from the detailed study of the silk net catches necessary in the Scillies–Cornish coast region, the main results of the investigation were known before ever the plankton sample bottles were opened in the laboratory. The division of the three main masses—*elegans*, Channel and Biscay waters—could be shown by visual inspection of the metre net catches as soon as they came out of the water. The differences in the catches from the three types of water were so obvious that they could be seen immediately by any member of the crew. Typical examples of these catches are shown in Figure 5 by photographs kindly taken for me by Mr. D. P. Wilson.

In the silk net catches, however, these differences were not obvious until examined more carefully because the great numbers of small copepods hid the true indicators. It should be possible to simplify such observations in the future by using silk nets with meshes large enough to allow copepods of the size of Pseudocalanus to pass through and yet retain sufficiently small Sagitta to indicate the size composition of the population. The other indicators are large enough to be retained by such a mesh.

A chart is given in Figure 6 showing the general distribution of the water masses as inferred from the plankton collections. The *elegans* water may possibly have bulged slightly further into the Channel mouth than there indicated, but certainly did not reach the Lizard–Ushant line.

This distribution is quite in accord with previous conclusions from hydrographic data alone. There can probably now be little doubt that the *elegans* water represents that area of cyclonic circulation shown by Matthews (1914), and on this occasion it practically blocked the mouth of the Channel as Lumby (1925, p. 12) has shown for the summer months. From its plankton content there can be no doubt that a large body of this water was present off Plymouth in 1930 (Russell, 1935, b) and moreover the *S. elegans* were of the same size as those found off Plymouth in July of that year (Russell, 1932). The complex nature of the water movements in the Scillies–Land's End region is well known and the study of the plankton here could probably be of great help in the future. The flow of water round Land's End as shown by the high percentage of *S. elegans* is in accord with previous hydrographic observations at certain times. (See Harvey, 1930, pp. 804–807.)

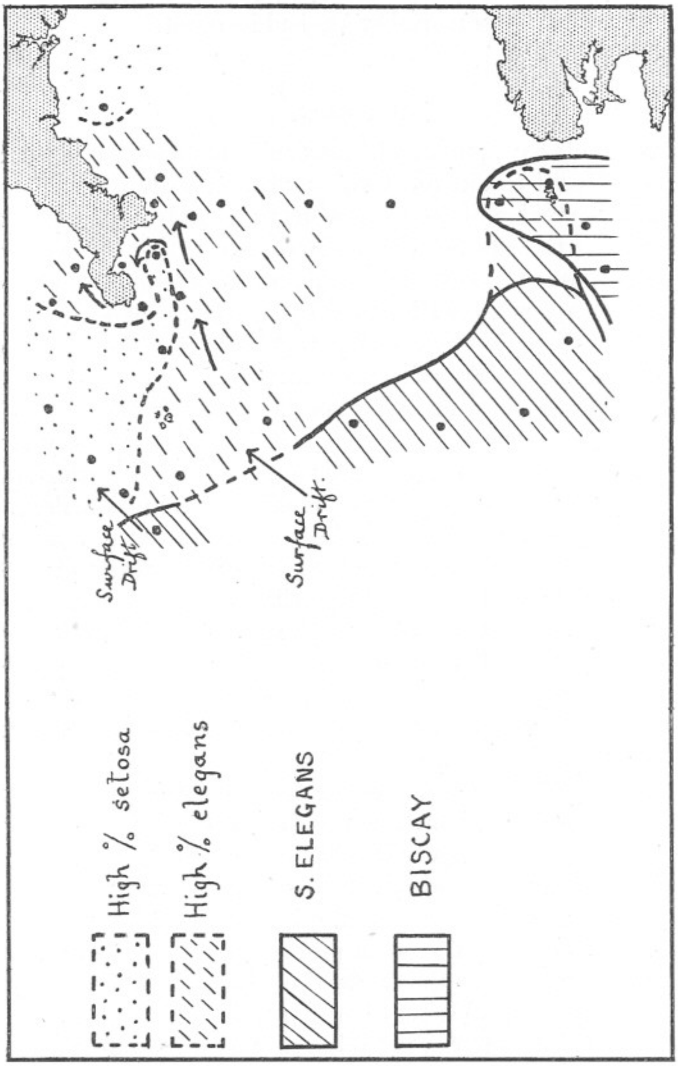

Fig. 6.—Distribution of water masses in English Channel mouth region as inferred from collections of plankton made on Col. Peel's yacht *St. George*, July, 1935.

In my previous report (Russell, 1935, b) a list of plankton indicators for *elegans* water was given. To these should now be added *Themisto gracilipes*, a distinctive species easily seen. It would appear that Metridia can also be regarded as an indicator but its small size renders it less practical. The Channel water is characterised by the absence of any indicators, except *S. setosa* when it occurs. On this occasion that species appeared to be confined to the coastal area; future observations alone can show whether it may at times also be found in the offshore water.* Acartia (Fig. 4) also appears to be confined on this occasion to Channel water, both coastal and offshore. But its small size renders it impracticable for rapid identification. Such few as were submitted to microscopic examination proved to be *A. clausi*, but it is impossible to identify large numbers without great labour. In Figure 4 I have included also Pseudocalanus (plus Paracalanus), Calanus and Centropages. The increase in numbers shown so definitely by the former in *elegans* water is probably significant, but the fact that these species may occur in numbers in Channel water also makes them of no use as indicators. The distribution of Aglantha (Fig. 4) was consistent. The large individuals were found in *elegans* water and very small specimens in the coastal Channel water. This species is however probably a very rapid breeder, having a number of successive quickly maturing broods in the summer months, and its presence should therefore be treated with caution unless supported by the other indicators.

It appears that *S. elegans* alone is sufficient for practical purposes. It is an abundant holoplanktonic species, and its shape and size make a study of the age composition of its populations a much simpler matter than for any other animal. If its presence is supported by other indicators, as it always appears to be, we can feel doubly confident.

The observed increase in the abundance of the plankton in *elegans* water and its fatty nature supports the supposition that this water is likely to be found to be richer in nutrient salts than Channel water (Russell, 1935, a, p. 171, and 1935, b, p. 321). The changes in the distribution of plankton with a high fat content shown by Wimpenny (1929) in the North Sea may possibly also find their explanation in the movements of Atlantic and North Sea water.

SUMMARY.

In July, 1935, a cruise was made in Col. E. T. Peel's yacht *St. George* to study the distribution of certain plankton animal indicators in the mouth of the English Channel.

Three bodies of water were clearly shown by their plankton content: (1) water characterised by the presence of *Sagitta elegans*, Clione, *Themisto*

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* At the Station E2, approximately mid-way on a line between Plymouth and Ushant, a sample of plankton collected in the metre stramin net on September 13th, 1935, contained *S. setosa*. At the same position on November 21st, 1935, only *S. elegans* were found.

gracilipes, Euphausian larvæ, Stephanomia and Aglantha; (2) Biscay water, on this occasion characterised by Noctiluca and a paucity of zooplankton; and (3) Channel water characterised by the presence of *Sagitta setosa* and absence of other indicators.

It has been shown that the study of certain plankton animals should prove of help in understanding the hydrography of the Channel mouth region.

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TABLE I.

STATION LIST—*St. George* CRUISE, JULY, 1935.

Station Number.	Date.	Time.	Position.
1	23.vii.35	7.00–7.10 p.m.	50° 08′ N. : 4° 32′ W.
2	,,	9.05–9.15 p.m.	49° 56′ N. : 4° 58′ W.
3	24.vii.35	5.30–5.45 a.m.	Anchorage 1 mile off Cadgwith.
4	,,	9.00–9.10 a.m.	49° 51′ N. : 5° 11′ W.
5	,,	10.15–10.25 a.m.	49° 44′ N. : 5° 08′ W.
6	,,	12.35–12.45 p.m.	49° 26′ N. : 5° 08′ W.
7	,,	2.52–3.02 p.m.	49° 02′ N. : 5° 08′ W.
8	,,	5.13–5.23 p.m.	48° 36′ N. : 5° 08′ W.
9	,,	9.00–9.45 p.m.	Anchorage behind Ushant.
10	25.vii.35	7.00–7.10 a.m.	48° 20′ N. : 5° 15′ W.
11	,,	8.20–8.30 a.m.	48° 18′ N. : 5° 27′ W.
12	,,	10.40–10.50 a.m.	48° 25′ N. : 5° 53′ W.
13	,,	1.00–1.10 p.m.	48° 35′ N. : 6° 21′ W.
14	,,	3.15–3.25 p.m.	48° 54′ N. : 6° 24′ W.
15	,,	5.30–5.40 p.m.	49° 13′ N. : 6° 23′ W.
16	,,	8.05–8.15 p.m.	49° 32′ N. : 6° 22′ W.
17	26.vii.35	9.00–9.15 a.m.	Anchorage off Penzance.
18	,,	4.35–4.45 p.m.	49° 52′ N. : 5° 40′ W.
19	,,	5.55–6.05 p.m.	50° 00′ N. : 5° 44′ W.
20	,,	7.40–7.50 p.m.	49° 57′ N. : 5° 57′ W.
21	,,	9.00–9.45 p.m.	Anchorage in Crow Sound, Scilly.
22	27.vii.35	8.00–8.10 a.m.	49° 52′ N. : 6° 42′ W.
23	,,	9.30–9.40 a.m.	49° 55′ N. : 7° 00′ W.
24	,,	11.00–11.10 a.m.	50° 03′ N. : 6° 49′ W.
25	,,	12.35–12.45 p.m.	50° 11′ N. : 6° 35′ W.
26	,,	2.15–2.25 p.m.	50° 21′ N. : 6° 20′ W.
27	,,	4.30–4.40 p.m.	50° 21′ N. : 5° 40′ W.
28	,,	5.35–5.45 p.m.	50° 17′ N. : 5° 35′ W.

Both the 1-metre stramin and coarse silk nets were used at all stations except Stations 3, 4, 9, 17 and 21 where the coarse silk net alone was used: at the anchorages this net was fished in the tide.

TABLE II.

LENGTH MEASUREMENTS OF *S. elegans* IN SILK NET CATCHES.

Station	Body Length in millimetres.											14 &
number	3	4	5	6	7	8	9	10	11	12	13	over
1	–	2	19	16	20	1	–	–	–	–	–	–
2	3	18	17	7	7	2	–	–	–	–	–	–
3	–	9	16	5	5	1	1	–	–	–	–	–
4	1	16	16	20	26	14	7	1	–	–	1	–
5	2	2	18	9	8	4	–	–	–	–	–	–
6	3	3	2	–	1	–	–	–	–	–	–	–
8	–	–	–	–	1	–	–	–	–	–	–	–
9	–	–	–	1	4	9	13	7	5	9	6	4
12	–	1	2	14	37	32	19	10	3	5	1	–
13	–	–	–	–	1	4	8	21	22	29	16	19
14	–	–	2	3	9	18	9	20	20	11	7	17
15	1	6	6	14	12	19	30	17	34	16	19	7
16	11	23	17	14	13	21	6	–	–	–	–	–
17	3	15	12	2	1	–	–	–	–	–	–	–
18	4	15	23	31	25	7	11	6	5	2	1	–
19	3	11	19	21	19	12	5	4	1	1	–	–
20	5	17	8	9	3	2	–	–	–	–	–	–
21	1	5	10	3	–	–	–	–	–	–	–	–
22	1	21	18	17	11	18	17	9	6	2	–	–
23	1	11	19	18	13	11	12	9	7	6	1	–
24	9	24	9	4	–	–	–	–	–	–	–	–
25	5	14	7	2	–	–	–	–	–	–	–	–
26	6	1	–	1	–	–	–	–	–	–	–	–
27	–	–	6	6	4	2	–	1	–	–	–	–
28	–	1	3	1	1	–	–	–	–	–	–	–

TABLE III.

LENGTH MEASUREMENTS OF *S. elegans* IN METRE NET CATCHES.

Station number	Body Length in millimetres. 4	5	6	7	8	9	10	11	12	13	14	15 & over
12	–	–	–	–	1	1	3	4	8	5	–	3
13	–	–	–	–	1	2	12	18	18	23	16	23
14	–	–	–	2	2	4	7	10	10	12	20	23
15	–	–	–	1	–	4	18	23	26	16	8	8
16	–	1	–	2	3	4	1	1	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	1	–
19	–	–	1	–	–	–	1	–	–	–	–	–
22	–	1	–	–	2	4	7	3	–	2	–	–
23	1	–	–	–	1	–	1	3	2	1	–	–
24	1	–	–	–	–	–	–	–	–	–	–	–
25	–	1	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	1	–	–	–	–	–	–

TABLE IV.

LENGTH MEASUREMENTS OF *S. setosa* IN SILK NET CATCHES.

Station number	Body Length in millimetres. 3	4	5	6	7	8	9	10	11	12
1	–	5	11	16	24	22	7	3	–	–
2	–	3	2	3	1	–	–	–	–	–
3	–	4	3	5	5	6	9	5	1	–
4	–	4	4	–	4	6	11	8	–	–
5	–	1	1	1	–	–	4	–	–	1
16	4	8	2	16	17	8	2	–	–	–
17	–	–	–	1	–	–	–	–	–	–
18	–	–	4	2	–	3	1	2	3	–
19	1	–	2	4	2	–	2	5	1	2
20	3	8	10	9	5	3	–	–	–	–
21	1	5	4	2	–	–	–	–	–	–
22	–	2	3	2	3	4	4	1	–	–
24	3	10	14	20	14	8	–	–	–	–
25	1	9	20	13	12	–	–	–	–	–
26	–	10	10	20	9	3	–	–	–	–
27	1	3	6	5	1	–	–	–	–	–
28	–	1	–	–	–	–	–	–	–	–

TABLE V.

LENGTH MEASUREMENTS OF *S. setosa* IN METRE NET CATCHES.

Station number	Body Length in millimetres. 3	4	5	6	7	8	9	10	11	12	13
15	–	–	–	–	1	–	–	–	–	–	–
16	–	–	–	–	3	1	–	–	–	–	1
18	1	–	3	–	–	–	–	–	–	1	–
20	–	–	1	1	–	–	–	–	–	–	–
22	–	–	2	2	2	2	2	–	–	–	–
24	2	–	–	3	1	–	–	–	–	–	–
25	–	3	6	7	6	–	–	–	–	–	–
26	–	1	5	3	3	1	–	–	–	–	–

The Occurrence, Ecology and Life History of *Tigriopus fulvus* (Fischer).

By

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With 5 Figures in the Text.

WHILST investigating the rock-pool fauna at Port St. Mary, Isle of Man, in April, 1932, the pools above high-water mark were found to be teeming with the orange-coloured Harpacticid *Tigriopus fulvus* (Fischer). Their presence in such numbers in so exacting an environment suggested that their ecology and life-history might be of interest.

OCCURRENCE AND ECOLOGY.

Tigriopus fulvus is distributed widely throughout the European coasts, its presence being recorded from:—the British Isles (Brady), Norway (Sars), Sweden (Lilljeborg), France (Canu), Gulf of Genoa (Issel). Brady records it also from the Kerguelen Islands and Fischer from Madeira.

Its general habitat is in those pools at or above high-water mark and thus liable to extreme changes; they may be evaporated into salt-cakes or washed out by heavy rainfall, a hot sun will raise the temperature very considerably, while a high tide will suddenly lower the temperature and materially alter the salinity. Such an environment would prove intolerable to most marine animals.

Many biologists* have commented on this strange habitat, but generally speaking have not studied further. Issel (**6**), however, says: "Poche settimane di periodiche osservazioni nelle pozzanghere avevana sin dal 1912 richiamanto la mia attenzione sopra un fenomeno degno di studio; il Copepodo *Tigriopus fulvus*, appena la densità dell'acqua raggiunge un certo grad, cade in uno stato di morte apparente dal quale può ridestarsi anche dopo un tempo assai lungo e riaquistare attività normale quando l'acqua venga sufficientement diluita."†

Gurney (**5**) does not include Tigriopus in his monograph of British

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* For example, Sars (**10**); Brady (**1**); Brian (**2**); Marine Biol. Assoc. Fauna List (**8**).

† "A few weeks of periodical observations of the pools since 1912 have drawn my attention to a phenomenon worth studying; as soon as the density of the water reaches a certain degree the copepod *Tigriopus fulvus* falls into a state of apparent death, from which it can awake even after a very long time and regain normal activity when the water is sufficiently diluted."

Freshwater Copepoda. I have found it in the rock pools at Plymouth, Port Erin and Port St. Mary, Isle of Man ; on the north and north-west coasts of Wales ; the west coast of Scotland and the north Yorkshire coasts. It was not to be found in the pools on the muddy shores of the Mersey and Humber, or on the clayey and sandy shores of South Yorkshire and Lancashire.

A quantitative analysis of Tigriopus from rock pools at Port St. Mary has been made and correlated with tidal level (Table I). It is remarkable that their density can reach 9 per cubic centimetre.

TABLE I.

NUMBERS OF *Tigriopus fulvus* PER LITRE IN A SERIES OF NINE POOLS DURING APRIL AND AUGUST, 1932.

Level of Pool.*		Volume in litres.	No. of Tigriopus per litre of water.	
			April.	August.
I	−1·33	84	0	0
II	−0·47	39	0	0
III	+2·61	7½	0	0
IV	4·91	16	0	0
V	4·78	13½	1	4
VI	7·53 (H.W.M.)	39	54	1680
VII	9·13	84	11	2250
VIII	11·00	9	1768	8900
IX	12·73	36	806	7800

The remaining fauna of pools 6–9 during August was : Pool 6, *Littorina rudis* 200 small, 8 large, Patella 1. Pool 7, *L. rudis* 100 small. Pools 8–9, apparently none. The chief plant content of the upper pools was dead and decaying Enteromorpha.

Living Tigriopus were collected from these pools and forwarded to the University College of Hull, where they were bred in the laboratory under conditions as natural as possible, as well as in varying environments as experiments on the anabiotical phenomena described by Issel (**6**).

A number of Tigriopus kept in a sealed jar half-full of sea water and deprived of any special nutrient material thrived well for almost a year. During this time the sides of the jar became coated very thinly with a green film and some Enteromorpha was seen growing ; all traces of green gradually disappeared leaving only a colourless scum. Observations made through the sides of the glass clear enough for the purpose revealed the fact that some of the Tigriopus were still very active, while large numbers

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* In feet above or below ordnance datum.

of others apparently were resting. The latter still retained their orange colour and could readily be distinguished from the dead. A few remained active for as long as 18 months, after which no activity could be seen. After two years the jar was opened and stirred, and a green film soon became evident. After three weeks, living, active Tigriopus were found. These specimens, although adult, were very stunted (about 500μ in length) and several casts of previous copepodid stages, correspondingly smaller, were found. One can infer from the presence of these casts and their stunted nature that some copepods had remained slightly active throughout the two years although growth was small, and their presence three weeks after opening was not due to the revival of dormant adults or to the development of resting eggs.*

Other specimens were kept in small covered dishes and were provided with food in the form of a culture of *Nitzschia closterium*. These remained active and healthy for 3–9 months and reproduced rapidly, but when the addition of diatoms was stopped the stock died.

A further experiment was made by placing specimens in small dishes and allowing the contents to dry up. Revival experiments showed the following results. When the dishes were refilled with tap-water after two or three days, and before the salt crystals became anything like dry, the Tigriopus revived, but if left for longer periods before refilling no revival took place. The various stages of Tigriopus, although resistant, could not stand as severe a treatment as the adults. This ability to withstand temporary desiccation is probably due to the very thick chitinous covering and not to a protective case provided by dermal glands as has been described by Calman (**3**) in freshwater Harpacticoida and Cyclopoida.

Various colours of Tigriopus appeared in some of the cultures which had been kept for months. In addition to the normal orange colour there were shades varying from dark brown, through orange to apple green. In more than one culture the whole stock became green after some six months. Examination revealed that an exceptionally thin chitinous coat covered the specimens and the dark green gut and pale green flesh was the cause of the coloration, whereas in the normal type the chitin is very thick and is itself of a bright orange colour.

Life History.

Guiglia (**4**) appears to be the only author who gives any account of the development of Tigriopus, and she confines herself to a morphological description of the various stages of nauplii and of the first copepodid stage, not including any data showing the times taken in development

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* A complete account of this experiment is printed in the *Journal of Animal Ecology*, Vol. 4, No. 2, 1935, pp. 229–230.

either prior to or after hatching, and her figures are inadequate. Some significant differences were found between the larval stages from English coasts and those described by Guiglia and it was therefore thought worth while to continue a series of observations and experiments in order to work out the life history afresh and to include the copepodid stages as well as the nauplii.

As in other Harpacticoida, there are five successive stages of nauplii and six of copepodids (the sixth being the adult), in Tigriopus.

The Adult.

The adult males of the specimens from Port St. Mary measure 1·0–1·2 mm. in length and the females about 1·2 mm. (This is the same figure as given by Sars (**10**) for Norwegian specimens.) Those from the Gulf of Genoa (Brian **2**) average 0·7–0·8 mm. in length. Mating takes place throughout the year and females with egg sacs are usually abundant. During mating the fully grown male swims above the female, attached by the hooks of the first antennæ. The mating female is usually much smaller (about 800μ) and at the fifth copepodid stage although fully grown females can often be seen mating. The pairs swim about actively together, the times ranging from a few minutes to several days. Isolated pairs never remained together for more than one week.

A number of females were isolated after mating and kept under observation. The egg sac first appeared within seven or ten days and soon after the final moult if the female had been at the fifth copepodid stage during mating. When the egg sac first appears it is minute and dark olive-green in colour. It quickly grows, becoming a paler green and gradually turning to a bright orange colour as the nauplii develop. Hatching takes place five to fifteen days after the first appearance of the egg sac, the time being shorter in summer and longer in winter. Most of the eggs of a brood hatch out within a few hours of each other, but occasionally odd ones remain, often not completing development. Nicholls (**9**) finds this occurring in Longipedia.

Each egg is enclosed in a fairly tough sphere of jelly, and the nauplius when ready to hatch wriggles its way out. Its efforts are slight at first, but become more vigorous later: finally it bursts through the jelly until it remains attached only by the long spinulated setæ of the third appendage. This process lasts about thirty seconds, but only more violent and prolonged wriggling, often for five minutes, serves to withdraw these and leaves the nauplius free to swim away. From the first slight wriggling right through the whole development the larvæ are active, remaining still only for a few seconds at a time.

The mass of jelly left attached to the female is soon discarded, leaving space for the development of a second egg sac without further mating.

This may be repeated several times without the presence of the male, no further mating being necessary. Nicholls (**9**) finds this occurring in Longipedia, one female having produced at least nine batches of eggs. If a male Tigriopus was added to a dish containing a female which had previously mated no association took place. Union may take place between a single pair several times before the first egg sac appears even if earlier fertilisation had been successful, but it was never seen after the egg sac had appeared.

Some actual examples are given :—

No. I.

Nov. 30th, 1931, mated 5.15 p.m. separated 5.30 p.m. ; Dec. 9th, 1st egg sac appeared, male removed ; Dec. 14th, egg sac still green ; Dec. 20th, egg sac orange ; Dec. 23rd, all eggs but 3 hatched ; Jan. 5th, 2nd egg sac appeared ; Jan. 20th, 3rd egg sac appeared ; Feb. 6th, 4th egg sac appeared ; Feb. 7th, pair from 1st brood seen mating ; Feb. 14th, original female died.

No. VIII.

March 10th, 1932, eggs of 1st sac hatched ; March 14th, 2nd egg sac appeared ; March 22nd, 3rd egg sac appeared ; April 3rd, 4th egg sac appeared ; May 1st, original female died.

No. X.

Jan. 24th, 1934, mating pair isolated ; Jan. 30th, separated, cast skin of 5th ♀ copepodid found ; Feb. 7th, egg sac appeared ; Feb. 16th, partly hatched ; Feb. 23rd, died.

No. XI.

Jan. 24th, 1934, mating pair isolated ; Jan. 25th, 10 a.m. separated ; 8 p.m. together again ; Jan. 29th, separated for a short time while ♀ moulted ; Feb. 2nd finally separated, egg sac appeared same day ; Feb. 7th, eggs hatched ; Feb. 16th, 2nd egg sac appeared.

No. XII.

Jan. 24th, 1934, mating pair isolated ; Jan. 26th, separated ; Jan. 31st, egg sac appeared ; Feb. 7th, eggs hatched ; Feb. 9th, 2nd egg sac appeared ; Feb. 16th, eggs hatched ; Feb. 23rd, 3rd egg sac appeared.

No. XIII.

Jan. 24th, 1934, mating pair isolated ; Jan. 26th, separated ; Jan. 27th, cast skin of 5th ♀ copepodid found ; Feb. 4th, egg sac appeared ; Feb. 9th, eggs hatched ; Feb. 16th, 2nd egg sac appeared.

While these observations were being carried out, others were made to see if parthenogenesis occurred. Lowndes (**7**) was unable to find parthenogenesis in Cyclops and other copepoda and concluded that, in Cyclops at any rate, it does not occur. Egg sacs produced by females which had been kept separately merely decomposed and dropped off, and in no case gave rise to living nauplii. Nicholls (**9**) finds no evidence of parthenogenesis in Longipedia, although Gurney (**5**) finds it in Canthocamptus. Many female Tigriopus copepodids were kept isolated through their final stages, and these failed to produce egg sacs at all, although if a male was added egg sacs soon developed.

In order to work out the life history, females bearing egg sacs were isolated in small dishes and kept provided with *Nitzschia closterium*, and the development of each batch watched. As an additional check on the sequence of ecdyses, single nauplii were isolated and the changes noted. Examination of the external features and the structure of the various appendages was carried out on the cast skins instead of on the living or fixed animals. The details are then much clearer and the appendages easier to remove and the various stages of the same animal could also be kept for comparison as well as examined in the living form. A dozen or more specimens of the various stages of nauplii were mounted in glycerine jelly and compared, and in the case of the more complicated copepodids the appendages of several specimens of each stage were taken off for comparison.

The Stages of Nauplii.

The *first nauplius* (Fig. 1, A) varies in length from about 116–126μ, is round and flattened, orange, and has a very distinct red eye. It has three pairs of appendages, the first and second antennæ and the mandible, details of which are given in the figures. The caudal appendages consist of two fairly long but very fine setæ.

This description differs from that of Guiglia (**4**), who records a length of 142–145μ, finds the caudal setæ thick and stumpy and notes no segmentation of the second antennæ nor that it (or in any of the succeeding stages) possesses any structure extending inwards towards the mouth. This extension of the second antennæ seems to act as a primitive jaw in all the stages of nauplii.

This first stage swims about actively from 3 to 7 days and then moults, emerging into the *second nauplius*, or *first metanauplius* (Fig. 1, B). It is slightly larger than the first, measuring 143–153μ in length, but the only radical change is in the number and arrangement of the caudal setæ. It has now developed a ventral lobe, representing a rudimentary abdomen, which bears two setæ corresponding with those of the first nauplius and two extra ones, larger and more robust, spinulated and attached near the proximal end.

Second nauplii from the Gulf of Genoa measured by Guiglia are 165–170μ in length, and still show no signs of segmentation in the second antennæ.

This stage rarely lasts longer than 24 hours before moulting.

The *third nauplius* (second metanauplius) (Fig. 1, C) measures 165–176μ in length. It is much more advanced than the second stage, chiefly in the abdominal region, where the lobe is now clearly distinct and even shows a slight division into two at the posterior end. There are three pairs of caudal setæ, all setose ; a long and a short distal pair and a rather short but robust proximal pair. The abdomen itself has a number of spinules arranged in three pairs of combs. The other appendages show

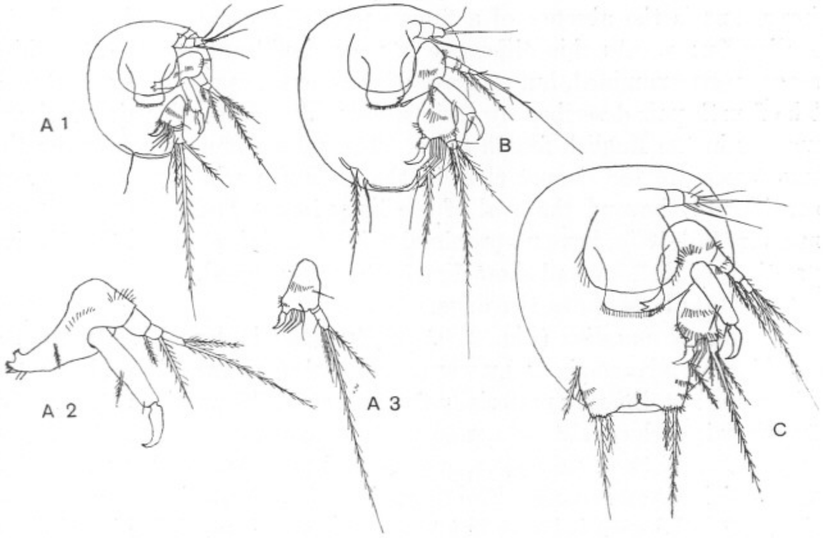

FIG. 1.—A 1, 1st nauplius. A 2, 2nd antenna ; A 3, mandible, further enlarged. B, 2nd nauplius ; C, 3rd nauplius.

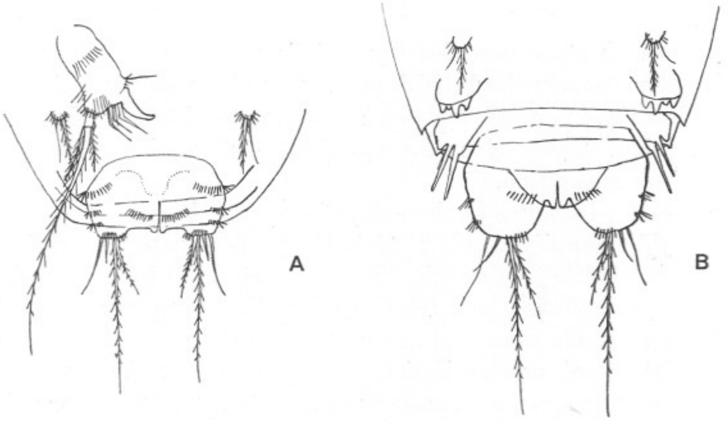

FIG. 2.—Posterior halves of A, 4th nauplius ; B, 5th nauplius.

little significant change, the first antennæ have a few more small setæ; the other two pairs are rather stouter and the terminal setæ relatively shorter. The abdomen barely protrudes behind the rest of the body.

These observations differ from Guiglia's in several ways. The most important is the absence of a fourth pair of appendages found in the Italian forms. As this difference is very significant many extra third stages were examined, but no trace of these extra appendages was found. The fourth pair described by Guiglia resemble the fourth pair which are present in the English fourth stage. The other differences between the two types are the deeper cleft in the abdomen which protrudes very considerably beyond the oval of the body in the Italian forms. These measure 176–185μ, have no proximal pair of caudal setæ, and the relative positions of the long and short distal setæ are reversed.

This stage lasts one or two days.

The *fourth nauplius* (Fig. 2, A) is 210–233μ in length and shows a considerable advance in many ways. It has four pairs of appendages, the first three not differing materially from those of the previous stage. The fourth pair each consists of a small protuberance with a comb of fine setæ, and at the tip two longer setæ, one fine and unornamented and the other more thick-set and setose. The thoracic region shows signs of segmentation. The abdomen is larger but does not protrude much behind the rest of the body. Its cleft is now quite deep and there are four pairs of caudal setæ, all distal, two of these pairs are setose. There is an additional pair of combs of setæ on the abdomen, this new pair approximating on the cleft.

The fourth stage described by Guiglia possesses a rudimentary fifth pair not present in the English ones. The abdomen protrudes considerably, has three pairs of caudal setæ, and the combs do not bear the same relationship. This stage measures 235–247μ in length and has no trace of thoracic segmentation.

Stage four lasts two or three days before moulting.

The *fifth nauplius* (Fig. 2, B) is the final stage of the series and it measures 243–256μ in length. The segmentation of the thoracic region is much more distinct and there are six pairs of appendages. Pairs five and six resemble flaps and are not provided with setæ in the normal sense of the word, such projections as there are seem to be part of the body of the appendage rather than extraneous setæ. The first four pairs show little change. The abdomen protrudes considerably and has the same formation of the four pairs of caudal setæ as in the previous stage, but the combs are, relatively, not so obvious.

The Italian fifth stage measures 272–282μ in length and shows no thoracic segmentation, but otherwise resembles the English stage, having six pairs of appendages and four pairs of caudal setæ.

Stage five lasts about three days.

The fifth nauplius moults into the first copepodid stage. Guiglia describes this stage but goes no further with the development. It would be interesting to compare the two types right through the life history, especially as the Italian nauplii are very much bigger than the English ones, yet the English adult is half as big again as the Italian adult.

The Copepodid Stages.

In all there are five stages of copepodids before the adult. The oral appendages are all represented and rather similar in each, but the succession of the thoracic appendages is worth noting.

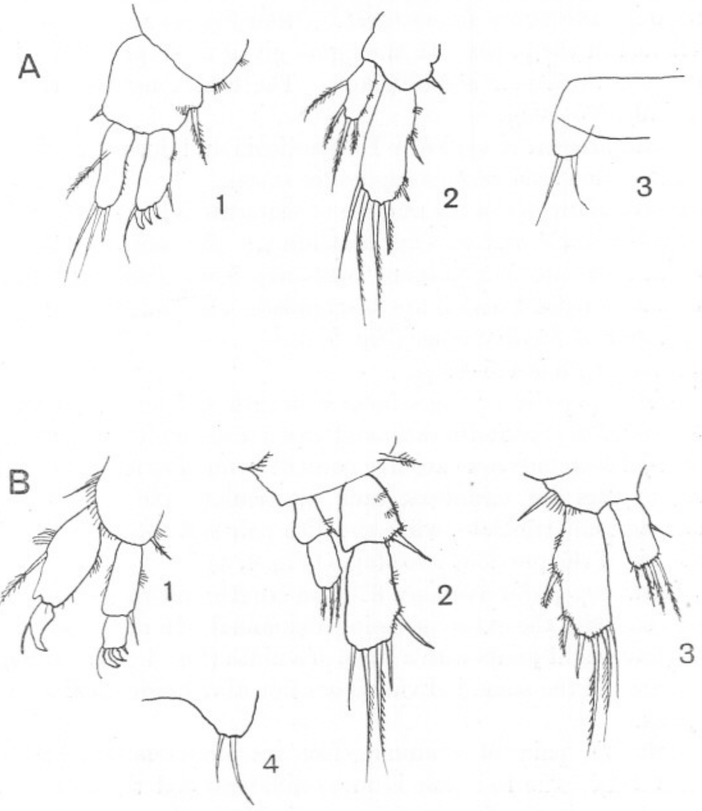

FIG. 3.—The thoracic appendages of A, 1st copepodid ; B, 2nd copepodid.
1, p.1; 2, p.2 ; 3, p.3 ; 4, p.4.

The *first copepodid.* A typical first copepodid of the Harpacticoida has four segments, three in the cephalothorax and one, sometimes with a trace of a second, in the abdomen (Brian, **2**). Guiglia gives four segments to the first copepodid of Tigriopus, but according to the figure, two are cephalothoracic and two abdominal with a trace of an additional segment in the former, the third pair of swimming feet originating at the second segment in conjunction with the second pair.

Examples of Tigriopus from the Isle of Man had this segment quite pronounced making five in all, three cephalothoracic and two abdominal. These Manx specimens measure 360–400μ in length (excluding the long caudal setæ). The antennæ are six-jointed and there are three pairs of swimming feet, two of these are biramous but the third pair are each represented by a flap-like protuberance with two hairs (Fig. 3, A).

Guiglia's description of the appendages of this stage differs slightly. According to the text there is but one hair on the third pair of swimming feet although the figure shows three. Other figures are referred to, but not included in the paper. In the figure given the representation of the origin of the third pair is ambiguous. The total length of this Italian stage is only 295–300μ.

The caudal region is typically Harpacticoid and does not alter significantly throughout the various copepodid stages.

In the *second copepodid* the number of segments is increased to six, four are cephalothoracic and two are abdominal. The antennæ have seven joints and there are four pairs of swimming feet. Pairs 1, 2 and 3 are biramous and pairs 1 and 2 are biarticulate, the fourth pair resemble the third pair of the first stage (Fig. 3, B).

The total length is 415–470μ.

The *third copepodid* averages 530μ in length and has seven segments, five of which are cephalothoracic and two are abdominal. The antennæ are seven-jointed and there are five pairs of swimming feet. Of these the first three pairs are biramous, each biarticulate and the fourth pair biramous and uniarticulate, while the fifth pair is flap-like and similar to the last pair of the previous two stages (Fig. 4, A).

The *fourth copepodid* averages 670μ in length and the segments have increased to eight, the extra one being abdominal. In most cases the first antennæ have eight joints with a trace of a ninth (Fig. 4, B 2) although the two antennæ of the same individual are not always identical about this ninth joint.

The first four pairs of swimming feet are biramous and biarticulate (Fig. 4, B 2–4). The last pair is more differentiated than those of the previous stage; in the female they are distinctly biramous (Fig. 4, B 5), but in the male one seta is slightly removed from the rest of the appendage and may be assumed to be a rudimentary endopodite (Fig. 4, B 6).

Females at this fourth stage can be seen swimming about with males attached, although copulation either does not take place or is ineffective.

The *fifth copepodid* is 770–850μ in length, has nine segments—five cephalothoracic and four abdominal—and the antennæ are nine-jointed. Swimming feet 1–4 are each triarticulate in both rami (Fig. 5, 4–6). The fifth pair is markedly biramous in the female (Fig. 5, 7), but in the male the endopodite is still represented by a single hair on a short protuberance (Fig. 5, 8) and remains so in the adult.

Another difference between the sexes at this stage is observed in the antennæ. In both there are nine joints, but in the male the distal six are greatly foreshortened (Fig. 5, 2) compared with those of the female (Fig. 5, 1), so that the male antennæ have a stumpy appearance, but not the prehensile structure as in the adult. It is at this stage that the female is normally fertilised, although the fifth stage male is not functional as such.

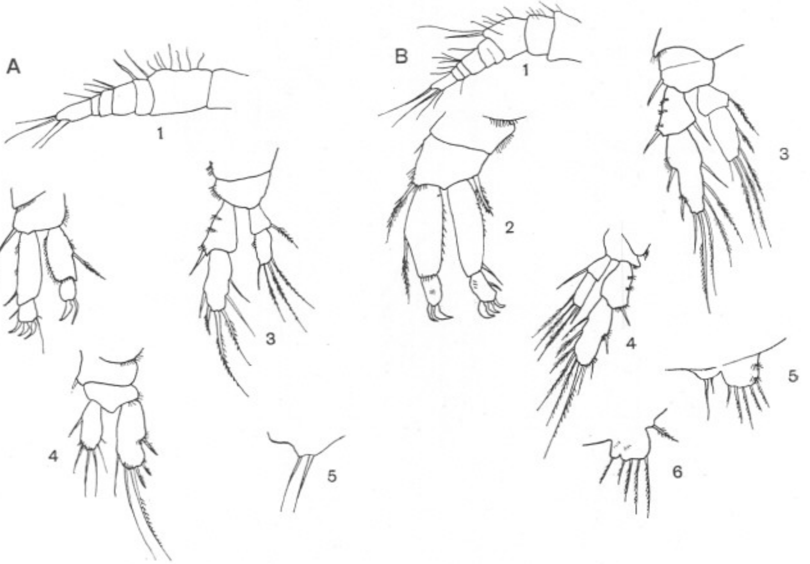

FIG. 4.—A, 3rd copepodid ; 1, 1st antenna ; 2, p.1 ; 3, p.3 ; 4, p.4 ; 5, p.5. B. 4th copepodid ; 1, 1st antenna ; 2, p.1 ; 3, p.3 ; 4, p.4 ; 5, p.5 female ; 6, p.5 male.

The *adult* reaches a length of 1,000–1,200μ. It has been described fully by Sars (**10**), and hence a brief summary of the most marked differences between this and the preceding stages will be sufficient. The *female* has five cephalothoracic segments and four abdominal ones ; the first antennæ are nine-jointed, the first four pairs of swimming feet are triarticulate in both rami and the fifth pair biramous but uniarticulate. The *male* has five cephalothoracic and five abdominal segments. The first four pairs of swimming feet are triarticulate in both rami, but the endopodite of the second pair is modified as a copulatory organ. The fifth pair is similar to that of the fifth copepodid. The first antennæ are each modified into a robust claw-like structure used in grasping the female; three of the segments are fused, making a total of seven joints.

As will be seen from the records of the nauplii, the first copepodid stage is reached about 15 days after hatching. The first copepodid stage lasts 2–5 days, the second stage lasts about a week, the third and fourth last a week to ten days each, and the fifth about a fortnight, making a total of about two months to complete the life-cycle.

Some actual figures are given: fifth nauplii became first copepodids on February 11th–13th, and second copepodids on February 16th. Eggs hatched on March 7th became first copepodids on March 22nd, and third copepodids on April 3rd. Eggs hatched on December 23rd became adults on February 7th. Eggs hatched on February 20th became adults on April 22nd. These figures are given as an indication of the times of development in the laboratory under favourable conditions. In the absence of food or in other unfavourable conditions the life cycle would be increased, possibly very considerably.

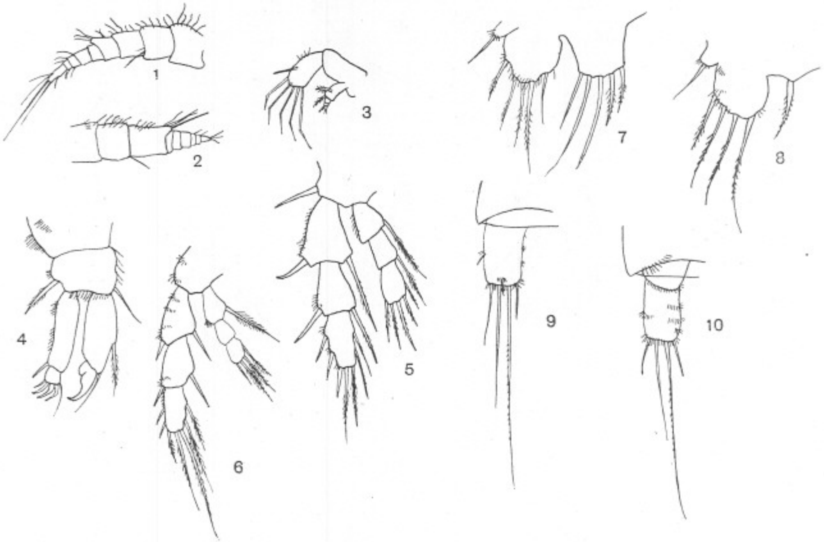

FIG. 5.—5th copepodid. 1, 1st antenna female; 2, 1st antenna male; 3, 2nd antenna; 4, p.1; 5, p.3; 6, p.4; 7, p.5 female; 8, p.5 male; 9, caudal furca, dorsal view; 10, ventral view.

An interesting point raised by Nicholls (**9**) in the life history of Longipedia is the presence of spinules on the caudal setæ throughout the whole series of copepodids but which are absent in the adult. This is not so in Tigriopus, as small spinules persist in the adult.

ACKNOWLEDGMENTS.

Acknowledgments are due to the Marine Biological Station at Port Erin and to Dr. H. B. Moore for the samples of living Tigriopus ; and to Miss F. H. Roscoe, of the Liverpool School of Italian, for many translations and for confirmation of others.

SUMMARY.

The peculiar and exacting environment of *Tigriopus fulvus* is discussed and a census of Tigriopus from a series of pools in the Isle of Man is given.

Experiments have been made determining the resistance of Tigriopus to desiccation and its revival in favourable circumstances.

The life history has been worked out, times taken in development noted, and the various stages compared and contrasted with those described by Guiglia.

Sex can be determined at the fourth copepodid stage. Females are normally fertilised as fifth copepodids, but the males are not functional until the adult stage. A single female may produce several egg sacs giving rise to living nauplii from a single fertilisation.

There is no evidence for parthenogenesis.

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Gigantism and Variation in *Peringia ulvæ* Pennant 1777, caused by Infection with Larval Trematodes

By

Miriam Rothschild.

With 2 Figures in the Text.

In 1933 an examination of *Peringia ulvæ** for larval trematodes was undertaken at Plymouth (Rothschild, 1936). No actual measurements were made at the time, but there appeared to be a relation between the species of trematode and the size of the individual infected snails. Thus the commonest species, *Cercaria oocysta* Lebour, 1907 (14% infection), and *C. ubiquita* Lebour, 1907 (4% infection), were found in 75% of the largest snails, while the rarer species, such as *C. ephemera* Lebour, 1907 (non Nitsch) (2% infection), and *C. pirum* Lebour, 1907 (0·1% infection), occurred most frequently in medium sized individuals.

Later, random samples of *Peringia ulvæ* were obtained from St. John's Lake, Plymouth. These were measured to procure a rough estimate of the number of individual snails of a given size-group per thousand (Tables I and IA). One hundred snails of each size-group were then selected and examined for cercariæ (Tables II and III, p. 541). Specimens over 5 mm. were rare and only twenty-five individuals of this size were obtained.

Exposure of *Peringia ulvæ* to Infection.

Before examining the result of this investigation it is as well to consider the exposure of snails to infection with miracidia.

TABLE I.

"Random" Sample of *Peringia ulvæ* from Plymouth (June).

Size groups in mm.	Number of snails to each size group.
1 mm.	517
2 mm.	344
3 mm.	451
4 mm.	701
5 mm.	8
5+ mm.	2
Total	2023

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* = *Hydrobia ulvæ* (Pennant) of Plymouth Marine Fauna, 1931.

TABLE IA.

THE SAME RANDOM SAMPLE OF *Peringia ulvæ* FROM PLYMOUTH (OF 3 MM. AND OVER) IN SIZE-GROUPS OF ¼ MM.

Size groups in ¼ mm.	Number of snails to each size group.
3 mm.	114
3¼ mm.	67
3½ mm.	123
3¾ mm.	147
4 mm.	266
4¼ mm.	216
4½ mm.	161
4¾ mm.	58
5 mm.	8
5¼ mm.	2
Total	1162

The degree of infection of a population of *Peringia ulvæ*, and the age at which the infection occurs, chiefly depends on the presence and infection of the final host of the Trematode. It is for this reason that practically all workers on larval trematodes, who have carried on their investigations in a particular locality over a long period, have noted the irregular appearance of certain species of cercariæ. In some cases the fluctuations are seasonal. This occurs, for example, when the final host visits the locality regularly, at comparatively long intervals, and when the trematode is common. More often there is no regular seasonal fluctuation ; this applies particularly to marine or brackish water species, where the parasites are either always present to a greater or lesser degree or very sporadic in their appearance. Many other factors, such as climate, the drying up of pools, the concentration of mineral salts in the water, changes in vegetation and the fluctuations in the numbers of the intermediate host can affect the trematode fauna of a snail population, but there is no doubt that the percentage of infection of the snails is more closely linked with the movements of the final host than with any other factor.

A number of authors have agreed with the suggestion put forward by Kemp and Gravely (1919) that immature snails are probably immune to infection. Although this may be true of some species, it does not apply to *Peringia ulvæ*. This species can become infected before it reaches 1 mm. in length and the gonads do not ripen before it attains 2¾–3 mm. At this early age (1 mm.) the infections themselves must of necessity be very young and have not had time to develop. They are difficult to find, and doubtless many infections have been overlooked at this stage.

The longer a snail survives, the greater are its chances of becoming infected. Consequently the young stages will be the least heavily parasitised.

Roughly, three types of infections were found in the samples from Plymouth, which departed from the average 0·5 to 2% infection.

(1) Example. *Cercaria oocysta* Lebour, 1907. Common at all times of the year. This indicates an indigenous final host (or hosts), and the final stage of the parasite is probably of frequent occurrence.

(2) Example. Cercaria near *Cercaria lophocerca* Lebour, 1907 (non Fil.). Common in some samples and completely absent in others. This indicates the sudden appearance of the final host in large numbers—a flock of birds or shoal of fish—or possibly the appearance of the second intermediate host in large numbers, and the subsequent infection of the final host, on a large scale.

(3) Example. Cercaria near *C. sagittarius* Sinitzin, 1911. Very rare, 1 per 2,000. This indicates a scarcity of hosts, an accidental infection, or a rare parasite.

The risk of exposure to miracidia is different in all these cases and in consequence affects the percentage of infection per age group. For example, if a random sample of Peringia were examined three weeks after the sudden exposure to a heavy infection of one of the sporadic species, a larger number of small individuals would be found to be infected than is usually the case. If, however, a period of a few months had elapsed, the small individuals of the sample which had metamorphosed and since settled among the population previously exposed, would be quite free from infection.

In the case of one of the very rare species the time factor—i.e. the increasing chances of infection with age—operates more noticeably than in the case of a fairly common species.

Another point which cannot be entirely disregarded is a possible difference in behaviour of young and old snails. Under laboratory conditions no such difference was observed; moreover the cysts of the "Ephemera" group of cercariæ were found equally frequently on the shells of large and small individuals. If, however, in the wild, recently metamorphosed snails were inclined to remain buried in the mud, they would presumably come less into contact with free swimming miracidia, and more frequently with the type of miracidia which never hatches, but is ingested within its egg capsule.

THE TYPES OF TREMATODE INFECTION FOUND IN *Peringia ulvæ* AT PLYMOUTH.

Almost every group of larval Trematodes differ in some manner in their mode of reproduction within the snail. For the requirements of this study it is only necessary to consider the broad distinctions.

Group 1. Cercariæ requiring a second intermediate host, produced in sporocysts. Primary seat of infection : the gonads.

Example : " Ubiquita " group.

Group 2. Cercariæ encysting within their sporocysts in the first host. Primary seat of infection : the gonads.

Example : " Oocysta " group.

Group 3. Cercariæ developing in rediæ from which they escape directly into the open and seek a second intermediate host. Primary seat of infection : the interlobular spaces of the liver.

Example : " Echinostomum " Group, and " Pleurolophocerca " Group.

Group 4. Cercariæ developing in rediæ, which escape from them into the tissues of the host, where they continue developing before leaving the snail to encyst in the open. Primary seat of infection : the interlobular spaces of the liver.

Example : " Metentera " Group. " Ephemera " Group.

In Group 1, the daughter sporocysts appear to produce cercariæ indefinitely, multiplying themselves meanwhile by transverse fission. No infection was ever found to die down, however long the snail survived. In Group 2, when the infection reaches a certain age the sporocysts degenerate and hundreds of encysted cercariæ remain, packed tightly together, apparently occupying the entire spire of the shell. Only one infection which had actually reached this stage was found, but many have been noted in which the process was clearly taking place.

Group 3 is characterised by very large daughter rediæ which produce large members of cercariæ simultaneously. No dying down of an infection has been noted in this group.

The daughter rediæ of Group 4 are smaller and less numerous, a condition which may have evolved together with post-redial development of the cercariæ in the tissues of the host. Two infections of *Cercaria ephemera* Lebour, 1907 (non Nitsch) have been found which appeared to be waning. Only one old, empty redia was noted and a few cercariæ in the tissues.

OUTSTANDING FEATURES OF THE INFECTIONS AT PLYMOUTH.

The most striking general features were (1) the lightness (only a few rediæ producing cercariæ) of the infections belonging to Groups 3 and 4,* generally found in medium-sized shells, and absent in the largest size group, (2) the very high percentage of infection of the largest size group of snails (see Tables II and III) with the common species of cercariæ of Groups 1 and 2, and the heaviness of these infections.

TABLE II.

SAMPLES OF *Peringia ulvæ* FROM PLYMOUTH, 1934–1935.

Size group in mm.	Number of snails dissected.	Percentage of infections of cercariæ developing in rediæ (Groups 3 and 4).	Percentage of infections of cercariæ developing in sporocysts (Groups 1 and 2).
1 mm.	200	1	0·5
2 mm.	400	1	1·5
3 mm.	400	1	2·5
4 mm.	400	7	9
5 mm.	100	1	50
5+ mm.	25	0	100

TABLE III.

SAMPLE OF *Peringia ulvæ* (OF 3 MM. AND OVER) FROM PLYMOUTH, JUNE, 1935.

Size group in ¼ mm.	Percentage of infections of cercariæ developing in sporocysts.	Percentage of infections of cercariæ developing in rediæ.
3 mm.	2	0
3¼ mm.	2	2
3½ mm.	4	0
3¾ mm.	2	2
4 mm.	6	2
4¼ mm.	4	2
4½ mm.	8	4
4¾ mm.	18	0
5 mm.	50	1
5¼ mm.	100	0

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* Except cercaria near *C. lophocerca*, Lebour. This species, which was common in some samples (3% infection), showed fairly heavy infections and was most frequently found in snails of 4¾ mm. size-group. It was also recorded from one snail of 5 mm.

The lightness of the infections of cercariæ of Groups 3 and 4 appears to be due to their age. These species are comparatively rare. The chances of a snail becoming infected in the young stages would be small, and those infections in the older snails would have had a correspondingly short time in which to develop. There are also numerous very young rediæ in the infections. Moreover, if kept for a sufficiently long time, these infections ultimately become very heavy.

A possible alternative explanation was the supposition that a host in an estuarine environment was unsuitable for the development of the trematode, which failed to attain the usual degree of fertility—but comparison with the same species from Scotland proved this to be incorrect.

The heaviness of many of the infections of *Cercaria oocysta* and *C. ubiquita* is likewise accounted for by the incidence of their occurrence. The snails become infected at an earlier age with these common parasites, and the sporocysts have time in which to develop and reproduce.

The incidence of infection, however, cannot account for the peculiar phenomenon mentioned above—that the few snails per thousand which attain a height of 5–5¼ mm. show a 75% infection with these species, and that the infections in question are all of long standing. The evidence suggested that the parasites themselves were closely linked with, and probably responsible for, the size of the snails. This theory was enhanced by the fact that the primary seat of infection of *C. oocysta* and *C. ubiquita* is the gonads. Partial or complete castration which results must seriously affect the metabolism of the host.

COMPARISON OF INFECTION OF PLYMOUTH *Peringia ulvæ* WITH SAMPLES FROM SCOTLAND.

Lebour (1911) and Quick (1920) have recorded much higher incidence of infection in *Peringia ulvæ* from Scotland and Swansea Bay. In collected samples the tendency is to select the larger snails which would account for a somewhat higher percentage of infection than that recorded for a random sample which includes very young snails. The discrepancy was too large to be explained in this manner and consequently an effort was made to obtain samples of *Peringia ulvæ* where the proportion infected reached at least 50 per cent, and to compare the size of the snails with those from Plymouth.

Mr. Richard Elmhirst and Dr. Edith Nicol kindly supplied collected samples from different localities in Scotland. With one exception these more or less agreed, both in size and the degree of infection, with *Peringia ulvæ* from Plymouth. The largest snails measured 5 mm. or a little less in height, and the percentage of infection ranged from 10–20%. The sample from Millport, however, displayed a most striking departure from the norm. The percentage of infection was 90 and numerous snails* reached the relatively colossal size of 8–9 mm. in height (Figs. 1 and 2).

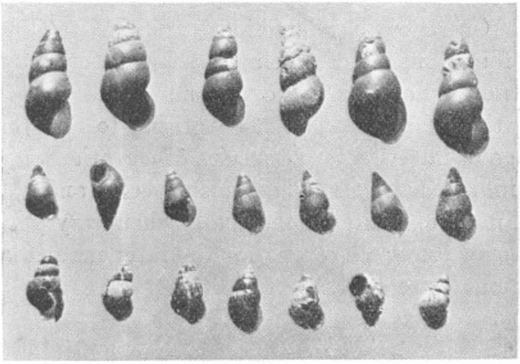

FIG. 1.

Upper row: Living specimens of *Peringia ulvæ* from Millport, showing gigantism and abnormal development of the shell.
Middle row: Living specimens of *Peringia ulvæ* from Plymouth.
Bottom row: Living specimens of *Peringia ulvæ* from near St. Andrews.

All the snails were chosen from the larger size groups of each sample. All × 2.

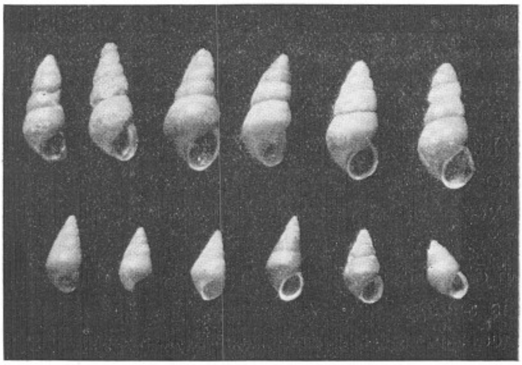

FIG. 2.

Upper row: Living specimens of *Peringia ulvæ* from Millport.
Lower row: Living specimens of *Peringia ulvæ* from Plymouth.

All the snails were chosen from the larger size groups of each sample. All × 2.

The shells in many cases displayed variations and abnormalities such as "ballooning" of certain whorls and asymmetrical development of the spires. The thickness of the shells appeared normal.

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* A few of these were kindly submitted to Mr. F. Taylor by Major M. Connolly, who identified them as "varieties of *Peringia ulvæ*." A small series is deposited at the British Museum (Natural History) together with samples from Plymouth.

The infections which included all four groups mentioned on p. 540 were all very heavy and obviously of long standing in the large shells. Thus in the " Echinostomum " group, the rediæ had attained twice the length of those of the same species from Plymouth. Several dozen were present in each snail. On the whole, infections of Group 4 (*Cercaria ephemera* Lebour) were found in smaller specimens than the other groups.

There were no uninfected snails over 5 mm. in height.

Considering these facts it was not surprising to find that despite the high percentage of infection fewer species of cercariæ were found in this sample. The infections were all of common species, and in most cases the miracidia had no doubt entered the snails when very young; thus the competition would prove too strong for the rarer miracidia which would fail to find an uninfected host.*

INFECTED *Peringia ulvæ* IN THE LABORATORY.

Specimens of *Peringia ulvæ*, emitting *Cercaria ubiquita* and cercaria near *C. lophocerca*, Lebour, were isolated and kept well fed on Zostera in the laboratory for six months. They reached a size of 5–5¼ mm. Isolated non-infected individuals kept under similar conditions did not attain these dimensions. A small sample of snails were kept together in one jar, and at the end of six months the surviving individuals were examined. One specimen only measured over 4¾ mm. This proved to be heavily infected with a cercaria of the " Metentera " group. The other snails harboured no parasites.

A few experiments were made to test the effect of starvation on host and parasite. One hundred snails from Millport, all heavily infected, were enclosed in an empty bottle for three weeks, and subsequently placed in water. All proved to be alive and large numbers of cercariæ emerged immediately.

One specimen of *Peringia ulvæ* emitting *C. ubiquita* was kept in water for four months and starved periodically for 2–14 days consecutively. Cercariæ emerged at intervals throughout. The snail measured 5 mm. when it was isolated and increased in bulk and in length by ¼ mm.

A study of the behaviour and external appearance of *Peringia ulvæ* infected with trematodes gives the impression that parasite and host are perfectly adapted to each other. However, examination of the tissues of the host show serious injury and pathological changes like those described by Faust (1920), Agersborg (1924), Dubois (1929) and Rees (1934) in their studies of the histology and cytology of infected snails. In the case of old infections castration is complete and the digestive gland reduced to a remnant. It is difficult to understand how the snail survives at this stage.

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* No double infections were ever recorded from *Peringia ulvæ*.

Discussion.

A great number of workers on Trematode larvæ have recorded an apparent relation between the age of the mollusc host and the degree of infection. It is accepted as a general rule that the larger snails, which have been presumed to be the oldest, are more frequently infected than smaller specimens.

To account for this Kemp and Gravely's theory of the immunity of immature snails has been tentatively accepted, and the more rapid growth of gastropod snails after three months of age (Sewell, 1922) is considered a contributing cause to the higher infection of larger individuals.

Only three exceptions to this rule have been recorded (Sewell, 1922; Dubois, 1929) but unfortunately no details of the infections are given.

Wesenberg-Lund (1934) was the first to point out that infected snails are sometimes abnormally large. He receives the credit of originally suggesting that their large size was not indicative of their age, but was due to the presence of the parasites which "cause excessive growth, not the opposite as might perhaps be expected." He also noted ballooning of certain whorls, thinning and corroding of the shells, and colour changes.

He attributed this increase in size to the fact that infected snails ingest abnormally large quantities of food in order to satisfy the demands of the parasites.

The observations on *Peringia ulvæ* strongly support the view of Wesenberg-Lund that parasitism is responsible for an abnormal increase in the size of the host, although it seems more likely that this is brought about by the destruction of the gonads and other glands rather than in the manner suggested by him.

The variation in the shell and asymmetrical development of the spire is probably due to the pressure exerted by the parasites from within.

Such a high percentage infection as displayed by the Millport sample of *Peringia ulvæ*, and the resulting variation in the shells, suggests that the presence of larval trematodes is a factor which cannot be overlooked by conchologists describing local races and "phases" as well as individual varieties.

ACKNOWLEDGMENTS.

My best thanks are due to Major M. Connolly for the great trouble he has taken identifying various samples of snails, to Mr. Richard Elmhirst and Dr. Edith Nicol for sending samples from Scotland, and to Mr. A. E. Lambert for taking the photographs.

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Notes on the Eggs and Larvæ of Some Plymouth Prosobranchs.

By

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With Plates I—III.

The following short descriptions of several of the eggs and larvæ of Plymouth prosobranchs, hitherto unknown or imperfectly known, are brought together, although many of them are not fully worked out. It is hoped in the near future to publish a general account of the British species with reference to all known forms, including those which have been specially described from Plymouth.

Some of those described below have not yet been identified, but it is thought that it is worth while noting them for the benefit of future workers, especially some striking forms, important in the plankton on account of their size. This is notably the case with the three larvæ probably belonging to the Turridæ.

Family **TROCHIDÆ.**

Calliostoma zizyphinum (L.).

(Plate I, Figures 1–5.)

Robert (1902) has described briefly the spawn and young of this species. It has spawned twice in the Plymouth tanks, the second time the young hatching out and living for some weeks, although not growing to any great size. Eggs laid June, 1915, and June, 1934, in a long gelatinous ribbon, several inches long and 3 or 4 mm. broad, attached at intervals to the glass of the aquarium and part of it floating. Inside the ribbon are numerous yellowish eggs irregularly arranged, each 0·25 mm. to 0·28 mm. when newly laid, covered by a thin membrane, and floating in a nutritive layer in the egg covering, the latter surrounded by a thick layer of jelly, which, originally spherical, by pressing against its neighbour becomes more or less polyhedral (Plate I, Figs. 1, 2). A micropyle is present in the egg-covering of the unfertilised egg. Fertilisation is usually regarded as external, but the second specimen, taken from the tank and placed in a bowl whilst depositing its spawn, continued to lay eggs which developed into crawling young. In two days the developing larvæ had spiral shells of about $1\frac{1}{4}$ whorls and a round velum in front of, and dorsal to, the foot (Plate I, Fig. 3). Egg covering at this stage about 0·4 mm. across. The velum is soon lost and the young emerges, shell 0·32 mm. across, the first whorl and a quarter ornamented with sunken polygonal pits, the edge beginning to be longitudinally striated. The velum has disappeared, front tentacles, eyes and two pairs of lateral tentacles well developed (Plate I, Fig. 4). As the shell grows the sculpture of the shell consists of large sunken areas, at first rounded, then elongated and oblong. Although living for about three weeks the young did not grow much more.

The young of a closely related form, probably Cantharidus sp., was found in the crawling stage, shell 0·50 mm. across. This resembled *Calliostoma zizyphinum* closely, but the older part of the shell was marked with simple striations and there was only one pair of lateral tentacles (Plate I, Fig. 6). Robert (*op. cit.*) has shown that the species of Cantharidus (as Trochus) lay their eggs in gelatinous masses, much more compact and smaller than those of Zizyphinus (=Calliostoma), and that the young also hatch in the crawling stage.

Family **RISSOIDÆ.**

Genus CINGULA.

Sub-genus *Parvisetia.*

Cinqula fulgida (J. Adams) = *Parvisetia fulgida* of Plymouth Fauna 1931.

(Plate I, Figure 7.)

This species is now found to be very common among seaweeds and corallines on our coasts. Breeding recorded and described here for the first time. Eggs laid singly in small tough spherical capsules attached to corallines by a small portion of the surface. Capsule 0·32 mm. across (Plate I, Fig. 7) ; newly laid egg 0·14 mm. across, enlarging as the animal develops. Hatches in the crawling stage when the small shell is about 0·16 mm. across, dark brown. The capsule, egg and young are very similar to those of *Barleeia unifasciata*, but very much smaller and the young can always be distinguished by its light yellowish brown operculum, that of *B. unifasciata* being red (see Lebour, 1934 a).

Sub-genus *Cingula.*

Cingula cingillus (Montagu).

(Plate I, Figures 8–10.)

Lives in large numbers under stones below the Laboratory, usually just above high-water mark where there is a good deal of moisture and occasional submergence, sometimes below. Both the type and the uncoloured variety are equally common, living together. Breeding recorded and described here for the first time. Eggs laid in captivity in glass bowls with stone, in very narrow cracks and crevices in the stones. Capsules of the typical lens-shape of the rissoids, but only contain one to, rarely, four eggs. Capsule 0·64–0·72 mm. across (Plate I, Fig. 8); newly laid eggs about 0·16 mm., covered with a thin membrane and floating in a nutritious fluid. Young emerge in the crawling stage having passed the veliger stage within the capsule. Newly hatched young 0·48 mm. across with 2½ whorls (Plate I, Fig. 9–10). Not more than two larvæ were seen in one capsule and usually only one. Shell brownish, except in the colourless variety when it is a dirty white; operculum yellowish. Breeding March. One specimen laid an egg capsule in the dead shell of one of its own species.

Genus ALVANIA.

Sub-genus *Manzonia*.

Alvania crassa (Kanmacher).

(Plate I, Figures 11, 12.)

Egg capsules not yet known. Newly hatched larva and later stages common in the plankton, usually in summer and autumn, rarely in spring, occurs both inside and outside. This larva is described and figured as "unknown rissoid" (Lebour, 1934, a, pp. 529–538, Pl. IV, Figs. 8–10). Youngest larva seen, probably newly hatched, about 0·10 mm. across shell which has spiral sculpture with irregular lines in between. After the first whorl and soon after hatching the top of the whorl is unsculptured, the periphery with dots forming irregular spiral striæ. Whorls somewhat more scalariform than most of the older rissoid larvæ (Plate I, Figs. 11, 12), the embryonic shell of about 2½ whorls being longer and narrower, about 0·48 mm. high when ready to metamorphose. Animal colourless or yellowish. Before metamorphosis there is brown pigment at the base of the the foot which disappears. The embryonic whorls with the characteristic sculpture of the first one show plainly on an adult specimen reared in a plunger jar from a late planktonic larva, but the sculpture is usually rubbed off in adults collected in their natural habitat (apparently they live on sandy bottoms in shallow water) and it is therefore impossible to identify the larvæ by the sculpture of the adult whorls except by rearing.

Lovén (1839) described and figured the first recognisable rissoid larva (a late stage with a large velum and several whorls) which he attributed to the present species (*Rissoa costata*). This might be, however, from the figure, any typical rissoid which remains as a veliger for some time, and it resembles *R. parva* more closely than *A. crassa* now described. Simroth (1911) reproduces Lovén's figure in "Nordisches Plankton" which at that time appeared to be the only late rissoid larva known.

Sub-genus *Turboella.*

Rissoa sarsii Lovén.

(Plate I, Figure 13.)

It has already been shown (Lebour, 1935) that the planktonic egg capsules attributed to this species in a former paper (Lebour, 1934 a, pp. 533–536, Pl. I, Figs. 2–8) do not belong to it but to *Littorina neritoides*. The true eggs of this species have now been seen, for adults reared in plunger jars from the late larvæ laid egg capsules on weeds (October), the late larvæ having been obtained in April. The capsules, 0·48 mm. across, laid on the sides of glass aquaria and on weeds were of the typical rissoid form (Plate I, Fig. 13). They were quite colourless, with thick walls, and about 0·18 mm. high, containing from 10 to 14 eggs, each egg about 0·09 mm. across. Larvæ in all stages are described in the previous paper where it is shown that the very young larvæ serve as an important food for the larval herrings in winter.

EXPLANATION OF PLATE I.

FIGS. 1–5.—*Calliostoma zizyphinum.*

1. Portion of egg ribbon.
2. The same more highly magnified.
3. Veliger inside egg covering.
4. Newly hatched young, much magnified, 0·32 mm.
5. Shell of slightly older young 0·40 mm.

FIG. 6.—*Cantharidus* sp.? Crawling young soon after hatching 0·5 mm. across.

FIG. 7.—*Cingula fulgida.* Egg capsule with developing egg 0·32 mm. across.

FIGS 8–10.—*Cingula cingillus.*

8. Egg capsules with newly laid eggs, capsule 0·72 mm. across.
9. Egg capsules with developed young nearly ready to hatch.
10. Shell of newly hatched young 0·64 mm. high.

FIGS. 11, 12.—*Alvania crassa.*

11. Late larvæ, shell 0·32 to 0·48 mm. high, showing under surface of foot.
12. Apex of adult shell, showing typical sculpture.

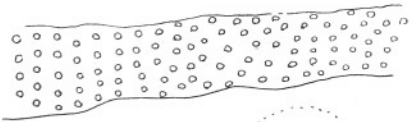
FIG. 13.—*Rissoa sarsii.* Egg capsules 0·48 mm. across.

FIGS. 14, 15, 16. *Tornus subcarinatus.*

14. Young veligers.
15. Shell of some more highly magnified.
16. Metamorphosed animal 0·48 mm. across.

FIG. 17.—*Rissoella diaphana.* Egg capsules 0·48 mm. long and newly hatched young, shell 0·24 mm. across.

PLATE I.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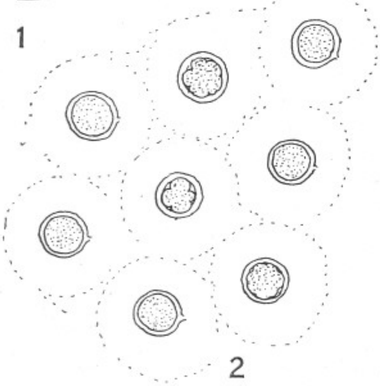
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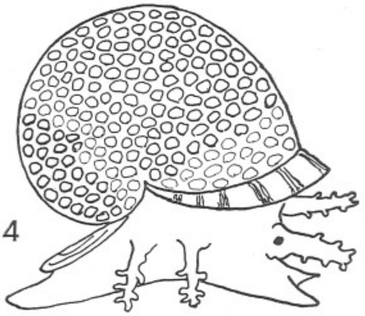
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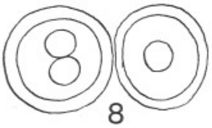
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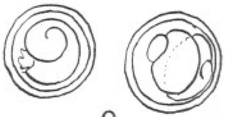
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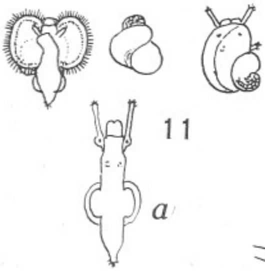
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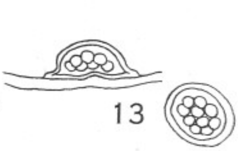
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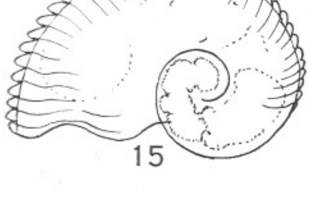
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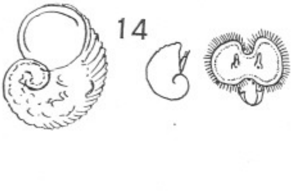
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Family **TORNIDÆ.**

Genus TORNUS.

Tornus subcarinatus (Montagu).

(Plate I, Figures 14–16.)

Adults very local on rocks between tide marks. Larvæ common in the inside plankton at Plymouth in summer. Eggs unknown. Larvæ described here for the first time. Smallest veligers seen about 0·16 mm. across shell with bilobed velum, shell smooth. At the beginning of about the second whorl there are conspicuous ridges which appear in side view as knobs round the periphery (Figs. 14, 15). Shell very flat with almost circular aperture; velum colourless; animal very dark. Late larva, about 0·48 mm. across shell, metamorphosed in bowl, showing the peculiar and characteristic bilobed pallial tentacle (Fig. 16). No eyes could be seen in the metamorphosed larva.

Family **RISSOELLIDÆ.**

Genus RISSOELLA.

Rissoella diaphana (Alder).

(Plate I, Figure 17.)

Common in the rock pools round about Plymouth among weeds on which it deposits its eggs which were also laid in captivity. Jeffreys (1867, IV, p. 60) states that " the spawn deposited by one individual consisted of only two ova, which are enclosed in a hemispherical case." The Plymouth specimens agree with Jeffreys' description. Capsule hemispherical, thick-walled, 0·48 mm. long and about 0·25 mm. broad, attached by the flat base to green or red algæ, each with one or two eggs about 0·2 mm. across covered with a thin membrane, albuminous layer and egg covering, and floating in a fluid within the capsule. Young emerge in the crawling stage, having passed the veliger stage within the covering. Shell of newly hatched young about 0·24 mm. across, light brown, transparent; animal with two pairs of tentacles already developed and a conspicuous black patch dorsally on the left side, resembling in appearance the primitive kidney of the Opisthobranchs. Young in all stages to be found crawling among the weeds in summer.

This species is a new record for Plymouth.

Family **CÆCIDÆ.**

Genus CÆCUM.

Cæcum imperforatum (Kanmacher).

(Plate II, Figures 1–5.)

Occasionally dredged in the Plymouth neighbourhood, but must be abundant as its larvæ are common in summer and autumn plankton. Owing to its small size the adult is probably overlooked. Mr. D. P. Wilson found two live specimens in dredgings on fine sandy mud from the Eddystone grounds, 1·2 mm. long (Figs. 4, 5). The apex of the young shell is spiral and this always breaks off in the adult leaving a flat top filled in by a shelly mass. Veligers in inside and outside plankton, with about 2½ whorls to the spiral planorbiform shell (Fig. 3), body whorl beginning to uncoil and aperture round, 0·32 mm. across. Animal with yellowish digestive gland and purple near the head. Velum bilobed, with purple at the sides (Fig. 1). Metamorphosed in a bowl, losing the velum and crawling. Operculum very thick.

Family **CERITHIIDÆ.**

Genus BITTIUM.

Bittium reticulatum (Da Costa).

(Plate II, Figures 6–8.)

Meyer and Möbius (1872) have described and figured the spawn on a flat slimy spiral coil, *ca.* 3 mm. across. Lo Bianco (1888, p. 417) describes it as a white ribbon irregularly folded on itself, breeding January, May. Such an egg mass was collected by Mr. F. S. Russell from 2 miles off St. Ives, in July, 1935. It almost certainly belongs to this species, ribbon *ca.* 24 mm. long, doubled twice on itself, and 0·48 mm. wide, containing round masses *ca.* 0·32 mm. across of very opaque eggs, causing the whole to appear white. Veligers almost certainly belonging to this species are common in the Plymouth plankton, usually inside, occasionally outside, in spring and summer, the shells corresponding well with the adult apex (Fig. 8). Late larva (Figs. 6, 7) with pale horn-coloured shell, smooth, with 2½ whorls, loosely coiled, the whorls much rounded; outer lip produced into a large process as in the other known larvæ of the family. Velum colourless. Metamorphoses when shell is about 0·32 mm. high.

Genus CERITHIOPSIS.

Cerithiopsis tubercularis (Montagu).

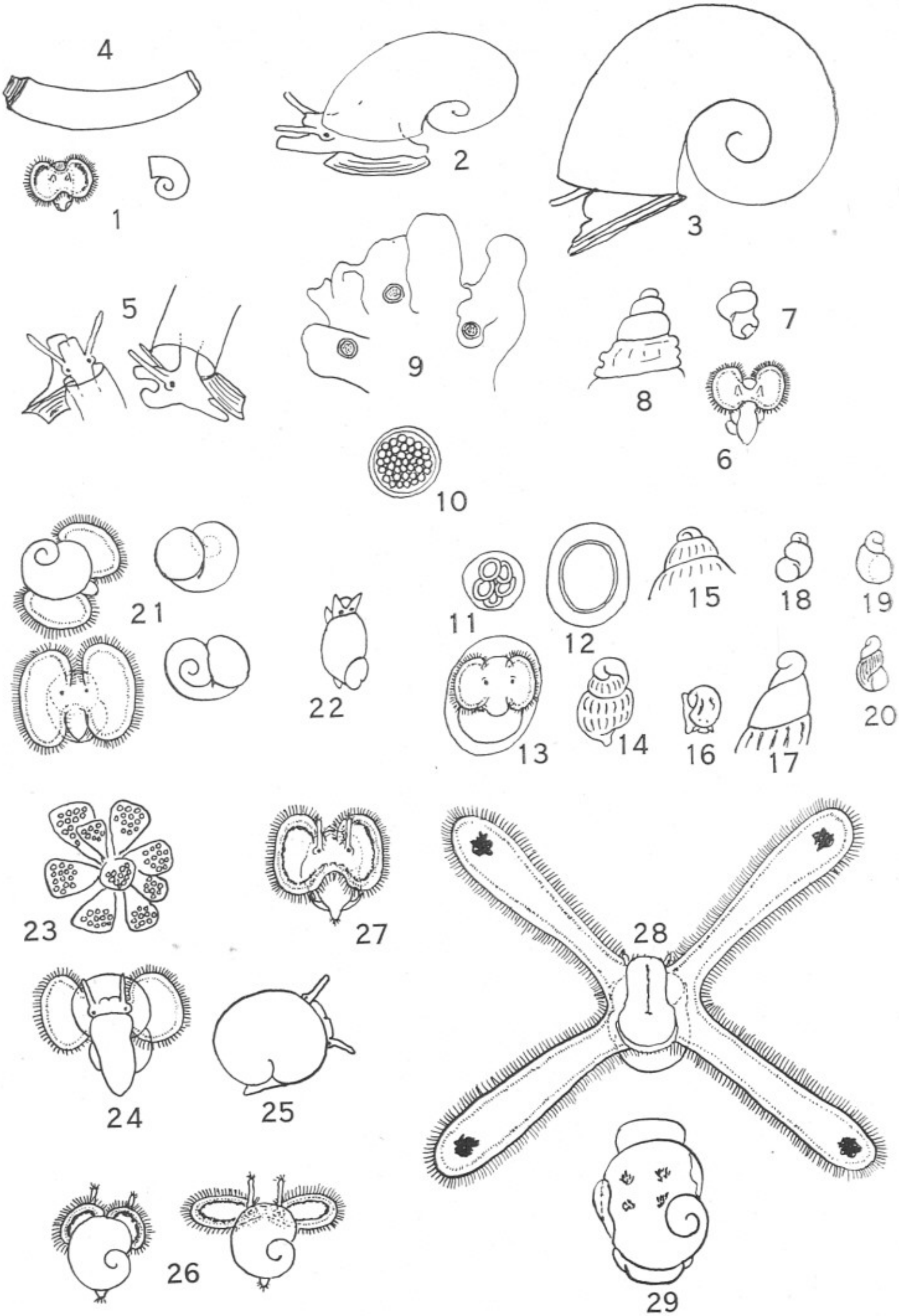
(Plate II, Figures 9–10.)

The larvæ have already been described (Lebour, 1933). The eggs have now been obtained from the parent in captivity. This species lives commonly at Plymouth among sponges, especially *Hymeniacedon sanguineum* in the Sound. Holes were bitten in the sponge and the eggs laid in little nests, looking very white from the opacity of the eggs.

EXPLANATION OF PLATE II.

FIGS. 1–5.—*Cœcum imperforatum.*
  1–2. Larvæ from plankton, shell 0·32 mm. across.
  3. Newly metamorphosed animal.
  4–5. Adult, 1·2 mm. long.
FIGS. 6–8.—*Bittium reticulatum.*
  6. Planktonic veliger, shell 0·32 mm. high.
  7. Shell of same.
  8. Apex of adult *Bittium reticulatum.*?
FIGS. 9, 10.—Eggs of *Cerithiopsis tubercularis* on Hymeniacidon.
  9. Capsules laid in sponge.
  10. Capsule more highly magnified, 0·35 mm. across.
FIGS. 11–15.—*Chrysallida decussata.*
  11. Egg capsule, 0·35 mm. across.
  12. Egg from same, 0·12 mm. long.
  13. Developing larva.
  14. Young shell, crawling, 0·48 mm. high.
  15. Apex of adult.
FIGS. 16–17.—*Turbonilla elegantissima.*
  16. Crawling young 0·25 mm. across.
  17. Apex of adult.
FIGS. 18–22.—Various planktonic larvæ of the *Pyramidellidæ.*
  18. (*a*) 0·32 mm. long.
  19. (*b*) 0·32 mm. long.
  20. (*c*) 0·35 mm. long.
  21. (*d*) 0·56 mm. across.
  22. (*e*) 0·5 mm. long.
FIGS. 23–25.—*Calyptrœa chinensis.*
  23. Cluster of egg capsules from under parent shell, 7 mm. across.
  24. Veliger taken from capsule.
  25. Newly hatched young, 0·64 mm.
FIGS. 26, 27.—*Natica catena.*?
  26. Two views of late larva, shell 0·5 mm.
  27. Late larva beginning to metamorphose, shell 0·5 mm.
FIGS. 28, 29.—*Natica poliana.*?
  28. Late veliger, shell 0·8 mm.
  29. Metamorphosed young, shell 0·9 mm.

PLATE II.



Egg capsule 0·35 mm. across, laid at wide intervals in the sponge. Egg about 0·03 mm. across (Figs. 9 and 10).

Family **PYRAMIDELLIDÆ.**

As all the members of this family have a reversed apex but a dextral animal the veligers are easy to recognise in the plankton. All whose larvæ are known hatch in the free-swimming stage and many veligers occur in the Plymouth plankton, only few of which can be attributed to the adults. All these have a colourless and transparent shell, smooth at the apex. The eggs which are known are either enclosed in an irregular gelatinous mass (as in *Odostomia eulimoides*) (see Lebour, 1932) or in small lenticular capsules. The eggs, each covered by a thin membrane and enclosed in an egg covering with a very thick albuminous layer, float together in a fluid enclosed by the capsule. As so little is known of the breeding and larval stages of the members of this family, the few instances given below are worth recording.

Genus CHRYSALLIDA.

Sub-genus *Parthenia.*

Chrysallida decussata (Montagu)=*Pyrgulina decussata* of Plymouth Fauna 1931.

(Plate II, Figures 11–15.)

Adult fairly common dredged in the outer grounds. Eggs laid in May on the glass of a plunger jar in very thin-walled lens-shaped capsules, 0·24 to 0·35 mm. across, attached by the lower flat surface to the glass. Four to eight eggs in each capsule (Plate II, Figs. 11, 12), transparent, each egg 0·09 to 0·12 mm. long, oval. Young nearly ready to hatch with sinistral, colourless, and transparent shell of about 1½ whorls, bilobed velum (Plate II, Fig. 13). Young shells (Plate II, Fig. 14) sometimes found in the plankton with sculpture of lower whorls showing that metamorphosis probably takes place when the shell has about 2 to 2½ whorls, when it becomes dextral.

Genus TURBONILLA.

Turbonilla elegantissima (Montagu)=*T. lactea* in Plymouth Fauna 1931.

(Plate II, Figures 16, 17.)

The crawling young found with the adult are very small, 0·25 mm. across the shell which is already dextral, therefore the free-swimming stage, probably present, must be very short. Eggs unknown. Adults common in the Sound, dredged from muddy ground with stones.

Several different planktonic larvæ with sinistral apices belonging to this family are found at Plymouth. Some of these, not at present identified with any species, are here figured and denoted *a* to *e* (Plate II, Figs. 18–22).

(*a*) Smooth shell, 0·32 mm. long, *ca.* 3½ whorls, colourless and transparent, velum bilobed. From inside Sound (Fig. 18).

(*b*) Very similar to (*a*) but probably a different species, with a rounder body whorl. Smooth shell, *ca.* 0·32 mm. long, *ca.* 3½ whorls, colourless, transparent, velum bilobed. From outside plankton (Fig. 19).

(*c*) Shell 0·34 mm. long, *ca.* 3½ whorls, third whorl finely striated longitudinally, brown digestive gland, dextral but with sinistral apex, bilobed velum. From station E1, 14 miles beyond Plymouth Breakwater (Fig. 20).

(*d*) Shell 0·56 mm. across, 2½ whorls, broad, sinistral, colourless except for a brownish internal lip by the columella. Animal colourless with large colourless bilobed velum. This is the commonest larva of the family at Plymouth, occurring inside the Sound spring, summer and autumn. Metamorphoses with 2½ whorls when the shell becomes brownish and dextral (Fig. 21).

(*e*) Crawling young from inside the Sound, shell smooth, 0·5 mm. long, with hardly more than two whorls. Very little sinistral apex showing. Colourless shell and animal. From inside the Sound on mud (Fig. 22).

Family **CALYPTRAEIDÆ.**

Calyptræa chinensis (L.).

(Plate II, Figures 23–25.)

The eggs of this species are well known, described by Milne-Edwards (1832), Lo Bianco (1888) and Fischer (1892), the last figuring them. The triangular capsules (Plate II, Fig. 23) are covered by the front part of the parent shell until they hatch in the crawling stage. Capsules fixed in a bunch by their narrow ends to a stone or shell, transparent and colourless, 3 to 3½ mm. long, containing about 12 to 25 eggs, each egg about 0·48 mm. across, with thin membrane and all floating in a fluid within the capsule, usually the eggs are concentrated at the broad end. A veliger stage with large bilobed velum is passed within the egg (Fig. 24) and the velum disappears before hatching, the young hatching when the shell is about 0·64 mm. across with 1½ whorls, whitish, with colourless or yellowish animal. The embryonic shell shows clearly in the adults, which are very common at Plymouth in shallow water among stones and shells.

Family **NATICIDÆ.**

Genus NATICA.

Sub-genus *Lunatia*.

Two larvæ belonging to Natica are important in the Plymouth plankton, representing *Natica catena* and *N. poliana*, both occurring commonly in spring and summer. Only these two species are recorded from Plymouth, but it is not absolutely certain which larva belongs to which species as they have not been reared until a late enough stage for absolute identification. It is, however, almost certain that the smaller of the two belongs to *N. catena*, being almost wholly confined to the coastal plankton, and the larger to *N. poliana*, which is found commonly both in inshore and outside plankton. They are therefore attributed to these two with a query. *N. catena* lives on sand in coastal bays, very rarely further out, *N. poliana*, which is much smaller, has a much wider distribution and is found in coastal waters as well as on the outer grounds. Although the latter is the smaller species, the eggs are larger. Both species, like all the members of the family whose breeding is known, lay their eggs in sandy spirals, the eggs themselves being in capsules glued together in sand, the spawn of *N. catena* being a well-known object and frequently described by the older naturalists. Both the British species from Plymouth have pelagic larvæ which remain as veligers for some time. Odhner (1914) has described the spawn and veliger of either *Natica maculata* or *millipunctata* which has a well-developed veliger stage in the plankton, but hatches at such a late stage that on hatching it can both swim and crawl. Thorson (1935) has described the eggs and larvæ of three species, including *Natica grœnlandica* (which is a British species) from East Greenland, all of which hatch in the crawling stage, the veliger stage being passed within the egg.

Natica catena (da Costa).

(Plate II, Figures 26, 27.)

Although the spawn is well known, the larvæ, except those newly hatched from the egg, have not been described. The spawn coils are commonly dredged from sandy bottoms near Plymouth, usually in spring, about 130–160 mm. across, 40–45 mm. wide. Egg surrounded by a thin albuminous layer and an egg covering 0·16 mm. across, several together in a capsule surrounded by sand grains. Hertling (1932) gives a good photograph of the spawn. Ankel (1930) has described the developing eggs and young in the capsule, some of the eggs devouring the others (nurse eggs). The planktonic larva which I have assigned provisionally to this species has at first a smooth transparent shell of about

1½ whorls and a bilobed velum which is colourless but soon has a thin purple-brown border, the shell enlarging and becoming very much flattened with a wide umbilicus. Later stages have a very globular shell, large bilobed velum with a purple-brown border and yellowish white animal (Fig. 26). These larvæ somewhat resemble those of *Nassarius reticulatus* (see Lebour, 1932), but as they grow the absence of a large tooth-like process on the outer lip and of the shell siphon in Natica readily distinguishes them. Late larvæ, 0·48–0·5 mm. across, with 2½ whorls, shell globular, yellowish, foot somewhat pointed. It is now ready to metamorphose and it can both swim and crawl (Fig. 27), then loses the velum and the processes from the foot begin to come up over the shell. These larvæ are almost always found in shallow water, very rarely outside.

Natica poliana Chiagi=*Natica alderi* of the Plymouth Fauna 1931.

(Plate II, Figures 28, 29.)

This species is common both inside and outside the Sound on sandy and muddy bottoms. The spawn is frequently seen round Plymouth and was also obtained in captivity. It is in the form of a very much flattened, usually incomplete, slightly spiral ring, about 25 mm. across and 7·8 mm. wide. Hertling (*op. cit.*) has described and figured it as *N. pulchella* and also the eggs and newly hatched larvæ. Eggs 0·24–0·32 mm. across the egg covering, egg itself barely 0·16 mm. across. Hertling describes the newly hatched larva as having a four-lobed velum which makes the identification of the Plymouth veligers nearly certain. There are no nurse eggs. The later larvæ attributed to this species are larger than those attributed to *N. catena*, especially those nearly ready to metamorphose, about 0·8 mm. across (Fig. 28). At this stage they have about 3½ whorls, the form and texture of the shell being similar to the shell attributed to *N. catena*. Velum, at first small and only slightly four-lobed, becomes very large, the lobes being drawn out each with a large brown spot at the end; foot rounded behind, front squarish with a groove ventrally in front. At this stage the larva can both swim and crawl, the velar lobes when expanded being much longer than the shell, the larva being very like that of *Nassarius incrassatus*, but without the large hook-like process on the outer lip and shell siphon. It is thus interesting to find a parallel between the veligers of *Nassarius* and *Natica*, each at Plymouth represented by an inshore form (*Nassarius reticulatus*, *Natica catena*) and one which also is widely distributed outside (*Nassarius incrassatus*, *Natica poliana*), the first pair being small with a smallish bilobed or slightly indented velum, not spreading far outside the Sound, and the second pair having a very large velum with four long lobes, having a wide distribution further out.

After metamorphosis the foot lobes begin to grow up round the shell

(Fig. 29). This larva of *N. poliana* resembles the figure of a Natica larva given by Simroth (1913) in the Gastropoda in "Nordisches Plankton."

Family **MURICIDÆ.**

Genus TROPHON.

Sub-genus *Trophonopsis.*

Trophon muricatus (Montagu).

(Plate III, Figures 1–4.)

Jeffreys (IV, p. 317) describes and figures the egg capsules, but somewhat inadequately. Capsules laid in plunger jar, February to June, lens-shaped, 2·5 mm. across, transparent and colourless, attached by the flat surface to the glass, free surface rounded (Figs. 1, 2), each containing from 5 to 8 eggs, 0·48 mm. across when newly laid. Surface of capsule with small raised flecks, large thin portion near centre where the young emerge. One individual may lay from 2 to 9 capsules at intervals. Eggs develop slowly into veligers which probably lose the velum before hatching, but this is not certain as the young never hatched although they developed shells and the velum appeared to be diminishing. Shell of veliger inside egg capsule 0·64 mm. across, having a slight sculpture of dot-like spiral line s, with about $1\frac{1}{2}$ whorls (Figs. 3, 4). Adult dredged fairly frequently near Plymouth.

EXPLANATION OF PLATE III.

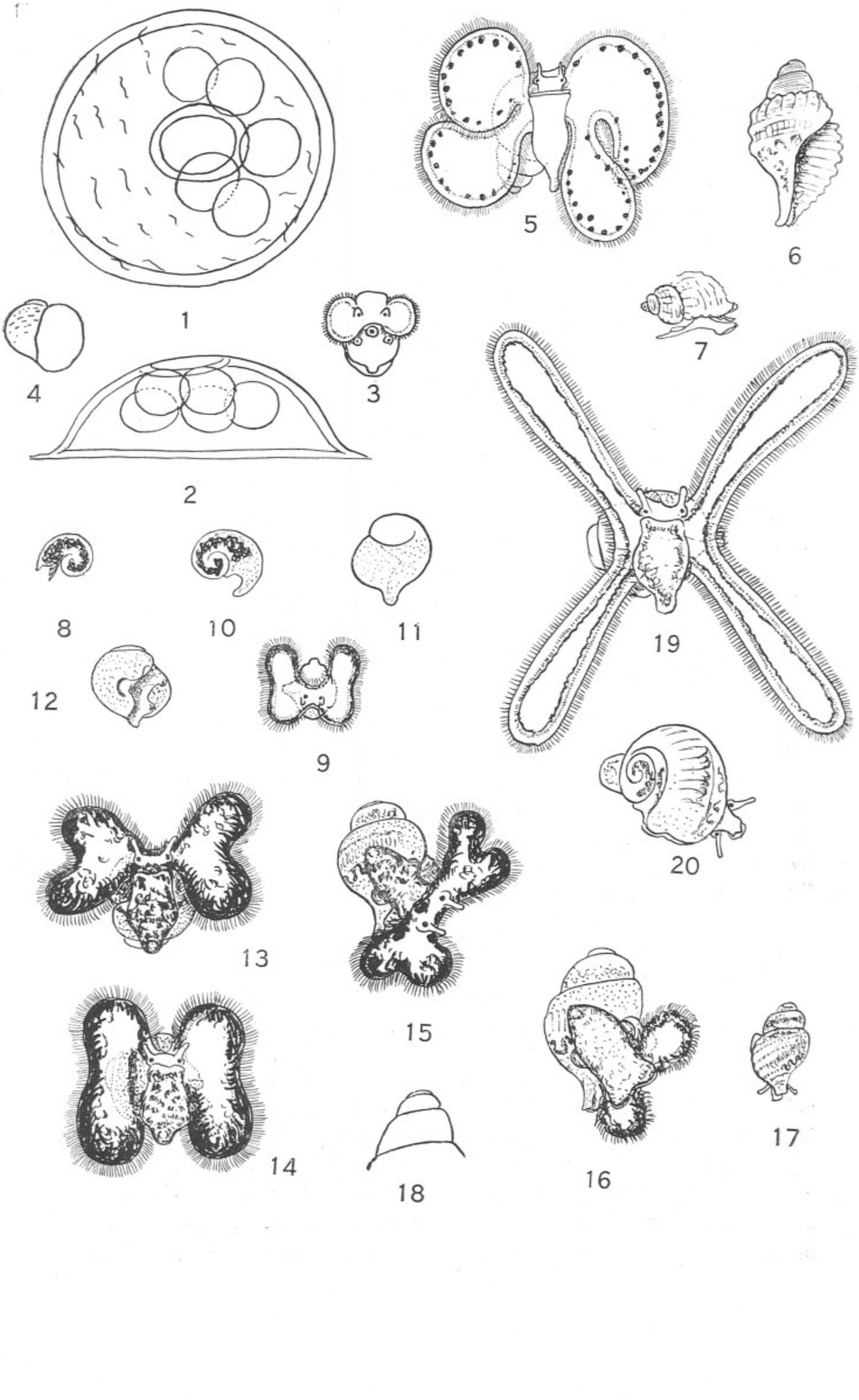
FIGS. 1–4.—*Trophon muricatus.*
- 1–2. Egg capsule, 2·5 mm. across.
- 3. Veliger still in egg, dissected out.
- 4. Shell of same, 0·64 mm. across.

FIGS. 5–7. Larva provisionally attributed to *Mangelia coarctata.*
- 5. Late veliger, shell 1·25 mm. long.
- 6. Shell of same.
- 7. The same, metamorphosed shell 1·25 mm. long.

FIGS. 8–18.—Larva attributed provisionally to *Hædropleura septangularis.*
- 8. Smallest larva, shell 0·48 mm. across.
- 9–12. Slightly older larvæ.
- 13–14. Older larvæ shell 0·8 mm. long.
- 15. Larva beginning to metamorphose, shell 1 mm. high.
- 16. Metamorphosing larva, shell 1·28 mm. high.
- 17. Metamorphosed larva, shell 1·44 mm. high.
- 18. Apex of adult shell.

FIGS. 19–20. *Unknown turrid* (cf. Lora).
- 19. Veliger, shell 1 mm. high.
- 20. The metamorphosed animal.

PLATE III.



Family **TURRIDÆ.**

The eggs and young of several of the Turridæ have already been described (Lebour, 1934 b) all of which have very conspicuous planktonic veligers remaining long in the swimming stage and all having lens-shaped egg capsules. Thorson (*op. cit.* p. 36) has, however, found in East Greenland that several species of Bela (=Lora of Winckworth's list) hatch in the crawling stage and that there are no planktonic larvæ. There are three species almost certainly belonging to this family which occur in the plankton and are peculiarly handsome and conspicuous, but have not yet been identified definitely. One of these is very similar to the larva of *Mangelia nebula* (see Lebour, 1934 b, Plate I–II), but when it metamorphosed it still retained its operculum. Now the genus Mangelia so far as is known has no operculum, although the closely related genera Hædropleura and Lora possess one. The newly metamorphosed larva of *Mangelia nebula*, described by myself, loses it directly the velum disappears. It is therefore impossible to be sure that this new larva belongs to Mangelia, especially as Vestergaard (1935) has recently described the newly hatched veligers of *Bela turricula* (=Lora of Winckworth's list) which are extremely like those of *Mangelia nebula*. It is therefore possible that this new larva belongs to *Lora rufa* the adult of which has been recently found at Plymouth, or it may belong to *Mangelia coarctata* which is fairly common and which is very like *M. nebula*. In the latter case the operculum may be lost later. It is provisionally placed as *M. coarctata*. The other two larvæ which are not identified must also remain for a long time in the plankton for those ready to metamorphose are large with powerful velum. The first of these probably belongs to *Hædropleura septangularis*, rarely found in the adult stage at Plymouth although these larvæ are fairly common in summer; the second, only one of which has ever been seen, is still absolutely unidentifiable. This is referred to as "Unknown Turrid."

Genus HÆDROPLEURA.

Hædropleura septangularis (Montagu) ?

(Plate III, Figures 8–18.)

Only one adult specimen has been found alive near Plymouth, as far as is known. This was dredged in the Sound. The apex (Fig. 18) is of much the same shape as the larvæ here attributed to this species which are fairly common in the coastal plankton, rarely further out, and which metamorphosed in captivity into a species of turrid. The youngest larva seen measures about 0·48 mm. across with about 1½ whorls, smooth shell, process from outer margin of aperture, animal very dark and bilobed velum with a very heavy brown border, of the colour of burnt sienna (Fig. 8). Slightly older larvæ have a shell canal, the shell granular on its second whorl, the process on the aperture much larger, the velum large and a still heavier brown border (Figs. 9–12). Later larvæ with shell 0·8 mm. and slightly larger have a heavily granular shell, conspicuous canal, tentacles long, foot slightly lobed behind, very dark animal including heavily pigmented grey foot and the brown of the velum very thick, spreading beyond the margin, the velum being slightly four-lobed (Figs. 13–14). The larva beginning to metamorphose has the shell about 1 mm. high, the velum beginning to dwindle, the foot with opercular lobes (Fig. 15). One with shell 1·28 mm. high had very little velum left (Fig. 16). The newly metamorphosed animal has the shell 1·44 mm. high, the operculum being retained (Fig. 17).

The chief argument against this identification is the very dark colour of the animal in all the larval stages, the adult *Hædropleura septangularis* being yellowish white. It seems possible, however, that this pigment disappears at any rate in the outer exposed parts of the animal, for in the larval Philbertias there was often grey pigment present which disappeared later.

Unknown turrid (probably belonging to the genus LORA).

(Plate III, Figures 19, 20.)

Only one specimen has been seen of this form which was a late larva and it metamorphosed in a plunger jar but did not live. From the animal it seems to be certainly a turrid, and from its smooth apex and opercular lobes to the foot it is probably a species of Lora. It is a striking form, shell about 1 mm. long, smooth with a few granular dots, colourless; conspicuous shell siphon, outer lip compressed so that the aperture is narrowed; foot roundish behind with opercular lobes; velum very large with four long lobes, each rather more than twice the length of the shell, bordered with a thin line of brown pigment. Animal greyish, not so dark as the previous species. Tentacles rather long and thin. When metamorphosed the animal siphon projected from the shell siphon. A deep channel runs below the suture from about the second whorl to the anterior corner of the aperture, causing a deep notch. From inside the Sound, July 28th, 1931.

Genus MANGELIA.

Sub-genus *Bela*.

Mangelia coarctata (Forbes) ?

(Plate III, Figures 5–7).

This larva is very like *M. nebula* but instead of having a smooth apex it is spirally striated and the animal metamorphoses at a slightly larger size. It was only seen once, a late larva, which metamorphosed in a plunger jar. For the reasons given above it is uncertain whether it really is a Mangelia, although this seems highly probable. Shell 1·25 mm. high, first whorl and a half to two spirally striated, the last with longitudinal ribs and spiral lines giving it a somewhat reticulated appearance. Shell siphon fairly long, shell pale yellowish; foot pointed, animal siphon projecting from shell; tentacles rather long; velum very large, when in action almost covering the shell, four-lobed with large brown and orange spots round the border; animal greyish. When metamorphosed the operculum is still there, but there are no conspicuous opercular lobes on the foot.

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The Development of *Audouinia tentaculata* (Montagu).

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With 12 Figures in the Text.

CONTENTS.

HISTORICAL INTRODUCTION.

LITTLE is known about the development of the Cirratulidæ. The earliest record of young stages is that of Claparède and Mecznikow who in 1868 described and figured in colour two young Cirratulid worms, one with nine setigers being ascribed to *Audouinia filigera*. It had two pairs of branchiæ, the first pair arising anterior to the first pair of bristle bundles. The other specimen belonged to a viviparous species and had been removed from the body cavity of the parent. It had five to six bristle-carrying segments, two pairs of long branchiæ, and buds of others. The species was not identified. Both types corresponded in essentials to the young Audouinia worms discussed in this paper. In 1887 Cunningham and Ramage gave an account of the spawning of *Cirratulus cirratus*. They related how the eggs were " enveloped in mucus excreted from the skin " to form little clusters. With the allied Audouinia, in my experience, the discharged eggs are always separate and free. The first figures of larval stages of a Cirratulid were those of Caullery and Mesnil (1898). These larvæ were obtained from their A form of *Dodecaceria concharum*. The early stages undergo development in the body cavity of the mother, being liberated when about three segments have been marked out between prototroch and telotroch. Apart from the viviparity the development follows fairly closely that of Audouinia, but the larvæ are easily distinguishable by the characteristic shape of the Dodecaceria bristles, the succession of which was fully described and figured. In 1911 Sokolow gave a detailed account of the viviparous *Ctenodrilus branchiatus* Sokolow (=*Raphidrilus nemasoma* Monticelli). Development continues internally until the young are almost as large as the parent, when they escape by breaking through the body wall. For a time they have branchiæ on most segments but these are subsequently lost. More recently Hofker (1930) has published rough sketches of larvæ from the Zuidersee which he supposes to be those of *Streblospio dekhuyzeni* Horst. They resemble ordinary Spionid larvæ. Streblospio is regarded by some authorities (e.g. McIntosh) as belonging to the Spionidæ, while others (e.g. Fauvel) class it with the Cirratulidæ.

METHODS.

After repeated failures to get an artificial fertilisation of *Audouinia tentaculata* by using eggs and sperm cut from apparently mature adults, it was decided to try to secure naturally spawned eggs. On June 30th, 1928, some worms, newly dug from fairly clean sand on the shore of Drake's Island, were washed in sea water and placed in large glass jars half filled with ordinary aquarium tank water. Two females and one male were put into each jar. The sexes are easily distinguished at maturity by their colour; the middle part of the male's body is bright yellow, that of the female tending to a dark olive. By the next morning (July 1st) one female, but no male, had spawned. The eggs were transferred to finger bowls of sea water that had been brought in from outside the Breakwater, and filtered through a Berkefeld filter, and were fertilised with sperm cut from the body cavity of a male. This gave a successful fertilisation, many larvæ swimming to the surface on July 2nd. Some were transferred to a plunger jar, others to finger bowls. In both kinds of vessel they were reared to early bottom stages. A culture of Nitzschia (kindly supplied by Dr. Allen) was used to feed the young worms after all the yolk had been absorbed.

In the summer of 1933 it was decided to check over the work and several more fertilisations were made in a similar way, only this time a circulation of aquarium water was maintained through the jars in which the adult worms were confined. On most occasions the naturally shed ova were fertilised with sperm freshly cut from the body cavity of a male, but once a male spawned in the same jar and at the same time as a female; these naturally fertilised eggs gave rise to an exceptionally healthy and vigorous culture. A few experiments were made on eggs cut from the body cavities of apparently mature females, but these eggs never fertilised. Males occasionally shed sperm without stimulating females in the same jar to shed their eggs.

Most of the drawings are from life, made with the aid of a squared net micrometer in the eyepiece. They were checked on whole mounts. Figure 11 is from a mounted specimen. Bristles were drawn with a *camera lucida*. A number of larvæ were sectioned in various planes but owing to the minuteness of the cytological detail little was gained from their study.

THE EGGS AND PELAGIC STAGES.

When the naturally spawned eggs were found it was not known what time had elapsed since shedding, except that it was not likely to have been more than a few hours. By keeping some of the eggs in filtered sea water until they histolysed it was definitely ascertained that they had not been fertilised, with the single exception mentioned above. In the mass they appeared pale green by reflected light; to transmitted light they were almost opaque. The cytoplasm was finely granular and at one place a rather more transparent spot indicated the position of the nucleus. The cytoplasmic mass of the egg (Fig. 1) was shaped slightly like a hen's egg with a long axis of approximately 112μ. It was enclosed in a 5μ thick egg membrane consisting of at least two layers. For most of the way round the egg this membrane was closely adherent to the cytoplasm, but at the broad end it lifted off the surface to a height of about 9μ to form a domed cavity about 40μ in diameter across its floor. The nucleus was situated generally, but not invariably, just below this cavity, the size of which varied considerably; it enlarged slightly in unfertilised eggs on standing. It was not present, nor did it form later, in eggs cut from the body cavity of females, although they were invested in an egg membrane structurally similar. Eggs so obtained directly from the body cavity were irregular in outline and had a conspicuous germinal vesicle of different appearance from the nuclear patch in the naturally shed eggs.

After fertilisation polar bodies are extruded into the domed space and the egg membrane separates from the cytoplasm all round the egg, but the separation is so slight that here and there the two are in contact.

The cilia of the prototroch are first visible when the embryo is about twelve hours old. They are very fine and short and their passage through the thick egg membrane can be seen. At this stage the cells of the embryo are rather large but the egg membrane is not quite completely filled by them. The cilia soon lengthen and begin to beat, moving the embryo slowly over the bottom of the bowl, but they are not sufficiently powerful to raise it from the ground. Eventually they strengthen and their efforts are aided by the telotroch, which becomes visible later than the prototroch. When about twenty-four hours have elapsed the strongly swimming trochosphere (Fig. 2) is fully formed. It is slightly longer than broad and is widest in the region of the prototroch, now a broad band of fine cilia completely encircling the body. The telotroch is also an encircling band of fine cilia but it has a short gap in the mid-ventral line. An apical tuft of long and short fine cilia, often twisted together and directed forwards, arises at the anterior end. There are one or two long fine and presumably sensory cilia at the posterior end. The trochosphere is closely enveloped in the thick egg membrane, which from now on forms the cuticle of the larva. The tissues are finely granular and considerably opaque; the central gut region being denser than the rest. The mouth is a very small transverse slit immediately behind the slightly overhanging rim of the prototroch; posterior to it the ventral surface is a little flattened and as yet without the neurotroch. These trochospheres swim at a fast pace, moving in circles or along almost straight courses for relatively long distances, rotating slowly on their longitudinal axes as they go. They do not seem to be in any way phototropic.

Further development consists mainly in the elongation of the trunk, the loss of the long apical cilia and the acquiring of additional cilia on the head and body. A three-day-old larva is shown in dorsal and ventral view in Figures 3 and 4. The trunk is indistinctly segmented, but it is difficult to say of how many segments it is composed, for some of the apparently intersegmental grooves do not completely encircle the body and do not correspond dorsally and ventrally (see lateral view Fig. 7). Septa cannot be seen through the finely granular and moderately opaque body wall. There are no bristles; they do not appear until after metamorphosis. The prototroch is a broad band that narrows slightly in the mid-dorsal

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EXPLANATION OF TEXT-FIGURES 1–11.

Developmental stages of *Audouinia tentaculata* Montagu. Unless otherwise stated drawn from life; × 156. All measurements given below exclude apical cilia.

FIG. 1.—Recently spawned unfertilized egg (see page 569).

FIG. 2.—Ventral view of trochosphere 24 hours old. Actual length approx. 135μ (see page 569).

FIG. 3.—Dorsal view of larva three days old. Actual length approx. 245μ (see page 570).

FIG. 4.—Ventral view of same stage as Fig. 3.

FIG. 5.—Dorsal view of larva seven days old. Actual length approx. 290μ (see page 572).

FIG. 6.—Ventral view of same stage as Fig. 5.

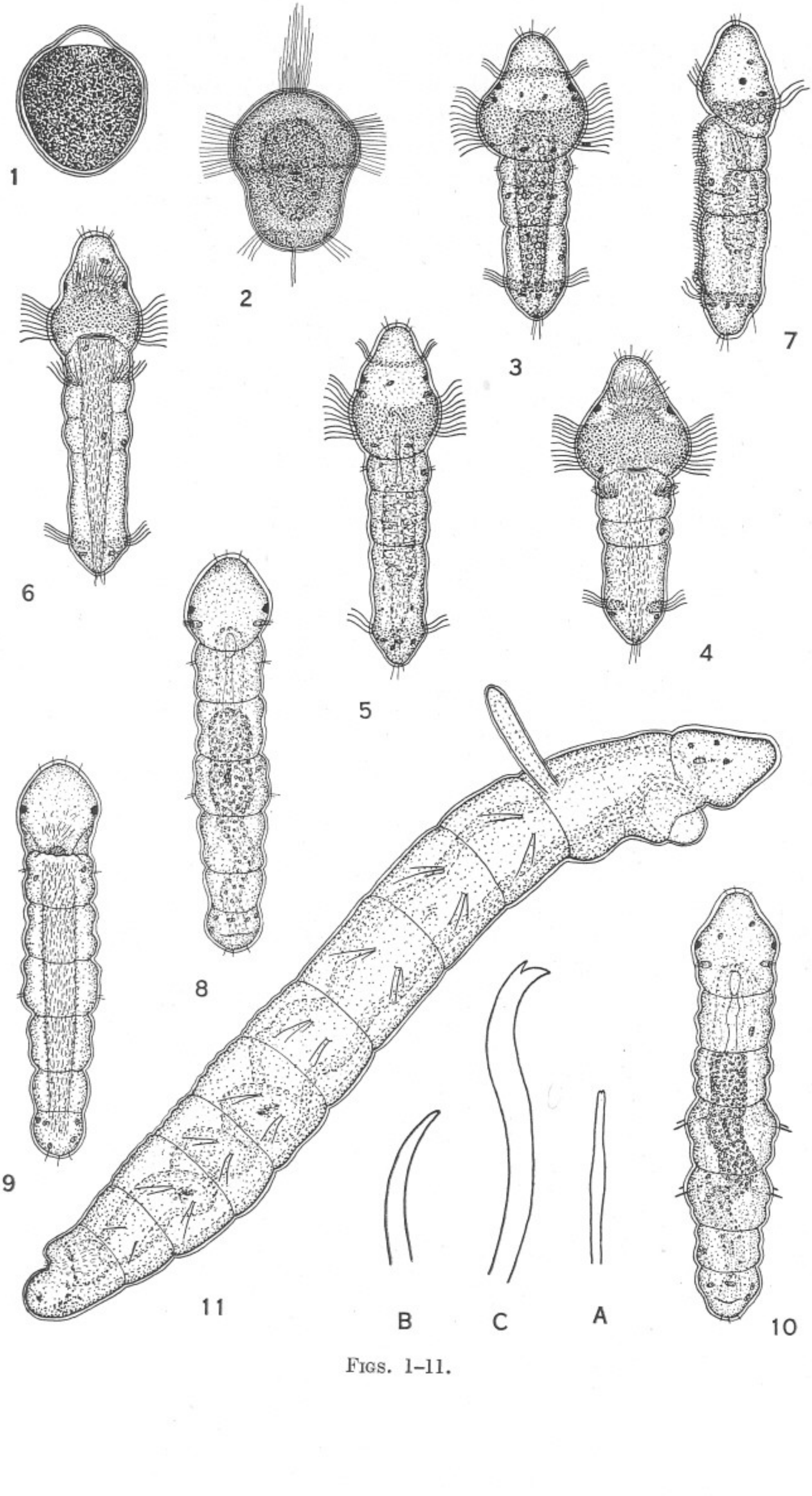
FIG. 7.—Lateral view of metamorphosing larva ten days old. Actual length approx. 270μ (see page 573).

FIG. 8.—Dorsal view of young worm fifteen days old. Actual length approx. 335μ (see page 573).

FIG. 9.—Ventral view of same stage as Fig. 8.

FIG. 10.—Dorsal view of young worm twenty-two days old. Actual length approx. 365μ (see page 574).

FIG. 11.—Lateral view of young worm sixty-three days old. Actual length approx. 800μ. Drawn from a fixed and mounted specimen; × 156.
A. Crotchet of stage of Fig. 10; × 1200.
B. Simple crotchet of young worm nine months old; × 1200.
C. Toothed crotchet of young worm nine months old; × 1200.



FIGS. 1–11.

line. The body is of greatest diameter in this region, but as it is actively contractile the relative widths of the various parts are continually changing. Immediately in front of the prototroch there is on either side a minute ciliated pit, the nuchal organ, and in front of this again a cup-shaped eye-spot composed of brown oily globules. Across the dorsal surface of the head anterior to the eyes is a band of cilia (the akrotroch) which ends level with the eye on either side. On the ventral surface there are two patches of cilia anterior to the prototroch, one almost semicircular, the other in front of it a curved band. All these head cilia are rather long, fine and actively beating, and in addition there are a few seemingly sensory cilia at the extreme apical end. The mouth opens as a narrow transverse slit ventrally a short distance behind the prototroch ; from it there runs a broad thickly ciliated neurotroch back to the posterior extremity, narrowing a little and passing through the ventral gap in the telotroch. There are a few sensory cilia at the posterior end. On each side of the neurotroch in the anterior part of the trunk there is a short transverse band of fine cilia. These two bands together may be regarded as a gastrotroch with a large mid-ventral gap. One or two short sensory cilia occur on the lateral body walls of this region. The whole larva is enclosed in the two-layered egg membrane (the layers are not indicated in Figs. 3–11), and the cilia can be seen clearly passing through it. The colour of the larva is pale brown by transmitted light and there are a number of brown pigment globules, similar to those composing the eye-cups, scattered about the head and body, generally in clusters ; they are specially concentrated behind the telotroch. Little internal structure is visible, except the gut, which now has some large yolk globules in its walls.

The larva slowly elongates and at the same time becomes thinner in a normal state of relaxation—it is very contractile. A seven-day-old larva is shown in Figures 5 and 6. There has been no great change in structure since the three-day-old larva of the preceding figures. The gut has now three well-marked regions : œsophageal, stomachic and intestinal. The neurotroch has been sunk in a very shallow ventral trough. Very little yolk is left but there is no sign of feeding. The egg membrane forming the cuticle is thinner on the body than on the head. On the former it is $1{\cdot}5\mu$–2μ thick, on the latter $2{\cdot}5\mu$–3μ thick. It is thinner than it was on the egg and earliest stages and appears to have been stretched by growth of the larva inside it. The larva swims relatively fast, mainly in a spiral path. This is the last pelagic stage before metamorphosis.

METAMORPHOSIS AND EARLY BOTTOM STAGES.

The individuals in a culture do not metamorphose simultaneously. As is usual with other species, some are more advanced than others. The first larva metamorphosed when about eight days old, the last about five days later.

Metamorphosis consists in loss of most of the cilia. It is interesting in that the cells comprising the prototroch and telotroch are definitely got rid of by internal absorption. In both regions the cilia apparently fall off, not all together but in patches; possibly those belonging to one cell are shed simultaneously. Some little time after the cilia have gone the cell breaks down and its contents round up into large oily looking brown and yellow spheres of varying size and of a type not previously seen and not visible elsewhere in the body. These spheres eventually disappear; there can be little doubt that they are internally absorbed. Figure 7 shows in lateral view a metamorphosing larva. Most of the cilia of the prototroch have fallen off but a small dorsal patch remains. It seems that it is usual for the ventral cilia to go first. Where the cilia have disappeared absorption spheres are seen. The dorsal akrotroch has gone and the ventral anterior crescent of cilia also. The ventral semicircular patch of cilia however remains and it is usual for it to be present for a while after metamorphosis. The gastrotroch has disappeared and in the telotroch only a few of the ventral cilia remain, but the cells that have lost their cilia have not yet broken down into absorption spheres. The neurotroch is scarcely affected by metamorphosis; however, it no longer quite reaches the extremity of the pygidium and in some individuals stops just short of the mouth opening. The buccal organ is fully formed and the creature is beginning to feed. The anus is situated on the dorsal surface of the pygidium.

A specimen a few days after completion of metamorphosis is seen in Figures 8 and 9. The segmentation is considerably more distinct than formerly and there appear to be five segments between head and pygidium. No chætæ are visible, the short lines that resemble them in the drawings are short, fine, but very stiff cilia, exactly similar to those on the head and pygidium. Sense organs on the head are the eyes and the nuchal organs, both unchanged from the larval stages. Some cilia of the ventral semi-circular patch (there are occasionally signs of the anterior crescent-shaped band as well), of the larval head remain, but the patch is now rather irregular and it is in continuity posteriorly with the strongly ciliated dorsal wall of the œsophagus. The buccal organ is large and often protruded; it resembles that of a Terebellid. The lower lip fold is as wide as the body, the mouth itself being very large. The stomach and intestine contain food; their walls are darkly granular with oily globules, probably not yolk globules but absorption products. The gut is longer than the trunk at normal extension, throwing the intestine into folds. Some of the internal septa are now visible. A few brown pigment spots are found here and there on the body wall, especially the pygidium. The cuticle has the usual two-layered appearance and is thickest on the head.

Four or five days later bristles protrude for the first time (Fig. 10). The first pair appears on what is apparently the third segment behind the head ; there is one dorsal and one ventral bristle on each side. The next segment also bears bristles and in some specimens at this age the following one also. These bristles are minute crotchets (Fig. A), almost straight with slightly swollen shafts and some, if not all, have a slightly bifurcated tip, this latter feature being very difficult to see. Apart from the bristles the body structure is almost identical with the preceding stage. There is a ciliated proctodæal invagination. The neurotroch extends from just behind the mouth to half way on to the pygidium. The worms crawl actively when stimulated, but normally they glide slowly about the bottom of their bowl, probably on their neurotrochs.

When about five setigers have formed the first branchial filament appears. It arises from the posterior part of the achætous region, immediately in front of the first setiger, and is situated indifferently on either the right or left side. Figure 11 shows a somewhat older worm with a well-grown branchial bud on the right side. There are roughly four eyespots instead of two as formerly but the eye pigment becomes rather irregular from now on. The bristles are more numerous than before. They are mainly crotchets, some plain, others toothed. A few capillary bristles arise dorsally and ventrally in the anterior and middle parapodia.

The worm increases in length and girth by the addition of new segments and by growth of old ones. Additional branchial filaments bud out from the posterior dorsal borders of the achætous region and the first, second, etc., setigers. Their relative lengths are extremely irregular, they are never alike on the two sides and no two individuals ever correspond. Sometimes the branchial filaments of one side are very long, while those of the other side are indicated only by small buds ; more often there are long and short on both sides. They often spring so close to the intersegmental grooves that it is difficult to discover to which segment they really belong, but comparison with other individuals shows that these branchial filaments arise from posterior borders of segments with the exception of a pair of buds that sooner or later appears on the anterior part of the second setiger. A small bud of this type is seen in Figure 12 on the right side just behind the intersegmental groove between setigers one and two—the left bud has not yet developed. These buds arise a little nearer to the mid-dorsal line than do those of the branchial filaments and sometimes are inserted in the intersegmental groove, when it becomes difficult to ascertain whether they belong to the first or the second setiger. There are indications that they sometimes belong to the first. They grow out into rather thicker filaments than the ordinary branchial filaments and are probably homologous with the tentacular filaments of the adult and other Cirratulids. These latter are usually distinguished

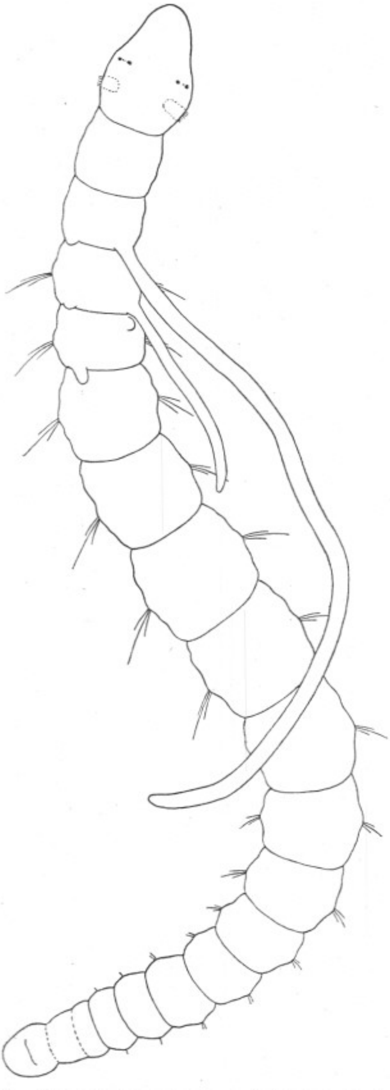


FIG. 12.—Dorsai view of young *Audouinia tentaculata* Montagu three months old. Drawn from life; × 120. Actual length approx. 2mm.

from the branchial filaments by the possession of only one blood vessel instead of two; unfortunately I have not been able to satisfy myself that these minute filaments in the young worm possess only one vessel, so that this distinction cannot here be used.

Figure 12 shows a typical specimen selected from a number of worms three months old that since metamorphosis had been kept in a flat-bottomed glass dish containing fine sandy gravel, which had originally been washed clean and boiled to ensure that any life it might have contained was killed. The branchial details of this specimen have been discussed in the preceding paragraph but a few other points are worthy of mention. The fourteen setigers all bear dorsal and ventral bristle bundles. Anteriorly long capillary bristles predominate; these become scarcer and shorter posteriorly and the last few segments bear only crotchets. The crotchets are either simple or carry a secondary tooth above the first. They are most numerous in the middle region of the body. The minute crotchets that first appeared (Fig. A) have either grown larger and been transformed by wear or have fallen out. The neurotroch runs from the mouth to the intersegmental groove between the second and third setigers, where it ceases; it is thus relatively shorter than it was during early post-metamorphosis stages and is confined to those segments that were formed during larval life. It persists thus to the latest stage to which I have reared the worms. The anus is dorsal. The tissues of this very contractile worm are transparent and the whole animal is enclosed in a cuticle which in its two-layered appearance is identical with that of the larva.

The most advanced specimen I have reared and actually fixed and mounted is nine months old and has over forty setigers. In its preserved state it is five to six millimetres long and about half a millimetre maximum diameter of body. The anterior parapodia each carry a few long capillary bristles and crotchets. As before the posterior bristles are mainly crotchets. The crotchets are of two kinds, plain (Fig. B) or with a secondary tooth (Fig. C). The first pair of long branchiæ springs from the posterior border of the achætigerous region. The first setiger bears branchial buds only. The second setiger bears a long branchia on either side from just above and close behind the parapodia, while nearer the mid-dorsal line a pair of thicker "tentacular processes" arise, the right-hand one being much longer than the left. Their positions of attachment are so close to the intersegmental junction between the second and third setigers as to make it a little doubtful whether they should not really be ascribed to the third setiger. The third setiger bears two long branchiæ inserted as usual dorsal and posterior to the parapodia. The fourth and fifth setigers each carry a long branchia on the right but have buds only on the left. This arrangement is reversed on the sixth setiger. The seventh carries a very small bud on either side and there is one tiny bud on the left side of the eighth. The ninth has a fairly large branchial bud on the left side. Eye-like pigment spots are still present in this specimen.

Two other worms, the same age as the preceding but possessing only 25 and 30 setigers respectively, correspond in most details excepting that they have fewer branchiæ and that the thicker "tentacular filaments," of which each has a pair, spring from the anterior part of the second setiger.

Discussion.

While the actual pelagic stages of this worm are of little interest, apart from the unusual feature for a Polychæte larva of the absence of bristles, the appearance of which is delayed until after metamorphosis, the early bottom stages raise several points requiring attention. The most puzzling feature is the position of those filaments I have ventured to homologize with the tentacular filaments of the adult. In these young worms they arise on segments well anterior to those which normally carry them in the adult (setigers 6–7). Perhaps it may be assumed that with growth these tentacular filaments in the region of the intersegmental groove between first and second setigers are lost and replaced by others further back. The condition of the most advanced specimen described above, in which these filaments arise from the intersegmental region between the second and third setigers, may be a hint of this, but otherwise the worms have not survived long enough for this process to be observed.

The young worms also differ from the adults in that the first pair of branchial filaments springs from the achætigerous region. In all the adults I have examined they have never been inserted further forward than the posterior border of the first setiger; this is in accordance with general descriptions of this worm. In *Cirratulus norvegicus* Southern (1914), which Fauvel (1927) regards as a variety of *Audouinia tentaculata* Montagu, a pair of branchiæ does arise, however, from the posterior border of the achætigerous region. This condition in any case is probably more primitive than that of the adult *A. tentaculata*. Southern's *C. norvegicus* also approaches my young *A. tentaculata* in that the tentacular filaments spring from a more anterior setiger (the fourth) than in the adult of the latter species. In passing one may remark that the characters, including size and number of segments, by which Southern (p. 109) distinguishes *C. norvegicus* from *A. tentaculata* are in general those that may occur in young of the latter species. Southern however records (p. 108) that he obtained one mature female of *C. norvegicus*, which after all may quite well be a good species.

In connection with the branchiæ it may be noted that McIntosh (1915, p. 246) records two specimens of *Cirratulus* (*Audouinia*) *filigerus* from

Naples in which " a branchia springs in front of the dorsal of the first series of bristles." In Fauvel's later description of *Audouinia filigera* (1927, p. 93) the first pair of branchiæ arises from the first setiger.

The anterior achætigerous region of the adult is usually regarded as being composed of three segments, in addition to the prostomium, but there does not seem to be any real evidence in support of this view. It is true that the region is roughly equivalent in length to three of the immediately succeeding setigers, but this is not necessarily a safe criterion to adopt. The external annulations are numerous and rather irregular, so that it is not possible with certainty to pick out intersegmental grooves. This remark applies also to the larvæ and young worms, though in the latter the intersegmental annulations do appear for a time to be rather more definite than in the adult and they mark out two achætigerous segments rather than three. Thus in my drawings I have indicated this region as composed of two segments only but it must be remembered that in the living worms, especially stages as late as Figure 12, the segmentation was by no means as definite as the figures would lead one to suppose. Sections of larvæ and young worms do not help in deciding the matter. Cunningham and Ramage long ago pointed out that the achætigerous region is devoid of septa and that the ventral nerve cord does not extend further forward than the first setiger. In very young larvæ the tissues are too minute, compact and yolky to permit of the point being settled by examination of the condition of the early mesoderm.

In the young Audouinia many of the crotchets bear a secondary tooth above the main one (Fig. C), whereas in the adult all the crotchets are plain and resemble the simple ones of the young worms (Fig. B). Bidentate crotchets are found in the adults of the allied genus *Heterocirrus* Grube and they are closely similar in shape to those of the young Audouinia.

In conclusion it seems important to emphasize that young *Audouinia tentaculata* worms nine months old and with over forty segments differ so much in appearance from the adult that had they been collected directly from the sea it would have been extremely difficult, if not impossible, to have identified them. Indeed they might very easily have been regarded as a new species. The same may be said of a number of other Polychætes which have been reared from the egg ; the young worms only very slowly acquire those characters by which the genus and species are recognized. This is, of course, in accordance with general evolutionary theory, but is none the less disconcerting to the worker attempting to identify pelagic Polychæte larvæ by keeping the young worms after metamorphosis until they have grown up to be recognizable.

SUMMARY.

(1) Adults of *Audouinia tentaculata* Montagu were induced to spawn in the laboratory; the eggs were fertilized and the larvæ reared to metamorphosis and early bottom stages for the first time.

(2) The larvæ are yolky and do not feed. They have a broad prototroch and telotroch and a broad neurotroch. The ciliation of the head is rather complex. There are no bristles. When about ten days old they metamorphose.

(3) During metamorphosis most of the cilia, except those of the neurotroch, disappear and their cells are absorbed internally.

(4) Bristles appear for the first time a few days after metamorphosis. After a while branchiæ appear, followed by what are apparently tentacular filaments situated on segments anterior to those on which they occur in the adult.

(5) Discussion centres on the position of the tentacular filaments and the first pair of branchial filaments in the young worm as compared with the adult. The segmentation of the anterior achætigerous region also receives attention.

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On the Hydroid of *Laodicea undulata* (Forbes and Goodsir)

By

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With 7 Figures in the Text.

In 1866 Hincks described the hydroid *Cuspidella humilis*: later, in his *History of the British Hydroid Zoophytes* (1868, p. 210), he added two further species to the genus, *C. grandis* and *C. costata*. At that time the reproduction of Cuspidella was not known.

Metschnikoff (1886, p. 83 and Taf. V, Fig. 1) described the development of the eggs of *Laodicea cruciata* and reared them to the hydroid stage. These had sessile hydranths and elongated polyps with ten slender tentacles, long and short alternating. Metschnikoff remarked on their similarity to Cuspidella.

In 1906 Browne (1907, p. 464) received a letter, with drawings, from Miss M. J. Delap of Valencia Island, Ireland, saying that she had kept a colony of *Cuspidella costata* from which medusæ were liberated. Examination of these medusæ led Browne, after comparison with young stages taken in the tow-net, to the conclusion that they were *Laodicea undulata*. The hydrothecæ of Miss Delap's Cuspidella had the transverse rings as shown in Hincks' drawing of *C. costata* (1868, Pl. 40, Figs. 5 and 5a), but the hydroid reared by Metschnikoff lacked these rings. Hincks (1868, p. 211) regarded these as growth rings and their method of formation has been described by Ritchie (1910, p. 814; Pl. LXXVII, Fig. 8).

Browne (1907, p. 464) presumed that Metschnikoff's *L. cruciata* was *L. mediterranea* (Gegenbaur), and Kramp (1919, pp. 21–25) in a critical discussion of the species of Laodicea has concluded that *L. mediterranea* is synonymous with *L. undulata* (Forbes and Goodsir).

In September, 1935, a number of hydroid colonies were successfully reared in the laboratory at Plymouth from *Laodicea undulata*. These confirm the previous observations that the hydroid of this species is a Cuspidella.

Description of Hydroids reared in Laboratory.

The majority of the hydroids were single individuals in which one hydrotheca had developed at the end of the stolon (Fig. 1). In most isolated individuals the hydrotheca was attached to the substratum for about half its length, when it then curved upwards (Fig. 2) (cf. Ritchie, 1910, p. 814). Where a large number of planulæ had settled together and a close clump of hydroids had been formed, the central hydrothecæ were growing upwards (Fig. 3). In some colonies kept alive for a considerable period more than one hydrotheca was developed and these came off at right angles from the stolon with no indication of a stalk (Fig. 4, A–B). The hydrothecæ varied considerably in length (Fig. 4, A–E) and individuals could be found varying between the short type, *C. humilis*, and the more elongated *C. grandis* (Hincks, 1868, Pl. 39, Fig. 4A, and Pl. 40, Fig. 4). In one vessel in which the water was kept agitated the hydroids lived for several weeks, and a number of the hydrothecæ were then found to have developed growth rings (Fig. 4, F), and were of normal type, while in still water they had grown into filamentous formless stolons.

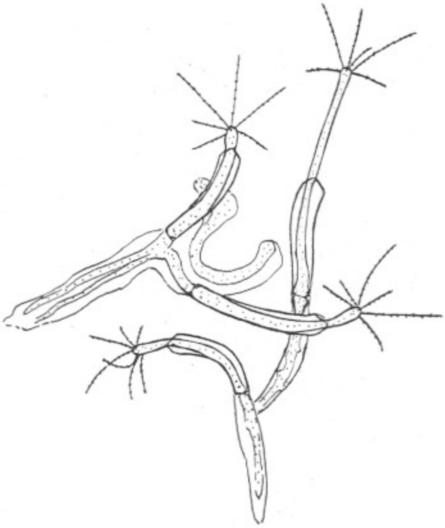

FIG. 1.—Early stages of Cuspidella reared from Laodicea at Plymouth, September, 1935.

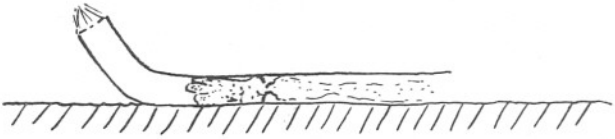

FIG. 2.—Cuspidella reared from Laodicea at Plymouth, September, 1935, showing how hydrotheca may be attached to the substratum for half its length before curving upwards.

The transition from the stolon to the hydrotheca was marked by a hardly discernible diaphragm (Fig. 5, A). This diaphragm is not mentioned by Hincks, but Hartlaub (1897, p. 503, and Taf. XX, Figs. 17 and 18) remarks that the hydranth is clearly marked off from its stalk in *C. grandis*. A diaphragm is described by Spassky (1929, p. 37) in his new species *C. mollis*. In the Plymouth specimens a ring of a few irregularly spaced spines is also visible above the diaphragm (Fig. 5, A) as described by Spassky in *C. mollis*. In well-preserved individuals these spines can be clearly seen acting apparently as points of attachments for the basal tissue of the hydranth (Fig. 5, B). The hydrotheca is crowned by the typical Cuspidella operculum consisting of a number of triangular folded facets in direct continuation with the perisarc of the hydrotheca (see Kramp, 1911, p. 379, and 1932, p. 23).

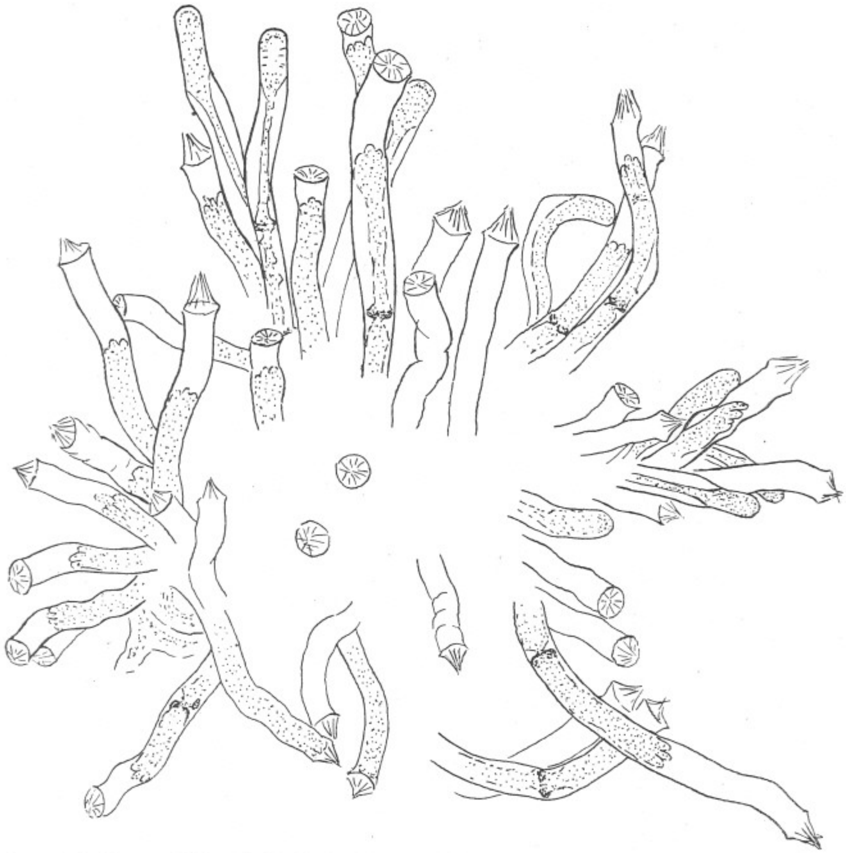

FIG. 3.—Clump of Cuspidella hydroids reared from Laodicea at Plymouth, September, 1935: many individuals in the centre have been omitted from the drawing.

The length of the hydrotheca measured from the diaphragm to the base of the operculum varied from 0·28 mm. to 0·95 mm., and the width was

0·09–0·11 mm. The length of the opercular teeth approximates to the width of the hydrotheca.

The polyp is very extensile and can extend to twice the length of the hydrotheca (Fig. 4, B). Most of the polyps developed eight tentacles, but in some there were only six and in one there were ten. Half the number of tentacles are short and half are long; and these alternate one

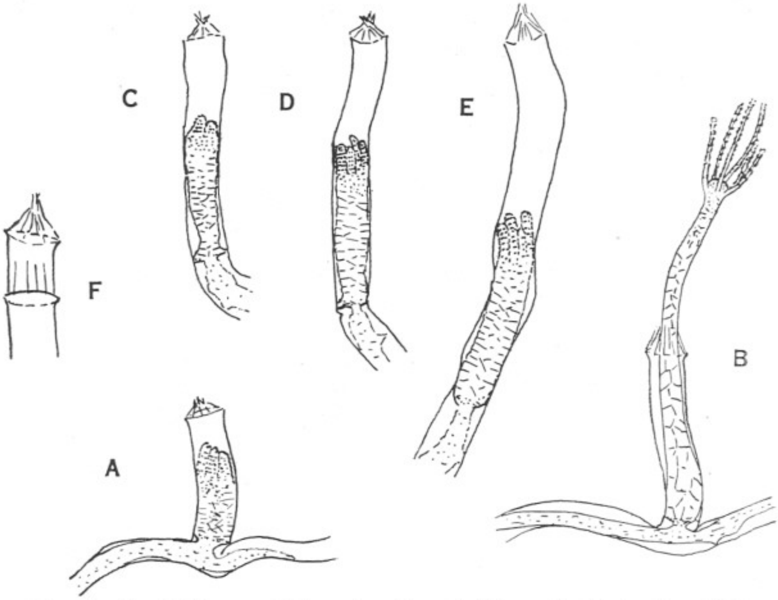

Fig. 4.—Cuspidella reared from Laodicea at Plymouth, September, 1935. A, hydrotheca growing off at right angles to stolon, *C. humilis* type, hydrotheca 0·28 mm. long; B, preserved specimen with polyp extended, hydrotheca 0·42 mm. long by 0·09 mm. broad; C, D, E, hydrothecæ of different lengths, dimensions 0·53 mm. long by 0·09 mm. broad, 0·66 mm. by 0·09 mm., and 0·95 mm. by 0·11 mm. respectively; F, showing formation of a growth ring.

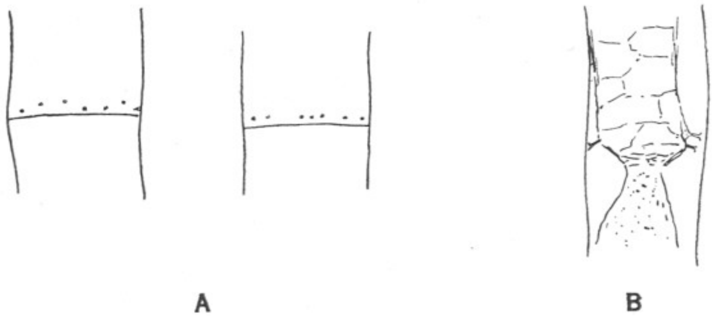

Fig. 5.—Base of Cuspidella hydrotheca reared from Laodicea at Plymouth, September, 1935. A, showing diaphragm and spines; B, showing apparent attachment of basal hydranth tissue to spines.

with the other. In life the long tentacles, which arise slightly nearer the apex than the short ones, are held forwards, while the shorter tentacles stand out at right angles or pointing slightly backwards. The tentacles bear a number of nematocysts in ring-like clusters.

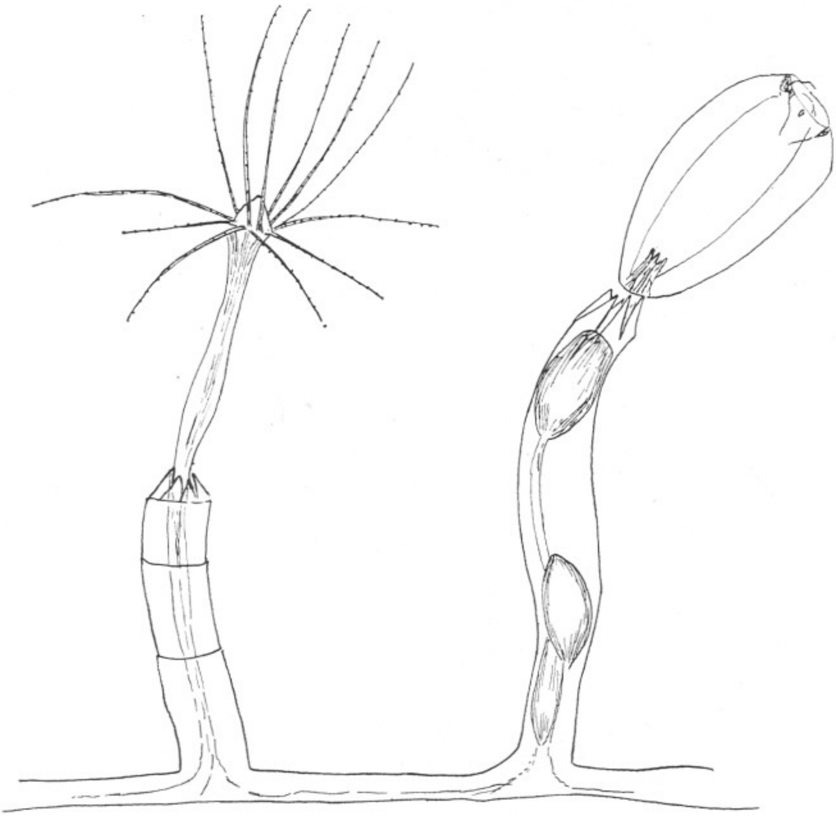

FIG. 6.—Hydrotheca and gonotheca of Cuspidella. From a tracing of the original pencil drawing by Miss M. J. Delap. Miss Delap's notes ran as follows: "Hydroid found 13.iii.06. A colony of *Cuspidella costata* on shell has been kept under observation and on 14.vi.06 a number of small medusæ were seen in same tank. The shell was isolated in a beaker and watched and the medusæ seen liberated. The gonotheca is very similar in shape to the hydrotheca and has a similar operculum, but no rings on stem. The medusa is very small, 8/10 mm. across and about 1 mm. high, two opposite tentacles and two opposite bulbs. No sense organs. Two small tentacles or filaments between the bulbs and tentacles. Can it be Laodice ?

I reared a hydroid from what I thought were eggs of Laodice, Sept. '01, and a Cuspidella-like hydroid was the result. The hydroid only lived a short time."

There can now be no doubt that the hydroid of *Laodicea undulata* is a species of Cuspidella, and the early work of Metschnikoff and Delap is thus confirmed. The original drawings made by Miss Delap have never been published. Since these include drawings both of the gonotheca and of the newly liberated medusa it is fitting that they should be reproduced here (Figs. 6 and 7). I am greatly indebted to Miss M. J. Delap for her permission to publish these drawings and to Mr. E. T. Browne, in whose care they have lain for so many years, for the suggestion. The newly liberated medusa has already been described by Browne (1907, p. 465).

The above observations raise the question of the validity of certain Cuspidella species. Browne (1907, p. 464) has already suggested that *C. humilis* Hincks and *C. costata* Hincks are the same species. It appears possible that *C. grandis* Hincks should also be included; while the form of growth of the hydrothecæ in a number of the specimens reared at Plymouth resembles very closely that of Kramp's *C. procumbens* (1911, p. 384 and Pl. XXIV, Figs. 2–6). Hartlaub (1897, Taf. XX, Figs. 17 and 18) figures two individuals of *C. grandis*; he mentions that the hydrotheca cannot accurately be described as sessile, but that it passes over continuously into the perisarc of the hydranth stalk which at its base shows weak indications of ringing. Spassky (1929, Taf. II, Figs. 10–12) figures *C. grandis* (?) with clearly marked rings.

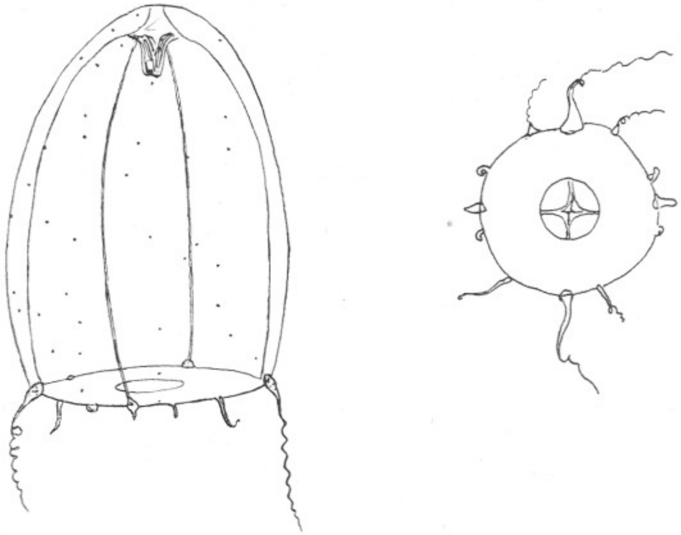

FIG. 7.—Medusæ liberated from Cuspidella. From a tracing of the original pencil drawing by Miss M. J. Delap. For Miss Delap's descriptive notes see Figure 6.

Cuspidella-like hydroids have however been reared from *Mitrocoma annæ* by Metschnikoff (1886, p. 82, and Taf. IV, Figs. 15 and 16), and by Delap from *Cosmetira pilosella* and *Dipleurosoma typicum*. Until hydroids have been reared from these medusæ again and carefully compared it will not be possible to come to any final conclusions on the validity of the different Cuspidella species.

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On a New Species of Medusa, *Eucheilota hartlaubi* n. sp.

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With 6 Figures in the Text.

In November, 1933, a few medusæ were found in the plankton off Plymouth belonging to the genus *Eucheilota*. The only species of this genus so far recorded from northern European waters is *Eucheilota maculata* Hartlaub. The medusæ differed in several respects from this species, one constant difference being that the marginal vesicles never contained more than one concretion. In this respect they resembled *E. duodecimalis* A. Agassiz, but differed in having a much greater number of tentacles and marginal vesicles.

In October, 1934, the medusæ appeared again in considerable numbers and it was now possible to establish the constant features of the species which has apparently never been described before, except possibly for a drawing given by Hartlaub without a description (see below).

The youngest specimens obtained were just over one millimetre in height. These had four fully developed perradial tentacles, two bulbs having a spiral cirrus on either side, two with one cirrus and the rudiments of four interradial tentacle bulbs some with their cirri just appearing (Fig. 1). In one specimen there were four marginal vesicles, each with a single concretion, situated at the left-hand side of each rudimentary interradial bulb. In another specimen there were six marginal vesicles, an additional pair being present one on either side of the base of one of the perradial tentacle bulbs (Fig. 2). The first traces of the gonads were already appearing about half-way along the narrow radial canals.

At a later stage, *ca.* 2·5 mm. diameter, the four interradial tentacles were further developed and one specimen had eleven marginal vesicles, the four perradial bulbs each having one on either side. Figure 3 shows a slightly later stage, 3·5 mm. in diameter.

Development proceeds fairly regularly until when full grown the medusa may have sixteen tentacles with occasionally two or three extra rudimentary ones (Fig. 4). Some of the adradial tentacles also are often not fully developed. The number of marginal vesicles may vary from 16 to 23 in number, and each has always only a single concretion. In many specimens there may be two lateral cirri on one or both sides of some of the tentacle bulbs. There are no marginal cirri.

The gonads are oval in outline and situated at the distal ends of the four radial canals and are separated from the margin of the umbrella by a distance of about half their length. Measurements made on a number of specimens gave the average dimensions of the gonads as *ca.* 0·7 mm. long and 0·4 mm. wide. The largest was 1 mm. long. The gonads lie on the lateral surfaces of the radial canals and do not surround them ventrally, being distinctly longitudinally divided.

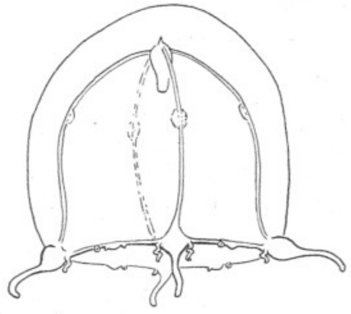

FIG. 1.—*Eucheilota hartlaubi* n. sp. 1·1 mm. high. Plymouth, Sept. 29th, 1934.

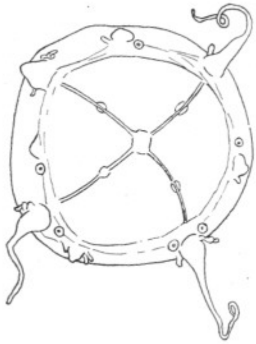

FIG. 2.—*Eucheilota hartlaubi* n. sp. 1·25 mm. diameter. Drawn from above umbrella surface. Plymouth, Nov. 30th, 1933.

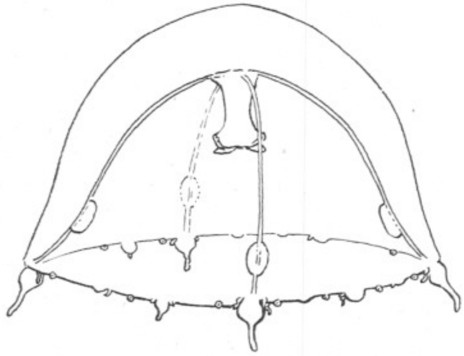

FIG. 3.—*Eucheilota hartlaubi* n. sp. 3·5 mm. diameter. Velum and ring canal omitted. Plymouth, Oct. 30th, 1934.

The mouth has four simple lips whose edges are thickly beset with nematocysts (Fig. 5).

The adult medusæ were generally 5–7 mm. in diameter, though occasional specimens greater than 7 mm. were met with. The colour of the tentacle bulbs by reflected light is rather distinctive, the main colouration being orange with a very vivid green central core, while the upper curve of the bulb is reddish (Fig. 6). In superficial appearance the medusæ resembled *Phialidium hemisphericum*, but the tentacle bulbs are decidedly larger than in that species, so much so that it is possible to separate preserved specimens of the two species with the naked eye. The tentacles also are shorter and do not coil spirally as they do in Phialidium.

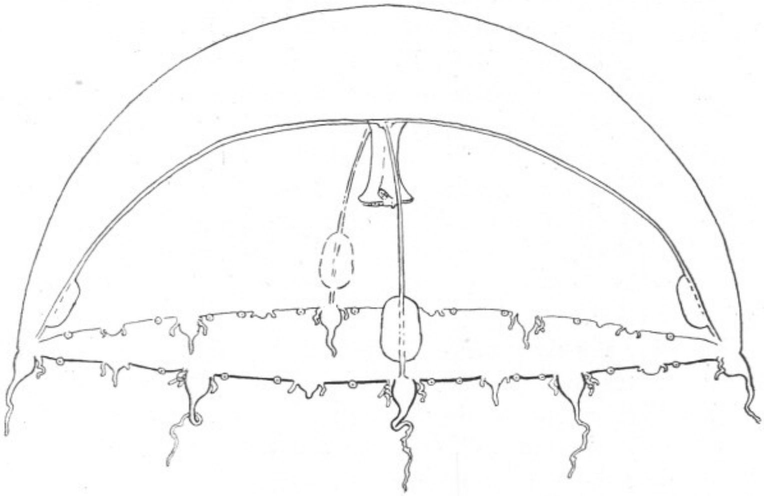

FIG. 4.—*Eucheilota hartlaubi* n. sp. 7 mm. diameter. Drawn slightly diagrammatically; velum and ring-canal omitted.

FIG. 5.—Mouth of *Eucheilota hartlaubi* n. sp.

FIG. 6.—Perradial tentacle bulb of *Eucheilota hartlaubi* n. sp. 2½ mm. diameter. Dots reddish; black, green; and line shading orange.

In its earliest stages of development this medusa somewhat resembles the medusa described by Hartlaub (1897, p. 498; Taf. XXI, Figs. 15–17 and Taf. XXII, Fig. 11) as produced by the hydroid *Campanulina hincksii* Hartlaub.* He was only able to keep these medusæ for a short time. When first budded off they had four perradial tentacles each with one cirrus at its side; there were also four interradial marginal cirri, and between each cirrus and tentacle was a marginal vesicle with a single

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* I am indebted to Dr. P. L. Kramp for pointing out this similarity.

concretion. On further development the interradial cirri were thrown off and the rudiments of tentacles appeared in their places, while at the base of each perradial tentacle bulb there was now a cirrus on either side. It is at this stage that they resemble the medusæ here described. Hartlaub associated this young medusa with *Eucheilota maculata* Hartlaub, giving *C. hincksii* as its hydroid. Kramp, however (1926, p. 244) has shown that this conclusion was wrong since the youngest stages of *E. maculata* are not the same as the little medusæ described by Hartlaub.

On the last page of his work on the Craspedote Medusæ in the Nordisches Plankton (1917, p. 418), Hartlaub figures an adult medusa that resembles very closely the medusa that I am now describing. Hartlaub describes this medusa as " Medusa n.g. n.sp." reared from the hydroid *Lovenella clausa* Lovén, with the remark that the fully developed tentacles are mostly 16, but can increase to 24. Except for the figure and its legend Hartlaub gives no description of the medusa or how he reared it. The drawing shows each tentacle to be flanked by two lateral cirri, and on the nearer umbrella margin are shown six marginal vesicles each with a single concretion.

On receiving my manuscript for perusal Mr. E. T. Browne kindly sent me drawings and notes that he had made many years ago obviously referring to the present species at Plymouth, and mention of which he had made under the name of *Mitrocomium* sp. (?) (1898, p. 190).

Some of the details of his specimens were as follows :—

Sept. 23rd, 1893. 3 mm. diameter. 4 perradial tentacles ; 4 interradial developing tentacles ; 3 rudimentary adradial bulbs. Each of the per- and interradial bulbs had a cirrus on either side. 16 marginal vesicles, with single concretions.

Sept. 25th, 1893. 1½ mm. diameter. 4 perradial tentacles ; 4 interradial bulbs developing ; each bulb with a cirrus on either side ; 3 very rudimentary adradial bulbs. 10 marginal vesicles, with single concretions.

Aug. 24th, 1895. 1½ mm. diameter. 4 perradial tentacles ; 4 interradial bulbs ; all bulbs with a cirrus on either side. 9 marginal vesicles, with single concretions.

Sept. 8th, 1897. 5 mm. diameter. 4 per- and 4 interradial tentacles ; 8 adradial bulbs ; pair of cirri at base of each bulb.

Sept. 8th, 1897. 2 mm. diameter. 4 perradial tentacles ; 4 interradial bulbs and 8 adradial bulbs. One cirrus on each bulb, 8 marginal vesicles with single concretions.

Other specimens were taken from Salcombe, in July and August, 1900, from tow-nettings sent by Mr. R. A. Todd ; and in September, 1897, ½-mile off Mewstone and 2 miles S.W. of the Eddystone.

Attached to Mr. Browne's notes was the following very interesting extract from a letter written by Hartlaub from Helgoland on January 15th, 1913.

"Last summer I had the good fortune to rear the medusa *Lovenella clausa* from the Hydroid to the fully grown sexually adult stage and to make sure that it is a new Eucopid which is quite common in our Plankton, but because of its likeness with Phialidium has remained unnoticed till now. I send you some specimens."

Mr. Browne in his manuscript notes states that the medusæ received from Hartlaub are identical with his Mitrocomium sp.

Although the hydroid *Lovenella clausa* is not given in the Plymo th Marine Fauna, it is recorded by Allen from the Prawle stony ground (1899, p. 449). Hincks in his "History of British Hydroid Zoophytes" also records the species from Torbay.

We would seem therefore to have conclusive evidence that the medusa described in this paper is indeed that figured by Hartlaub as coming from *Lovenella clausa* and I propose to call it *Eucheilota hartlaubi* n.sp. in memory of one who devoted the greater part of his life to the study of hydroids and medusæ and whose critical revisions placed our knowledge on a much surer foundation.

The following is the description of this new species.

EUCHEILOTA HARTLAUBI N.SP.

Flattened hemispherical medusa, apical jelly moderately thick. Four narrow radial canals. Stomach small, no peduncle; manubrium with four simple lips thickly beset with nematocysts. Sixteen, occasionally more, tentacles with large conical bulbs, flanked on either side by one or two lateral spiral cirri. No marginal cirri. 16 to 23 marginal vesicles, closed, each with a single concretion, and situated roughly one between each tentacle. Velum narrow. Gonads oval, longitudinally divided, situated on distal ends of radial canals, *ca.* 0·7 mm. long by 0·4 mm. wide.

Colour: by reflected light, tentacle bulbs orange with a core of bright green and a reddish summit, manubrium pale greenish yellow, gonads with greenish tinge.

Size, *ca.* 5–7 mm. in diameter, occasionally up to 9 mm.

Time of year: present in plankton from July to January, mainly October and November.

Hydroid: *Lovenella clausa* Lovén.

Eucheilota hartlaubi does not usually occur in great numbers at Plymouth although it is quite common. Once, however, on October 11th, 1934, several hundred specimens were taken in a 30-minute oblique haul with the stramin ring-trawl.

ADDENDUM.

Since going to press I have seen the description by Neppi and Stiasny of *Eucheilota maasi* (Arbeit. Zool. Inst. Univ. Wien u. Zool. Stat. Triest. Bd. XX, p. 46; Pl. III, Figs. 32 and 33). These authors had not a full series of developmental stages and suggested a possible connexion between this species and *Eirene plana* Neppi. From the description and figures given by them there is a possibility that *E. hartlaubi* n. sp. and *E. maasi* Neppi and Stiasny may prove to be the same species.

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The Seasonal Abundance of the Pelagic Young of Teleostean Fishes in the Plymouth Area. Part III. The Year 1935, with a Note on the Conditions as Shown by the Occurrence of Plankton Indicators.

By

F. S. Russell,

Naturalist at the Plymouth Laboratory.

With 4 Figures in the Text.

Observations on the seasonal abundance of the pelagic young of teleostean fishes as shown by half-hour oblique hauls with the 2-metre stramin ring-trawl for the period 1924 to 1934 have already been published (Russell, 1930, b, and 1935, a). The data were given in two reports covering six- and five-year periods respectively. Now that a foundation for the comparison of future years has been laid it is thought advisable to publish the results of each new year separately. If publication of these results is delayed for a period of years it is likely that they will lose considerably in value, since in the science of fishery research it is necessary to keep abreast of the times so that data obtained may be available as soon as possible for workers in other areas.

The present report gives the results for the year 1935. Collections have been made in exactly the same way as given in the last report (1935, a). The dates on which collections were made are given in Table I, and the monthly average catches for all young fish, all young fish less clupeids, and each species of fish, are given in Table II. In Figure 1 is shown the curve for the fortnightly average catches of all young fish less clupeids. Superimposed on this curve in Figure 1 is that for the fortnightly average catches averaged over the years 1930 to 1934 inclusive. This curve had been given in Figure 1, page 150, of the last report (1935, a) to act as a basis for comparison of future years. It is obvious from Figure 1 that the total yield of young fish in 1935 was far below the average. In the last report the decline in the numbers of the young of summer spawning fish in recent years was commented upon. It is evident that in 1935 not only was there a further decline in the young of summer spawning fish, but a decline also in the young of spring spawning fish. The sum of the monthly average catches for all young fish less clupeids (last column on Table II) was 427; this is less than half of that for 1934 which was 1144.

The sum of the monthly average catches for the post-larvæ of those species which show maximal abundance in the months June to October inclusive, excluding clupeids, was only 37 in 1935, compared with 79 in 1934 (see last report, 1935, a, page 170). In the last report, pages 170–171, attention was drawn to the parallel between the abundance of these summer young fish and the quantity of phosphate present in the water in the previous winter. It was suggested that the available phosphate was likely to determine to some extent the production of young fish. In the winter 1934–35 the maximum phosphate content of the water at E1 (kindly supplied me by Dr. L. H. N. Cooper), given as the mean content of the water column as mg.P per cubic metre corrected for salt error, was 12·5 mg. on January 15th, 1935. This is a deviation of −27% from the mean of the years 1923–33, and is the lowest value yet recorded as a winter maximum.* The correlation between the abundance of young fish

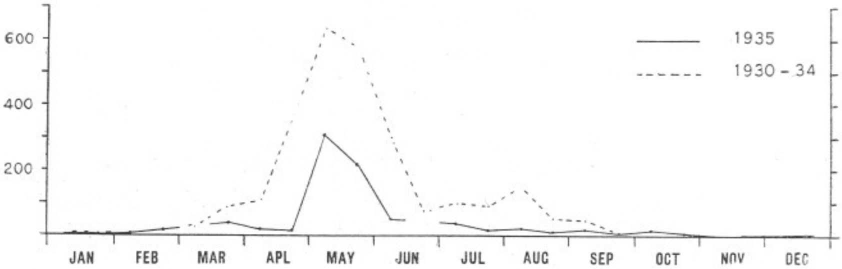

FIG. 1.—Curves showing the average catches in half-hour oblique hauls with the 2-metre ring-trawl for each fortnight for all young fish, excluding Clupeids, in 1935 (————) and the same averaged over the whole period 1930 to 1934 inclusive (– – – –).

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* Dr. Cooper has informed me of two slight mathematical errors in the figures previously published (Russell, 1935, a). The maximum for the year 1927–28 should read 20 instead of 19; and that for 1928–29, 20 on January 7 instead of 17 on January 2. Dr. Cooper has included the winter 1934–35 and recalculated the percentage deviation from the new mean. I give these results below together with the young fish results for summer spawning fish (excluding Clupeids).

	Phosphate.		*Young fish.*
Winter.		*Year.*	
1923–24	+20	1924	696
1924–25	+ 2	1925	140
1925–26	+29	1926	909
1926–27	− 3	1927	170
1927–28	+17	1928	(no records)
1928–29	+17	1929	321
1929–30	(no records)	1930	403
1930–31	− 6	1931	230
1931–32	−21	1932	197
1932–33	− 9	1933	117
1933–34	−18	1934	79
1934–35	−26	1935	37

The only discrepancy in this series of observations occurs in 1932 when for a perfect fit the young fish figures might have been expected to have been lower. There was, however, a marked influx of *elegans* water in July-August, 1932, which may have brought with it a larger number of young fish.

and the phosphate available at the beginning of the year is thus further confirmed. The effect of low phosphate content in 1935 appears moreover to have shown itself not only on the young of summer spawning fish but also on those of spring spawners.

This correlation is worthy of further consideration. If in an enclosed body of water there is a given content of manurial salts at the beginning of the year a certain proportion of this will be passed on during the year through the plankton to the fish and bottom-living fauna. The phosphorus accumulated in plankton organisms not eaten during the year will be returned to the water on their death ; and similarly that contained in the bodies of bottom-living animals whose life-histories do not exceed one year will find its way back into the water on their death and decay. But those fish or bottom animals living for a greater period than one year will have added a certain quantity of phosphorus to their tissues during the first year that will not be immediately returned to the water. The phosphorus content of the water will thus be diminished by that amount by the end of the year. It is thus likely that an enclosed body of water should show a gradual decrease in its phosphorus content until after a number of years a balance is set up according to the length of life of the different inhabitants.* If added to this a certain weight of fish is caught and removed each year there will be a further drain on the phosphorus content of the water.

There are indications that we have a possible analogy to this in the waters of the English Channel. On the whole there exists a body of Channel water kept distinct from that of the Atlantic. Apart from replenishment from Atlantic sources the only addition of phosphate to Channel water comes from the rivers flowing into it. Observations made on the plankton content (Russell, 1935, b, and 1936) have shown that the Atlantic water off the mouth of the Channel appears to be richer than Channel water, and as such might be supposed to have a higher phosphate content. A large incursion of Atlantic water far into the Channel may thus lead to a replenishment of phosphate in the Channel in areas where the two waters can become well mixed, and possibly also by its potentiality for increasing the bottom fauna by better survival of larval stages in the plankton rich water and the introduction of new stock.† Similar

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* It should not be overlooked that there are other factors which may control the winter phosphate maximum. It is probable, for instance, that in sunny autumns a proportion of the phosphate will be removed from the water by a diatom outburst which may not return until the following spring and much of which will be passed on to animals whose winter survival may consequently be high. In such years the winter maximum may then be lower than in years when conditions are unfavourable for an autumn outburst of phytoplankton.

† In this connexion it is interesting to record that in 1930 there were many Luidia larvæ (which are indicators of *elegans* water, Russell, 1935, b, p. 325) ; in July, 1932, Mr. D. P. Wilson informed me that Luidia were unusually abundant in the trawl catches off Plymouth.

causes may operate in the southern bight of the North Sea, either from Atlantic water entering from the north or by exceptional passage of this water from the Channel through the Dover Straits.

Examination of the Sagitta populations off Plymouth over a number of years has shown that since 1932 Channel water has predominated (see below). In certain years there have been major incursions of Atlantic water from the mouth of the Channel, and it is noteworthy that in those years the production of young fish was high. In its bearing on fishery problems there are two possibilities to be considered. Firstly the bulk of the spawning population of fish may live in the Atlantic water and move with it. In this case a large production of young fish will be due to a large spawning stock. Secondly, the spawning population may be spread over the whole Channel area and the presence of plankton-rich Atlantic water in that area may lead to a high survival of young. As far as our knowledge goes at present the latter possibility seems the more likely, and if such be true the bearings of water movements and the phosphate content of the water on the fluctuations of fish populations in the Channel and southern North Sea are obvious.

An account of the possible origin and movements of water masses in the neighbourhood of Plymouth as shown by plankton indicators for the years 1930 to 1934 inclusive has already been published (Russell, 1935, b). In that report the occurrence of "western" and of "south-western" water was mentioned. It has now been shown in a paper in the present number of this Journal (Russell, 1936) that probably the "western" water is that water in cyclonic circulation to the south of Ireland, while the "south-western" water is that passing up past Ushant. The "western" water is characterised by the presence of *S. elegans* and referred to as *elegans* water. There is also another body of water, Channel water, characterised by the presence of *S. setosa* in places, and everywhere by the absence of the planktonic indicators of *elegans* water.

In the belief that the changes in abundance of young fish off Plymouth from year to year may eventually be associated with the distribution of these water masses I have included in this report the conditions existing off Plymouth during 1935 as indicated by plankton animals. The curves for the numbers of *S. elegans* and *S. setosa* in the half-hour ring-trawl collections are given in Figure 2, together with the percentage composition of the Sagitta population by these two species. The dates of these catches are the same as those for the young fish (Table I). A diagram is given in Figure 3 showing the presence or absence of certain plankton animal indicators during 1935 in the same collections. Both these figures are direct continuations of the diagrams given in my previous paper (Russell, 1935, b, Figs. 1 and 2, pp. 312 and 313, and Fig. 4, p. 318; the months January and February are repeated in the present Fig. 2). These diagrams

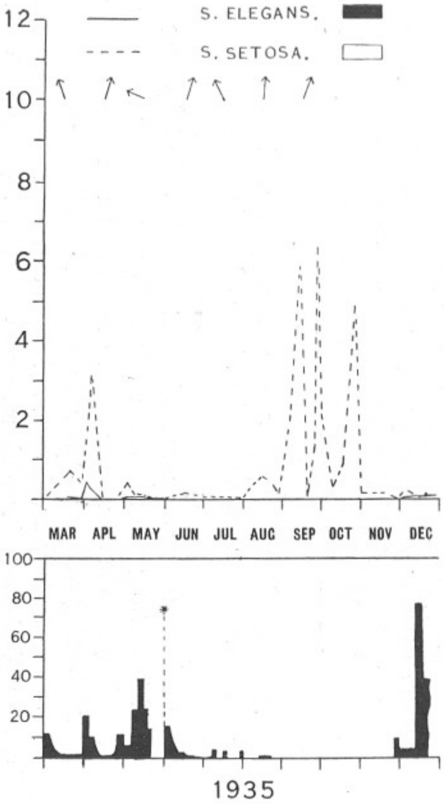

Fig. 2.

Fig. 2.—Above, curves showing the actual abundance of *S. elegans* (————) and *S. setosa* (– – – – –) in half-hour oblique hauls with the 2-metre ring-trawl made usually at weekly intervals during the period March to December, 1935. (The numbers are in thousands.) Below, the percentage composition of the Sagitta populations during the same period; *S. elegans*, black; *S. setosa*, white.

At the top of the diagram the arrows indicate the mean direction (true) of flow of water through the Straits of Dover for each month as indicated by the Carruthers Current Meter working from the Varne Lightship. The current data for October and November were received too late for inclusion in the diagram. They were October, N. 24° E.; and November, N. 29° E.; in comparison with September, N. 20° E. (Continued from Russell, 1935, b, Fig. 2, p. 313.)* = *S. setosa*, 1; *S. elegans*, 2.

Fig. 3.—Diagram showing the occurrence of the various planktonic indicators in collections off Plymouth during the year 1935. (Continued from Russell, 1935, b, Fig. 4, p. 318.)

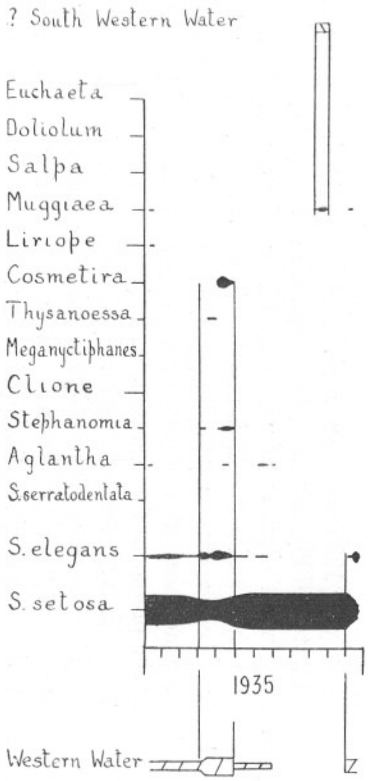

Fig. 3.

show that the year 1935 was characterised by the predominance of *setosa* or Channel water off Plymouth. At the beginning of the year there was a slight admixture of *elegans* water which, as in previous years, increased somewhat in April and May. This may possibly have been an indication of a tongue of *elegans* water extending up the centre of the Channel well offshore. An increase in the proportion of *S. elegans* is shown in December, backed by the presence of euphausian larvæ (Russell, 1936); a collection taken at E2, midway between Plymouth and Ushant, on November 21st, 1935, showed the presence of pure *elegans* water in that locality. In 1935 the occurrence of "south-western" water was almost negligible off Plymouth. At the top of the diagram in Figure 2 showing the occurrence of the two Sagitta species have been inserted arrows showing the directions (true) of the average daily flow for each month of the residual current through the Straits of Dover. These data have been kindly sent me by Dr. J. N. Carruthers. This shows that the flow through the Dover Straits has not yet resumed its predominant easterly direction as was shown in 1930 and 1931 when *elegans* water was so conspicuous off Plymouth.

The above indications of the conditions off Plymouth are in agreement with the hypothesis that the paucity of young fish in 1935 may be related with the presence of Channel water poor in phosphates. The plankton off Plymouth in the autumn and early winter of 1935 was exceptionally scarce.

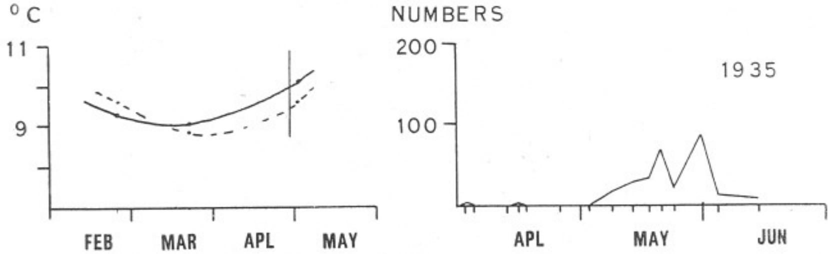

FIG. 4.—*Right:* Curves showing the actual catches of young whiting, *G. merlangus*, in half-hour oblique hauls with the 2-metre ring-trawl on each day of collection in the months April, May, and June for the year 1935.
Left: Temperatures in February, March, April and May for the year 1935. ——— surface at L5; – – – – – bottom at E1.

For comparison with previous years it will be helpful to make a further analysis of the young fish results in 1935. It was shown in the last report (1935, a) that in some years the time of maximum abundance of the young of spring spawners occurred early and in others late. In this respect 1935 was a late year, the peak of maximum abundance occurring in the first half of May. In previous years a possible connexion between late or early years and the temperature of the water was shown, using

G. merlangus as an example (Russell, 1935, a, Fig. 4, p. 159). Similar curves have been given here in Figure 4 for *G. merlangus* in 1935. The right-hand curve shows the actual catches of this species on each day of collecting in April, May and June. The peak of this curve occurred on May 20th (that on May 30th has been discounted because the majority of whiting caught on that day were of a large size and in association with the jelly-fish Cyanea). The left-hand curves show the temperatures of the water during the months February to May at the surface at L5 near the Eddystone and at the bottom at E1, ten miles beyond. The upright line cutting the curves in this figure indicates a point 3 weeks earlier than the date of maximum abundance of young whiting. As in the previous years this point occurs somewhere about 9·5° C.

Since the year 1935 has been the worst year recorded in this series of observations it is worth comparing it with other years to find the extent of fluctuation. Below are given figures for the sum of average monthly catches for the more important species in 1935 (last column in Table II, p. 604) divided by the sum of the average monthly catches for the period 1930 to 1934 (last column but one in Table I, pp. 152–3 of the last report, 1935, a). In the second column are shown the results of dividing the best years in the period 1930 to 1934 by the year 1935. A similar table was given in the previous report on page 165.

	1935/Av. 1930–34.	Best/1935.
G. merlangus	0·25	6·3 (1932)
G. minutus	0·07	40·3 (1931)
Onos spp.	0·17	13·0 (1930)
Arnoglossus spp.	0·21	9·9 (1931)
S. norvegicus	0·27	5·4 (1932)
P. limanda	0·11	14·0 (1931)
P. microcephalus	0·09	20·5 (1932)
S. variegata	0·39	4·1 (1932)
Callionymus spp.	0·20	3·1 (1930)
S. scombrus	0·23	11·2 (1930)
Gobiid spp.	0·07	39·7 (1930)

The first column shows that 1935 was a much worse year even than 1929, in which year the spring peak of abundance appeared to have been wiped out possibly by depredations of Ctenophores (see Russell, 1935, a, pp. 165–166).

In the previous report the largest fluctuations as shown by dividing the best year by the worst year were 11·9 for Gobiid spp. and 11·5 for *S. scombrus*; apart from these the fluctuations for most species lay below 5 times. The figures given here for 1935 show very large fluctuations for

G. minutus, Gobiid spp., Onos spp., *P. limanda* and *P. microcephalus*. Although the fluctuations for the first two named may be exaggerated owing to the habit of the young fish living possibly deeper than the net has sampled (Russell, 1930, a, p. 648), it is evident that we are reaching magnitudes comparable with the major fluctuations known to occur in the populations of certain food fishes.

From the above figures it can be seen that the best years (in brackets in the second column) for each fish have not fallen together. They have however only occurred in the years 1930, 1931 and 1932. While 1930 and the first half of 1931 were periods during which *elegans* water was predominant off Plymouth, 1932 was the first year of the *setosa* predominance which has continued to the present day. The success of any one species of fish cannot therefore as yet be linked with water movements as shown by the Sagitta population. It is however notable that, except for *Cottus bubalis* which is only caught in very small numbers, no fish has had its best year during the period 1933 to 1935, and the worst year so far recorded has fallen after a prolonged continuation of *setosa* predominance. Full agreement cannot yet be expected as so many other factors not dealt with here may enter into the picture. It is, for instance, especially necessary to know more about the spawning regions of the different species of fish.

In continuation of data given in the previous report (1935, a, pp. 168–169) it should be recorded that the landings of whiting by British sailing trawlers in area VII, d–e, in the English Channel fell in 1934 to 2·3 cwt.* per 100 hours' fishing. The curve of landings of whiting has thus continued to follow the curve of abundance of young whiting in the ring-trawl collections.

As regards the scarcity of young fish in 1935 it should be noted that the numbers of young clupeids were also far below those for other years. There was however a great abundance of the eggs of the pilchard. These ocucrred in the catches on the following dates : April 12, June 15, July 3 (many), July 14 (many), July 17 (many), September 18, September 24, October 9 (many), October 16, October 31 (many) and November 19.

SUMMARY.

Records are given on the abundance of the pelagic young of teleostean fishes off Plymouth as shown by half-hour oblique hauls with the 2-metre stramin ring-trawl.

In comparison with similar observations made since 1924 the year 1935 has been the poorest yet recorded.

A parallel between the quantity of phosphate in the water at the

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* In the previous report (1935, a) in Figure 8 " cwt " should read " 1/10 cwt."

beginning of the year and the abundance of young fish is further confirmed. In January, 1935, the winter maximum phosphate value was the lowest yet recorded.

Observations are given on the conditions off Plymouth as shown by plankton animal indicators during 1935. The year was marked by a predominance of *Sagitta setosa* or Channel water. The possible correlation between the scarcity of young fish and the presence of Channel water is indicated.

The difference between the numbers in 1935 and those in the best years since 1930 show that for certain species of fish the changes in abundance may be regarded as nearing the dimensions of the major fluctuations known for certain food fish.

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TABLE I.

Dates on which Collections were made, 1935.

All 2 miles east of Eddystone unless otherwise stated.

Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
2*	5	20	2§	2	4	3	6	5	1	19	4
2	13	28	4	8	15	10	14	12	9	28	10
10	19		12	13		17	21	18‖	16		17
16			15	16		23	28	24	25		
21			17	20		23‡		25	31		
29†			25	23		30					
				30							

* Haul taken in the dark. † Haul taken at L4–L5. ‡ Haul taken at E1.
§ Haul taken 4 miles S.S.E. of Mewstone. ‖ Haul taken at L3.

TABLE II.

AVERAGE MONTHLY CATCHES OF POST-LARVÆ PER HALF-HOUR.
Oblique haul with 2-metre ring-trawl, 1935.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Σ
Total Young Fish	50	15	206	80	273	55	36	18	11	88	15	14	861
Ditto, less Clupeids	2	7	40	17	250	50	24	15	11	9	2	3	430
All Clupeid spp.	48	8	166	63	23	5	12	2	1	78	13	11	430
Clupea harengus	39	1	–	+	–	–	–	–	–	–	–	–	40
Gadus pollachius	–	–	–	+	4	–	–	–	–	–	–	–	4
Gadus merlangus	–	–	–	1	36	10	2	–	–	–	–	–	49
Gadus minutus	–	–	1	1	5	–	–	–	–	–	–	–	7
Gadus luscus	+	+	–	1	1	–	–	1	+	2	1	2	8
Gadus callarius	–	–	–	+	–	–	–	–	–	–	–	–	+
Onos spp.	–	–	–	1	4	3	–	–	+	–	1	–	9
Molva molva	–	–	–	–	+	–	–	–	–	–	–	–	+
Merluccius merluccius	–	–	–	–	–	–	–	+	–	+	–	–	+
Raniceps raninus	–	–	–	–	–	–	+	–	–	+	–	–	+
Capros aper	–	–	–	–	–	–	–	–	–	–	–	–	–
Zeus faber	–	–	–	–	–	–	–	–	–	+	–	–	+
Arnoglossus sp.	–	–	–	–	–	1	1	2	2	1	–	–	7
Rhombus lævis	–	–	–	–	+	–	–	+	–	–	–	–	+
Rhombus maximus	–	–	–	–	–	–	–	1	–	–	–	–	1
Scopthalmus norvegicus	–	–	–	–	8	8	+	–	–	–	–	–	16
Zeugopterus punctatus	–	–	–	–	2	1	–	–	–	–	–	–	3
Zeugopterus unimaculatus	–	–	–	–	–	–	+	+	–	–	–	–	+
Pleuronectes limanda	–	–	–	+	6	–	–	–	–	–	–	–	6
Pleuronectes flesus	–	–	–	2	–	–	–	–	–	–	–	–	2
Pleuronectes microcephalus	–	–	–	–	2	–	–	–	–	–	–	–	2
Solea vulgaris	–	–	–	+	1	–	–	–	–	–	–	–	1
Solea variegata	–	–	–	–	27	4	+	–	–	1	–	–	32
Solea lascaris	–	–	–	–	–	–	–	–	+	–	–	–	+
Solea lutea	–	–	–	–	–	–	–	–	–	–	–	–	–
Serranus cabrilla	–	–	–	–	–	–	–	–	–	–	–	–	–
Caranx trachurus	–	–	–	–	–	–	–	1	2	–	–	–	3
Mullus surmuletus	–	–	–	–	–	–	–	–	–	–	–	–	–
Morone labrax	–	–	–	–	–	1	–	–	–	–	–	–	1
Ammodytes sp.	2	6	36	2	–	–	–	–	2	1	–	–	49
Ammodytes lanceolatus	–	–	–	2	2	1	1	1	+	–	–	–	7
Cepola rubescens	–	–	–	–	–	–	–	–	+	–	–	–	+
Callionymus sp.	–	–	1	2	150	19	9	4	1	2	1	+	189
Labrus bergylta	–	–	–	–	+	1	+	–	–	–	–	–	1
Labrus mixtus	–	–	–	–	–	1	–	–	–	–	–	–	1
Ctenolabrus rupestris	–	–	–	–	–	–	2	–	+	–	–	–	2
Crenilabrus melops	–	–	–	–	–	–	2	+	–	–	–	–	2
Centrolabrus exoletus	–	–	–	–	–	–	–	–	–	–	–	–	–
Trachinus vipera	–	–	–	–	–	1	+	2	2	–	–	–	5
Scomber scombrus	–	–	–	–	+	1	2	2	–	–	–	–	5
Gobius spp.	–	+	–	1	+	–	1	–	–	–	1	+	3
Lebetus scorpioides	–	–	–	–	+	–	–	–	+	+	–	–	+
Blennius ocellaris	–	–	–	–	–	–	–	+	+	+	–	–	+
Blennius pholis	–	–	–	–	–	–	+	–	–	–	–	–	+
Blennius gattorugine	–	–	–	–	–	2	3	1	+	+	–	–	6
Chirolophis galerita	–	–	3	–	–	–	–	–	–	–	–	–	3
Agonus cataphractus	–	–	–	+	–	–	–	–	–	–	–	–	+
Trigla spp.	–	–	–	–	1	1	–	–	+	+	–	–	2
Cottus bubalis	–	–	–	3	1	–	–	–	–	–	–	–	4
Liparis montagui	–	–	–	+	–	–	–	–	–	–	–	–	+
Lepadogaster bimaculatus	–	–	–	–	–	–	–	–	–	–	–	–	–
Lophius piscatorius	–	–	–	–	–	–	+	–	–	–	–	–	+

Migrations and Growth of the Thornback Ray (*Raia clavata* L.)

By

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With 2 Figures in the Text.

I. INTRODUCTORY.

ALTHOUGH workers in several European countries (England, Germany, Russia, Scotland) are stated (**5**) to be carrying out marking experiments on rays or skates, the writer is not aware of any recently published account of the results of any of these researches. Fulton (**4**, p. 191), however, records that in the years round about 1890 he marked 71 thornback rays (*R. clavata*) and 23 specimens of grey skate (*R. batis*) in Scottish waters. Two of the thornbacks and one skate were subsequently recovered. Of the former, one—about 36·5 cm. in width* on marking—remained at liberty for about three months before being recaptured and had travelled about 13 miles from the place where it had been set free. The other—35 cm. in width—remained at liberty for 278 days and travelled about six miles. The single skate, recaptured after only 10 days, had in that time changed its position by 10 miles. No records of size increments are given.

In order to collect data on the migrations and growth-rate of thornback rays in the English Channel, marking experiments have been carried out on certain inshore fishing grounds in the vicinity of Plymouth. For various reasons, not least of which is the high price† of these fish, the numbers involved are somewhat small—compared with those of plaice-marking experiments in the North Sea, for example. Nevertheless, the results already obtained are of such interest that it seems worth while presenting them at this stage.

After considerable preliminary experimentation with several types, a mark consisting of two vulcanite discs, one white and one black, was selected for use. On the white plate the identification letters and serial number are stamped in black (*vide* **5**, p. 139). The mark is placed on the

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[*] In these fishes, width of disc is the most convenient measure of size.

[†] Full market value (current price) is paid for a returned fish, in addition to a reward of two shillings if full particulars concerning it are furnished. Rays are prime fish, and as much as seven shillings (inclusive) has had to be paid for the recovery of a marked individual.

right wing (pectoral fin) of the fish, the white (numbered) plate above and the black one below. It is found that in thus having a white disc on the dark, upper surface and a black one on the white, under side, the mark is more readily observed by fishermen when a marked fish comes on board. This is of especial importance with regard to this laboratory's own research vessel in which, when a haul of fish arrives on deck, a marked individual at once catches the eye and is immediately transferred with all speed to circulating sea-water. If, as is usual, it remains vigorous, it is returned alive to the sea after its measurements have been taken. In this way repeated captures of the same fish have been made and valuable data not otherwise obtainable have been acquired (*vide*, pp. 609 and 612 *infra*).

For fishes of about 30 cm. and over in width of disc, mark plates 15 mm. in diameter are used. To all fishes of smaller size mark plates of only 8 mm. diameter are affixed.

II. MIGRATIONS.

Although rays are only moderately plentiful in the immediate neighbourhood of Plymouth, where these experiments have been carried out, there is one small fishing ground on which at least a few thornback rays can usually be found at all seasons. On this ground, locally known as the "Corner" (*vide* Fig. 1—shaded area), between 28th November, 1930, and 24th May, 1935, 538 thornbacks have been captured and released again after marking. Releases on other grounds in the vicinity (Fig. 1) have been: Cawsand Bay, 49; Bigbury Bay, 30; Plymouth Sound (inside Breakwater), 7. Of this total of 614 releases, 203 individuals (approximately 33 per cent) have been recaptured after periods varying from 12 to 1357 days. Details of these recaptures are given in Table I.

TABLE I.

DISTANCES TRAVELLED BY RECAPTURED FISH.*

		Number recaptured and distance travelled.			
Place released.	Number released.	Stationary.	Up to 5 miles.	5–20 miles.	20–50 miles.
"Corner" . . .	528	117^{256}	15^{240}	39^{334}	10^{300}
Cawsand Bay . . .	49	2^{71}	3^{705}	5^{391}	1^{415}
Bigbury Bay . . .	30	5^{363}	1^{179}	2^{721}	
Plymouth Sound . .	7		1^{312}	1^{82}	
Totals .	614	124^{280}	20^{311}	47^{350}	11^{311}

From this table it will be seen that of the 202 fishes whose place of recapture is known, no less than 124, or approximately 61 per cent of them,

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* Indices refer to average number of days free.

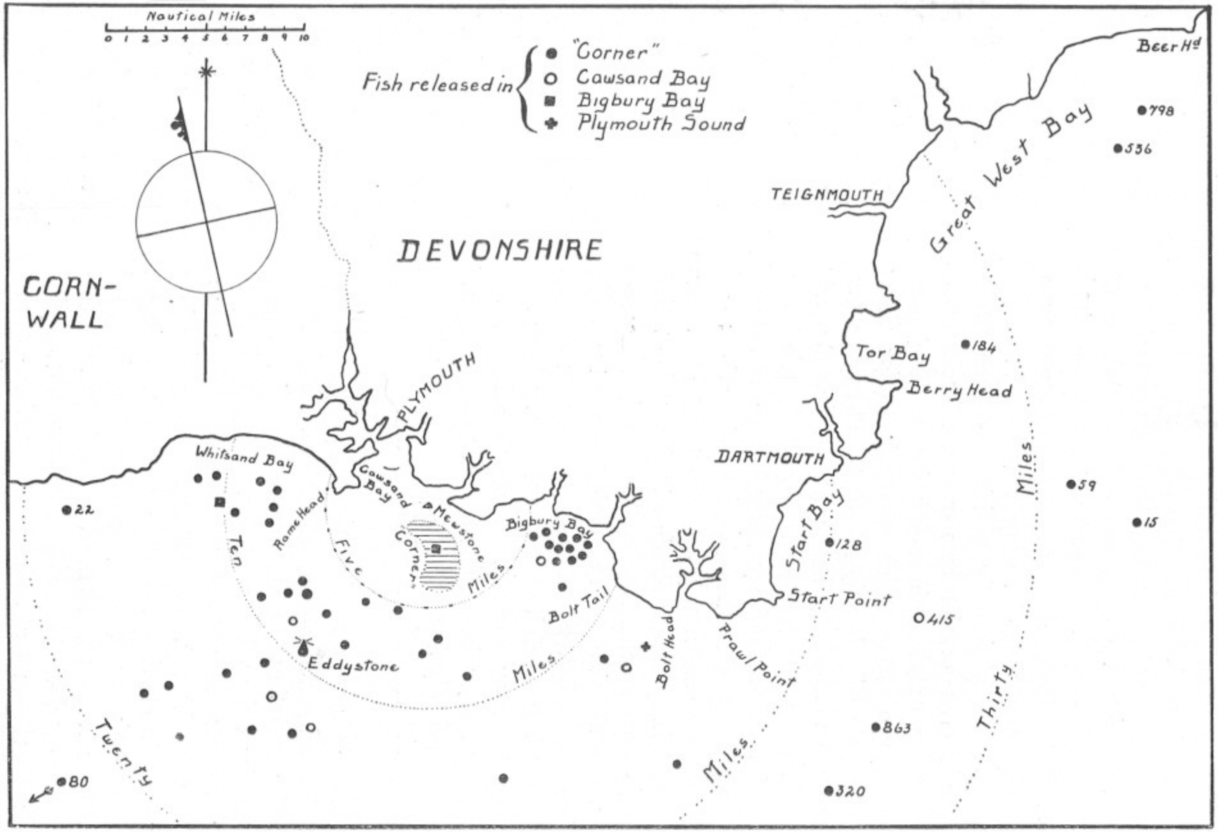

FIG. 1.—Positions of recapture of marked rays which had moved more than 5 miles. Fishes which had exceeded 20 miles have period of liberty shown (in days). For further explanation see text p. 608.

. . . . –. . . . . – = circle of 5 mile radius from Mewstone. .. .. .. = circle of 20 mile radius from Mewstone.
. . . . = ,, 10 ,, ,, ,, ,, ... = ,, 30 ,, ,, ,, ,,

were retaken on the exact spot* where they were set free, and this in spite of the fact that the times which had elasped between marking and recapture again varied from 12 to 1357 days. These returned fish came in at all seasons of the year, and the average period of absence was 280 days. One hundred and forty-four individuals, or 71 per cent of the recaptures, had moved less than 5 miles while only 11 had travelled over 20 miles. Not a single fish has as yet been returned from a distance greater than 50 miles from the point where it was set free.

In Figure 1 are plotted the positions† of recapture of all fishes which had changed their location by more than 5 miles, the different symbols indicating place of release in each instance. The great majority of these recaptures are of fishes which were released on the "Corner" ground (closed circles). Six had been set at liberty in Cawsand Bay (open circles); two in Bigbury Bay (closed squares); and two just inside Plymouth Breakwater (crosses). Bearing in mind that 144 fishes which had moved less than 5 miles are not plotted on it, examination of Figure 1 shows very clearly that there is no definite migratory movement of fish from these grounds. It must be noted, however, that most of the fish marked were immature individuals. Throughout their growing period, therefore, the young thornbacks show no migratory movement. There is simply a very slow diffusion of some fishes outwards in all directions.

Unfortunately, because of their scarcity on the trawling grounds, a sufficient number of adult thornbacks has not been marked to yield data concerning their movements. There is evidence from other sources, however (**1**, p. 20), which suggests that a certain amount of migratory movement (probably not very extensive) is shown by the sexually mature fish. A special effort is now being made to trace the extent of these migrations.

Because of the very marked non-migratory habit of the young fish it has been found possible to capture the same individual more than once at varying intervals in the same place. Of the 150 fishes which had moved less than five miles subsequent to marking, 23 have been recaptured by our own vessel, measured, and returned alive to the sea where, presumably, they are still at liberty. In addition, 10 fishes have been recaptured more than once. In one instance the same fish was caught by the *Salpa* no fewer than 4 times within a year after it had been marked, at intervals varying from 13 days to $4\frac{1}{2}$ months. This fish, therefore, was on a ship's deck five times within 12 months, having been trawled up on each occasion from exactly the same place in about 25 fathoms of water. It was caught

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* i.e. as nearly as can be ascertained at sea. As the grounds in question are all close by the land, the positions were fixed with considerable accuracy by the use of landmarks on shore.

† One fish was recaptured beyond the limits of this chart at a point 22 miles farther on, in the direction indicated by the arrow.

again a sixth time, still in the same place, 14 months after marking. Unfortunately, on this final occasion the capture was effected by a commercial vessel which killed it. Details of this and other repeat captures are given in Table II.

TABLE II.

RECORDS OF REPEAT CAPTURES.

Serial No.	Date marked.	Dates recaptured.					Whether released again.
		I	II	III	IV	V	
12	13/2/31	8/4/32	10/5/33				No
30	do.	5/2/32	22/5/32				Yes
51	10/10/31	8/12/31	21/12/32	29/3/33			Yes
63	do.	9/2/32	6/8/35				No
68	do.	24/8/32	26/9/33				No
133	23/12/31	22/1/32	14/5/32	13/9/32			Yes
226	25/4/32	22/5/32	25/8/32	5/1/33	18/1/33	1/7/33	No
285	12/5/32	29/7/32	7/12/32				No
103 S	25/4/32	22/3/33	26/1/34	23/4/34			Yes
143 S	12/5/32	15/7/32	2/8/32				No

All the fishes recorded in the above table were captured and released on the "Corner" grounds in from 20 fathoms to 25 fathoms of water, and all except one were in every instance recaptured exactly where they had been originally set free. The single exception was No. 63 which, in the interval between its second and third (final) captures, had moved to Bigbury Bay. Where in this table fishes are recorded as being no longer at liberty it means that, on the final occasion of their capture, they were taken by a commercial vessel and returned dead to this laboratory. Those still at liberty were on every occasion taken by the laboratory's research vessel and returned alive to the sea after measuring.

It is important further to note that all of the fishes included in Table II —except No. 63—were immature at the time of marking and were still immature at the time of their final recapture, the largest, a female (No. 285), being then approximately 49·5 cm. in disc width. The single individual (No. 63) which on its final capture was found to have moved a few miles away was an adolescent female 64·5 cm. in width.

In trawling for rays for marking purposes each haul has seldom been less than 1 hour and never exceeded 2 hours in duration. That numerous fish have survived repeated capture, as recorded in Table II, indicates that they can successfully withstand pretty severe treatment. But still further, and at first rather unexpected, evidence of their capacity to withstand rough handling has been obtained. During marking operations, immediately after a catch of fish has been brought on board, the trawl frequently has been lowered again at once and the captured fish marked and released while fishing continued in progress. This is now the routine method of working. In these circumstances it occasionally happens that a newly marked fish goes straight to the bottom and is caught again forthwith in the advancing trawl.* Most fishes taken twice in rapid succession in this way have survived the double capture and several have been caught again after further periods of liberty. One individual (222 S), a young male 22·5 cm. in width, was caught and brought on board three times on the day of marking and, having survived, was finally released only to be taken yet again after an interval of approximately 11 months. Details of this and other repeat captures on the day of marking, and the further history of each fish, are given in Table III.

TABLE III.

Repeat Captures on Day of Marking.

Serial No.	Details of capture on day of marking.	Subsequent history.
222 S.	Retaken twice, after marking, in consecutive hauls of the trawl.	Caught again after 333 days' liberty. Still free.
242 S.	Retaken once after first release on day of marking.	Caught again after 169 days' liberty.
12	Do.	Caught again after 14 months' and 25 months' liberty (*vide* Table II).
209	Do.	Caught again after 111 days' liberty
266	Do.	,, ,, ,, 27 ,, ,,
397	Do.	,, ,, ,, 12 ,, ,,

In addition, eleven other individuals have been retaken once after first release on the day of marking but have not been heard of again.

Three small thornbacks, however, each under 14 cm. in width, which at different times were taken in consecutive hauls, failed to recover after the second capture. Only on one occasion has a larger fish (48 cm. wide) failed to recover after two captures. This fish, when it arrived on deck the second time, received a severe knock from a large stone which had found its way into the cod end, the injury so received being the probable cause of death.

It is hoped to carry out further tests on the survival powers of rays of different species. The results so far obtained, however, suggest that where these fishes form an important part of the catch—as in English Channel

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* Rays returned to the sea after having been in the trawl, irrespective of whether or not they have been marked, usually swim about at the surface for a considerable time before descending to the bottom.

waters—it would well repay commercial trawl-fishing vessels to take the shortest possible hauls which are consistent with fishing efficiency, and to return at once to the sea all rays which are too small to be marketable. Possibly the very smallest individuals might not recover, but the larger unmarketable sizes would almost certainly live. Being non-migratory, these young fish would remain on the same grounds until they reached saleable size; they would not move away to another area where other fishermen (perhaps less careful of their own stocks) would reap the benefit. The non-migratory habit of these fishes in their growing stages, coupled with a relatively long juvenile life (*vide* p. 614 *infra*) is also important in that it increases the possiblity of reducing the stock on any particular fishing ground by too intensive fishing. Unlike migratory species which are exposed to capture only for so long as they remain in a fishable area, and whose numbers tend to be sustained or replenished by immigrants from other localities, the rays present on fishable ground remain constantly exposed to capture, and their numbers will be augmented only very slowly by gradual infiltration of individuals from adjacent regions where fishing is impossible or less intense.

III. Growth.

Of the 202 recaptured fish whose place of recapture is known, figures relating to size* have been received for 197 of them. Ten of these have been captured more than once and more than one record of growth has been obtained.

In Table IV the mean growth increments grouped at monthly intervals for fishes of 10-cm. size groups are given, the indices denoting the numbers of fish upon which the entries are based. Only 2 fishes of the very smallest size group (10–19·5 cm.) have been returned. It would seem that many of these very small individuals do not survive the ordeal of marking although returned to the sea in very vigorous condition. Notwithstanding that the smaller of the two marks in use is invariably affixed to them, it is relatively an enormous encumbrance to such tiny fishes, not to mention the relative severity of the operation when placing it in position. The use of a still smaller mark is impracticable.

At the other end of the scale, only very few fishes over 60 cm. disc width have been marked, and only one returned. As mentioned above, most of the fishes present on the Plymouth grounds are immature individuals and it is therefore mainly to those sizes, from about 20 cm. to 50 cm. disc width, that the data so far collected apply.

Examination of Table IV shows that, over this range—although there is considerable variation in the data owing to individual differences in

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* All measurements are made to the nearest half-centimetre next below.

growth rate—both sexes grow at a rate of from slightly under 4 cm. to slightly over 8 cm. in width of disc in the course of a full year.

In Figure II the growth increments of fishes which several times have been captured are shown graphically.* From this figure it will be seen that fishes No. 30, 51, 133, 226, and 103 S, which happened to be caught

TABLE IV.

Mean Size Increments of Marked *Raia clavata*.

Grouped at monthly (=4-weekly) intervals. Size increments in cm. Indices denote numbers of fish upon which entries are based when more than one.

Months at liberty.	Size group (cm.).												
	10–19·5		20–29·5		30–39·5		40–49·5		50–59·5		60–69·5		
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
0			0·17^{6}	0·0^{4}	0·3^{2}	0·0^{4}	0·0^{2}	0·2^{3}	0·5^{2}	0·0			1 year.
1				0·1^{4}	0·5^{5}				1·3^{2}	0·0			
2			0·5	0·5	2·3^{2}	1·2^{3}	0·5			0·3^{2}		0·5	
3			1·2^{3}		2·0^{3}	1·2^{3}	0·5^{2}		0·0	2·0			
4			2·0^{2}		1·5^{2}	1·8^{3}	1·0	0·5^{3}		1·0			
5					0·5	1·0	3·0			2·0^{2}			
6			0·0	3·0	3·1^{3}	3·0		0·5	2·0	3·0^{2}			
7				1·5	2·5^{2}	4·2^{3}	3·8^{2}	3·5					
8			3·3^{2}		3·5		2·5	3·0^{2}					
9			6·0	4·5	5·0	3·3^{3}		5·2^{3}	0·5				
10			5·0			4·5		5·5	3·5	6·5			
11			2·5		3·5	3·0^{2}	3·0	6·5	5·0				
12				4·5	8·0	3·0							
13			5·5				5·5^{2}						
14			7·3^{2}			4·5^{2}		6·5		9			2 years.
15		5·5			7·5	7·3^{2}	5·5		5·5				
16					9·0	11·5				3·8^{2}			
17			8·3^{2}		5·5	7·0^{2}							
18			8·0					8·0					
19					9·8^{3}	16·0	7·5	9·5					
20					7·5					11·5			
21						4·5	10·5^{2}	6·0					
22							5·5						
23					4·5								
24							5·5						
25			17·0		12·0								
26				16·0									
27										18·0			3 years.
28								13·0					
30						17·5							
31							7·8^{2}						
33	7·5												
34						6·5	12·5			11·5			
36						16·5	12·0						
39				13·0									
43						31·0							4 years.
45			23·0				9·0						
48				29·5^{2}									
52													

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* It should be noted that the lines joining the points plotted in this graph are inserted simply to facilitate reference to the several records for each fish; they have no mathematical significance.

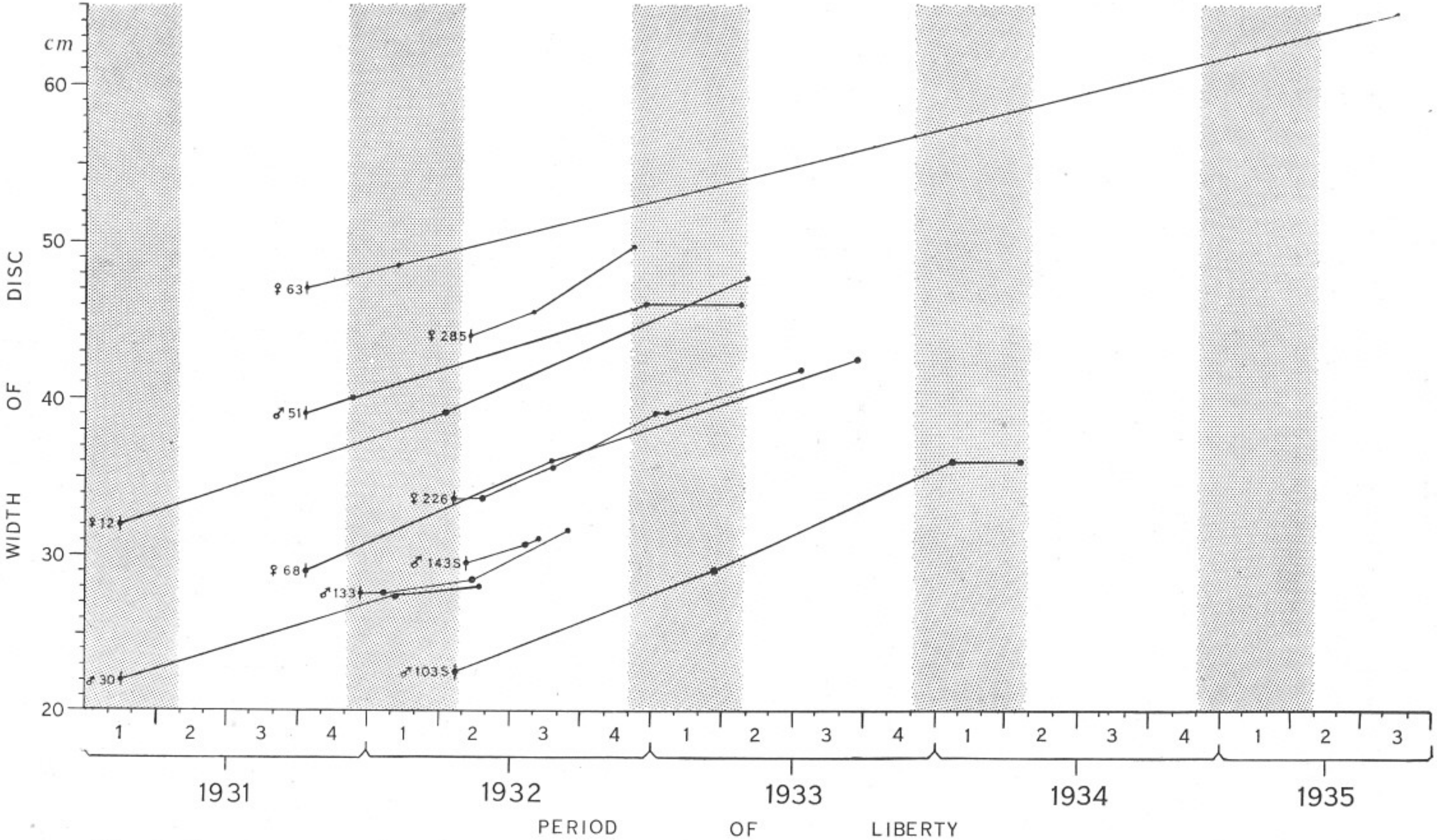

FIG. 2.—Growth of fishes for which more than one record has been obtained. The sex and serial number of each fish are given. Stippled areas = winter (non-growing) periods. ⧳ indicates first measurement and time of marking.

twice in the course of a winter period, show little or no growth in the winter interval. This winter period of slackened growth rate appears to extend from about the beginning of December until the end of April.

From this figure, too, it will be seen that the rate of growth in both sexes is approximately the same over the size range represented. For reasons already stated no data are available from marking experiments on the growth rates of the largest size groups. Observations on market categories (**3**, pp. 890 *et seq.*), however, reveal that in the males first-maturity is reached at or shortly after a disc width of 50 cm. is attained, and that thereafter their growth rate rapidly falls off. Male thornbacks seldom exceed and usually fail to reach 60 cm. disc width.

The females, on the other hand, do not reach first-maturity until they have attained a disc width of from 65 to 70 cm., and old adults of over 80 cm. disc width are not uncommon. Since both sexes grow at about the same rate until the male reaches first-maturity it follows that the males become adult at a younger age than the females. Thornback rays hatch out from the egg having an average disc width of approximately 8 cm. (**1**, p. 595). Taking 6·0 cm. per annum as an average growth rate in both sexes until the onset of sexual maturity, it follows that the males reach this stage when they are about 7 years of age whereas the females do not become sexually mature for another 2 years or so.

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An Investigation of the Seaweeds within a Marked Zone of the Shore at Aberystwyth, during the Year 1933–34.

(With special reference to the Use of the Spores as food for Oyster Larvæ).

By

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Introduction.

The following piece of research has been undertaken at the suggestion of the Conway Fisheries Research Station of the Ministry of Agriculture and Fisheries.

For some years experiments have been in progress at Conway in connection with oyster breeding. During the oyster season, from May to August, when the tanks of the Research Station are not being used for mussel cleansing, cultural work on the oyster (*Ostrea edulis*) has been carried out. One of the greatest difficulties is the feeding of the larvæ in the free swimming state and this problem affects both tank culture and culture on a smaller scale. In some years a settlement of spat has taken place, but it is not known what conditions made that phenomenon possible. It has been suggested that the available food supply might be of importance, since both detritus on the one hand, and seaweed spores and gametes on the other, have been regarded as constituting the food of larvæ (Martin, 1923). As nothing over 10μ can be ingested by the larvæ, there is a limit to the spores and gametes which may be used. The carpospores of the Rhodophyceæ will obviously be too large, and in the brown and green Algæ the range of possible food bodies will be restricted.

Ladd (1933) has investigated the possibility of using Enteromorpha zoospores for the purpose, but owing to the restrictions necessarily afforded by any one genus, it was felt that it was imperative to make careful observations on a portion of shore over a set period and to study the times of fruiting of some of the commoner algæ. So little has been written on the subject that data have not been available which would enable an investigator to see what suitable material might be obtained at any particular time of year.

A strip of shore was chosen on the college rocks at Aberystwyth. It was marked and was selected so as to include as far as possible the seaweeds available at Conway which could be used in the above connection.

The species present were listed and a record was kept of their epiphytes and of their fruiting periods.

The records of the succession of species occurring within the area were taken monthly from September, 1933, to August, 1934. The Rhodophyceæ found in the strip were added to the list for the sake of completeness, although they appear to be of no direct use in connection with the problem at Conway.

A complete ecological account of the vegetation has not been attempted, as the collecting of the records themselves was a considerable task. A table is given showing the fruiting periods of each recorded species.

THE FRUITING PERIODS OF THE SPECIES RECORDED.

After records had been made of the species, it became necessary to examine carefully their fruiting periods, and to prepare a table so that workers at Conway might be able to see what plants were fruiting at any particular time when food might be needed for the oyster larvæ. In the accompanying table is shown (*a*) the duration of the fruiting period, and (*b*) the type of fruiting body.

It is hoped that this table will be of value in showing the wide range of time over which certain species fruit and the large number of species which can be considered in connection with the oyster cultural work. In point of time, the species which can be used are those that fruit from May to August, i.e. during the oyster breeding season. However, not all the species that are fruiting during these months can be used as the spores must be of the required size, i.e. under 10μ. The following are the spores which could be used if sufficient material were available :—

1. Zoospores of *Enteromorpha compressa* and *Ulva lactuca.*
2. Gametes of *Cladophora rupestris*, *Cladophora gracilis* and *Cladophora flexuosa.*
3. Sperms of *Fucus vesiculosus*, *Fucus serratus* and *Fucus spiralis.*
4. Spores of the unilocular sporangia of *Pilayella littoralis*, *Ectocarpus ovatus*, *Ectocarpus repens*, *Myrionema strangulans* and *Chorda Filum.*
5. Spores of the plurilocular sporangia of *Pilayella littoralis*, *Ectocarpus ovatus* and *Ectocarpus repens.*
6. Spermatia of *Polysiphonia nigrescens* and *Polysiphonia fastigiata.* These would probably be of little use as they have no food reserve.

The eggs of the species of Fucus and the carpospores and tetraspores of

TABLE I.

TYPE OF FRUITING BODY AND DURATION OF FRUITING.

		Months of the Year.											
		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	Zoosporangia.												
1.	*Enteromorpha compressa*	—	—	—	+	+	+	+	+		—	—	—
2.	*Ulva lactuca*		—	—	—	+	+	+	+	—	—	—	—
3.	*Laminaria digitata*	+	+								+	+	+
4.	*Laminaria saccharina*	+	+								+	+	+
	Gametangia.												
1.	*Fucus spiralis*					—	+	+	+	—	—	—	—
2.	*Fucus serratus*	+	+						—	—	+	+	+
3.	*Fucus vesiculosus*		—	+	+	+	+	+	+	+			
4.	*Ascophyllum nodosum*		+	+	—	—							
5.	*Halidrys siliquosa*	—	+	+	—								
6.	*Cladophora rupestris*			+	+	+	+	+	+	+			
7.	*Cladophora gracilis*			+	+	+	+	+	+	—			
8.	*Cladophora flexuosa* (?)								+	+			
	Unilocular sporangia.												
1.	*Cladostephus spongiosus*	+	—								+	+	+
2.	*Pilayella littoralis*	+	+	+	+	+	—	—	—			—	+
3.	*Sphacelaria cirrhosa*												+
4.	*Ectocarpus ovatus*								+	+			
5.	*Ectocarpus repens*								+	+			
6.	*Myrionema strangulans*						+	—	—				
7.	*Castagnea virescens*						+						
8.	*Chorda Filum*								+				
	Plurilocular sporangia.												
1.	*Cladostephus spongiosus*	+	—								+	+	+
2.	*Pilayella littoralis*	+	+	+	+	+	—	—	—				+
3.	*Scytosiphon lomentarius*	+	+	—	—	—	—	—	—				+
4.	*Ectocarpus ovatus*								+	+			
5.	*Ectocarpus repens*								+	+			
	Tetrasporangia or Monosporangia.												
1.	*Hildenbrandtia prototypus*	+	+	—	—	—	—				+	+	+
2.	*Dictyota dichotoma*											+	
3.	*Dumontia incrassata*					+	+						
4.	*Plocamium coccineum*	+	+	+	—	—					+	+	+
5.	*Ahnfeltia plicata*	+	+	—									
6.	*Chondrus crispus*	+	+										+
7.	*Lithothamnion Lenormandi*	+									—	+	+
8.	*Furcellaria fastigiata*	+	+	—									+
9.	*Polyides rotundus*	+	+									—	+
10.	*Ceramium rubrum*	+	+	—	—	+	+	+	+				+
11.	*Ceramium strictum*					+	+	+	—				
12.	*Ceramium flabelligerum*					—	+	+	+				
13.	*Rhodymenia palmata*	+	+	+	—	—							+
14.	*Rhodomela subfusca*	+	+	+							—	+	+
15.	*Polysiphonia fastigiata*						+	+	+				
16.	*Polysiphonia nigrescens*	+	+	—	—	+	+	+					+
17.	*Polysiphonia urceolata*					+	+						
18.	*Grateloupia filicina*		+										
19.	*Lomentaria articulata*					+							
	Procarps and Cystocarps.												
1.	*Polyides rotundus*	+	+								—	+	+
2.	*Phyllophora membranifolia*	+	+	+	—						—	+	+
3.	*Phyllophora Traillii*		+	+	—								
4.	*Chondrus crispus*	+	+	—							—	+	+
5.	*Plocamium coccineum*	+	+	+	—							—	+
6.	*Ceramium rubrum*			—	—	+	+	+	+				
7.	*Ceramium strictum*			—	—	+	+	+	+				
8.	*Ceramium flabelligerum*			—	+	+							
9.	*Polysiphonia fastigiata*						+						
10.	*Polysiphonia nigrescens*						+						
	Spermatangia.												
1.	*Rhodomela subfusca*	+	+										+
2.	*Polysiphonia fastigiata*	+	+	+	+	—							
3.	*Polysiphonia nigrescens*			+	+	—							
4.	*Furcellaria fastigiata*	+	+										+

+ Maximum fruiting period.
— Intermittent fruiting.

the Rhodophyceæ cannot be considered as they are too large to be ingested by the larvæ.

It is evident from the tables that a correlation occurs between the position of the various algæ on the shore and their respective times of fruiting. Most of the algæ near high-water mark are fruiting in summer e.g. *Fucus spiralis*, *Enteromorpha compressa*, *Ulva lactuca* and the species of Cladophora. In winter *Fucus serratus*, *Laminaria digitata* and *Laminaria saccharina* are fruiting. These grow near low-water mark. Certain of the Rhodophyceæ, e.g. *Rhodymenia palmata* and *Plocamium coccineum* which grow near low-water mark are also fruiting at this season. Species that grow in the mid-tidal zone reach the maximum of their fruiting in the seasons between, e.g. *Ascophyllum nodosum* (spring), *Fucus vesiculosus* (spring) and *Cladostephus spongiosus* (autumn). This phenomenon was noticed formerly by Harris working at Aberystwyth on the fruiting periods of Laminaria and is mentioned by her in a thesis. The present work, however, extends the observations to a larger number of genera.

CONCLUSIONS.

The ascertaining of the fruiting period of a number of plants gives an indication of what species are available for consideration as food for oyster larvæ. Although the Rhodophyceæ are not in themselves of use, it is realised that the smaller green and brown algæ which are often epiphytic on them may prove very important. Species like *Pringsheimia scutata* Reinke, *Endoderma viride* Lagerh., and *Ectocarpus ovatus* may be taken as examples. These smaller species may prove very difficult to handle, but if they can be used a much wider range of food would be available and the chances of obtaining food at any particular time might be greatly increased.

The tabulated list of the fruiting periods gives the species that are fruiting from May to August, i.e. in the oyster-breeding season. Any of the species, which fruit at this period could be used, provided the motile bodies produced were of a size suitable for ingestion by the larvæ. A list of the spores that could be used is also given.

Having shown which species are available, the next step seems to be a detailed investigation of conditions most favourable to the discharge of spores and gametes. It would be necessary to be able to produce these conditions in the laboratory so that food might be provided in quantity at any given time. An adequate culture method by which experiments could be performed on plants at the same stages of development would be necessary.

Experiments on Enteromorpha have been carried out formerly in the department of Botany of the University College of Wales, Aberystwyth.

The results suggest that there is a periodicity in the ejection of the spores as the present writer believes to be the case in *Pilayella littoralis*. *Fucus serratus* and *Ascophyllum nodosum* will freely eject their sperms in a damp chamber, though even here there is a possibility that a maximum is reached periodically. If the periodicity could be ascertained and definitely established, the plants could be collected at suitable intervals. Then with the knowledge of the fruiting times of suitable plants, a supply of material might be kept available.

It is realised that some of the smaller algæ might not be suitable for feeding spat in large tanks, but provision must also be made for work in culture tanks where a smaller amount of food would need to be available.

It is hoped that the information now obtained on the fruiting periods of many common algæ may at all events prove a small contribution to the ultimate solution of the problem.

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Note on the Ubiquitous Cercaria from *Littorina rudis*, *L. obtusata* and *L. littorea*.

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With 1 Text-Figure.

This cercaria was found to be very common in specimens of *Littorina rudis* (Maton) and *L. obtusata* (Linné) collected at Aberystwyth during February and March, 1935, occurring in twenty out of fifty specimens of *L. rudis* and in four out of forty specimens of *L. obtusata*. It was, on the other hand, very rare in *L. littorea*, only two infested individuals being found out of a total of two thousand molluscs examined. In all three species of mollusc the parts of the digestive gland most heavily infested appeared white or creamy-white in colour.

The form described here appears to be almost identical with *Cercaria ubiquitoides* recorded by Stunkard (1932) from *L. littorea* and *L. rudis* occurring on the coast of Brittany. Certain differences are found between my specimens and those of Stunkard. It is difficult to determine whether these differences are individual or specific because there are so few larval characters in cercariæ of the Ubiquita group which can be used for separating species. The problem is rendered more difficult by the close resemblance of the adult trematodes (species of the genus *Spelotrema*).

PARTHENITA.

The sporocysts are small oval or rounded and colourless, and may contain from six to thirty cercariæ in various stages of development. The sporocysts vary in length from 0·25–0·75 mm., with an average length of 0·6 mm., so reaching a much greater length measurement than that recorded by Stunkard for *C. ubiquitoides*, which was from 0·25–0·45 mm.

CERCARIA.

Below is given a comparison of measurements of the present specimens with those of Stunkard, based on the measurements of twenty-five normally emerged cercariæ. All the figures except that for the body length expanded are average values, and are expressed in mm.

	Writer.	Stunkard.
Body length, expanded	0·16–0·21	0·1–0·24
Body length, normal	0·14	
Body length, contracted	0·07	
Body breadth, expanded	0·04	0·034
Body breadth, contracted	0·065	0·07
Tail length, expanded	–	0·25
Tail length, normal	0·11	–
Tail length, contracted	0·06	0·06
Diameter of Oral Sucker	0·03	0·03
Length of Stylet	0·028	0·025

The present form was never observed to reach a length of 0·24 and the stylet also seems a little longer than in *C. ubiquitoides*.

Stunkard observes that the penetration gland cells do not stain with neutral red. In the present specimens the penetration gland cells do not readily take up neutral red as an intravital stain. The gland cells consist of four pairs of cells each with its own duct which arises dorsally in each case. Each cell of the anterior pair sends a median duct forwards and these ducts cross the face of the sucker to open on either side of the stylet. The ducts of the remaining three pairs of cells are grouped in a common bundle and also open separately on either side of the stylet. The penetration gland cells are not lobed in the present form and the most anterior pair is situated a little way in front of the other cells. Of these four pairs of cells only the two anterior pairs and their ducts take up the intravital stain, staining a deep red. The remaining cells and their ducts have never been observed to take up the intravital stain. The arrangement of these cells which differs a little from those of Stunkard is shown in Figure 1.

The body also contains cystogenous cells scattered over its whole surface. Their cell outlines are very diffuse and they have not been figured.

The excretory vesicle is reniform, the main collecting tubules arise from it antero-laterally and pass forwards laterally to the level of the penetration gland cells where each divides into anterior and posterior collecting tubules. Two flame cells were observed, one lateral to the group of penetration gland cells and the other also lateral midway between the latter and the anterior border of the excretory vesicle.

In the region between the excretory bladder and the penetration gland cells there is a compact median mass of cells which is very difficult to see even in intravitally stained specimens. There is a very small papilla

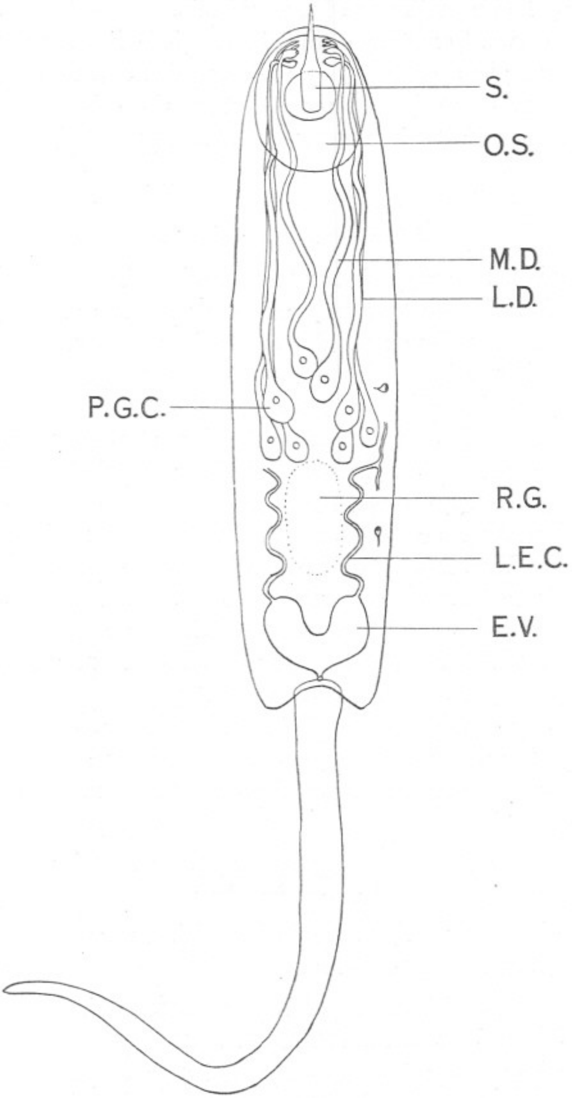

FIG. 1.—General Anatomy of the Cercaria. (The figure has been drawn with the aid of a *camera lucida* and is semi-diagrammatic.)

e.v., excretory vesicle; l.e.c., lateral excretory duct; l.d., lateral group of ducts; m.d., median duct; o.s., oral sucker; p.g.c., penetration gland cell; r.g., rudiment of genital organs; s., stylet.

situated over this mass. It may be the anlage of the genital sucker and the mass may be the rudiment of the genitalia.

This form differs from that of Stunkard chiefly in the arrangement of the penetration gland cells. They are more distinct, not lobed and the most anterior pair of cells is separated from the other three pairs. In addition there are slight differences in measurements.

Note on Life History.

This cercaria is also very similar to *Cercaria ubiquita* Lebour, differing chiefly from it in having four pairs of penetration gland cells instead of six pairs. Lebour believed *C. ubiquita* to be the larval form of *Spelotrema excellens* Nicoll, but did not experimentally prove this to be so. The encysted stage probably occurs in a shore crustacean.

The only marine birds which are commonly seen near the rocks from which the present snails have been collected are the gulls, more particularly the herring gull, *Larus a. argentatus* Pont. The only *Spelotrema* sp. which Lewis (1926) records from the herring gull in his survey of the " Helminths of Wild Birds " of the area is *Spelotrema simile* Jagerskiöld, who found it to be very common in this bird. The writer has also found *Spelotrema simile* to be very common in all species of gulls (except *L. marinus* L., which has not been examined for helminths). Only one specimen of *Spelotrema excellens* was found.

The unusually high percentage infestation of *Littorina rudis* with this cercaria, together with the high percentage of gulls parasitised by *Spelotrema simile,* suggests that this may be the larval form of this species.

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The Estimation of Zinc in Sea Water using Sodium Diethyldithiocarbamate.

By

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Sea water contains very little zinc. Values from 0–73 mg. per cubic metre have been cited in *Physics of the Earth*, V, 180, Washington, 1932. According to Orton it is less than 0·1 parts per million in the English Channel. Dieulafait found 2 mg. and Bodansky 7·3, erroneously quoted as 73 above. The method described here permits of the detection of as little as 8 mg. per m^3 using 200 ml. of distilled water in a Hehner tube, the delicacy of the reaction being much greater than that of any other for zinc. Sea water from the English Channel gives no turbidity and so is unlikely to contain as much as 8 mg. per m^3. The method is brought forward on account of its usefulness in detecting and estimating zinc in sea water contaminated by contact with metallic surfaces. Its use in fresh water has already been described (*Analyst*, 1935, **60**, p. 400, No. 711, June), and to this paper reference may be made for some possible sources of interference and for the origin of the reagent.

The turbidimetric estimation of the zinc is carried out by adding 10 ml. of a 0·1 per cent solution of the reagent to Nessler tubes containing suitable concentrations of zinc in neutral solution. Having thus found the approximate concentration, the comparison is completed using Hehner tubes. If concentrated sea water is used a light golden colour appears on account of the copper present. This renders difficult exact comparison with the white standards. The use of a Schott (Jena) filter No. OG2, which is a close match to the colour that appears, gets over this difficulty.

It has long been known that galvanized iron should not be used in marine aquaria. A fish merchant recently used this material for a tank in which to keep lobsters. Though well aerated and not overcrowded the water in this tank rapidly proved fatal, all the animals dying within four days. The water was analysed as described and was found to contain about 25 parts per million of zinc, a concentration about 3,000–10,000 times greater than that found in sea water. It was ascertained by Miss D. M. Mees that small crabs died within four days in sea water containing 25 p.p.m. of zinc, so there is no doubt that the zinc dissolved from the galvanised iron was the cause of the trouble in the lobster tank.

The Preservation of Fishing Nets by Treatment with Copper Soaps and Other Substances. Part III.

By

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It is over five years since Part II appeared and the method of testing preservatives by placing netting in jars filled with Aquarium tank water has been continued and final results obtained for those samples still under observation when the last report was written. The water in the jars was changed three times a week. At intervals tensile tests were made on the specimens by means of a spring balance and hand tests were made in general every week upon those that appeared to be weakening. In addition to the jar tests, treated netting was immersed under Plymouth Pier, where the tide runs strongly, where there is considerable wave action and where the water is at times contaminated with sewage. Here the nets were out of the water about four hours at each tide. Netting was also exposed in a tidal basin at Pier Cellars, Cawsand, just outside Plymouth Sound Breakwater. These samples were always wholly immersed.

PRESERVATIVES AND THEIR APPLICATION.

(*a*) *Coal distillation products.*

Crude gas-works benzene, used as a solvent for copper soaps; this blackens iron vessels.

Motor benzene, purer solvent, Anglo-American Oil Co.

Creosote oil, purchased locally.

Coal tar from local gas-works; a very thick tar, becomes moderately dry in one month.

Coal tar, "Corroid tar," specially prepared for nets by Messrs. Hardman, Hull; a less viscous tar, becomes moderately dry in a fortnight.

(*b*) "*Coalite*" *low temperature distillation products.*

Crude phenol, b.p. 180–230° C., a dark mobile liquid.

A neutral oil, b.p. 170–230° C. ("oil A"). Does not darken much on standing; has been extracted with alkali and with acid; kindly presented by Prof. G. T. Morgan, Director Chemical Research Laboratory, Teddington, as was also "oil B."

Oil B, b.p. 225–250° C. at 14 mm. pressure, extracted like oil A.

Coalite neutral oil, b.p. 100–245°; sp. gr. 0·971; alkali extracted, darkens on standing. Presented by Coalite Works, Gawber, Yorkshire, as were also other samples.

Coalite heavy neutral oil, b.p. 220–370°; sp. gr. 0·975; alkali extracted.

Coalite middle oil, b.p. 180–320°, with 47% crude tar acids; sp. gr. 0·966.

Coalite heavy oil, b.p. 230–280°, with 39% crude tar acids; sp. gr. 1·018.

Coalite low temperature tar, dries moderately in about three weeks, rather quicker than the more viscous local tar; all drying rates are approximate and vary with the conditions.

(*c*) *Wood distillation products.*

Stockholm tar, from coniferous wood (softwood). A tar of low viscosity and pleasant odour, dries in about a week. It is good, but cost is somewhat high.

"Shalco" tar, a hardwood tar of moderate viscosity prepared by Messrs. Shirley Aldred, Worksop; becomes fairly clean and dry in five days.

"Shalco" oil, a yellowish tar oil, b.p. 150–270°.

"Shalco" tar, export quality, contains copper resinate blended with it.

Resin spirit, sp. gr. 0·883.

Resin spirit, sp. gr. 0·930.

(*d*) *Petroleum products.*

White spirit is a distillate (Shell Co.) between 140–200°; it is of low flash point.

Kerosene or paraffin oil (Shell) distils at 150–300°; it has a higher flash point being prepared for domestic use.

Petrol, as for motor cars, Anglo American Oil Co.

Lubricating oil, Shell Mobiloil A.

(*e*) *Cutch varieties.*

Cutch from The Bakau and Kenya Extract Co., probably a mangrove extract, but the company's representatives in Glasgow refused all information; sold as Caller Herrin Brand.

Forestal brand cutch, from the heart wood of the South American Quebracho tree, *Quebrachia schinopsis lorentzii.*

Elephant brand extract, from the bark of the South African mimosa or black wattle, *Acacia decurrens* var. *mollissima*. These have approximately the following composition and are completely soluble in hot water.

	Mimosa extract.	*Quebracho extract.*
Soluble tannins (cold water)	62·5	63·4
Soluble non-tannins (cold water)	19·5	8·3
Insolubles (cold water)	0·3	8·0
Water	17·7	20·3
	100·0	100·0

The "insolubles" are soluble in hot water. These two samples and analyses were kindly supplied by the Forestal Land, Timber and Railways Co.

(*f*) *Copper compounds.*

Copper sulphate, crystals, commercial quality. For Olie's method use a 1% solution in water and add just enough ammonia solution to redissolve the precipitate first formed; this requires about 44 volumes of ammonia solution (sp. gr. 0·88) for 1000 volumes of copper solution; the result is a deep blue solution; it is used after cutch. Soak 10–15 min.

1. Mixed copper soap, containing stearate with oleate, palmitate and laurate; made by Lever Bros. (Messrs. Ogston and Tennant's "Pilot Protective Copper Soap"). This is a dark green greasy solid, rather less soluble in petrol than is the oleate. For use with nets it is prepared to contain about 20% of creosote or of thick mineral oil. It appears to be rather more effective as a preservative than oleate alone. We are indebted to Lever Bros. for a number of samples.
2. Copper oleate, a dark green greasy solid. Use and properties very similar to the foregoing. Obtained like the resinate from Messrs. Wm. Bailey & Sons, Wolverhampton; the firm kindly provided a number of samples. The oleate contains about 2% of added creosote.
3. Copper resinate, a light green dry powder, clean to handle; not very soluble in petrol, soluble in benzene, solvent naphtha and in oil A (neutral low temperature tar distillate).
4. Copper naphthenate, a dark green greasy solid, sold for use in solvent naphtha or various petroleum oils. It is on the market as "Cuprinol" of various grades; formerly made in Denmark, it is now made in England also. As a result of tests done here a certain proportion of coal tar is now incorporated with the quality sold for nets. The samples of the Danish and British products were kindly presented by the Companies. The "colourless Cuprinol for ropes" is the corresponding zinc salt; the "brown Cuprinol" contains the iron salt.

Copper naphthenate is also the basis of the Shell Canvas Preservative, and Shell Wood Preservative, which also contain paraffin wax and petroleum distillates, such as white spirit, kerosene or gas oil. Samples were kindly presented by the Company.

FINAL RESULTS OF TESTS REPORTED IN PART II.

When Part II appeared (this Journal, 1930, Vol. XVI, pp. 583–588) nets which had received certain treatments were still sound. The further results are given in Tables 1 and 2, from which it may be seen that the preservation of nets by Olie's method is a great advance over cutch alone. It is cheap, simple and where the nets can be re-treated at appropriate intervals it gives good results. Among the copper soaps the mixtures of both copper oleate and of copper naphthenate solutions with coal tar are very good, and a single treatment may last a long time.

TABLE 1.

(Table 2 of Pt. II, final results.)

Cotton net rotting in Aquarium tank water ; initial strength, dry, 18 lb. Immersed 20/10/'26. Untreated lasted 5½ months.

Treatment.	Re-treatments.	Time till rotten, in years.
Cutch, two boilings	Every two months	1¼
Do.	Every three months	2¾
Do. and Olie's ammonia copper sulphate	Every four months	6⅔

TABLE 2.

(Tables 12 and 13 of Pt. II, final results.)

Hemp and cotton netting rotting in Aquarium tank water or in tap water. Initial strength, dry, hemp 16½ lb., cotton 18½ lb. Immersed 25/11/'26.

	Time till rotten, in years.			
	Hemp.		Cotton.	
Treatment.	Salt water.	Fresh water.	Salt water.	Fresh water.
Mixed copper soaps, 10% in petrol . . .	1	3½	1	6
Do. with coal tar, 10%	3¾	4	3½	6¾
Cuprinol (Danish) with equal vol. of petrol . .	3½	2	4	6½
Do. with coal tar, 10%	3½	8	4½*	8½
Equal volumes of mixed copper soaps and Cuprinol as above (viz. diluted)	3½	8	2½	7¼

* Still 9 lb., jar missing.

FURTHER TRIALS OF NET PRESERVATIVES.

In the light of the experience already gained a large number of trials were made with the object more especially of testing different varieties of cutch, of trying Cunningham's cutch bichromate method which is still largely used and of testing various tar products. Above all it was desired to combine copper soaps with different organic solvents and tar with a view to cheapening and, if possible, still further improving these mixtures, which had already given very good results.

Table 3 shows that Olie's method is effective on three cutch extracts, very different in origin; compared with the advantage of using Olie's method the differences between the preservation afforded by the extracts alone become insignificant.

TABLE 3.

Cotton netting rotting in Aquarium tank water; initial strength 20 lb., dry. Two boilings in cutch, alone or with Olie's treatment.

	Life of net in months.	
	Alone.	Olie's method.
Untreated control	2	2
Cutch, mangrove (?)	8	16
Quebracho extract	8	18
Black wattle extract	9	16

Olie's method appears to be much used by the Dutch, but is unfortunately never used in this country. It was introduced in 1917. When re-treating a net according to Olie's process it is not enough to dip again in the ammoniacal copper sulphate, but the net must have two boilings in cutch and then the blue dip. A net which received re-treatments of the latter only failed after 20 months as against over six years for the complete re-treatment.

CUTCH AND LOW TEMPERATURE TAR PRODUCTS.

Table 4 shows the value of certain low temperature tar products alone or after cutch. Oil A is volatile; oil B leaves the net somewhat messy, but is cleaner than tar. The low temperature tar is of relatively low viscosity as compared with ordinary gas works tar.

TABLE 4.

Cotton net as in Table 3, with similar cutch treatment, alone or with tar product.

	Life of net in months.	
	Tar product.	Tar product after cutch.
Neutral tar oil A	13	14
Neutral tar oil B	15	54+*
Low temp. tar	54+†	54+‡
Untreated control	2½	2½

* Strength still 17·3 lb. † Strength still 18·6 lb. ‡ Strength still 10·8 lb.

Cunningham's Cutch Bichromate Method compared with Copper Soap Mixtures.

Cunningham's book, which is out of print, advises the use of a bichromate solution after two boilings in cutch. It directs that the net should be placed in, or passed through, a previously boiled 2½ per cent solution of potassium bichromate. " The best way is to pass the net through, adding more hot bichromate from time to time, as the hotter and cleaner the bichromate solution is, the better it will act." . . . " The bichromate should not be used more than once a year, or once at the beginning of a season. During a season the nets are to be boiled—that is cutched—in the usual way, but not so often."

At the outset of the net tests here this method was omitted because Dr. Olie must have known of it and introduced the ammoniacal copper sulphate method as superior. Taylor and Wells also tried it and rejected it. As, however, it is largely used still in England we have tried it. It is apparently a method that may or may not prove a success. One of the leading net preserving firms once showed me netting thus treated which had quite inexplicably rotted.

TABLE 5.

Cotton herring netting, cotton $36^s/9$-ply, rotting in Aquarium tank water ; strength at start 5·3 lb.

	Breaking load.	Time elapsed, months.
Untreated control	0	2
Cunningham's cutch bichromate applied by net makers	0	7½
Copper resinate 10%, coal tar 10% in benzene	3	18
Copper oleate 10%, coal tar 10% in benzene	6·0*	24
Danish Cuprinol	3	24
Danish Cuprinol with 10% coal tar	4·7	24
Untreated control, warmer weather series	0	1
Cunningham's cutch bichromate applied by net makers	0	5½
Copper resinate 10% in benzene	0	5½

Table 5 shows that even when carried out by an experienced firm the cutch bichromate method is not nearly as effective as the copper soap and tar mixtures. Moreover, the latter leave a pliable net and cause no shrinkage, whereas cutching hardens and shrinks the net with each successive re-treatment. To avoid slipping of the knots with the copper soap and tar mixtures they may, when new, be hand tightened or may be given an initial short boiling in cutch. According to Filon this is an advantage.

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* Slightly stronger than initial strength of untreated net, probably due to local variation in the twines or possibly to the cementing action of the tar.

PRESERVATION BY MEANS OF COPPER SOAPS WITH WOOD AND COAL TAR DISTILLATES.

Several series of tests have been combined in Table 6; a few combinations with tar are missing owing to the disappearance of the jars. It may be seen how greatly the tar products are improved by having a copper soap added, also that solutions of the latter are much improved by having 10% of a tar added.

TABLE 6.

Cotton netting rotting in Aquarium tank water; strength when new 20 lb., dry. The figures denote the life of the netting in months, or the time when the final examination was made; for strengths then see footnotes. Untreated controls lasted about $2\frac{1}{2}$ months.

Treatment.	Tar product, alone.	Copper oleate, 10% in petrol.	Copper resinate, 10% in benzene.	Cuprinol.
Hardwood oil b.p. 150–270° C. (Shalco)	10	—	—	—
Hardwood tar (Shalco)	22	50[*]	—	—
No tar	—	24[†]	29[††]	54[‡]
Crude phenols	5	22[‡‡]		
Neutral tar oil A	13	36[‡‡]		
Neutral tar oil B	16	46[‡‡]		
Low temperature tar	53[§]	53[‖] [‡‡]		
Coal tar, Plymouth	36[§§]	36[§§]		
Coal tar, Corroid	36[§§]	36[§§]	49[‡‡][**]	

The tar and copper soap mixtures are very good. These mixtures were prepared by adding the tar to the hot melted copper soap. Where a solvent was also used the warm mixture was then poured in with stirring. The object of using the solvents is that the 10 per cent copper soap, with 10 per cent tar in a solvent, is far lighter and cleaner to handle than are copper soap and tar mixtures. The cheapest solvent, and the best, as shown by the tests on ropes in the accompanying paper is the neutral tar oil, low temperature process; either oil A or the closely similar product extracted with alkali only may be used. Oil A, with copper resinate or with copper oleate gives a pliable net, very clean to handle and having an attractive green appearance. Oil B is rather messy alone,

[*] Blended with tar by the makers, no petrol.

[†] A hemp net lasted 28 months, its control $3\frac{3}{4}$ months; initial strength 18 lb., dry.

[‡] Original strength maintained, also in a hemp net.

[§] Still strong, average 18·6 lb.

[‖] Strength 6·6 lb.

[‡‡] Had 10% of the tar product in oleate solution.

[††] Only 22 months in solvent naphtha.

[**] Strength still 8·2 lb.

[§§] Strength still 17·0 lb., Plymouth tar; 21 lb. Corroid tar; Plymouth tar-oleate mixture 13·7 lb.; Corroid tar-oleate mixture 17·2 lb.

but with copper soap and petrol in the proportions given it is considerably less messy than tar used similarly. In the pound, pound and gallon* proportions the tar even is tolerably clean to handle, especially when copper resinate is used instead of oleate.

Solutions of copper resinate in resin oil with or without added resin, or diluted with petrol all proved unsatisfactory; they gave sticky nets which lasted in the three cases tried just 19 months, whereas a control with copper oleate alone in petrol was still well above half-strength after 21 months.

It also seemed desirable to compare the various types of "Cuprinol" now on the market and the original Danish product. Strong cotton net, $32^s/30$-ply, was again used, and the pieces averaged 17·0–19·0 lb. when new and treated. The material was soaked in each mixture for the usual 15 minutes, though less would probably have sufficed on account of the good penetration of Cuprinol. The series comprised: No. 131A, green Cuprinol for nets, British made and containing a proportion of added tar; No. 132A, brown Cuprinol for nets—this is an iron naphthenate; No. 133A, colourless Cuprinol for ropes, a zinc naphthenate; No. 134A, untreated control and No. 135A, Danish green Cuprinol, the copper salt, without tar. The control perished in 4 months. After 29 months the strengths were, in order, 19·6, 15·0, 17·8, 0 and 20 lb. Green algæ were growing on the zinc naphthenate net. The tests are still in progress, but other experiments with ropes are strongly in favour of the green (copper-containing) Cuprinol with tar.

THE PRESERVATION OF SILK PLANKTON NETS.

These nets, made of bolting silk of mesh from 200 to the inch for the finest to 25 to the inch for the coarse, are costly and liable to damage at sea, especially once they have become weakened. It was established that it was deleterious to rinse in fresh water after use, or to disinfect periodically with formalin. Exposure to sunlight was found to be a potent source of deterioration. For many years now it has been the practice at this laboratory to treat the nets with a copper soap solution. First of all copper oleate was used with good results, but it was hard to secure an even treatment since sizing prevented the penetration of the soap. Washing in "Lux" was not found to effect any very marked improvement in removing the sizing. Then copper resinate was used for a while as nets so treated were a uniform light green, but they had a tendency to be somewhat stiff at first. Finally green Cuprinol was used; it gives a uniform colour and leaves the net pliable. As the present issue for nets

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* 1 lb. of soap and 1 lb. of tar to 1 gal. of solvent gives approximately a 10% solution for soap and for tar.

has some tar we tried diluting it to avoid blocking of the meshes and to cheapen the process.

Furthermore a series of tests was made in which portions of 200-mesh netting were treated according to the various methods and placed in jars to rot. As a result it was established that by far the best treatments as regards durability were: (*a*) green Cuprinol undiluted; (*b*) green Cuprinol with tar, as sold, with equal volume of petrol and (*c*) the same with three of petrol to one of Cuprinol. The last-named treatment is not costly either in view of the value of the nets. With Cuprinol at 9s. per gallon and with petrol at 1s. 3d. per gallon, the 25 per cent mixture comes to 3s. 2d. per gallon as compared with the copper oleate solution in benzene, 3s. 6d. per gallon, or in petrol, 2s. 9d. per gallon. The three Cuprinol treatments mentioned prolonged the life of the net to about 11 months of continuous immersion, as against $3\frac{1}{2}$ months for the untreated net; even $3\frac{1}{2}$ months is an unusually long life for this fine mesh, as earlier tests gave about one month.

Thus on the score of durability, pliability, freedom of blocking of the mesh, and of cost, the dilution of the green Cuprinol for nets with three volumes of petrol is recommended as the best treatment for silk nets. As however copper oleate is sold in solid form it may be more conveniently sent by post and quite good results are obtainable with it. Probably a mixture of equal volumes of oleate and of resinate solution would behave well, but we have no extensive experience of it.

Shell canvas preservative and Shell wood preservative were also tried for silk nets, since in them the basis is also copper naphthenate. Neither proved satisfactory, probably on account of the large amount of paraffin wax present.

Tests on Net Preservatives in the Sea.

With the results already obtained as a basis, sixty-five pieces of netting were placed below the Plymouth Promenade Pier where the rope tests were conducted. No information was obtained from this since the pieces of net fouled the supports and barnacle-covered girders. Within a month they were torn to pieces. Duplicate sets were then suspended from ropes slung across the laboratory's fish pond at Pier Cellars, Cawsand, just outside Plymouth Sound Breakwater. This basin never becomes dry, but is completely filled and more than half-emptied again each tide.

The methods tested were as follows: cutch, Olie's, Cunningham's, coal and wood tars, neutral low temperature tar oils and creosote, varieties of Cuprinol, Shell canvas and wood preservatives, copper oleate, copper resinate and a series of tests with these and different solvents such as petrol, paraffin oil, benzene and tar oils, total 64 and one control. The netting was cotton $32^s/12$-ply, 100 mesh deep, 26 rows to the yard, initial strength 7 lb. per thread.

The water being very clean, the untreated netting took 5¼ months to become rotten, and treatment with Coalite oil A did not prolong its life. Cunningham's cutch bichromate method was tried in three ways, since no exact times or temperatures are specified in the description quoted. When the net was placed in boiling bichromate for 5 minutes it was rotted at once; leaving it in bichromate, cooling down from boiling, for 5 minutes gave a net lasting 7 weeks only, and soaking for one hour in cold bichromate gave exactly the same result. Two boilings in cutch without bichromate lasted 3½ months only, though our jar tests showed that cutch had a preservative action.

The duplicates were slung on different ropes, there were four ropes in all, so that the effects of chance local conditions might be eliminated. Nevertheless, seaweed collected in places and soon rotted nets, the duplicates of which remained sound. With these exceptions all the treatments were found to keep the netting sound from May 15th to November 8th, 1934. When examined again on November 22nd it was found that almost all had become rotten. It was also observed that up to November 8th the bottom of the basin was covered with Laminaria etc., whereas on November 22nd the bottom was devoid of seaweed and remarkably clean, yet on the rocks outside the seaweeds had continued as usual. It appears that the large amount of rotting seaweed must have made the water so foul as to subject the nets to very heavy bacterial infection. It was noticed that many of those containing copper compounds had become black owing to the formation of sulphide; the low solubility of the latter renders it practically non-toxic.

The nets which had rotted included specimens treated, by one of the best makers, according to Cunningham's method. The five remaining out of the two sets of 65 each included No. 61, copper resinate 1 lb., "Corroid" tar 1 lb., Coalite oil A 1 gallon; this lasted a little longer, up to 6¼ months. No. 37, copper resinate 1 lb., to 1 gallon "Coalite" low temperature tar, lasted 8 months; No. 36, copper resinate 1 lb., Corroid tar 1 gallon, lasted 9 months. In all three cases, however, only one of the duplicate samples remained sound. Only No. 29 remained in duplicate, one lasting 7 and the other 8 months; the treatment was green "Cuprinol" with tar added, the British product. The other copper naphthenates, "Shell" products, had gone.

There is no doubt that the ones which did remain are good, but one is not at all sure that the conditions were always comparable, on account of the draping of the loose seaweed along the nets. As a whole, this large series gave less information than had been expected, but the relative merit of the treatments is better shown in the following paper in which they were applied to ropes, which were immersed beside the nets simultaneously.

The Preservation of Trawl Nets.

These nets are very commonly used without any preservative in England, on the score that they are in any case liable to damage by tearing. They are, however, made in sections, and commonly only the lowermost of these gets torn. Furthermore, though even new trawl nets may get caught in an obstruction and be badly damaged, yet in many cases tears occur only after considerable use when the net has already become much weakened through rotting of the twine. Were new nets to tear thus, the obvious way of meeting the difficulty would be to use stronger twine, and this would have been done long ago. The alternative is to maintain the twines now used as near as possible at their original strength by proper preservatives.

Some tests were carried out with twines supplied by the Advisory Committee on Vegetable Fibres to ascertain whether certain fibres produced within the British Empire were as suitable as manila for use in trawl nets. The small amount of material available was made up into netting in order to see whether the bending at the knots was a potential source of weakness, also to test the penetration of the preservatives into the knots. No evidence was obtained of failure at the knots.

The fibres used were sisal (*Agave sisalana* Perr.), New Zealand flax (Phormium sp.), and Benares *sann* hemp (*Crotalaria juncea* L.). The twine all averaged well over 100 lb. when new. In Aquarium sea-water the untreated controls were rotten in about 5½ months, rather less for the *sann* hemp. This treated with the usual mixture, copper oleate 1 lb., coal tar 1 lb., petrol 1 gallon, lasted for 8 months, whereas the sisal lasted for 24 and the Phormium fibre for 29 months. It was obvious that none of the twines had been properly penetrated in a ten minutes' dip, which was unfortunately the treatment. Far better results should be obtainable with longer soaking which is necessary for these hard fibres, though unnecessary for cotton.

The results obtained with Olie's method were, however, extraordinarily good. *Sann* hemp and Phormium fibre lasted 34 months, and the sisal twines still averaged 12 lb. after 48 months—and this with a single initial treatment.

The matter was not pursued further, but it is highly probable that Olie's method followed by a dip in one of the tar oils or in tar would give very good preservation indeed. There is some objection to the use of tar in quantity owing to cases of tar cancer having occurred. It is quite possible that the double washing, in alkali and in acid, used in producing the neutral oils, may remove the carcinogenetic substances, so that oil B could be used instead. It is less messy than tar. In any case, Olie's method alone is very good.

Fishing Lines.

A few tests were carried out upon lines for use with rods, sold as cotton, flax, silk and enamelled silk. Some unsatisfactory attempts were made to use the copper preservatives, but this was before the addition of tar improved the adherence of the preservative.

A solid braided green translucent silk fishing line remained fairly sound in both tap and Aquarium salt water for three months, but had perished inside four. In this case the application of a mixed copper soap (oleate, stearate, palmitate) was useful, for the line was fairly strong after four months in salt and after five in fresh water.

A plaited pure flax line remained sound in tap water for five months, but became absolutely rotten in sea-water in one month.

A fine Japanese silk line or artificial gut, dyed brown, was easily broken after one month in fresh water. A somewhat stouter Japanese silk line, undyed, also broke readily in one month, and had completely disintegrated in less than four. Another sample tested was Japanese silk worm gland line, obtained by drawing off the silk by hand from the gland ; the major portion of this line is translucent. After one month in fresh water this sample could be broken with some effort, but even after three the centre portion was quite sound, the breaks being at the ends. After five months the broken centre pieces were still fairly strong. It is thus much superior to the woven silk. For these three samples and for the information concerning their preparation I am indebted to Dr. Ikusaku Amemiya of the Imperial University, Tôkyô.

Good results were obtained with a thin green dyed line, sold as " Justice Brand plaited silk line." On enquiry it was found that this was made by Messrs. Tubb, Lewis & Co. of Wotton-under-Edge. The firm kindly presented a number of samples for testing. The plaited cotton lines averaged 13·5, 20·4, 25·0 and 29·6 lb. when new ; they became rotten after 4, 5, 6 and 8 weeks respectively in the jar tests with Aquarium water. The first and third were dyed yellow, the other two dark green, but the dye seems to have had no preservative action. Five samples of plaited flax line were tested ; these when new averaged 17·4, 28·5, 32·6, 41·7 and 47·0 lb. The first, third and fourth were brown, the second and fifth green. These flax lines perished in 6, 8, 5, 5 and 8 weeks respectively, but the two that lasted 8 weeks were green dyed, so this dye may have had some favourable action. In all this set of tests the lines were soaking in approximately twenty times their own weight of water. The seven lines denoted as plaited silk were in comparison outstandingly good, though usually silk becomes rotten quite soon in sea-water. The initial strengths were 5·2, 8·0, 15·6, 18·5, 21·8, 25·2 and 33·5 lb. ; of these the first, fourth and fifth were drab, the others white. They lasted 6¼, 6, 5, 8, 3½, 3½ and 8 months respectively, whereas none of the cotton or flax lasted more than 8 weeks. Obviously the green dye in the first sample of Justice Brand plaited silk line, purchased locally, had nothing to do with its resistance to decay.

It is obvious that these tests in which the lines are left soaking in water do not represent actual conditions for rod lines; they are, however, of comparative value. Furthermore, it must be remembered that, if even slightly damp, rotting goes on; some bacterial deterioration takes place even in the "air dry" condition. There is therefore a use for the copper soap preservatives in these lines also, to which they should be applied in weak solution and soaked to secure good penetration.

TESTS FOR COPPER AND ZINC SALTS AS PRESERVATIVES.

An approximate idea can be gained as to how a preparation containing salts of the above metals is likely to behave as a preservative by means of sodium diethyldithiocarbamate. A trace of the reagent gives a golden yellow-brown with copper, a darker brown with iron and a white with zinc, and these reactions are extremely sensitive.

With copper oleate it may be seen that copper is given off more freely than with copper resinate, hence the latter lasts longer. On the other hand copper naphthenate (Cuprinol) is a far more active source of copper ions; it is only on account of its higher concentration owing to its solubility in petroleum products and its excellent powers of penetration that it lasts as well as it does. Zinc naphthenate is even more active, but the ions are less toxic. The beneficial effect of added tar is largely due to the fact that it diminishes the rate at which copper ions are given off; they may thus continue to diffuse out long after the tar has lost its own toxic compounds.

Nets which remain sound after long immersion are found to be giving off appreciable amounts of copper or zinc ion, whereas those which are much weakened give off little or no copper or zinc.

SUMMARY.

1. Frequent treatment with cutch is injurious, but Olie's method (cutch and ammoniacal copper sulphate) applied every four months preserved cotton netting for six years and eight months in Aquarium sea-water.

2. Varieties of cutch tested showed differences which were quite insignificant in comparison with the improvement effected by adopting Olie's method, which was effective with all on cotton.

3. A single treatment by Olie's method preserved trawl twines of Benares *sann* hemp, New Zealand Phormium fibre and of sisal (E. African)

for 34, 34 and more than 48 months respectively under conditions such that the untreated twines perished in less than five months.

4. Cotton treated with cutch alone is but little improved by a dip in crude phenols, but a neutral tar oil obtained from the "Coalite" low temperature distillation process was found useful.

5. Cunningham's treatment with cutch and bichromate is not easy to get exactly right and the best results of net makers seem far inferior to those obtained with Olie's method or with copper soaps and tar.

6. Copper soaps dissolved in benzene, petrol, etc., may be arranged thus in order of effectiveness, but the first three are not very different in durability.

(*a*) Copper oleate.
(*b*) Mixed copper soaps (Lever Bros.).
(*c*) Copper resinate.
(*d*) Copper naphthenate (Cuprinol), best by far.

7. The addition of tar to the copper soaps brings them more nearly level. Effective mixtures contain 1 lb. of oleate, mixed soaps, or resinate, 1 lb. of coal tar to 1 gallon of benzene or petrol (save for resinate). Cuprinol as now sold for nets has tar incorporated by the makers. Single treatments with such mixtures have preserved cotton netting up to 3½ years under conditions which brought about the decay of untreated netting in 2–5 months, according to season and state of the water.

8. A very effective and cheap dip may be obtained by replacing the benzene or petrol in previous paragraph by "oil A," a neutral oil from "Coalite" process, b.p. 170–230° C. This is a good solvent for copper resinate, and if solvent is a non-darkening grade, resinate without tar gives a clean light green net; but the greasy nature of oleate and naphthenate is probably an advantage.

9. For hard use and where the extra weight is unimportant coal tar, hardwood tar (Shalco) or softwood tar (Stockholm tar) may be used; a specially prepared coal tar (Corroid tar) is particularly good, also "Coalite" tar.

10. These tars are all greatly improved by the addition of a copper soap, 1 lb. per gallon. In a tidal basin copper resinate with Corroid tar or Coalite tar and Cuprinol made with tar were all found to be very good.

11. Bolting silk plankton nets may be preserved by treatment with copper oleate or copper resinate in benzene, without—or with very little—tar. The most effective treatment, however, is to use a dilute solution of copper naphthenate with tar; this is obtained by diluting "green

Cuprinol for nets " as now made in England, with three volumes of motor car petrol.

12. Cotton and flax fishing lines for use on rods were found to become rotten in 4–8 weeks in Aquarium sea-water, but their durability can be improved by soap and tar solutions in benzene. Japanese silk gland (hand drawn) line is rather better than untreated cotton or flax, and a solid braided green translucent silk line lasted for 3 months. Best of all tried here were lines marketed as " Plaited Silk, Justice Brand " (Messrs. Tubbs, Lewis & Co.), which under similar conditions to the others lasted from 3½ to 8 months.

13. A rough idea of the serviceableness, as a preservative, of a copper or zinc soap can be obtained by testing the material treated with salt or fresh water to which a trace of sodium diethyldithiocarbamate is subsequently added. This will show the rate at which traces of copper (golden yellow) or of zinc (white) are being given off ; the test may be applied to freshly treated samples or to those which have had long immersion.

The Preservation of Fibre Ropes for Use in Sea-Water.

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Experience gained in the preservation of fishing nets and lines has led to the study of various methods of preserving ropes when immersed in sea-water. In normal use a rope deteriorates partly from wear and tear, partly from the destruction of its fibres by bacterial action. Which of the two is most severe depends upon the conditions under which the rope is used. The internal friction of the rope is much reduced and its useful life prolonged by the incorporation of a lubricant, which according to the United States Government specifications should be not less than 8 and not more than 12 per cent of the weight of the rope as sold. When ropes are wet, or even damp, bacterial action proceeds far more rapidly than when they are dry. Once a rope has been wetted by sea-water it is nearly always damp. Ropes may even become entirely useless while in store below decks, especially in tropical climates. The use of a proper preservative can completely stop all decay. The result that follows from this is twofold; firstly the rope lasts longer, risk of failure in service is reduced and the cost of the labour and material required for renewals is lessened; secondly, since one knows that the rope will maintain a figure close to its original strength for far longer, it may be possible in certain cases to use ropes of a lesser initial strength.

The destructive action of bacteria is far greater in dirty water than in clean water. Consequently tests have been carried out in both. The tests carried out in Plymouth Sound were exceptionally severe, since the water was at times contaminated by drainage from the Pier, under which the ropes were exposed; the site is also downstream and not very far away from the main sewer outfall of Plymouth, but not in the direct line of flow from this. The ropes were clamped at one end between three-inch strips of wood screwed together. These strips were tied to the iron columns of the pier at first by galvanized iron wire, later by galvanized steel wire after one set had been lost in a storm. The position of the ropes was such that they were hanging clear of the water for about four hours each tide. The ends were bound with twine so as to prevent unlaying. The ropes were subjected to the action of strong tidal currents and to considerable wave action in rough weather.

The exposures made under the pier were with ropes approximately two inches in circumference, three or four strand. Further exposures were made in an enclosed fish pond at Cawsand, just outside the Breakwater of Plymouth Sound, where the water was much clearer and rose and fell freely with the tide. Only when the accumulated seaweed was rotting in October–November was this water dirty. The ropes at Cawsand were always immersed.

FIBRE ROPES USED.

The terminology of the rope industry appears to be vague. Hemp fibre was most used formerly, so everything else is called hemp by some. The " hemp rope department " of one large firm supplied us with a hemp rope which proved not to be hemp at all but manila fibre. We speak of fibre ropes to distinguish them from metal ropes, which have nevertheless a fibre core in many cases, the preservation of which is most important. The preservatives adhere differently to the various fibres so their identification is necessary.

The fibres used were as follows :—

(*a*) Hemp fibre, derived from the bast of the stem of the hemp plant, *Cannabis sativa*, produced mainly in Russia and Italy.
(*b*) Manila fibre, derived from the sheathing leaf-stalks of *Musa textilis*, a plant of the banana family ; it is produced almost exclusively in the Philippine Islands.
(*c*) Sisal fibre, derived from the leaves of *Agave sisalana* Perr., a native of Central America now grown largely in East Africa.
(*d*) Coir, the fibre of the coco-nut.

METHOD OF TESTING THE TENSILE STRENGTH OF ROPES.

The mechanical tests of the rope specimens were carried out in the 10-ton Buckton Vertical Testing Machine in the Engineering Laboratory of Trinity College, Dublin University.

Owing to the short length of the specimens it was not possible to grip the ends in a way likely to avoid all damage. Various tests were made on rope similar to that used in the tests and eventually in the light of these it was decided to proceed as follows. Each specimen, one yard in length, was cut into two. The ends of each piece were partially unlaid and a 6-inch round wire nail was pushed into the rope endwise. The strands were then laid up tightly again and the ends served with fine twine. The end six inches of each piece were then soaked in glue for about an hour. This left a thick coating of glue on the ends and partially protected the outer fibres from the serrations of the grips.

It was thought that two results from each specimen, even if not giving a perfect test, would at least give comparable results; those of 12 tests on a 2-inch yacht manila of good quality are shown in Table 1.

TABLE 1.

To test the reliability of method of testing 2-in. yacht manila rope; breaking load given in pounds. Break at nail end, N, or at grip edge, G.

No.	Lb.	Break.	No.	Lb.	Break.
1	5840	N	7	5250	N
2	5390	N	8	4470*	N
3	5260	G	9	5590	N
4	5250	N	10	5310	N
5	5730	N	11	5400	N
6	5500	G	12	5650	G

* Neglected in average.

None of the pieces broke in the centre clear of the nails or grips, but the average strength is about 2·4 tons which is considerably in excess of the British standard's specification requirement, so that it may be assumed with some reason that the method of testing is moderately satisfactory. It will be noticed that the average strength of the three pieces that failed at the grip edge is the same as that of the eight pieces that failed at the nail end, namely, 5470 lb. each.

Slight chafing of the fibres was seen at the nail ends, but this really amounted to little more than bruising and it does not seem that the effect of the nail end was different from that of the grips. There was slight bending at this point, but the nail had a long tapering point and the bending stresses must have been small. There are several examples among the treated and exposed ropes which show that the strength of a specimen which failed at the grip or nail end was greater than that of its duplicate which failed clear of nail or grip. Seven such cases occurred in tests on hemp rope, two on yacht manila and two on coir.

In view of the variations to be expected in tests on ropes the above results seem to show that the method of testing is sufficiently good to enable the results to be relied upon for approximate comparisons. More exact results would have been obtained had the samples been more numerous and of greater length.

The tensile tests on the six-strand yacht manila rope, about 0·6 in. circumference, were carried out by making a loop passing over the hook of a spring balance, each piece being a yard in length. This served up to 200 lb. tensile strength. For those above 200 lb. we are indebted to Major

Hambling, Engineering Dept., of Devonport Technical College, for his assistance ; these were tested by suspending weights from a hook attached by a loop in the thin rope. The breaks did not occur at the loop.

Substances used in Preservation of Ropes.

These have been fully described in the accompanying paper (pp. 627–630) on net preservation. The completely volatile solvents used were petrol, paraffin, benzene and two " Coalite " products of low temperature distillation, namely, the neutral oil b.p. 100–245° C., which has been previously extracted with strong alkali to remove phenolic compounds, and " oil A," which has had an extra extraction with acid to remove basic sulphur and other basic compounds. The more highly purified product is no better as a solvent as may be seen from the results of Table 3, but it does not darken on standing, so that ropes treated with a green copper soap alone appear a pleasing green instead of a dirty brown ; when, however, tar is also used in the mixture this point is obviously of no importance.

A variety of coal tars and oils have been tried, including those produced by the Coalite process. Since these have not as yet been fully absorbed in industry they are still relatively cheap. Hardwood tar (Shalco) was also tried, and softwood tar (Stockholm), but the latter is somewhat expensive. Though better than hardwood tar the pleasant odour of the pinewood tar and its customary use are its chief recommendations, together with the fact that both the wood tars dry more rapidly and more thoroughly than the coal tars. The copper soaps were obtained as follows : naphthenates from the Cuprinol and Shell Companies, oleate and resinate from Wm. Bailey & Sons, Wolverhampton ; samples were kindly presented by these firms, also Shalco tar by Messrs. Shirley, Aldred & Co., Worksop, and Coalite products by the works at Gawber, Yorkshire.

The substances used in preserving ropes add somewhat to their weight in air, but many of them occupy interstices which would otherwise hold water, when wet, so in reality very little is added to the weight of the rope. It must be remembered also that an organic solvent may dissolve out a certain amount of the lubricant, 8–12 per cent by weight, incorporated in the rope. Quite apart from the preservation of the rope against bacterial attack it is therefore highly advisable to select a preservative which will act as a lubricant also. The tars and tar oils will have some such action, but copper oleate and the copper naphthenate of Cuprinol and the Shell preservatives are good lubricants ; copper resinate on the other hand is a dry powder with no such action. The various cutching processes, too, may be expected to leave a dry lifeless rope. These facts must be remembered when judging the most suitable preservative for any particular purpose.

Thus for prolonged immersion in the sea the highly effective heavy tars with copper soaps are desirable, whereas where immersion is not continuous or possibly where conditions are only occasionally wet an effective lubricant is the first consideration.

Cost is also an important item ; some of the proprietary compounds are comparatively expensive, though the great saving in loss of rope—and possibly the loss of what it serves to secure—must be borne in mind. Nevertheless some of the mixtures tried here may be considered as having merits on the score of lower cost ; this is especially true of the Coalite solvent and of the tar mixtures, except Stockholm tar. It is the solvent that contributes most to the price of the mixture since the copper soaps used are only about 12–18 pence per pound.

The mixtures tried were obtained as a rule by adding even pounds to a gallon of solvent ; for water this gives a 10 per cent solution, but for benzene, sp. gr. about 0·8, it is over 12 per cent. Allowing, however, for the fact that a pound of tar or of a melted copper soap is never all put in, and that with 1 lb. of tar the volume is over a gallon, the mixtures made as above have been termed 10 per cent solutions in the tables irrespective of their exact composition.

Discussion of Results.

The tests here described are not adequate for the detection of small differences between one method and another since the amount of rope taken only sufficed for two tensile tests, the mean of which is given in general. Where wide discrepancies were found both values are given. In some cases only one test could be made, especially with the fine rope used at Cawsand. For accurate results the mean of at least six tests should be taken. The results obtained, however, leave no doubt as to whether a method is or is not serviceable, for wide differences have been observed.

The results of Table 2 show that most of the mixtures tried gave reasonably good preservation on manila rope after one year, save two with copper resinate alone. These were tried on account of the low cost of the mixture, and later work has shown that the Coalite distillate, oil A, could have been used without benzene. This with 5 per cent of copper resinate is very cheap, the solvent being about 6d. per gallon at the works in bulk and the resinate added costs about the same. Including carriage the mixture would scarcely exceed 1s. 6d. per gallon. Coal tar alone was quite good on rope of this diameter, but the period is too short to bring out the benefit of the addition of a copper soap ; a rope with tar only is both heavy and stiff whereas the mixture with 10 per cent each of tar and copper oleate is pliable, lighter and far cleaner to handle. It also heads the list with 72 per cent.

TABLE 2.

Best two-inch yacht manila rope, three strand. In preservative 5 hours. Immersed under Plymouth Pier 20/4/'33. Breaking load when new 4090 lb., dry.

No.	Treatment.	Percentage strength after months of immersion.	
		4¼ months.	12 months.
1, 2.	Untreated	37	0*
3, 4.	Cuprinol green for nets, no tar	63	62†
5, 6.	Copper oleate 20 per cent in benzene, 1 vol.+oil A, 3 vols.	61	66‡
7, 8.	Copper oleate 20 per cent in benzene, 1 vol.+oil B, 3 vols.	59	57‡
9, 10.	Copper oleate and copper resinate, 10 per cent each in oil A	74	70‡
11, 12.	Coal tar (Corroid)	74	62‡
13, 14.	Copper oleate and Corroid tar, 10 per cent each in benzene	66	72‡
15, 16.	Copper resinate, 10 per cent in benzene	88	31
17, 18.	Copper resinate, 5 per cent in equal volumes of benzene and oil A	84	46*

* One test only. Other figures are means of two.

† Very good impregnation.

‡ Good impregnation.

Nos. 19–38, another manila rope series, were unfortunately washed away during a storm, but a four-strand yacht manila rope, two inch, averaging 4645 lb. when new was down to 23% after 6¾ months; colourless Cuprinol for ropes gave 66% and hardwood tar (Shalco) 63% after same period under Pier. These had 24 hrs. in preservative.

TABLE 3.

White cordage hemp rope, 2¼ inch, three strand. In preservative 24 hours. Immersed under Pier 12/7/'33.

No.	Treatment.	Percentage strength after immersion.	
		6¾ months.	12 months.
42A.	Untreated dry control	100 (3760 lb.)	100 (3430 lb.)
42, 59.	Untreated	19	0
43, 60.	Olie's method	25	0
44, 61.	Cuprinol, green for nets, no tar	79	76
45, 62.	Cuprinol, colourless for ropes	44	33
46, 63.	Low temperature coal tar, Coalite	69	73
47, 64.	Coal tar, Corroid	64	78
48, 65.	Softwood tar, Stockholm	77	57
49, 66.	Low temp. tar oil, A	29	0
50, 67.	Copper oleate 10% in benzene	64	55
51, 68.	Copper resinate 10% in benzene	87	52
52, 69.	Copper oleate 10%, Corroid tar 10% in benzene	71	83
53, 70.	Copper resinate 10%, Corroid tar 10% in benzene	89	57
54, 71.	Cuprinol, green with 10% Corroid tar	76	94
55, 72.	Coalite neutral oil b.p. 100–245° C.	27	0
56, 73.	Do. with 5% copper oleate	78	39
57, 74.	Do. with 5% copper resinate	50	30
58, 75.	Hardwood tar, Shalco	61	24

Table 3 for hemp rope agrees with Table 2 in that this copper oleate mixture shows up well. It was however surpassed by green Cuprinol with tar, which is a marked advance on Cuprinol without tar, good as is the latter. Colourless Cuprinol for ropes, which is the zinc naphthenate, is relatively much inferior, but the mixture is a good lubricant. Again the heavy coal tars do well and the softwood (Stockholm) tar is superior to the much cheaper hardwood tar, which nevertheless did reasonably well up to almost seven months. The very cheap mixture, Coalite neutral oil with 5 per cent copper oleate, is a good lubricant and was still up to 39 per cent after a year ; this is better than the resinate.

Table 4 relates to coir rope, which when untreated keeps its strength rather better than does either manila or hemp. In this respect sisal is better still, see Table 4. But according to the more extensive comparison between sisal and manila conducted by the Imperial Institute (Bull. Imp. Inst., 1927, **25**, No. 4), this varies with the quality of the fibres.

Coir being a cheap rope of lower strength than the others the aim in view was to find a reasonably effective cheap preservative. This is provided by 10 per cent copper oleate in Coalite neutral oil ; both oleate and resinate do even better in this than in oil A, the product doubly extracted, namely, by alkali and then by acid ; with resinate the latter acts almost exactly in the same way as the more costly benzene. As before, the addition of 10 per cent coal tar to the copper oleate mixture would probably have been beneficial, but was not tried. Both the low temperature and ordinary coal tars do well and would do even better with the addition of 5 or 10 per cent of the copper soaps. The green Cuprinol, though good, is probably too costly for use with this rope ordinarily.

TABLE 4.

Coir rope, 2 inch, four strand with central twine. In preservative 24 hours. Immersed under Pier 12/7/'33. Breaking load when new 1120 lb., dry.

No.	Treatment.	Percentage strength after immersion. 6¾ months.	12 months.
76, 86.	Untreated	29	6
77, 87.	Cuprinol, green for nets, no tar	70	67
78, 88.	Coal tar, Corroid	64	66
79, 89.	Low temperature tar, Coalite	74	65
80, 90.	Softwood tar, Stockholm	80	70
81, 91.	Copper oleate 10% in Coalite neutral oil b.p. 100–245° C.	69	70
82, 92.	Do. in Coalite oil A, doubly extracted . . .	68	64
83, 93.	Copper resinate 10% in Coalite neutral oil . .	64	65
84, 94.	Do. in Coalite oil A	59	45
85, 95.	Do. in benzene	59	41

When drawing up the list of treatments for coir one very important use was overlooked. On account of its extensibility and spring this rope is much used, in great thicknesses, for joining steel rope towing hawsers. The breaking of the coir may lose a ship, yet it is certain that most of the coir towing ropes in use have deteriorated very appreciably. With a proper preservative they could be maintained near their original strength for far longer. For such purposes even the most costly preservatives are an economy.

TABLE 5.

Sisal rope, 2 inch, three strand. In preservative 24 hours.
Immersed under Pier 1/3/'34.

No.	Treatment.	Percentage strength after immersion. 7½ months.	12 months.
112, 96.	Untreated control, dry	3320 lb., 100	3300 lb., 100
113, 97.	Untreated	29	18
114, 98.	Olie's method	70	Lost
115, 99.	Copper resinate 10% in benzene	90, 33	60, 51
116, 100.	Do. in Coalite Oil A	76, 42	62, 36
117, 101.	Do. in benzene with 6% Mobiloil A	86, 60	65, 35
118, 102.	Do. with 20% Corroid tar in benzene	105, 83	Lost
119, 103.	Do. in Coalite tar	94, 80	97, 92
120, 104.	Do. in Corroid tar	89, 58	97, 91
121, 105.	Do. in Stockholm tar	74	Lost
122, 106.	Do. in Shalco tar	72	Lost
123, 107.	Cuprinol green for nets, tar added by makers	76	Lost
124, 108.	Cuprinol colourless for ropes	56	Lost
125, 109.	Cuprinol brown for wood	98	81
126, 110.	Shell canvas preservative	72	66
127, 111.	Shell wood preservative	73	64

Table 5, for sisal, does not give as much information as it should owing to the fact that five ropes entirely disappeared though quite sound and apparently firmly fixed a fortnight previously. For this no explanation is forthcoming. It was unfortunate also that no oleate was included, for several of the resinates gave widely varying duplicates; this may have been occasioned by a weakening due to repeated bending by wave action or to imperfect penetration of preservative. It does not occur with the naphthenate series (Cuprinol and Shell). The best of the remaining ropes were those with 10 per cent copper resinate in Coalite or Corroid coal tar. The Cuprinol brown for wood is also good, due in its case chiefly to the presence of a specially good tar oil. For the sake of its lubricant action copper oleate in tar is to be preferred to copper resinate, or even a mixture of 5 per cent of each.

In order to settle a number of points raised in the foregoing experiments a series of 62 treatments with untreated control was tested in the tidal fish pond at Cawsand between 15/5/'34 and 28/3/'35, namely, 10½ months.

In order to get the results more rapidly a thinner rope was used, six strand yacht manila, approximately 0·6 inch in circumference; breaking load about 300 lb. when new. This is about the size used as head line on certain types of net.

Immersion in preservative was for 24 hours unless otherwise stated. The results are shown in Tables 6–11.

Table 6 shows that for prolonged immersion cutch is almost useless, nor are either Olie's or Cunningham's methods to be recommended for ropes.

From Table 7 it may be gathered that Coalite neutral oil is the best—and fortunately the cheapest—solvent for copper oleate and copper resinate; paraffin oil, which has been used considerably in U.S.A. as being safer and cheaper than petrol, is unsatisfactory for oleate though rather better for resinate. The addition of tar is beneficial, as found in the earlier work also.

In Table 8 it may be seen that using 1 lb. per gallon ordinary coal tar is effective with oleate and resinate in benzene; but with Coalite tar an increase up to 2 lb. per gallon is an improvement, especially in oil A, with which smaller amounts of tar seem strangely ineffective.

Table 9 brings out the value of the Cuprinol ready mixed with tar and shows that it is permissible to lessen the cost by diluting with an equal volume of petrol. Since this is completely volatile the cost could be still further lessened, it appears, by using Coalite neutral oil instead. The brown Cuprinol, containing iron naphthenate and probably some zinc naphthenate also behaved better than expected due to an efficient tar oil. Both the Shell products are improved for ropes by the addition of tar.

TABLE 6.

Cutch, probably mangrove with subsequent treatments. After 10½ months' immersion in fish pond open to sea. Rope six-strand yacht manila.

	Percentage strength.
Untreated	13
Cutch, two boilings	17
Olie's method	29
Cunningham's method, boiling bichromate 5 minutes	30
Do., hot bichromate 5 minutes	26
Do., cold bichromate 60 minutes	32

Both hot and boiling bichromate rotted the nets used. The untreated control is the same in Tables 6–11.

TABLE 7.

1 lb. of copper oleate or resinate alone or with 1 lb. of coal tar (Corroid) in one gallon of solvent. The figures denote percentage strength after immersion for $10\frac{1}{2}$ months, as in Tables 6–11.

Solvent.	Oleate.	Resinate.	Oleate, tar.	Resinate, tar.
Petrol	28	—	—	—
Paraffin oil	10	29	—	40
Benzene	42*	35	65	57
Coalite neutral oil, A	56*	37	57	33

* With 1 lb. of copper resinate added per gallon these gave 33 per cent in benzene, but up to 65 per cent in oil A ; see also Table 1.

TABLE 8.

1 lb. of copper oleate or resinate with 1 lb. of a tar, in benzene or oil A, one gallon.

Tar.	In benzene.		In oil A.	
	Oleate.	Resinate.	Oleate.	Resinate.
Coal tar, Corroid	65*	57	57*	33
Coal tar, Coalite	46†	33	42†	25
Hardwood, Shalco	35	30	42	20
Softwood, Stockholm	48	43	43	20

* With 2 lb. of Corroid tar, per gallon, 67 per cent in benzene, 53 per cent in oil A.
† With 2 lb. of Coalite tar, per gallon, 60 per cent in benzene, up to 70 per cent in oil A.

TABLE 9.

Naphthenate preservatives.

	No tar.	With tar.
Cuprinol green for nets	—	76, mixed by makers
Do. with equal volume of petrol	—	82
Cuprinol colourless for ropes	12	—
Cuprinol brown U for wood	—	47, this has a tar oil*
Shell canvas preservative (T.P.R. 78)	50	63, Corroid tar 10 per cent
Shell wood preservative (T.P.R. 28)	33	67, Do.

* In consequence it cannot be painted over as can green Cuprinol.

The mixtures thus far considered do not add very greatly to the weight of the rope and are in varying degrees tolerably clean to handle. Turning now to the heavy preservatives in Table 10 it must be remembered that save for the wood tars, which dry well, they are all rather messy ; this is a disadvantage for many purposes. But the heaviest tar, ordinary gas-works type, is excellent as a preservative, though the worst to handle. It is improved by copper oleate and copper resinate as shown in early net tests. Neither oleate nor resinate mixes well with Shalco tar and this is shown in the results, but by the use of a wood oil the makers have produced a blend which is quite useful. One of the most striking results is the great improvement in creosote oil, the quality used by Plymouth fishermen, by the addition of copper resinate, which also does well in the rather messy Coalite heavy oil; copper oleate in Corroid tar appears to be slightly better, but such differences lie in the region in which cost is the final arbiter.

Table 11 summarizes the best results, including three from Table 10.

TABLE 10.

Heavyweight preservatives, tar or tar oils alone or with copper oleate or copper resinate, 1 lb. per gallon. Untreated 13 per cent after immersion.

	Tar.	With oleate.	With resinate.
Creosote oil	45	35	70
Coal tar, Plymouth	68	—	—
Coal tar, Corroid	55	78	67
Coalite heavy oil	—	—	75
Coalite tar	55	67	67
Hardwood tar, Shalco	32	30	30
Shalco tar, export quality	—	—	40
Softwood tar, Stockholm	43	48	63

TABLE 11.

Summary of best results in Tables 5–9. Untreated control 13 per cent.

	Per cent.
Green Cuprinol for nets, tar formula, with equal volume of petrol	82
Copper oleate 10 per cent in Corroid tar	78
Green Cuprinol for nets, tar formula	76
Copper resinate 10 per cent in Coalite heavy oil	75
Copper oleate 10 per cent, Coalite tar 20 per cent in Coalite neutral oil, A	70
Copper resinate 10 per cent in creosote oil	70

SUMMARY.

1. For the preservation of ropes the importance of the preservative against bacterial decay being also an internal lubricant for the rope fibres must be remembered.

2. Tests have been carried out for one year in sea-water, which was much contaminated by sewage at times, under Plymouth Pier and in cleaner water of a tidal basin outside Plymouth Sound Breakwater for 10½ months, using 2-inch and 0·6-inch ropes respectively; the latter was manila, the former were manila, hemp, sisal and coir.

3. The preservatives included cutch, cutch bichromate, cutch ammonia copper sulphate, coal tar distillates, including those of the Coalite process,

also hardwood and softwood tars. The tars and tar oils were tried alone and mixed with copper soaps, naphthenate (Cuprinol and Shell products), oleate and resinate, also zinc and iron naphthenates (Cuprinol). The naphthenates and oleate are good lubricants.

4. Very good results were obtained with green Cuprinol containing tar and with 10 per cent copper oleate in a light coal tar; slightly inferior were 10 per cent copper resinate in Coalite heavy oil or in creosote oil as now used largely in Plymouth; also 10 per cent copper oleate with 20 per cent of Coalite tar in Coalite neutral oil, b.p. 100–245° C., which is a very cheap solvent. All these maintained the thin manila rope at or above 70 per cent of its initial strength after 10½ months; the untreated control was down to 13 per cent.

5. Mixtures which maintained this rope at 60–69 per cent of its initial strength were: copper oleate 10 per cent, coal tar 20 per cent in benzene; the same with 10 per cent of tar; copper oleate 10 per cent, Coalite tar 20 per cent in benzene; Shell wood preservative and Shell canvas preservative each with 10 per cent of coal tar; copper resinate 10 per cent in a light coal tar, Coalite tar or Stockholm tar; copper oleate 10 per cent in Coalite tar; 10 per cent each of copper oleate and copper resinate in Coalite neutral oil b.p. 100–245° C. and a very heavy coal tar, which, however, was very messy also.

6. At the end of a year the 2-inch ropes immersed under the Pier were down to the following percentage strengths: hemp 0, manila 0, coir 6, sisal 18. Sisal rope sinks in water at once, manila and hemp float when dry for a while, coir has considerable buoyancy.

7. Copper resinate 10 per cent in a light coal tar or in Coalite tar maintained the strength of 2-inch sisal rope under the Pier at 80–97 per cent of its original value for one year, save for one low figure, 58 per cent.

8. Used alone coal tars are superior to wood tars, but all are much improved by the addition of 10 per cent of copper oleate or copper resinate.

9. A dilute solution of sodium diethyldithiocarbamate is a useful reagent for testing whether ropes still give off copper after long immersion. The test is described in the accompanying paper on net preservation.

The Biology of *Echinocardium cordatum*.

By
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Marine Biological Laboratory, Plymouth.

With Plates I and II, and 5 Figures in the Text.

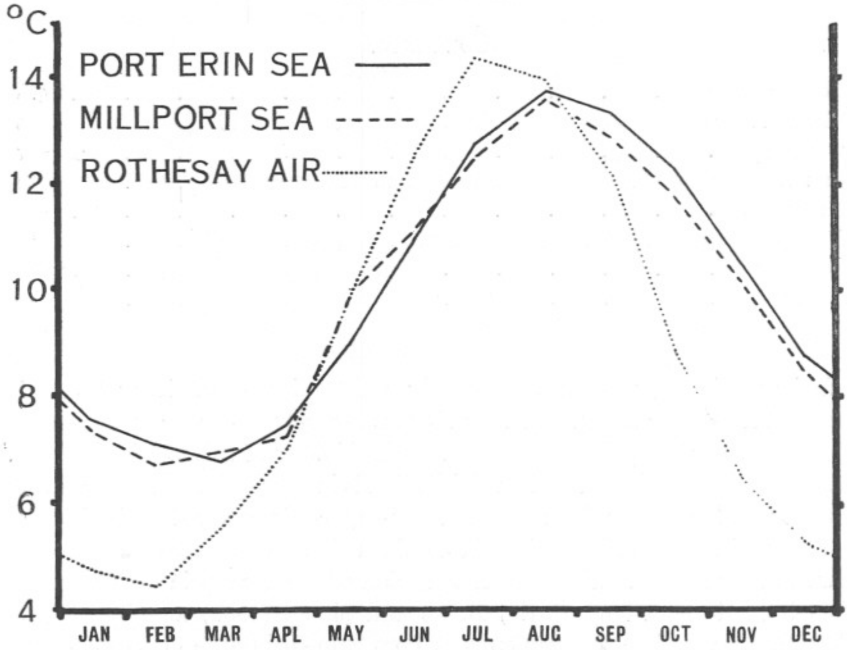
CONTENTS.

INTRODUCTION.

Echinocardium cordatum is essentially a littoral species, living in sand around low-water mark, and occurring more rarely in deeper water. The present paper comprises an account of the biology of this species at Port Erin, in the Isle of Man, and on Fairlie Sands in the Clyde. In both places it occurs abundantly from between low-water of neap and spring tides, downwards, and can be dredged in numbers close to the shore in depths of two to four metres. The general condition of the Port Erin sandy beach has been described by Pirrie, Bruce and Moore (1932) and by Moore (1933). Sea surface temperatures at Port Erin (being the mean monthly temperatures for the years 1903–1927) are shown in Text Fig. 1 and are taken from Bruce (1928). Sea temperatures taken at Keppel Pier, Millport, averaged over the period 1909–1921 (Elmhirst, 1923) are also given and can be taken as applicable to Fairlie Sands. Recent sea temperatures are not available for Millport, so air temperatures for Rothesay, as taken from the monthly weather reports of the Meteorological Office, are given.

MATERIAL AND METHODS.

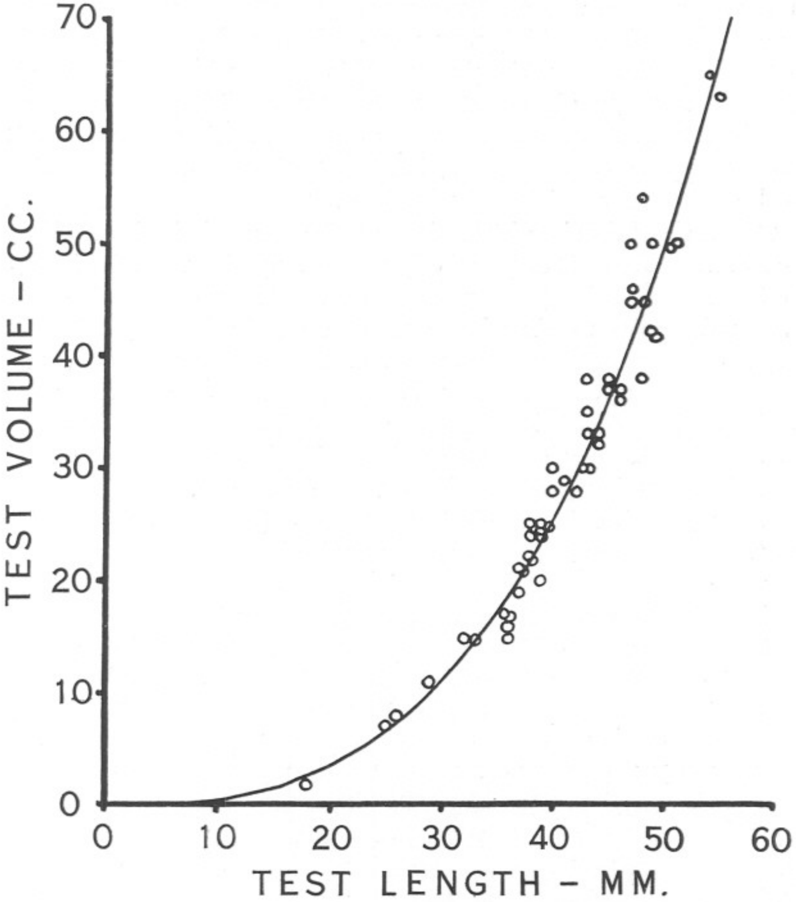
From February to May, 1932, monthly samples of about twenty-five specimens were collected from the shore at low water at Port Erin, and their gonads examined. From February, 1933, to May, 1934, considerably larger samples were taken in order to improve the size distribution analyses. The gonads also of a representative series of these were examined. At Fairlie Sands only a small number of scattered samples could be taken, but these proved most useful for confirming certain points, particularly with regard to the amount of growth in the first year. The length of the test of all urchins was measured from the anterior ambulacral groove to the posterior end of the test. Sliding calipers were used, reading to the nearest millimetre. As it is sometimes desirable to compare growths in terms of volume instead of length, a curve is given in Text Fig. 2 relating external volume to length of test. These volumes were estimated by immersion of the urchin in a known volume of water in a measuring cylinder, and measuring the displacement. Gonad volumes were estimated in the same way, by removing the entire gonad from the test and dropping it into a known quantity of water in a measuring cylinder.



TEXT FIG. 1.—Mean monthly sea temperatures at Port Erin and Millport, and air temperatures at Rothesay.

Gonad conditions are recorded from examination of a smear of the fresh gonad on a slide. Comparison of the degree of ripeness of males and females is always rather unsatisfactory. Females are not recorded as ripe unless more than 95% of the ova were mature. This gives a fairly representative picture of the condition in the gonad itself. But in the males, a smear swarming with active spermatozoa may be obtained from an urchin still containing many developing stages, and thus far from fully mature.

Throughout the winter of 1933–34 a series of gonads were fixed and sectioned from animals of known year groups in order to verify the representativeness of the earlier examinations, most of which had been made on urchins of at least three years old.



Text Fig. 2.—Relation of test volume to length in fifty specimens of *E. cordatum* from Port Erin.

Growth.

At Port Erin, at least three-year groups can be separated by the colour of the outside of the test, and, if confirmation is required, by the size and colour of the gonads. The first group consists of small urchins with a pale straw-coloured test and either small immature gonads or none at all: when present these gonads are pale in colour. These urchins, as will be shown later by comparison with the Scottish material, are in their first year. The second group, comprising urchins in their second year, has darker coloured tests than the previous group, though not yet as dark as in adults, and has well-developed gonads, although these are still pale in colour. Sometimes a third group also stands apart from the older urchins, but usually all older urchins form one third group with a still darker test, and large, darkly pigmented gonads. These differences were quite clearly defined, and were of the greatest value in tracing the growth of the successive year groups as shown in Plate I. In the Scottish material no such marked colour difference was observable.

The whole of the size distribution data for Port Erin is given in Table I and in Plate I. In 1932 practically no small urchins were obtained, but in the two following years young urchins of four or five months old appeared in large numbers between tide marks in the spring, forming a large proportion of the whole population. The suddenness of their appearance in February, 1933, and in January, 1934, must not be taken as evidence of a sudden migration onto the shore, but rather as the result of a slow migration up the shore combined with the onset of better weather conditions allowing access to a lower zone of the shore.

In the case of *Echinus esculentus* at Port Erin (Moore, 1935) it was found that, except immediately after metamorphosis, the period during which growth of the test took place was limited to about three months in the spring, and that practically no shell growth took place for the whole of the rest of the year. In Echinocardium growth seems to continue throughout the year with the exception of a short cessation in February–March. This coincides with the time of minimum sea temperature at Port Erin (Fig. 1), and as soon as the temperature commences to rise, growth recommences.

The Port Erin material was incomplete in that the smallest stages were not represented. The material from the Clyde, comprising a series of scattered samples taken in 1933, 1934 and 1935, helped to fill this gap. Here the successive year groups cannot be so readily separated by colour differences as they can at Port Erin. In October, 1933, a number of very small Echinocardium about three mm. long were obtained, and were clearly ones which had metamorphosed that summer, probably about September (Text Fig. 3). They were dredged in a depth of two to four metres below low-water at Fairlie Sands, close inshore. Digging on the shore produced a single specimen only of that year group. Clearly these small urchins had not yet invaded the intertidal region. A sample dug

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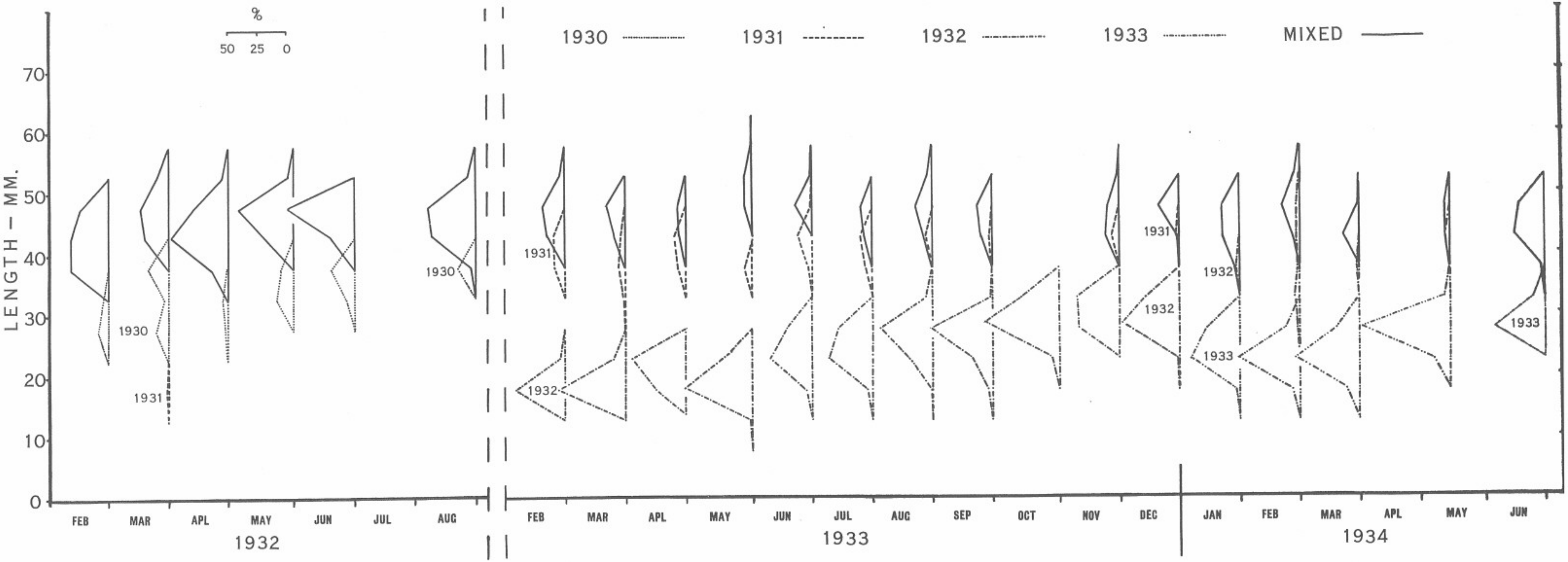
EXPLANATION OF PLATE I.

Percentage size distribution of *E. cordatum* at Port Erin. Those year groups which were separable by their colour are indicated.

PLATE I



%
50 25 0
1930
1931
1932
1933
MIXED
LENGTH – MM.
0
10
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40
50
60
70
FEB
MAR
APL
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JUN
JUL
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1932
1933
1934
SEP
OCT
NOV
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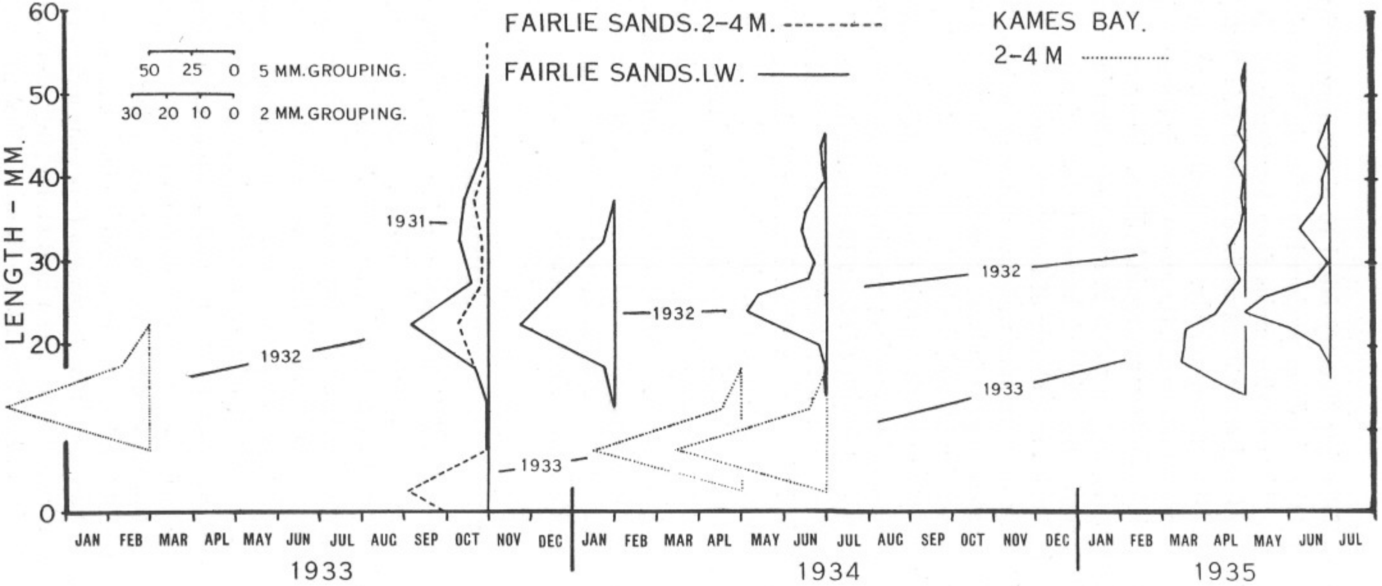
at low water the following January failed to obtain any of these small urchins, and one taken in June produced only a single specimen, now 15 mm. in length. Two small samples from low water at Kames Bay (? dredged) in April and early June again obtained this 1933 brood at lengths of 11 and 13 mm. respectively. In April, 1935, when the 1933 brood was about twenty months old, they were taken in enormous numbers at low water at Fairlie, as they were again in June. They were now about 20 mm. in length. A sample taken in about 4 metres in Kames Bay, Millport in February, 1933, yielded large numbers of small urchins of about 12 mm. in length, and clearly of the 1932 brood, and these again were taken in very large numbers at low water at Fairlie Sands the following October at a length of about 22 mm. As both 1932 and 1933 produced quite unusually heavy broods of young Echinocardium, it was easy to follow the year groups on this ground despite the rather long intervals between successive samples ; and it seems clear that at Millport Echinocardium reaches a length of about 10 mm. in its first winter, and about twenty in its second. An attempt was made to find similar small stages at Port Erin in December, 1933, both by sieving sand from low water and by dredging samples of sand. The intertidal sand yielded none, and the dredged samples only a single specimen 9 mm. in length. However, there seems to be little doubt that the group which appeared in such large numbers at Port Erin in February, 1933, at a length of 18 mm. was the same brood as that which appeared at Kames Bay at the same time at a mean length of 14 mm. The Port Erin urchins therefore attain a length of 15 to 20 mm. in their first winter, and 30 to 35 in their second.

THE RELATION OF GROWTH AND ABUNDANCE TO TEMPERATURE.

The growth rate at Port Erin, although varying somewhat from year to year, seems to be always greater than at Millport. Further, the maximum size attained is greater at Port Erin, and greater again at Salcombe, Devon. The difference in the sea temperatures at Port Erin and Millport seems too slight to account for this difference. There does, however, seem to be a marked correlation between temperature and both the abundance of settlement and the growth of the young urchins. At Port Erin, 1931 was a cold year, especially the summer, and the mean temperature for the year was 0·1° C. below the 25-years mean given by Bruce (1928). The year 1932 was warm, especially the summer, averaging 0·5° C. above the mean, while 1933 was very warm, averaging 0·9° C. above the mean. Similarly in the Clyde the air temperatures (sea temperatures were not available) were 0·4° C. below the mean in 1931, and 0·1°, 0·8° and 0·5° C. above the mean in 1932, 1933 and 1934 respectively (see Table III). At Port Erin we found in 1932 practically no representatives of the 1931



TEXT FIG. 3.—Percentage size distribution of *E. cordatum* in the Clyde—all localities combined. Note that some samples were limited to first-year urchins only. Also some samples were large enough to allow the use of two millimetre grouping and are therefore drawn to a different scale.

brood of Echinocardium, while the 1932 and 1933 broods were present in exceptionally large numbers in the years 1933 and 1934 respectively. At Fairlie Sands there are no data as to the abundance of the 1931 brood, but the 1932 and 1933 broods were present in exceptionally large numbers on the shore in 1934 and 1935. (Here the young urchins spend a longer period below low water, before appearing between tide marks, than they do at Port Erin.) Thus in both places the two warm years produced extra heavy settlement of young urchins, while the cold year, 1931, yielded very few young, at any rate, at Port Erin. This is closely comparable with the results observed in *Echinus esculentus* at Port Erin (Moore, 1935). For this species 1931 proved a very poor year so far as growth was concerned, while 1932 was a good year and 1933 an extra good one.

MIGRATION.

E. cordatum is most abundant at Port Erin between low water of ordinary and extreme spring tides. It is fairly common throughout Port Erin Bay in depths of down to 10 metres, and occasionally specimens have been taken outside as deep as 34 metres. Both at Port Erin and at Millport very small urchins were taken by dredging in a depth of a few metres some time before the same year group was found between tide marks. It is, of course, to be expected that the small and very delicate newly metamorphosed urchins would require more shelter than they would get at low water. At Port Erin the first year urchins were first taken on the shore in February in 1933 and in January in 1934. In part their sudden appearance was no doubt due to improvement in weather and tide conditions rendering a lower zone accessible than it had been earlier in the winter; but that they do migrate is shown by examination of a sample taken near the extreme top of their distribution on the shore, where no first-year and few second-year urchins are to be found, and the population consists almost entirely of large urchins of three or more years of age. Further, in Port Erin Bay, no urchins more than 27 mm. long were ever dredged, suggesting that all the older urchins, i.e. those more than two years old, had migrated into the intertidal area.

At Port Erin this migration seems to commence at about four months after metamorphosis. At Fairlie Sands, on the other hand, although a similar migration clearly takes place, it seems to be delayed much longer. Of the large 1933 brood which was found below low water in October, 1933, none were found between tide marks in January, 1934, and only one specimen in June of that year. They were, however, very abundant between tide marks in April, 1935. Actually they had probably appeared on the shore soon after the June sample was taken, since large numbers of the 1932 brood were taken on the shore at Fairlie in October, 1933. At any rate, they do not seem to appear between tide marks at Millport until about a year after metamorphosis, as compared with four months at Port Erin.

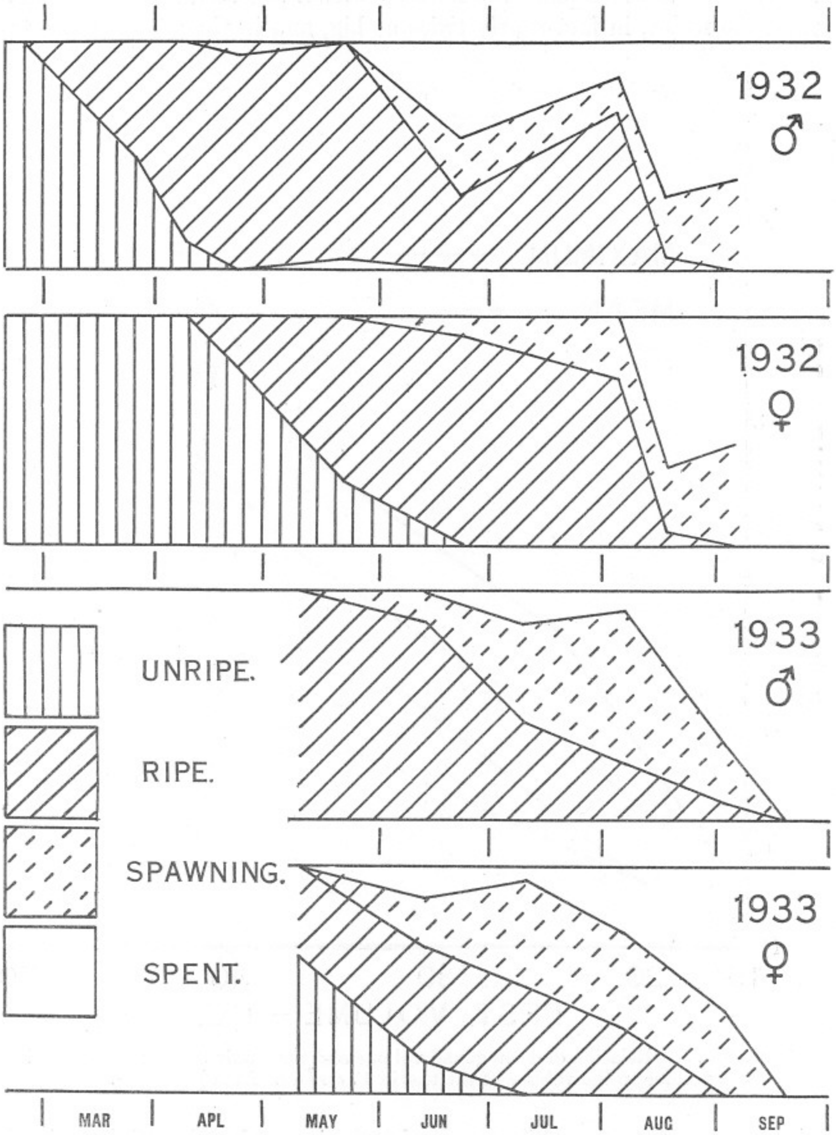
MATURATION OF THE GONADS AND SPAWNING.

The progress of maturation of the gonads was examined in sectioned material taken throughout the winter of 1933–34. In November, 1933, in the one-year-old urchins, the male gonads were very small, and their walls almost undifferentiated. The females contained plentiful oocyte about a quarter grown, but mostly still attached to the gonad wall. No nutritive bodies were present. Of two years old (1931 group), the males contained some quantity of relict sperm, and had not yet recommenced spermatogenesis. The females were all practically completely spent, and contained oocytes in a similar condition to those in the 1932 animals, but in this case plentiful nutritive bodies were present in the cavity of the gonad. Of the three-year-old (1930) and older urchins, the males were similar to those described above, as were the females, except for a number of relict and degenerating ova in the latter.

In samples taken in December and January, conditions were much the same except for an advance in the maturity of the oocytes, and for the appearance of early spermatogenesis stages in the males. The latter still contained a certain number of relict sperm from the previous summer. By February the female gonads were full of immature ova, while the male gonads were full of spermatogenesis stages with, in some cases, a few ripe sperm.

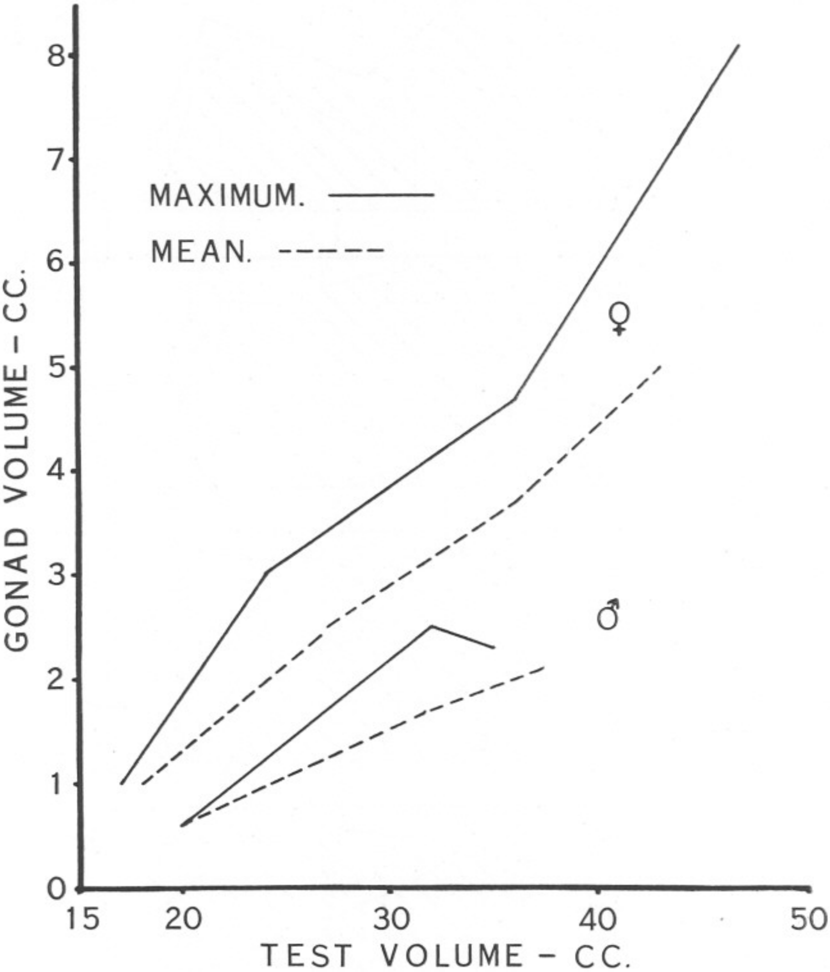
The process of spawning was recorded in detail in 1932 and 1933 (Text Fig. 4). The first sample taken in February, 1932, contained no fully ripe specimens of either sex, but by March about half the males, and by April practically all of them were ripe. In that year the females commenced to ripen in April, and were all fully ripe in June. Similar conditions obtained in 1933 : in the first sample taken in May all the males and about half the females were ripe. Spawning females were taken as early as April in 1933, but it was not until June of either year that any considerable numbers of either sex were found spawning.

In both years practically all individuals of both sexes were spent by the end of August, and in 1933, all were completely spent in mid-September. The same was probably the case in the previous year, but a sufficiently late sample was not taken to demonstrate it. Although a few spawning individuals may be found over a longer period, the main time of spawning may be taken as June–July–August. In the Plymouth Marine Fauna (1931) ripe specimens are recorded in April and June, and Elmhirst (1923) gives the spawning season in the Clyde as May to August. This is rather earlier than at Port Erin. The Port Erin results are summarised in Table V.



TEXT FIG. 4.—Seasonal changes in gonad condition at Port Erin.

In Text Fig. 5 and Table IV are given the size attained by full gonads of either sex (mean and maximum recorded size) in relation to the size of the animal. In the first place the females have a considerably larger gonad than the males, in fact nearly twice as big, and in the second place the relative size of the gonad increases with the increasing size of the animal. Thus a female with a test volume of 20 c.c. has a mean $\frac{\text{gonad volume}}{\text{test volume}}$ of 0·07, while in one of 40 c.c. the ratio is 0·11. It is probable that the accumulation of relict genital products, which in the female at least are



Text Fig. 5.—Relation of mean gonad volume and the maximum observed gonad volume to the volume of the test in *E. cordatum* from Port Erin.

transformed into the nutritive bodies which serve to nourish the growing oocytes of the succeeding season, may contribute to this result.

The absence of these nutritive bodies in the gonads of the second-year females, which have not spawned before, and their presence at the same season in the ovaries of older urchins is of interest, especially as the oocytes of the former seem to be growing quite as fast in their absence, although in smaller numbers. Miller and Smith (1931) state that in *Echinometra lucunter* the nutritive bodies are formed from the cells of the gonad wall, which develop either into nutritive bodies or into oocytes. They were, however, working only on material which was nearly ripe, and an examination of less mature gonads might possibly have indicated an alternative source for them. At any rate, in the case of *Echinocardium* there is no doubt that they are absent in those individuals which have not spawned once, and present in all those which have already spawned ; and in the earlier part of the winter, the relict ova left in the gonads of the latter can be seen to be breaking down into bodies which appear to be identical with the nutritive bodies (Plate II). Finally, the nutritive bodies in Echinocardium are most numerous towards the centre of the follicle, as would be expected if they were formed from relict ova. Were they produced from the wall of the follicle it would be expected that they would be most numerous close to it. Such must therefore be taken to be the source of, at any rate, a large proportion of the nutritive bodies in this species. A series of photomicrographs illustrating the above statements is given in Plate II. It is interesting to note that the effect of the absence of nutritive bodies in those urchins which are spawning for the first time appears to be the smaller number of oocytes produced, and not any reduction in their size or rate of growth.

The young urchins seem definitely to be immature until towards the end of their first year, when gonads begin to develop, and they spawn for the first time when they are nearly two years old. There is evidence for this from both localities. At Port Erin the 1932 group contained undeveloped gonads throughout 1933, until the autumn of that year when they commenced to develop for the first time. Similarly, the 1933 group, when taken in the spring of 1934, contained no gonads. At Millport, the samples of the 1933 brood taken in Kames Bay in April and June, 1934, contained no gonads in even the largest individuals, while the 1932 group obtained at Fairlie the same June all had fair-sized mature gonads. Here also it is therefore clear that the urchin is immature for the first year, and commences to mature its gonads in its second year.

I wish to acknowledge my great indebtedness to Mr. R. Elmhirst for assistance in obtaining the Millport material, and also to the staff of the Biological Station at Port Erin.

SUMMARY.

1. Monthly samples of *Echinocardium cordatum* were taken at Port Erin in 1932, 1933 and 1934, and at intervals at Fairlie Sands in the Clyde.

2. Growth is continuous throughout the year with the exception of February–March. In their first winter the young urchins attain a length of about 10 mm. at Millport and 15–20 mm. at Port Erin. In their second winter they are about 20 mm. at Millport, and 30–35 mm. at Port Erin.

4. The year 1931 was cold and produced a very small brood of young urchins ; 1932 and 1933 were warm years and produced very large broods.

5. The young settle below low water and migrate into the intertidal zone after an interval of four to twelve months.

6. The gonads of the young urchins mature in their second year. Spawning takes place in June–July–August.

7. The nutritive bodies in the ovaries are shown to be derived from the disintegration of relict ova.

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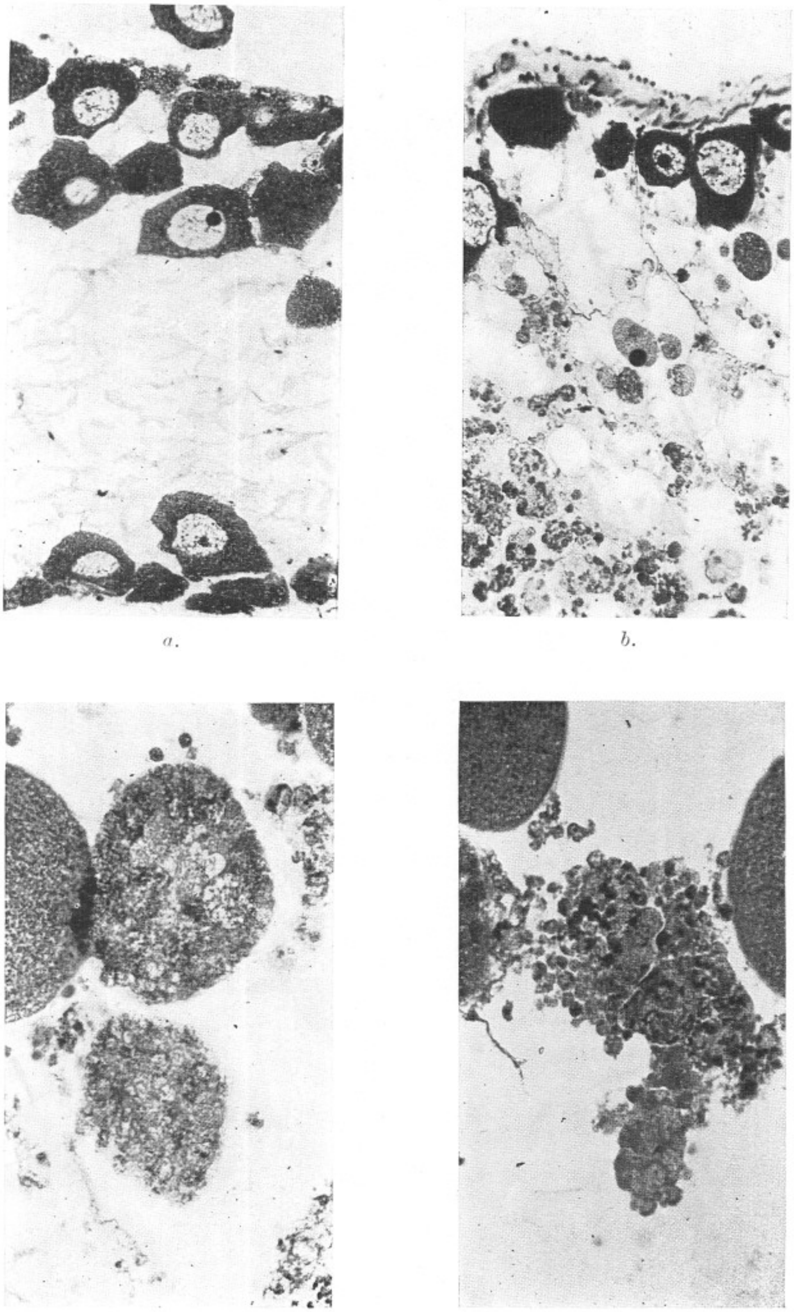
EXPLANATION OF PLATE II.

a. Transverse section of an ovary ripening for the first time, and showing oocytes, but no nutritive bodies. ×50.

b. Transverse section of a ripening ovary which has spawned at least once before, and contains numerous nutritive bodies, chiefly towards the centre of the follicle. ×50.

c.d. Transverse sections of relict ova in the ovary, showing stages in their break-down into nutritive bodies. ×370.

PLATE II.



a. *b.*

c. *d.*

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TABLE I.

Size Distribution at Port Erin (Percentage), with the Different Year Groups Distinguished as far as possible.

Lengths in mm.

Month.	Year Group.	Length of Test. 12·5	17·5	22·5	27·5	32·5	37·5	42·5	47·5	52·5	57·5	Number examined.
1932 Feb.	1930	–	–	–	8	4	–	–	–	–	–	25
	1929 or earlier	–	–	–	–	–	32	32	24	–	–	
March	1931	–	1	–	–	–	–	–	–	–	–	30
	1930	–	–	–	10	3	27	–	–	–	–	
	1929 or earlier	–	–	–	–	–	–	20	23	10	3	
April	1930	–	–	–	2	4	–	–	–	–	–	45
	1929 or earlier	–	–	–	–	–	13	47	29	4	–	
May	1930	–	–	–	–	13	11	–	–	–	–	47
	1929 or earlier	–	–	–	–	–	–	23	47	6	–	
June	1930	–	–	–	–	7	18	–	–	–	–	29
	1929 or earlier	–	–	–	–	–	–	18	54	4	–	
Aug.	1930	–	–	–	–	–	14	–	–	–	–	28
	1929 or earlier	–	–	–	–	–	4	36	39	7	–	
1933 Feb.	1932	–	42	4	–	–	–	–	–	–	–	53
	1931	–	–	–	–	–	8	8	–	–	–	
	1930 or earlier	–	–	–	–	–	–	15	19	4	2	
March	1932	–	55	10	–	–	–	–	–	–	–	58
	1931	–	–	–	–	2	5	3	–	–	–	
	1930 or earlier	–	–	–	–	–	–	9	16	–	–	
April	1932	–	25	45	–	–	–	–	–	–	–	55
	1931	–	–	–	–	–	7	9	–	–	–	
	1930 or earlier	–	–	–	–	–	–	5	7	–	–	
May	1932	1	56	25	–	–	–	–	–	–	–	72
	1931	–	–	–	–	–	6	–	–	–	–	
	1930 or earlier	–	–	–	–	–	–	–	6	6	1	
June	1932	–	5	40	21	–	–	–	–	–	–	168
	1931	–	–	–	–	–	3	12	1	–	–	
	1930 or earlier	–	–	–	–	–	–	2	14	1	–	

Month.	Year Group.	Length of Test.										Number examined.
		12·5	17·5	22·5	27·5	32·5	37·5	42·5	47·5	52·5	57·5	
July	1932	–	4	37	28	–	–	–	–	–	–	54
	1931	–	–	–	–	–	6	9	–	–	–	
	1930 or earlier	–	–	–	–	–	–	7	9	–	–	
Aug.	1932	–	1	18	49	5	–	–	–	–	–	88
	1931	–	–	–	–	–	–	5	–	–	–	
	1930 or earlier	–	–	–	–	–	–	6	14	3	–	
Sept.	1932	–	3	17	56	1	–	–	–	–	–	100
	1931	–	–	–	–	–	–	2	–	–	–	
	1930 or earlier	–	–	–	–	–	–	9	12	–	–	
Oct.	1932	–	–	7	62	31	–	–	–	–	–	29
	1931	–	–	–	–	–	–	–	–	–	–	
	1930 or earlier	–	–	–	–	–	–	–	–	–	–	
Nov.	1932	–	–	–	34	35	–	–	–	–	–	56
	1931	–	–	–	–	–	2	7	–	–	–	
	1930 or earlier	–	–	–	–	–	–	11	9	2	–	
Dec.	1932	–	–	2	49	28	–	–	–	–	–	53
	1931	–	–	–	–	–	–	2	–	–	–	
	1930 or earlier	–	–	–	–	–	–	2	17	–	–	
1934 Jan.	1933	–	3	40	27	–	–	–	–	–	–	112
	1932	–	–	–	–	–	3	–	–	–	–	
	1931 or earlier	–	–	–	–	–	1	13	13	–	–	
Feb.	1933	–	6	52	12	–	–	–	–	–	–	167
	1932	–	–	–	2	4	1	2	–	–	–	
	1931 or earlier	–	–	–	–	–	4	14	4	–	–	
March	1933	–	11	54	19	–	–	–	–	–	–	63
	1932	–	–	–	–	–	2	–	–	–	–	
	1931 or earlier	–	–	–	–	–	–	13	2	–	–	
April–May	1933	–	–	14	72	5	–	–	–	–	–	64
	1932	–	–	–	–	–	–	3	–	–	–	
	1931 or earlier	–	–	–	–	–	–	3	3	–	–	
June	1933	–	–	–	42	10	–	–	–	–	–	48
	1932 or earlier	–	–	–	–	–	2	25	21	–	–	
								Total				1444

TABLE II.

Size Distribution in the Clyde (Percentages).

Lengths in mm. L.W. = Low water.

Month.	Locality.	Depth.	Length of Test.											Number measured.
			0·25	0·75	1·25	1·75	2·25	2·75	3·25	3·75	4·25	4·75	5·25	
1933														
February	Kames Bay	4 m.	–	–	83	17	–	–	–	–	–	–	–	12
October	Fairlie Sands	L.W.	–	1	–	8	46	10	17	13	3	2	–	184
..	..	2–4 m.	47	–	–	8	17	4	4	8	–	4	8	24
1934														
January	..	L.W.	–	–	–	6	56	31	6	–	–	–	–	16
April	Kames Bay*	(4 m. ?)	–	88	12	–	–	–	–	–	–	–	–	7
June	.. *	(4 m. ?)	–	90	10	–	–	–	–	–	–	–	–	10
													Total	253

Month.	Locality.	Depth.	Length of Test.																			Number measured.
			16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	
1934																						
June	Fairlie Sands	L.W.	0·7	–	3·5	14·7	26·6	22·4	4·9	3·5	5·6	7·0	6·3	2·8	–	0·7	1·4	–	–	–	–	143
1935																						
April	..	L.W.	10·0	18·0	17·0	16·0	9·0	6·0	2·0	4·0	5·0	2·0	1·0	2·0	1·0	3·0	–	2·0	1·0	–	1·0	100
June	..	L.W.	–	0·5	3·6	12·2	26·0	19·4	4·6	1·5	4·6	9·7	6·6	2·6	2·6	1·0	3·6	1·5	–	–	–	196
																			Total			439 + 253 = 692

* indicates that only first year urchins are included in this count.

TABLE III.

SEA TEMPERATURES AT PORT ERIN AND MILLPORT.

Surface Sea Temperatures in Port Erin Bay (9 a.m.), being the monthly means for the years 1903–1927 (Bruce, 1928), and the percentage variations of the monthly means from these in the years 1930–1934.

Mean Monthly Sea Temperatures at Keppel Pier, Millport, for the period 1909–1920 (Elmhirst, 1923), and mean monthly air temperatures at Rothesay for the period 1926–1935 (Meteorological Reports).

All temperatures in °C.

		Port Erin Sea Temperatures. Departure (%) from mean.					Rothesay Air	Keppel Sea
Month.	Mean.	1930.	1931.	1932.	1933.	1934.	Mean.	Mean.
January	7·78	+0·8	+0·3	+1·4	+0·8	+1·0	4·76	7·36
February	7·08	0·0	0·0	+0·9	+0·2	+0·4	4·41	6·67
March	6·78	+0·1	−0·8	+0·7	+0·5	+0·2	5·53	6·95
April	7·43	0·0	−0·5	+0·6	+0·8		7·10	7·23
May	8·97	−0·1	−0·5	+0·1	+0·5		9·87	10·00
June	10·94	+0·5	−0·1	+0·3	+0·8		12·48	11·10
July	12·77	+0·3	−0·4	+0·5	+1·2		14·37	12·50
August	13·76	0·0	−0·3	+0·6	+1·1		13·96	13·60
September	13·32	+0·4	−0·1	+0·6	+1·4		12·17	12·82
October	12·29	+0·2	−0·9	−0·2	+1·1		8·80	11·80
November	10·44	+0·4	+1·1	+0·2	+1·0		6·50	10·13
December	8·74	+1·1	+1·4	+0·9	+0·8		5·33	8·47
Means	10·02	+0·3	−0·1	+0·5	+0·9		8·78	9·89

TABLE IV.

RELATION MEAN AND MAXIMUM GONAD VOLUMES TO TEST VOLUME (ALL IN C.C.) IN "FULL" URCHINS.

	Mean Test Volume.	Mean Gonad Volume.	No. of Specimens.	Test Volume.	Maximum Gonad Volume.
♂	20·0	0·6	1	20	0·6
	31·7	1·7	8	32	2·5
	37·4	2·1	5	35	2·3
♀	18·0	1·0	2	17	1·0
	24·3	2·4	3	24	3·0
	36·0	3·7	5	36	4·7
	43·4	5·0	7	47	8·1

TABLE V.

Seasonal Variation in the Condition of the Gonads: expressed as Percentages in each Sex in each Sample.

Date.	MALES.				FEMALES.				Number examined.	
	Unripe.	Ripe.	Spawning.	Spent.	Unripe.	Ripe.	Spawning.	Spent.	♂♂	♀♀
1932										
Feb. 23	100	–	–	–	100	–	–	–	15	10
Mar. 26	50	50	–	–	100	–	–	–	18	12
Apr. 9	12	78	–	–	100	–	–	–	9	5
Apr. 23	–	94	6	–	77	23	–	–	18	13
May 22	5	95	–	–	27	73	–	–	21	26
Jun. 23	–	33	25	42	–	92	8	–	12	17
Aug. 5	–	69	15	15	–	73	27	–	13	15
Aug. 19	–	6	26	68	–	6	28	66	19	18
Sep. 1	–	–	40	60	–	–	44	56	15	16
1933										
May 10	–	100	–	–	60	40	–	–	7	5
Jun. 13	–	87	13	–	14	50	22	14	8	14
Jul. 11	–	43	43	14	–	47	47	6	14	15
Aug. 7	–	25	67	8	–	29	42	29	12	7
Sep. 4	–	8	25	67	–	–	36	64	12	11
Sep. 20*	–	–	–	100	–	–	–	100	?	?

* This sample was 100% spent, but only two specimens were of determinable sex—both females.

Experiments in the Sea on Rate of Growth of some Crustacea Decapoda.

By

J. H. Orton, D.Sc.

With 2 Figures in the Text.

CONTENTS.

EXPERIMENTAL METHODS.

IN the course of studies on the rate of growth in marine animals by experiments and observations on material put in the sea at a known time, data on the rate of growth of a few Crustacea Decapoda have been obtained and are recorded in Table I. These experiments, except in two cases, were not designed for the purpose of following the rate of growth of Crustacea. The records obtained are nevertheless of value and may be compared with the heavy annual growth of sedentary organisms accompanying them (see **6**, **7** and **8** especially); for example, *Ciona intestinalis* commonly 15 cm. long, *Ascidiella aspersa* 7 cm. long, Teredo sp. 5–6 cm. long, Sycon 9·5 cm., *Sabella pavonina* with tube 36·5 cm. long, and all sexually mature.

In all the experiments given in Table I, except Experiments 2 and 3, some kind of experimental apparatus with small openings, whether small wire mesh (see **8**, Fig. 2, p. 10) or the circular holes in perforated zinc (see **6**, Fig. 1, p. 241), was put out in the sea with experimental animals, and left in the sea for varying periods, but usually about one year. During this time various small animals either crept into the cage, or were washed in, and feeding on the contained or adjacent animals grew *in situ* too large to get out again. No doubt some crabs entered the cage at various times, grew larger and became imprisoned, but some may have crept into the cage as soon as it was put into the sea. The experiments therefore can only give the rate of growth from the greatest possible size at

TABLE I.

EXPERIMENTS ON RATE OF GROWTH OF SOME DECAPODA.

No. of Expt.	Locality.	No. of larger individuals.	Species and maximum size (C.W.) in mm. admitted to apparatus.	Carapace width or width × length in mm. when taken from apparatus.	Maximum time in cage in months.	Experimental cage or apparatus put in sea.	Apparatus hauled or examined.	Maximum size of perforations of apparatus at end of expt. in mm.	Description of apparatus.
1	West Mersea	8	*Carcinus maenas*, 23	♂ 36, 34, 32, 26·5 ♀ 31, 25, 20, 15	3¾	18.vi.13	3.x.13	15 × 14*	Tray with perforated bottom and wire mesh lid
2	Cawsand Bay, Plymouth	2	*Portunus puber*, ca 18	♂ 35 ; ♀ 33	9	28.v.13	26.ii.14	14·5 × 9 average 11 × 6	Wire cage†
	do.	21	*Leander serratus*,‡ ?	37 to 68 (body length)	9	do.	do.	do.	do.
3	Cawsand Bay	5	*Carcinus maenas*, ca 7	♀ 22·5 ; ♂ 22·8, 21, 19·5, 19	3	27.vi.14	29.ix.14	ca 6 mm. diam.§	Box with perforated zinc sides
	do.	18	*Porcellana longicornis*,‡ 6	ca 7 × 7	3	do.	do.	do.	do.
	do.	8	*Galathea dispersa*,‡ 6	10 × 15	3	do.	do.	do.	do.
	do.	7	*Leander serratus*,‡ 6	43 to 47 (body length)	3	do.	do.	do.	do.
4	West Mersea	1	*Carcinus maenas*, 16	53	12¼	8.vii.22	14.vii.23	10 × 10	Wire cage
	do.	1	*Hyas araneus*	♀ 25·5 × 38	12¼	do.	do.	do.	do.
5‖	River Yealm	1	*Carcinus maenas*, 21·2	♀ 31·7	10½	23.vi.22	10.v.23	13 × 13	Wire cage
	do.	1	*Portunus arcuatus*, ca 21	♀ 27·5 soft	10½	do.	do.	do.	do.
	do.	1	*Portunus puber*, ca 21	♀ 28·0	12½	do.	10.vii.23	do.	do.
6	West Mersea	2	*Hyas araneus*	♂ 11·5 × 17	7½	22.x.23	7.vi.24	10 × 10	Wire cage
7**	River Yealm	3	*Cancer pagurus*, 21	♀ 49·7 × 31·6 ; ♂ 47·4 × 30·1	12	24.vi.24	26.vi.25	13 × 13	Wire cage
	do.	5	*Portunus arcuatus*, ca 21	♀ 25·5 ; ♂ 27, 24·9, 22·3, 21·3	12	do.	do.	do.	do.
8	West Mersea	12	*Carcinus maenas*, 16	♂ 37 × 29, 22·4 × 17·2, 20·8 × 16·0, 17·2 × 14·0, 10·0 × 8·0 ♀ 37 × 29, 34 × 27, 23·8 × 18·0, 25·5 × 21·0, 20·5 × 16·0, 21·0 × 17·0, 15·4 × 12·6	11¾	9.vii.24	2.vii.25	10 × 10	Wire cage

	do.	1	*Portunus corrugatus*, †† ca 16	♂ 36×29	11¾	do.	do.	do.	do.
	do.	1	*Macropodia* sp., ca 16‡‡	♂ 32×15	11¾	do.	do.	do.	do.
	do.	1	*Hyas araneus*	♀ 15·5×24	11¾	do.	do.	do.	do.
9	West Mersea	1	*Hyas* sp.§§	29 *long*	11½	21.vii.25	3.vii.26	10×10	Wire cage
	do.	4	*Carcinus maenas*, 16	♀ 36, 22 ; ♂ 48, 36	11½	do.	do.	do.	do.
10	West Mersea	1	*Carcinus maenas*, few	♀ 31, young ova	11½	21.vii.25	5.vii.26	few	Basket suspended
11	West Mersea	2	*Carcinus maenas*, 16	♂ 43, 42	10¼	14.vii.26	26.v.27	10×10	Wire cage
	do.	1	*Cancer pagurus*, 17·5	♀ 57	10¼	do.	do.	do.	do.
12	River Yealm	1	*Carcinus maenas*, ca 7·0	23·2 (cast shell 17·2)	2¾	16.viii.19	10.xi.19	6 diam.	Experimental box of perforated zinc
	do.	3	do.	♀ 23·2 ; ♂ 25·4, 24·2	6½	do.	5.iii.20	do.	do.
	do.	2	do.	♀ 30 ; ♂ 25	8¼	do.	21.iv.20	do.	do.
	do.	2	do.	♀ 29 ; ♂ 31	9	do.	19.v.20	do.	do.
13	Morecambe Bay	8	*Carcinus maenas*, 4·5	♀ 22·8 ; ♂ 26·0	2½	15.vii.33	3.x.33	4 diam.	Experimental box of perforated zinc
	do.	2	do.	♀ 31·0 ; ♂ 11·5	5	do.	16.xii.33	do.	do.
	do.	4	do.	♀ 44·6 ; ♂ 35·9 with Sacculina	14½	do.	29.ix.34	do.	do.
	do.	2	do.	♀ 44·7 in berry ; ♂ 31·0	19¾	do.	8.iii.35	do.	do.

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* This mesh was the largest used and would permit entry of a crab about 23 mm. C.W., the age of which from liberation as a zoea may be estimated at a maximum of four months.

† The apparatus rested against the bottom and sides of a floating raft on which a good growth of seaweeds and animals was available for food (see **7**).

‡ The records of *Leander serratus* are given, although their value may not be great. Relatively large prawns would be able to enter the cage in Experiment 2 at any time, and under the urge of finding food may be able to squeeze through a relatively small hole. On similar grounds the records of *Porcellana longicornis* and *Galathea dispersa* must be accepted with reservations.

§ This experiment was concluded hurriedly during the war and no record made of the size of the perforations ; these were however small and certainly not greater than 6 mm. in diameter.

‖ One *P. puber* ♂ 19·1 C.W. was also found in the cage 10.v.1923.

** On 24.vi.1924 the cage was cleared when the following animals were removed : *Cottus bubalis* 88 to 98 mm. long ; *C. maenas* 26 mm. C.W. ; *Galathea squamifera* ♀ 15, ♂ 14·2, 13·3 mm. C.W. ; *Calliostoma zizyphinus* shells 16·0 to 21·8 mm. wide ; *Botrylloides rubrum* colony 70×60 mm. ; *Botryllus violacea* colony 95×45 mm. On 26.vi.1925 the following animals were also taken : *P. arculatus* ♀'s in berry 19·6, 19·4, 18·9, 18·2, 16·0 mm. C.W. ; *Galathea squamifera* ♀ 15, ♂'s 14·2, 13·3 mm. C.W., but this species might enter the cage at a C.W. of about 15 mm.

†† Identified at sight in the field and not afterwards confirmed, but probably correct.

‡‡ Probably *Macropodia phalangium*.

§§ Probably *Hyas araneus*.

immediate entry to the size when recovered from the cage. This is, however, the maximum time required for the growth observed. Although there is good reason to believe that immediate permanent entry at the maximum size was not often made during the experiments as food material would not always then be available, it was nevertheless always possible. For these reasons it is probable that the crabs and prawns obtained in the cages had rarely spent the whole possible period in the apparatus, and that the rate of growth in the open sea may be greater than that indicated by the experiments.

In Experiments 2 and 3 cages made of iron wire mesh or perforated zinc were fitted into a large floating raft (see **7**, p. 399) which was covered with heavy growths of marine organisms (see **5**, p. 318). Food was therefore available from the outset for such animals as crept into the boxes.

The size of the greatest mesh was always noted at the end of the experiment, and if greater than at the beginning was so recorded. Usually the mesh became slightly smaller, but some meshes may be opened accidentally. (See Table I, Expt. 2.)

The probable age of the experimental crabs may be obtained by an allowance of time made from Lebour's (**3**) and Shen's (**13**) rearing experiments. Lebour states, in general, that " the usual time for reaching the first crab stage seems to be about three weeks to a month, judging from rearing experiments. In natural surroundings it may be less. After the first crab stage the skin is cast about once a week for the first month, after which there are longer intervals, until at about four months old it begins to change once a month or more. Temperature seems to affect them, for in winter the changes were very slow." The carapace widths of fourth stage crabs (i.e. at an age of two months or less from hatching) obtained by Lebour are: *P. puber* 7·36 mm., *C. maenas* 4·2 mm., *C. pagurus* 6·7 mm. Shen (**13**) finds the mean to be 4·4 mm. for the fourth stage of *C. maenas*. It is noteworthy that in the corresponding early crab stages *C. pagurus* is larger in carapace width than *C. maenas*.

The rate of growth of marine animals in aquaria is usually slower than in the sea where information is available for comparison. Therefore both the rearing experiments and the records given in Table I give probably slower inferential rates of growth than occur in normal life.

RATE OF GROWTH OF *Carcinus maenas*.

From the experiments recorded in Table I an approximation can be made to the natural minimal rate of growth of *Carcinus maenas*. Shen (**13**) has recently reared in the Plymouth Laboratory the early stages of 12 male and 10 female post-larval crabs from the megalopa at the following mean periods in days and mean sizes in mm. Carapace width (=C.W.) for males and females combined is shown in Table II.

TABLE II.

DATA FROM SHEN'S WORK ON POST-LARVAL *C. maenas*.

Stage	I.*	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Mean C.W. in mm.	1·84	2·58	3·43	4·41	5·83	7·92	10·3	13·5	18·23
Mean period between ecdyses in days	7·5	12·5	14·0	14 to 19·0?	17·5	18·5	14·5	14·0	14·5
Mean accumulative period in days	7·5	20·0	34·0	48 to 53·0?	65·5 70·5	83·0 88·5	98·0 103·0	112·0 117·0	126·5 131·5
Minimum accumulative period in days	4·5	15·5	24·5	36·0	46·5	60·5	71·0	82·0	94·5
Mean % increment in C.W. for ♂ & ♀	61·0	41·5	34·5	31·0	31·5	31·5	31·5	32·0	33·5

* From megalopa of C.W. = 1·15 mm.

The last-mentioned minimum period is in reality a mean of the shortest periods between successive moults of those males and females which moulted most quickly in each stage. The shortest total period from megalopa to Stage VIII was 108 days for a male and 102 days for a female, that is, about 3½ months; to Stage IX, 122 days for a male and 119 days for a female, that is, about 4 months. The average period of individual development from megalopa to Stage VIII was 117 days for 10 males and 114 days for 10 females, and to Stage IX, 125 days for 3 males and 120 days for 3 females. The average period for each stage is plotted against size in Figure 1, and an imaginary Stage X—assuming continuance of the same kind of increment in carapace width and moulting period as occurs in Stages VII to IX—is plotted at A.

On the basis of the work of Shen the maximum age of the small crabs entering the cages in Experiments 13, 12 and 3 has been estimated and entered in Table III, column 3.

TABLE III.

RATE OF GROWTH OF *Carcinus maenas*.

1	2	3	4	5	6	7	8
No. of Expt.	Maximum width at entry.	Estd. age of (2).	Width at end of expt.	Minimum increment in width.	Maximum period of growth in expt.	Estd. age at end of expt.	Approx. time zoea hatched.
13	4·5 mm.	1½ m.	♂ 26·0 mm.	21·5 mm.	2½ m.	4 m.	May–June
do.	do.	do.	♀ 22·6	17·1	do.	do.	do.
12	7·0	2	♂ 23·2	16·2	2¾	4¾	June–July
3	7·0	2	♀ 22·5	15·5	3	5	April–May
13	4·5	1½	♀ 31·0	26·5	5	6½	May–June
1	23·0	ca 4	♂ 36·0	13·0	3¾	7¾	Feb.–Mar.
11	16·0	3	♂ 48·0	32·0	10¼	13¼	April.
13	4·5	1½	♀ 44·6	40·1	14½	16*	May–June
do.	do.	do.	♂ 35·9 S†	30·4	do.	do.*	do.
13	4·5	1½	♀ 44·7 in berry	40·2	19¾	21¼*	do.
Cage Expts.							
West Mersea	16·0	3	♀ 37·0	21·0	12	15	April
			♂ 53·0	37·0	do.	do.	do.

* Age probably overestimated, see p. 679. † With Sacculina.

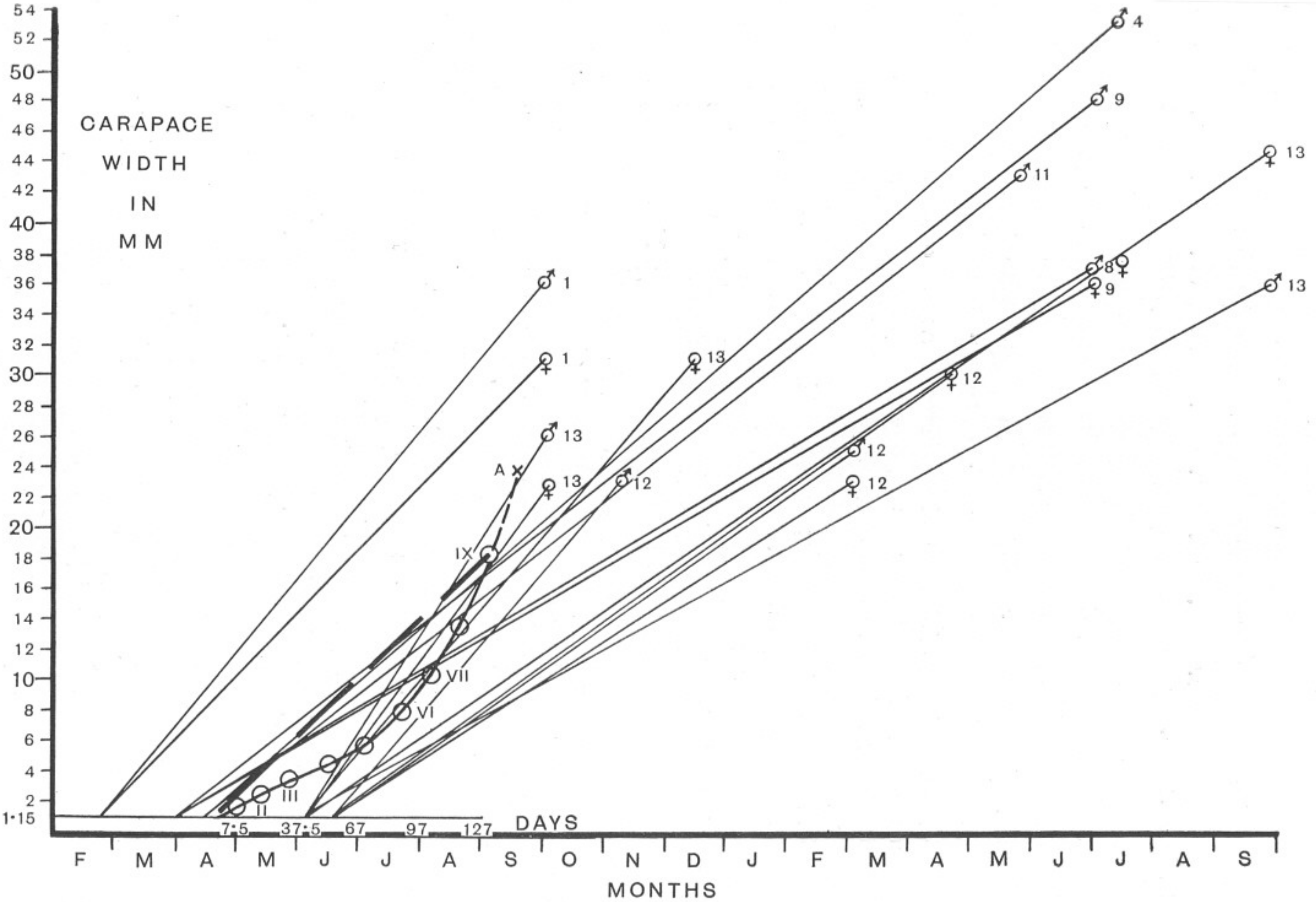

Fig. 1.—Graphs of mean minimal rate of growth of *Carcinus maenas* obtained in experimental apparatus in the sea, compared with rate of growth in the laboratory of post-larval Stages I to IX as obtained by Shen (**13**). (Carapace widths in mm. are plotted as a criterion of size.) The figures refer to number of experiment in Table I p. 674, and Shen's Stages I to IX (plotted for mean accumulative growth in days) are denoted by large circles. An imaginary Stage X is plotted at A.

The largest sizes at entry are given in carapace widths (C.W.) in column 2 of the same table with the maximum sojourn in the cage (column 6) and size at end of this period (column 4). The age at this latter size (column 3 + 6) is given in column 7.

From this analysis of the experimental data it is seen that Carcinus may attain in the first summer of growth a C.W. of at least 26 mm. for males and 23 mm. for females in 4 months; 31 mm. for females in 6½ months; 36 mm. for males in 7¾ months. In Experiment 13 a female 44·6 mm. was obtained at a maximum age of 16 months, and a female in berry 44·7 mm. C.W. at a maximum age of 21¼ months, but these two crabs were probably little more than 12 months old. In the annual experiments with the West Mersea oyster cage, extending usually from July to July, males commonly attained a width of 36 to 48 mm., although one male 53 mm. was taken, and females 31 to 37. The maximum age of these males and females is about 15 months. These individual results are plotted in Figure 1 to show the minimal rate of growth, i.e. assuming that crabs entered the cages at a maximum size as soon as the apparatus was put in the sea, and an allowance made for age at entry based upon Shen's laboratory experiments. The slopes of the graphs represent mean rate of growth and are very variable, due first to unknown date and size of entry and secondly to unknown decrease in rate of growth in the winter period. The acceleration in growth of Shen's crabs with time is well shown and if continued (as at A) would give a mean rate of growth—indicated by the slope of the graphs—not very different from the experimental results. It may be therefore that the rate of growth found by Shen does not fall far short of that found in nature.

The experiments therefore prove that both males and females may attain a C.W. of 3 to 4 cm. in the same year as they are spawned as zoeas, if the spawning is early, i.e. about February–March. Liberation of zoeas occurs in Carcinus in spring and early summer, although berried females and planktonic zoeas occur all the year round at Plymouth (Lebour, **3**). Somewhat similar breeding periods probably occur in the Thames and Morecambe Bay areas with restriction of breeding in the winter months. There will thus occur a great variation in size of crabs less than one year old at the end of any one breeding season. Nevertheless the minimal *increments* of growth occurring in the boxes with perforated zinc sides and top, e.g. for males 21·5 mm. from 4·5 mm. in 2½ months, for females 17·1 mm. from 4·5 mm. in 2½ months, 15·5 mm. from 7·0 mm. in 3 months, 26·5 mm. from 4·5 mm. in 5 months, indicate that sizes of 3 to 4 cm. at least will be attained in 12 months by males and females whatever be the period of the year the zoea is liberated. This conclusion is substantiated by the experiments in the wire mesh oyster cages where males increased in C.W. in one instance 37 mm. and in several other experiments from 20 to 32 mm. from 16 mm.; females increased about 20 mm. from 16 mm. in a period of at the most 12 months.

It is unlikely that the crabs found in the cages put out in July were second year individuals except in the probably remote occurrence of arrested growth. The experiments also indicate that the rate of growth is greater in males than in females.

Experiment 13 affords evidence that sexual maturity in the female is attained in the second summer at an age of not much more than 12 months; males probably mature at about the same age or earlier. These results show that in the sea more rapid growth occurs than in the interesting experiments on growth in captivity carried out by Waddington and Williamson (**14**). The latter writer concluded from his work that *C. maenas* attained a size (C.W.) of 8 to 22 mm. in the first year; males 45–56 mm. and females 35–48·5 mm. in the second year; and males 60, females 55 mm. in the third year. Shen's work as well as the experimental results given here show that growth in the first year is much greater than was estimated by Williamson. Similarly second year growth is also greater in the sea than was found in laboratory crabs, but the discrepancy is probably not so great as in the estimate for the first year. There is no information regarding growth in the sea at the end of two and three years, but there is some indication that although growth may be slower in the early stages of this species in captivity than in the sea, in the later stages growth in captivity may not differ much from that in the sea.

Williamson records the spawning of a female at an age of less than two years old although reared in captivity, an observation that accords well with the record of the gravid female in Experiment 13 herein, at a maximum age of about 21 months, but at a probable age of little more than 12 months.

It seems probable that in Experiment 13 there was a constant excess of food-material available as on the ground outside (see **9**, page 100), so that growth in this apparatus is likely to be closely comparable with that on the adjacent beds. In other experiments it is more difficult to assess the food-conditions and although there was probably a good supply in most cases, it is possible that at times there was less inside the apparatus than on the adjacent feeding grounds. For these reasons it is possible that the experimental results may, except in Experiment 13, give lower growth rates than would occur under natural free-living conditions.

RATE OF GROWTH IN SOME OTHER BRACHYURA.

Experiment 2 demonstrates a growth in at most 9 months in *Portunus puber* from at most 18 mm. to 35 mm. C.W. in a male and to 33 mm. in a female. In *Portunus corrugatus* a male attained a C.W. of 36 mm. from at most 16 mm. in at most 11¾ months. The rate of growth in these species is therefore in all probability comparable in the first year with that of *C. maenas*. The few records of *Portunus arcuatus* in Experiments 5 and 7 are less valuable, as the species is relatively small and entry into the cage could be made at a relatively large size at any time. The actual incremental growth proved in these cases is slight. There is, however, good probability that this species reaches sexual maturity in one year.

Hyas araneus, female, occurred in Experiment 4 at a carapace width of 25·5 mm. and length of 38 mm. The maximum size of entry of this species was not determined, but would probably be a carapace width of 14 to 16 mm. Smaller Hyas were taken on other occasions. It is not unlikely that a carapace length of about 4 cm. is attained by this species in one year.

Macropodia sp., male, of a carapace length of 32 mm. and width of only 15 mm. was taken in Experiment 8, but is of more value as an indication of the experimental potentialities than as a definite growth record.

RATE OF GROWTH OF *Cancer pagurus* DURING THE FIRST YEAR.

The records given in Table I, Experiments 7 and 11, of the growth of the edible crab, *Cancer pagurus*, during early life are of considerable value, as little of a definite nature is known of growth during this period. Lebour has found (**3**) that megalopæ of this species occur in the Plymouth district during spring and early summer, and that among Brachyura in general the usual period from hatching to the first crab stage is three to four weeks in rearing experiments, but probably less under natural conditions. Young Cancer may therefore begin to settle in the Plymouth district in late spring or early summer. Similar breeding conditions probably occur in the Thames Estuary, with possibly rather later appearance of young crabs there and in more northerly situations. There is, therefore, good probability that the Cancer found in the Yealm and West Mersea experimental apparatus entered the cages as young post-larval crabs in the summers when the cages were put in the sea.

The possibility that the crabs found had wintered from the previous spawning season as very small individuals must also be considered, as Williamson observed (see Fig. 2, p. 684 herein) that small crabs of 1 to 2 cm. (C.W.) occurred on the Scottish foreshore (Dunbar) all the year round; moreover, with the extended breeding season of this crab a wide range in size of one year individuals will undoubtedly occur. There are, however, two additional sources of information available on the growth of Cancer in the first year.

In the first instance young *Cancer pagurus* have been found year after year in October on the under side of bathing rafts put out in Plymouth

TABLE IV.

SIZES OF *Cancer pagurus* FOUND ON BATHING RAFTS AND BUOYS IN PLYMOUTH SOUND.

Raft[1] or buoy put out.	Raft or buoy brought in.	Months in sea.	Total* crabs.	*Cancer pagurus :* Carapace width in mm.											
				Less than 20	20	21	22	23	24	27	28	29	32	34	39
April 30, 1913	Oct. 13, 1913	5½	3	2	1	–	–	–	–	–	–	–	–	–	–
April 3, 1912[2]	March 5, 1913	11	1	–	–	–	–	–	–	–	1	–	–	–	–
May 14, 1913[3]	May 8, 1914	12	2	–	–	–	–	–	1	1	–	–	–	–	–
April 20, 1914	Nov. 12, 1914	6¾	5	1	–	1	–	–	–	–	–	1	1s†	–	1s†
May 2, 1919	Oct. 10, 1919	5¼	1	–	1	–	–	–	–	–	–	–	–	–	–
April 28, 1920	Oct. 12, 1920	5½	2	1	–	–	–	1	–	–	–	–	–	–	–
April 27, 1920	Oct. 13, 1920	5½	25	12	2	4	–	5	2	–	–	–	–	–	–
April 11, 1921	Oct. 14, 1921	6	∞	several‡	–	–	1	–	–	–	–	–	–	–	–
April 13, 1921	Oct. 14, 1921	6	5	4	–	–	1	–	–	–	–	–	–	–	–
April 19, 1923	Oct. 13, 1923	5¾	1	1	–	–	–	–	–	–	–	–	–	–	–
May 5, 1924	Oct. 13, 1924	5¼	∞	several§	1	–	–	–	–	–	–	–	–	–	–
April 18, 1928	Oct. 14, 1928	6	2	?	–	–	–	–	–	–	–		1s†	1	–

* Excluding in many cases small ones not recorded.
† s=soft-shelled crabs.
‡ Many less than 22 mm.
§ Many less than 20 mm.

[1] All rafts unless otherwise stated.
[2] No. 12 buoy, G.W.R. Docks.
[3] No. 10 buoy, G.W.R. Docks.

Sound in or about April. The sizes attained by these young individuals are recorded in Table IV and range from 8 mm. to 39 mm. in breadth of carapace. These rafts are treated on the under surface with a thick layer of well dried pitch, which permits of immediate settlements of growths such as barnacles, mussels, ascidians, hydroids, sponges and amphipods with an abundant micro fauna and flora. Ample opportunities are thus afforded for the settlement and feeding of young crabs, but it is unlikely that growths are sufficiently established for settlement before about June. As, however, the rafts are buoyed with mooring chains, it is not impossible for crabs to crawl up to the bottom of the raft along the links of the chain and across the swivel or shackle. For this reason these records have not the same value as those from the experimental cages ; nevertheless the constant occurrence year after year of young crabs and only young crabs on these rafts gives probability to their growth *in situ.*

The probability that young Cancer 20 to 40 mm. broad in October–November are the young of the current year is supported by the definite records given above and also by Williamson's well-known observations on beach crabs at Dunbar (**15**). Lebour also reared a crab in the laboratory to 14 mm. C.W. on November 30 from a megalopa moult on July 7. This growth may be regarded as probably slower than natural. The Dunbar beach crabs give the second class of data on rate of growth in the first year.

Williamson's data are given in Table V (p. 685) and Figure 2 (p. 684) in a different form from the original. The monthly collection of crabs have been assembled in cm. groups and plotted as a percentage of the monthly catch. The collections were begun in October, 1897, and continued regularly until September, 1898. The course of the graphs shows clearly that an influx of young crabs 2 to 3 cm. occurred on the foreshore in August, 1898, and that these crabs showed a modal value of 2·5 to 3·5 cm. in September 1898. The modal value 3·5 cm. in October, 1897, is in accordance with the trend of growth in August and September, 1898, and is comparable with the seasonal growth of *C. maenas.* The graphs from October, 1897, onwards indicate a stationary modal value until March, 1898, when it rose to 4·5 and was *apparently* maintained until as late as July. In May, however, a relatively high proportion of crabs 5 to 6 cm. was found and it is conceivable that an offshore migration began soon afterwards. Williamson suspected such a migration and set pots close inshore later (1900–1901) to obtain information. His results in a modified form in approximately cm. groups are included in Table V (excluding breadths above 12 cm.). By these investigations he proved that although crabs belonging to the 5 cm. group are relatively scarce, those belonging to the 6-, 7-, 8- and 9-cm. groups occurred close inshore in good numbers in May, 1901, and in June, July and August, 1900. These along with the beach observations lend support to the probability of a migration from the beach at a size of 5 cm. and as early in the life history as about the end of the first year of growth among those crabs which begin larval life and settle early in the season. The problem is complicated by the habit of inshore migration known to occur in sexually mature crabs after winter and possibly adopted in a lesser degree by adolescent crabs.

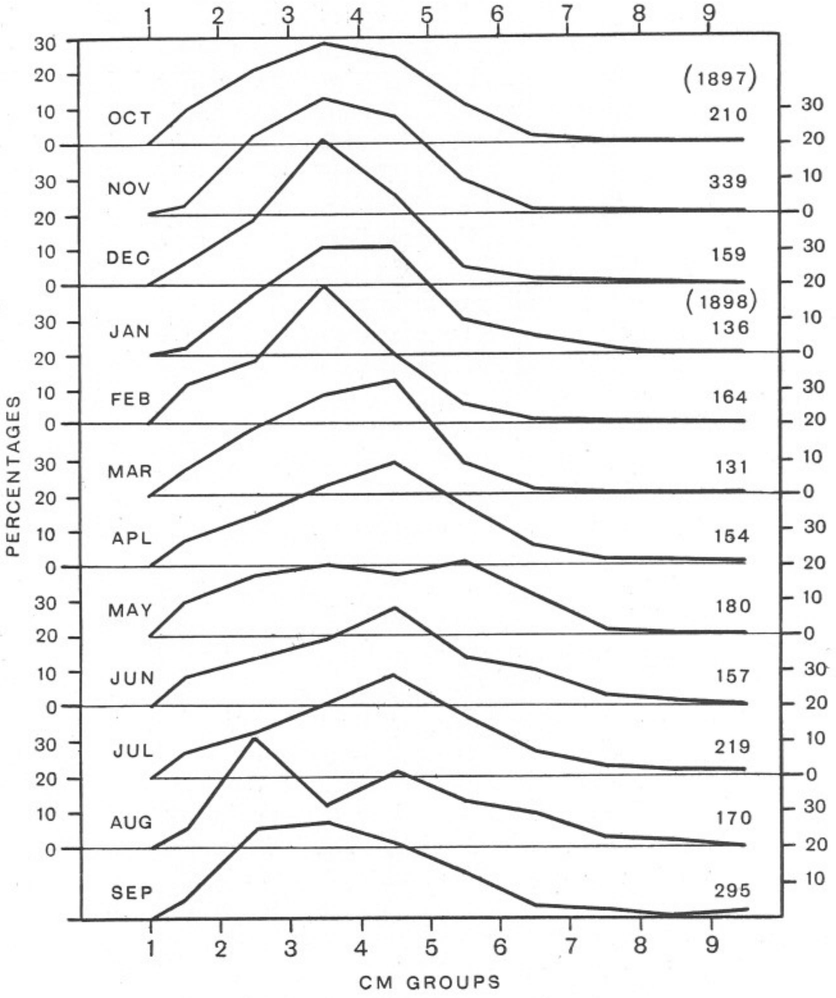

FIG. 2.—Distribution of size in monthly catches of *Cancer pagurus* taken on the beach at Dunbar by H. C. Williamson (**15**). The sizes are collected into cm. groups and graphed as group percentages.

From Williamson's observations, and Lebour's and the writer's experiments, there can be little doubt that *Cancer pagurus* attains a modal size of about 3·5 cm. (carapace breadth) at the end of the first summer of growth. Williamson's work also indicates that at an age of one year the crabs have a minimal modal value for carapace breadth of about 4·5 cm. ; but that the indications of an offshore migration about May, along with the experimental record of the attainment of a carapace breadth of 5·7 cm. almost certainly in about one year, render it possible that the modal value at an age of one year may lie between 5 and 6 cm. Definite experiments on rate of growth are required to obtain further information on

TABLE V.

NUMBERS OF *Cancer pagurus* (GIVEN IN CM. GROUPS) TAKEN ON THE BEACH AT DUNBAR AND IN CREELS JUST BELOW LOW WATER BY H. C. WILLIAMSON.

Percentages in cm. groups of beach crabs are also given in italics, with totals of monthly collections in brackets.

Cm. groups.			1·1 to 2	2·1 to 3	3·1 to 4	4·1 to 5	5·1 to 6	6·1 to 7	7·1 to 8	8·1 to 9	9·1 to 10	10·1 to 11	11·1 to 12
Oct.	beach	1897	20	45	61	53	24	5	1	1	0	0	0
	(210)		*9·5*	*21·4*	**29·0**	**25·2**	*11·4*	*2·4*	*0·5*	*0·5*	*0·0*	*0·0*	*0·0*
Nov.	beach		10	77	113	96	33	5	4	0	1	0	0
	(339)		*2·9*	*22·7*	**33·3**	**28·3**	*9·7*	*1·5*	*1·2*	*0·0*	*0·3*	*0·0*	*0·0*
Dec.	beach		10	29	65	41	8	3	2	1	0	0	0
	(159)		*6·3*	*18·2*	**40·9**	**25·8**	*5·0*	*1·9*	*1·3*	*0·6*	*0·0*	*0·0*	*0·0*
Jan.	beach	1898	3	24	42	42	14	8	3	0	0	0	0
	(136)		*2·2*	*17·6*	**30·9**	**30·9**	*10·3*	*5·9*	*2·2*	*0·0*	*0·0*	*0·0*	*0·0*
Feb.	beach		18	31	65	34	10	3	2	0	1	0	0
	(164)		*11·0*	*18·9*	**39·6**	**20·7**	*6·1*	*1·8*	*1.2*	*0·0*	*0·6*	*0·0*	*0·0*
March	beach		10	25	37	42	13	2	1	0	1	0	0
	(131)		*7·6*	*19·1*	**28·2**	**32·1**	*9·9*	*1·5*	*0·8*	*0·0*	*0·8*	*0·0*	*0·0*
	creel	1901	0	0	1	1	5	3	2	0	2	1	1
April	beach	1898	11	22	34	45	27	8	3	3	1	0	0
	(154)		*7·1*	*14·3*	*22·1*	**29·2**	**17·5**	*5·2*	*1·9*	*1·9*	*0·6*	*0·0*	*0·0*
	creel	1901	0	0	0	0	1	0	4	4	4	1	5
May	beach	1898	18	32	36	31	38	21	3	1	0	0	0
	(180)		*10·0*	*17·8*	*20·0*	**17·2**	**21·1**	**11·7**	*1·7*	*0·6*	*0·0*	*0·0*	*0·0*
	creel	1901	0	0	0	5	6	19	32	23	18	15	29
June	beach	1898	13	22	30	44	22	16	6	3	1	0	0
	(157)		*8·3*	*14·0*	*19·1*	**28·0**	**14·0**	**10·2**	*3·8*	*1·9*	*0·6*	*0·0*	*0·0*
	creel	1901	0	0	0	0	4	3	5	13	14	39	30
	creel	1900	0	0	0	0	2	20	32	44	35	25	19
July	beach	1898	16	28	46	63	38	16	8	2	2	0	0
	(219)		*7·3*	*12·8*	*21·0*	**28·8**	**17·4**	*7·3*	*3·7*	*0·9*	*0·9*	*0·0*	*0·0*
	creel	1901	0	0	0	1	1	0	3	2	9	10	8
	creel	1900	0	0	0	1	5	18	43	36	45	53	50
Aug.	beach	1898	10	54	21	37	23	17	4	4	0	0	0
	(170)		*5·9*	**31·8**	*12·4*	**21·8**	**13·5**	*10·0*	*2·4*	*2·4*	*0·0*	*0·0*	*0.0*
	creel	1900	0	0	1	2	8	10	24	22	26	18	23
Sept.	beach	1898	16	75	81	61	38	10	8	2	4	0	0
	(295)		*5·4*	**25·4**	**27·5**	**20·7**	*12·9*	*3·4*	*2·7*	*0·7*	*1·4*	*0·0*	*0·0*

this problem. The estimates of rate of growth given by Pearson (**11**) admittedly tentatively on the basis of growth in Waddington's aquarium-bred crabs (**15**) are out of harmony with facts from the wild. On the basis of a modal value for carapace breadth of 4·5 to 5·5 cm. in the first year of growth, continued rapid growth may be predicted until the attainment of sexual maturity at a breadth of about $4\frac{1}{2}$ to $5\frac{1}{2}$ inches = 11·4 to 14·0 cm. (**12**). If such rapid accelerative growth occurs in Cancer as in other marine animals, e.g. oyster (**10**), herring (**1**), lobster (**2**), it is not impossible that the edible crab may become sexually mature in about three years, for dimensions may be doubled in the second year, and very nearly the same increment in dimensions may obtain in the third year before the attainment of maturity. In Havinga's graph of increase in length of the lobster, *Homarus vulgaris,* the increments in length in the second and third years are each greater than the actual length at the end of the first year. Elmhirst's graph (**12**), which includes all observations, gives lower increments, as perhaps might be expected from the inclusion of all aquarium and pond-bred animals. In this respect it is noteworthy that a plotting of Williamson's crabs taken just below low water does give an indication of a modal value of edible crabs of 8 to 9 cm. in the months of June and July, which would rise rapidly with a single general moult. Further investigations may show that these are second year crabs.

ADDENDUM.

Since the foregoing account was submitted for publication it has been found that MacKay and Weymouth in a recent publication (**4**) have investigated growth in the Pacific crab (*Cancer magister*), from mainly southern British Columbia, by a study of moults and moulting with tagging and size-frequencies. They state that "it seems possible sex-maturity may be attained by some crabs as early as the third year and in some as late as the sixth year, but that normally crabs become mature in their fourth and fifth years." Mean carapace width at an age of "one year" is estimated at a little over 1 cm., at two years about 6 cm., at three years a little over 8 cm., and at four years on the attainment of sexual maturity a little over 10 cm. The length-breadth relation and general form of *C. magister* is closely similar to that of *C. pagurus*, and MacKay and Weymouth consider that growth in the latter would appear to be essentially similar to that of *C. magister*. These authors give percentage size distribution of live crabs for the months of April to September and remark "in September, three year groups may be distinguished ; the young *of the year* at 1 or 2 cm., of the preceding year 4 to 7 cm., and of the second season previous, less clearly, at about 10 to 12 cm."

It is clear from this statement and their reconstruction of the life-history in a growth-curve (Fig. 6, *loc. cit.*) that the authors use the term "year" to mean the first summer of growth and not actually a year of twelve months, as they record "Megalops appear during July–August; 1st post-larval crabs during August," and so on. Therefore, their 1-year group would—in accordance with common European practice—be the 0-year group.

When these facts are considered the work of MacKay and Weymouth indicates that the deductions made from the experimental and observed facts on *Cancer pagurus* are closely comparable to those made on *C. magister*, and that *C. pagurus* may therefore very probably be sexually mature at an age of about three calendar years.

ACKNOWLEDGMENTS.

Most of the experiments herein recorded were carried out as researches controlled from Plymouth by the Marine Biological Association of the United Kingdom. The experiments at West Mersea were conducted on the oyster beds and with the courteous permission of the Tollesbury and Mersea Native Oyster Company.

The Morecambe Bay experiment, from which results were obtained incidentally, was financed partly by Liverpool University Joint Research Committee and partly by the Lancashire and Western Sea-Fisheries Committee. My thanks are gladly tendered to these bodies and to Miss H. M. Lewis, B.A., Mr. L. French, Mr. Wm. Searle, Mr. J. Kingcombe, Mr. P. Bond and Mr. T. Wilson for valued assistance in various respects.

SUMMARY.

From experiments in the sea with wire cages and boxes with perforated zinc sides and tops more than 100 individuals of certain Crustacea which had grown inside the apparatus have been obtained at various subsequent dates.

Minimal mean rates of growth are obtainable from the difference between maximum size at immediate entry and size at a given later date, and the approximate age by an allowance for age at entry plus the maximum time occupiable in the experimental apparatus. It was found that *C. maenas* spawned early in the year may attain a carapace width of 30 to 40 mm. by the following winter. In experiments extending over twelve months from July to July male *C. maenas* attained a carapace width of 43 to 53 mm. and females 37 mm. at an estimated maximum age of 15 months.

In other experiments female *C. maenas* attained a carapace width of 44·6 mm. in at most 16 months and occurred in berry at this size at a

maximum age of about 21 months. It is inferred that female *C. maenas* become sexually mature in little more than 12 months at a carapace width of about 45 mm. or less and that males are mature at about the same age and size or less, and appear to grow more quickly than females.

Portunus puber and *P. corrugatus* appear to have rates of growth comparable with that of *C. maenas*.

Cancer pagurus grew from a carapace width of 17·5 to 57 mm. in at most $10\frac{1}{4}$ months in one experiment and from 21 mm. to 49·7 (female) and 47·4 (male) mm. in at most 12 months in another experiment. These results are discussed in relation to other investigations on rate of growth in this species, and the conclusion reached that a carapace width of 4·5 to 5·5 cm. may be commonly and normally attained at an age of one year, and that by increments in growth in the second and third years equal or sub-equal to that in the first become sexually mature at about three years old.

It is suggested that similar *ad hoc* experiments might add much to knowledge on rate of growth of Crustacea.

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Variations in the White Pigment of the Eye in *Gammarus chevreuxi* Sexton, with a Description of a New Genetic Type, the "Clotted eye."

By

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From the Plymouth Laboratory.

With 1 Figure in the Text.

A GREAT number of variations from the normal type have occurred in *Gammarus chevreuxi* during the course of the work carried out from 1912 until now.

In reviewing these variations it is convenient to class them according to the parts affected :

(1) Pigmentation of the body (**3**, p. 194).
(2) The Red retinal pigment of the eye (**4**, pp. 45–52).
(3) The Black retinal pigment of the eye.
(4) The white accessory pigment of the eye (**2**, p. 350).
(5) The structure of the eye, involving also the structure of the head (**1**, p. 274 ; **6**, pp. 356–369).

The two last classes are dealt with in this paper.

(4). VARIATIONS AFFECTING THE WHITE PIGMENT OF THE EYE.

In the normal type (Fig. 1, *a*) the eye is of compound structure, sessile, non-facetted, convex, reniform in shape with the margin entire and clearly defined. It is composed of rows of ommatidia each consisting of a two-celled cone, and five retinal cells arranged round a central axis, the rhabdome. The coloured pigment is contained in the retinal cells. The interstices between the ommatidia are filled with the so-called "accessory" cells containing the opaque* white-pigment which gives the effect, in the living animal, of a regularly spaced, chalky white reticulation spread over the eye, with the ommatidia showing through the meshes as shining black spots.

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* The two kinds of pigment, retinal and inter-ommatidial, differ in origin and in constitution. The eyes are usually described in terms of retinal colours, such as Black, White, Red, Purple, or Lilac, so, in order to avoid any confusion, particularly with the White Eye, the inter-ommatidial white accessory pigment is designated in this paper by the hyphenated term "white-pigment."

The principal genetic variations from the normal type are the No-whites; but there occur others covering almost the whole range between the two extremes, both the quantity and distribution of the white pigment in the inter-ommatidial cells being affected.

Even in the *normal* eye, in which the chalky white lines are regularly spaced and defined, the lines may vary in thickness from " very thin," i.e., threadlike in appearance (*deficiency* of white), to " heavy," i.e., about twice or three times the usual thickness (*excess* of white), the effect given being, in the one case, of ommatidia larger than normal, and in the other, smaller.

The *Sub-white* is a variation occasionally met with, more frequently in the Albino stock (especially when it carries the No-white factor), in which only the proximal inter-ommatidial cells appear to be pigmented, and the white-pigment therefore instead of the usual chalky white reticulation shows as a faintly marked, milky looking deposit deep down in the eye.

The *No-white* eye in which the white-pigment is completely inhibited was first found in 1914 in Stock I (**2**, p. 350), and has appeared in many stocks since. It behaved as a simple Mendelian recessive.

This is the type to which we have given the name of Genotypic No-white, to distinguish it from a second No-white type of exactly the same appearance which we have recently investigated, and called Phenotypic No-white. The two types may be defined thus:

No-whites, *genotype*, hatch no-white (may be coloured, Black (BN), or Red (RN); or White (WN); or Albino (AN)*); remain no-white throughout life; give no-white when mated *inter se* or with other genotypic no-white stocks; and an F_2 ratio of 3:1 when mated with normals.

No-whites, *phenotype*, hatch no-white; and remain no-white all through life like the genotypic, but give normals when mated with genotypic no-white stocks; and normals, or normals and no-whites when mated *inter se*.

The Phenotypic No-whites were first noted in 1931, in three of the stocks in the M experiment†; and again in 1933 in five stocks of the D experiment.†

The genetic No-white forms belong to the type of inheritance in which the characters segregate out sharply one from the other, but there is another type of inheritance amongst the No-whites in which every member of the particular strain where the variation occurs is affected to a greater or less degree.

In this type, practically all the young in each generation start from

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* When first found, the No-white form of the Albino was described as the " Colourless eye," but since the appearance of the White No-white to which the description of " colourless " could equally apply, we have dropped this use of the term entirely.

† Records of these experiments have not yet been published, but a paper is being prepared for a future number of this Journal.

normal (in appearance), diverging steadily from normality until at or about maturity they show the characters of the variation. Besides these, the "Gradual No-whites," two other types may be included in this division, viz., the "Irregular Coloured eye," in which the structure of the ommateum is affected, and the new "Clotted eye" in which both the structure and the pigment-cells, coloured as well as white, are modified.

In the *Gradual No-whites*, the characteristic feature is the steady and gradual *reduction* of the white-pigment till it vanishes completely

The first appearance of this type was recorded in 1917 (**1**, p. 329; **2**, p. 351), and as it is typical of all the others found later, the description of it will suffice for all. From a Black pair (male thin reticulation, and female a spotted Half No-white) 311 young were hatched in four generations, 309 perfectly normal-eyed, and 2 Half No-whites, i.e., with one eye normal and one eye no-white. Not only had they all the usual amount of pigment in the reticulation of the eye, but many showed an excess of white in the form of "heavy" reticulation, and 170 had numerous spots of white apart from the eye. By the time they were half-grown the white reticulation had become thin and threadlike, and by the time maturity was reached it had disappeared altogether. Not a single specimen in the four generations reached full growth with the reticulation normal. Animals which had become fully No-white were mated together, and also tested with genotypic No-whites; in all cases Black normal-eyed young were produced.

There have been many instances of this *gradual reduction* of white-pigment, especially of late years, but an even more remarkable genetic variation was the *gradual increase* of the white-pigment, which arose in the D experiment in several stocks.

The effect of the "increase" factor is the steady development of the white-pigment from no-white to normality—the *Gradual Normal*, as opposed to the effect of the "reduction" factor from normality to no-white—the *Gradual No-white*.

As far as we know now, the inheritance does not run on the same lines. In a stock carrying the reduction factor, as has been pointed out, *all* the members are affected, but in a stock containing the increase factor, it would appear that only a certain proportion are. It is difficult to judge, for few of the stocks survived beyond the F_2 generation, and in those which did produce an F_3 the figures were too small to be of value—but it looks as if there may have been a 3 to 1 ratio.

To give examples of the figures: in Stock *D LXV* an F_2 of 254 Black young was hatched, consisting of 186 normal-eyed at birth, and 68 with the white-pigment affected. Of these 68, 45 had very thin, threadlike reticulation; 17 were practically no-white, with only one or two flecks or spots of white in the eye; and 6 were completely Black No-white in appearance with no trace of the white-pigment visible under a high power. All the 68 became perfectly normal-eyed.

In another stock, *D XXXVIII* (2) in one brood-bowl containing one male and five females the offspring numbered 68 normal-eyed and 28 others of which 20 were Black No-whites (in appearance), 1 practically BN, and 7 had very thin reticulation. All these developed the white-pigment later.

An interesting fact is that a stock carrying the genotypic No-white factor can also carry the factor for Increase of white-pigment.

In one stock, *MMB LVII*, Red-with-Nowhite, a new recessive segregated out (**7**); mated *inter se*, Red-with-Nowhites were given; but in three crosses with proved genotypic Red No-whites of Stock I (double recessives r_1r_1 ww), all the young were normal-eyed.

(5) VARIATIONS AFFECTING THE STRUCTURE OF THE EYE INVOLVING ALSO THE STRUCTURE OF THE HEAD.

These are of very rare occurrence, and in fact only two such have been recorded up till now.

In all the mutating stocks described above, the eye or ommateum is regular in structure, with the margin clearly defined, increase taking place on the periphery at each growth-stage.

At the other extreme is the degenerate eye-structure, of which the *Albino* is the type, in which the ommateum is broken up, the retinal cells are completely lacking, and only a small proportion of the ommatidial cones, and the inter-ommatidial cells remain. No two eyes are alike, not even in the same animal. The white-pigment forms curd-like scattered masses (with the cones lying loosely in them), instead of the even reticulation seen in the normal-eye; and spots of white apart from the eye are of frequent occurrence.

This is a sharply defined and heritable variation behaving as a simple Mendelian recessive which has only appeared once in our cultures, in Stock I (**1**, p. 274) in 1915.

The second appearance of defective structure, in this case associated with malformation of the head and brain, was the *Irregular Coloured eye* (**6**, p. 355) which arose in 1918 from a mating of a dorsally spotted Albino female with a Black No-white male, heterozygous for red.

In this the range of variation extended from the perfect normal-eye, through all stages of degeneracy to the loss of the eye. In the extreme cases, the breaking-up of the ommateum was as marked as in the Albino, with this important difference, that the coloured retinal cells were always present. The white-pigment assumed many shapes, from regular reticulation to superficial clotted masses in the eye, and spots on the head.

The tracing of the inheritance was frequently obscured by the gradual onset of the irregularity common through the strain.

The "Clotted eye."

The same delayed action appears in this new variant and there is also a similar wide range of expression from the perfectly normal through degrees of Clotted, to an extreme which could be easily mistaken for Albino.

The character occupies a somewhat intermediate position between the normal and the aberrant types, Albino and Irregular-eye, and may perhaps throw light on some of the causes which produce the defects in eye-structure.

It seems to us that the Clotted effect is in all probability caused by a thinness or weakness of the cell-walls both retinal and inter-ommatidial, and that these cells breaking down sooner or later, liberate the pigments. The white inter-ommatidial pigment rises to the surface (cf. the same white-pigment action after death, as the cells disintegrate) to form curd-like clotted masses, while the coloured pigment from the retinal cells sinks to the bottom of the eye, collecting there as patches of colour.

All the young are hatched with perfectly normal eyes, but only a few remain normal. Unfortunately it is not possible to give the proportion of unchanging normals to changing. Their matings could not be controlled, owing to their scarcity and the difficulty of finding suitable mates for the survivors.

The irregularity makes its appearance shortly after birth, in only a few days, about the time of the first moult. The rate of progression is very rapid, although it seems to vary even in individuals of the same brood (see *MC* 131, for example, described below). When the change begins, the eye looks as if the white reticulation were made of highly glazed china, as if the pigments had liquefied here and there and run together to form little white patches on the surface, and black patches below. At this stage, some of the reticulation is still regular, and many of the ommatidia still intact; the others look as if the coloured pigment had collected like a blot deep down in the eye quite apart from the cones above.

As the animal grows older and the irregularity increases, the white-pigment collects in clotted lumps and masses, with only an occasional coloured ommatidium still intact, or uncoloured cone visible, or with small spots, specks, bars or streaks of black scattered over the eye.

Later, in the final stages, the white-pigment increases so much in quantity (or changes its consistency) that the masses coalesce, and cover the ommatidial cones completely, obliterating also the shape of the margin.

Sometimes, the shape of the ommateum is affected, and becomes more or less irregular in outline. The eye loses its convexity with the breaking of the margin and tends to flatten out, thus increasing the irregularity. But in other instances, where the outline appears irregular, the shape of the margin remains unchanged under the obscuring white-pigment, as has been proved by experiment. A specimen (*MC* 131*b*) was taken, which, hatched perfectly normal, had changed to the extreme type of Clotted before it reached maturity (Fig. 1, *b*). It was preserved in 70% alcohol and re-examined as soon as the white-pigment dissolved out. It was then seen that the shape was quite regular, and that numbers of cones representing ommatidia were present, although only one or two remained intact, the black pigment from the others having collected in a mass at the bottom of the eye (Fig 1, *c*).

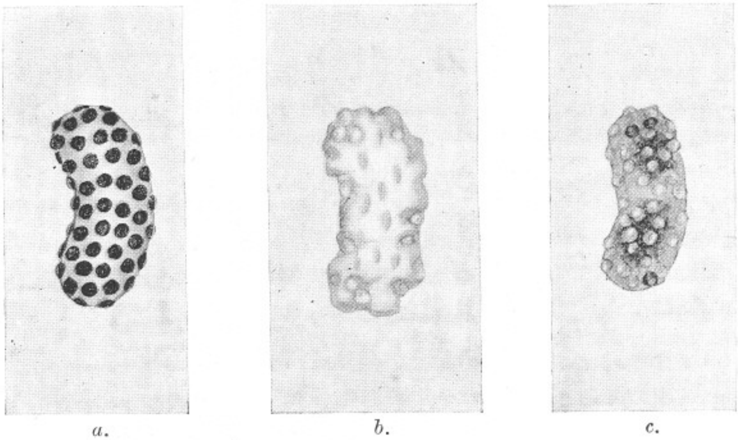

FIG. 1.—(*a*) Normal-eye type. Young male, 3 months old. × 65.

(*b*) Clotted-eye type. Young male, the same age as (*a*). Figured from life, Aug. 12, 1935. × 65.

(*c*) The same animal, figured Aug. 14 after the white pigment had been dissolved out, showing that, in this case, the ommateum margin was unbroken. × 65.

The Clotted eye appeared in the F_2 generation from a pair (*MV*) (male dilute Black, female jet Black) brought in on October 5, 1931, and set out in laboratory conditions.

The F_1 consisted of 91 Black normal, and 1 Black No-white, in 6 broods, of which 52 survived. These gave an F_2 of 300 Black normal, 1 Black No-white, 1 Black Half No-white and 17 Clotted and irregular eyes.

There was also a certain amount of variation both in the black pigment and the white.

The first three F_1 broods died without offspring. In the fourth (*M* 150) 15 survived, and mated *inter se*, producing the Clotted types referred to.

The fifth matured and gave 1 brood of 5 Black normals and 1 BN.

The sixth and last (*M* 350) was not examined till mature when 21 Black normal (5 males and 16 females) and 1 BN female were found, mature. The latter mated with a male from her own offspring, and gave 64 Black, two of them irregular-eyed.

In *M* 150, the brood which produced the Clotted eyes, 15 animals reached maturity, 7 males and 8 females, and were set out in pairs, giving offspring as follows :

Mixed matings in the brood-bowl. 28 Black (3 spotted) ;

Pair 1, 57 Black, including 1 spotted, and 1 with very thin reticulation ;

Pair 2, 15 Black, including 1 Half No-white spotted, and 2 with very thin reticulation (1 spotted) ;

Pair 4 (male's eyes reddish), 13 Black ;

Pair 6, 12 Black ;

Pair 7, 7 Black, including 2 spotted, and 2 reddish.

Pair 5. The matings of Pair 5 female, first in the brood-bowl, and then with male 5, gave 47 Black including 17 clotted, many irregular (*M* 768). Two of her brood with the first (unknown) male in the bowl also mated with male 5, and gave 6 Black normal and 1 clotted.

This was the first time the Clotted eye had been seen in numbers. It is true that it had occurred sporadically though very rarely, in different stocks, but never more than one specimen at a time.

The normals in Brood *M* 768 died without offspring. The clotted, many of them irregular, interbred and produced many young. The F_6 generation of this stock is now maturing.

One of the extreme examples, a female, was crossed with a Black Clotted male (heterozygous for red) from Stock II (*M. Cross LV*). One brood was hatched of which four Black normal survived, 2 males and 2 females.

These interbred, and gave an F_2 of 61 young in several broods, 29 Black normal, 9 Black clotted, 19 Black very irregular and clotted and 4 Reds, three clotted.

Six only of the normals survived, 1 male and 5 females, four with reduction of the white-pigment, and one reddish.

The 19 very clotted intermated in the brood-bowl, and gave 25 all clotted. One pair kept in a separate bowl produced 121 young ; all hatched normal, and became clotted. To give an example of the rapidity of the change, one of the broods *MC* 131, may be described. It was hatched on May 7, 1935, and consisted of 15 quite normal. By July 30, 12 were left, all clotted in different degree, three medium, and nine of the extreme type with eyes irregular in shape and the white-pigment thick and raised ; 6 of these had only specks of black in both eyes ; 1 had two spots of black in the left eye, none in the right ; 1 had a few tiny black specks in and around the right eye, none in the left ; and 1 was white all over, with a few colourless lenses showing, and no trace of black. This is the one figured from the living animal on August 12 (Fig. 1, *b* and *c*) and again on August 14 after the white had been dissolved out.

Of the Reds, the fourth one became clotted ; three reached maturity, one male and two females, but although the male was tried with the females, and with a Black one from the same stock, no young were produced.

The Clotted eye strain has now reached the F_6 generation, and the character has remained permanent in the laboratory cultures, but in two other cases now to be described, it seems as if the character is not inherited at all. Cf. e.g., the heritable White Eye of Stock II (**3**, p. 195) with the non-heritable White Eye of Stock I (**1**, p. 287).

Clotted eyes, as has been mentioned above, have very occasionally appeared, in other stocks or in the wild, but only one or two specimens at a time.

One such, in the *D* experiment, brought in May 9, 1933, was mated with two normal-eyed females of the same dredging, and gave an F_1 of 40, an F_2 of 113 and an F_3 of 47, all perfectly normal Black eyes.

This scarcity of specimens held good till about a year ago, when numbers were found in two dredgings. On January 15, 1935, 301 were brought in, 220 normal and 81 clotted ; on February 12 the numbers were 189 normal to 35 clotted. The degrees of " clotted " ranged from medium to the extreme type, as in the laboratory cultures.

Forty-three pairs were set out, 19 with one mate normal, and one clotted ; and 24 with both of them clotted. An F_1 of 1139 Black young was hatched, 1131 quite normal with 29 inclining to heavy reticulation, 3 Half No-whites and 5 with thin reticulation, but few survived to mate. The F_2 numbered only 180, viz., 173 Black normal, 2 Black No-whites, 1 Half No-white, 3 with thin and 1 with heavy reticulation.

Apart from the few instances quoted, of reduction of the white-pigment, the eyes are hatched normal and remain normal. Experiments are still being carried on with them but so far no sign of the clotted condition has shown itself in any of the offspring from these pairs.

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The Biology of *Balanus balanoides*. V. Distribution in the Plymouth Area.

By

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With 6 Figures in the Text.

PREVIOUS papers in this series (Moore, 1934, 1935 a and b) have described the biology of *Balanus balanoides* in the Isle of Man. There it is always living in water which is clean, non-estuarine, and not carrying any great quantity of detrital matter in suspension. Further, with the exception of *Verruca strœmia* which occupies rather a different habitat, and of isolated individuals of other species, it is the only species of barnacle found on the Manx shores.

Plymouth, on the other hand, lies in an intermediate position between the region to the west and south where *Chthamalus stellatus* predominates, and that to the east and north where *B. balanoides* does (Fischer-Piette, 1933). In the intermediate area, Chthamalus is more abundant in wave-exposed situations, while Balanus takes its place in more sheltered places. In addition to this, the rivers which discharge into Plymouth Sound carry with them a large quantity of suspended matter, which, together with the somewhat lowered salinity, give very different conditions from those observed in the Isle of Man. The following five localities were studied (Fig. 1).

Amory Bight, slightly east of Rame Head. Facing south-east, this situation is fully exposed to the open sea from south-west to east. The substratum is Dartmouth Slate (Lower old red sandstone). Owing to bad weather this locality was not very adequately worked.

Misery Point, on the south side of the River Yealm, facing north-east, and completely closed in from the open sea, though close to the mouth of the river. There is a tidal stream of up to 1¾ knots on the flood tide, and 2¼ on the ebb. Though carrying some suspended matter, the water is very much clearer than that in Plymouth Sound. The substratum is again Dartmouth Slate, and drops onto muddy gravel at low water.

Drake's Island. The part worked was on the north side, completely sheltered from the open sea, but subject to some wave action when the wind is in the north or east. There is a tidal stream of up to 1¼ knots past the island, and a good deal of suspended matter in the water. The substratum is volcanic rock (upper and middle Devonian).

Tinside, immediately below the Laboratory. Facing south, this is largely sheltered from the open sea by the Breakwater, but as this is two miles away, the rocks are subjected to considerable wave action when the wind is in the south. There is more sediment in the water than at Drake's Island. The substratum is limestone.

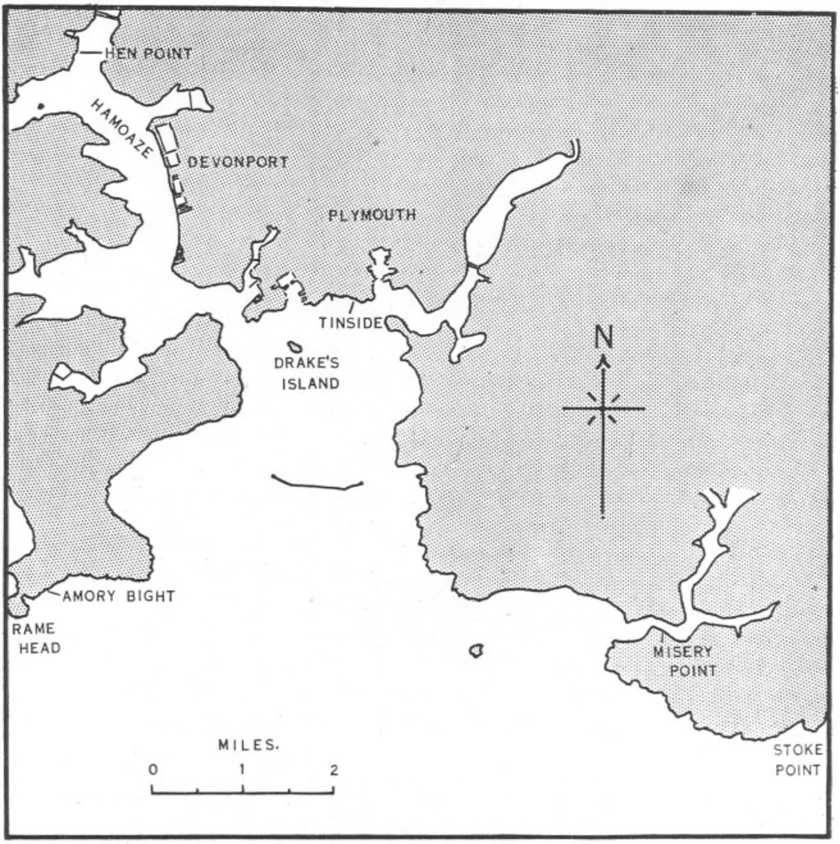

FIG. 1.—Map of the Plymouth area.

Hen Point in the Hamoaze. Facing east-south-east, this shore is completely cut off from the sea, though receiving a little wave action with a southerly wind. There is a one knot tide past the point, and the water contains a very large amount of material in suspension and a very rich diatom plankton. The substratum is volcanic rock, dropping to muddy gravel at low water.

No great accuracy is claimed for the levels. Those at Tinside were fixed by reference to known levels on the new swimming pool, and so are accurate to one or two inches. Those on Drake's Island were taken from water level on a very calm day, and compared simultaneously with water level at Tinside, so these also are fairly accurate. At the other three localities no local levels were available, so it was necessary here also to compare with the level of low water on a very calm day, measuring the level simultaneously at Tinside. This undoubtedly introduces an error, though it should not be great, but the present paper is concerned more with numbers and sizes of barnacles than with their absolute levels.

A number of levels were worked at each locality, their heights being determined either with a tape or with a dumpy level. A number of counts, usually between five and fifteen, were made at each level, on an area of either 100 cm^2, or 25 cm^2, according to the density of the population. Tissue weights were obtained by removing a representative series of barnacles from the rock, decalcifying them, and drying the tissues at 100°C (see Moore, 1935 a, p. 264). The various species present were distinguished, as described below, and in addition the first year and older barnacles were kept separate. The counts were made in July–August, 1934, and the first year groups present were those of 1934 in the case of *B. balanoides* and 1933 in the case of Chthamalus which has a later breeding season. As many of the characters by which the various species of barnacles can be separated are only apparent after dissection, the following notes are given to indicate the characters by which they may most readily be separated *in situ.*

Verruca strœmia. This species is restricted to low water, and occurs chiefly under stones, a habitat not really included in the present survey. It is easily recognised by the assymetry of the shell, and the striking interlocking folds of the suture between the two large plates of the wall.

Balanus perforatus. This also is readily distinguished by its large size, purplish-grey colour, thick and frequently perforated walls, curved in profile, and by the small size of its aperture. When removed from the rock, the basis is seen to be very thick and perforated by large canals.

B. crenatus. This species is extremely difficult to distinguish with certainty from *B. balanoides* without removing it from the rock. As it does not usually occur in numbers above low water, the difficulty does not often arise. Occasionally, however, we have taken it as high as half-tide level. When removed from the rock it is readily distinguished by the fact that it has a thin calcareous basis, while *B. balanoides* has only a membranous one. *In situ* it may sometimes be distinguished by its whiter shell, since it does not seem to become infected with boring algæ as *B. balanoides* does. The fluting of the walls is often less pronounced, and the apices of the plates sharper. These differences which are sometimes clear enough to allow population counts to be made *in situ,* after a certain amount of practice, can only be trusted when a sufficient number have been checked by removal from their attachment.

B. balanoides and *Chthamalus stellatus* (Figs. 2 and 3). These are the two really abundant species on the shore in the Plymouth area, and with practice all but very corroded specimens can be distinguished with certainty. In *B. balanoides* the rostral plate of the wall overlaps the two plates on either side, and thus appears to be wide, while in Chthamalus it is overlapped by them and appears to be only about half the width. This character is, however, usually rendered quite useless by the high degree of corrosion of the shell of Chthamalus, this corrosion itself being a character helping in distinguishing the species. In the young barnacles, before the shells become infected with algæ, the shell of Balanus is white, while that of Chthamalus is grey. In some localities the older stages also may be separated by a difference in the colour of the shells. The newly settled spat of Chthamalus also are very much smaller than those of Balanus.

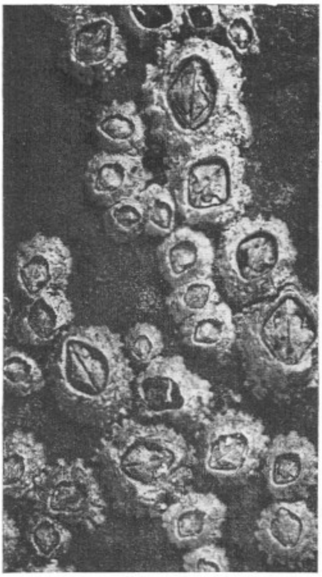

FIG. 2.—*B. balanoides* × 2.

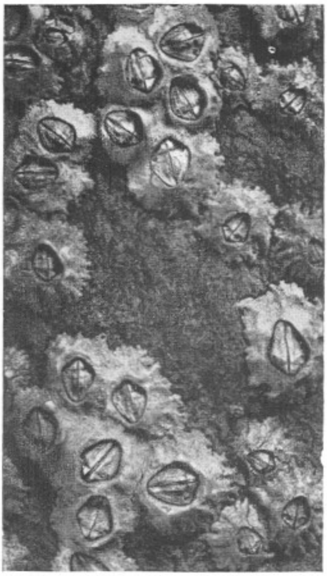

FIG. 3.—*Chthamalus stellatus* × 2.

These two photographs are of abraded specimens such as are usually found on the shore, and are intended to illustrate the points on which such imperfect specimens may be distinguished.

The shape of the opercular aperture is usually the best distinguishing character, this, in *B. balanoides*, being roughly diamond-shaped, with the sides of equal length, while in Chthamalus it is kite-shaped, with unequal

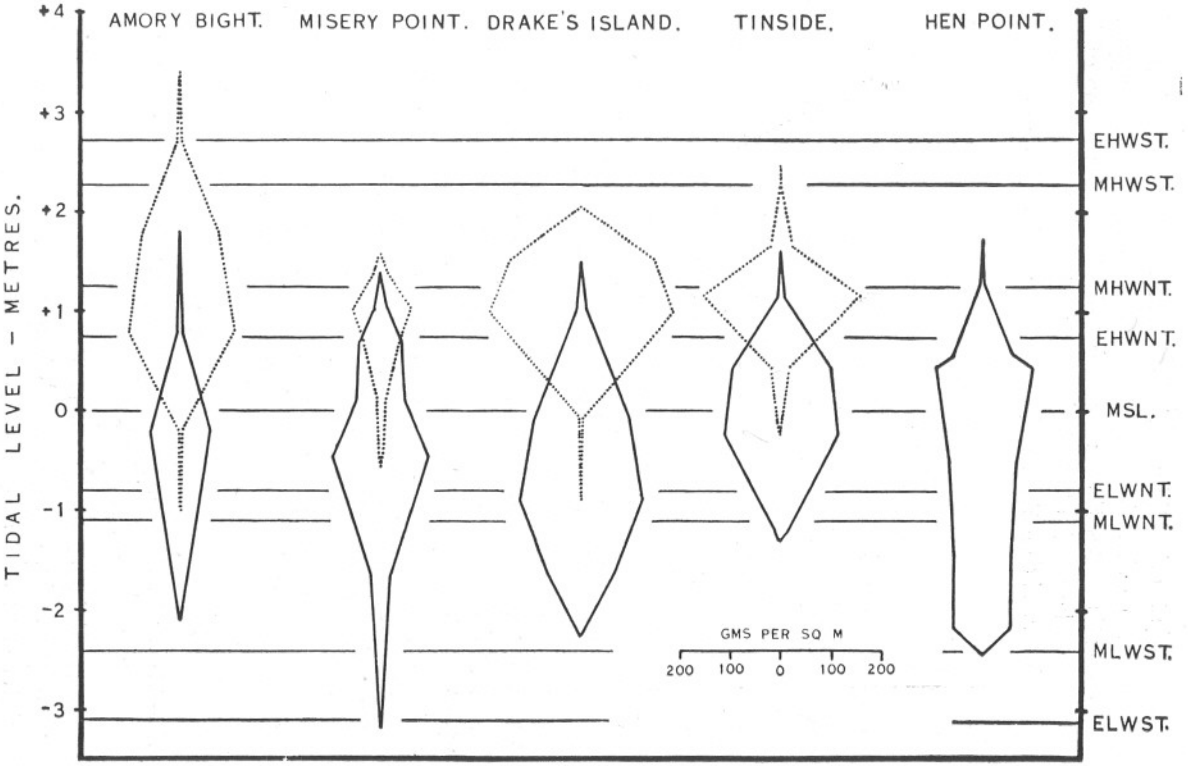

FIG. 4.—Distribution of the two species, *Balanus balanoides* (whole line) and *Chthamalus stellatus* (dotted), in relation to tidal level. Amounts of barnacles are in gm. per square metre.

sides. The opercular plates also fit together more tightly in Chthamalus than in Balanus.

It is known that, other things being equal, *B. balanoides* tends to grow more quickly in moving than in still water, and it has been suggested (Moore, 1935 b) that this effect is the result of the greater amount of food brought within the reach of the barnacle by the moving water. In the same paper it was shown that, while young barnacles grew most rapidly at low water, with increasing age the optimum level for growth moved up the shore to the highest level at which they occur. The only exception to this statement was that of a very wave-exposed locality where the optimum level remained permanently at low water at all ages.

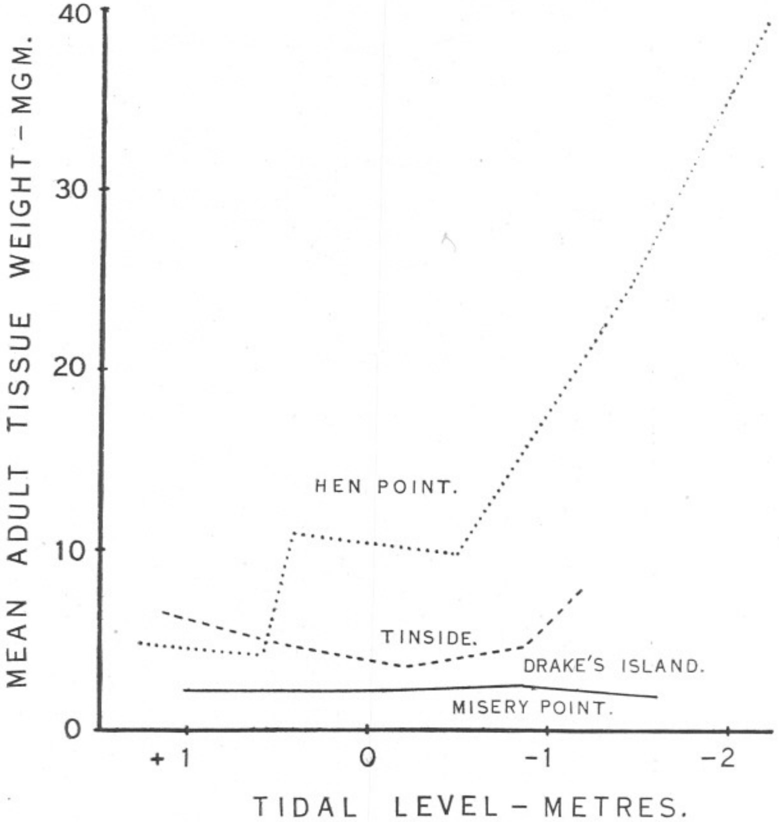

FIG. 5.—The relation of the mean tissue weight of adult *B. balanoides* to tidal level at the various localities.

Figure 4 shows the distribution of the two species, *B. balanoides* and *Chthamalus stellatus* in the Plymouth area. The localities worked do not form a simple series as did those in the Isle of Man, since here the two factors of wave exposure and sediment are both involved. Amory Bight, with a high wave-exposure and very little sediment in the water, compares with the Bradda locality in the Isle of Man. In both cases the lower limit of *B. balanoides* is between mean low water of neaps and spring tides, and the upper limit between mean high water of neaps and springs. In the upper levels at Amory Bight the Balanus is replaced by Chthamalus which reaches up above high water of the highest spring tides, into a zone only reached by splash. It is very hard to understand how an apparently plankton-feeding animal manages to survive in a situation where the only food-bearing sea water which reaches it is the splash during high tide on rough days. Taking Chthamalus and Balanus together, the total numbers of adult barnacles are far greater at Amory Bight—193,000 on a metre-wide vertical strip from high to low water—than at Bradda with only 86,300, but when tissue weight is compared, the conditions are reversed, there being 542 gm. at Bradda and only 290 gm. at Amory Bight. Of the latter, 107 gm. was Balanus and 183 gm. Chthamalus (Table VI). At Port Erin, a more sheltered locality in the Isle of Man, there was 106 gm. of barnacle tissue per metre strip.

Misery Point which is comparable with Amory Bight in the comparative clearness of the water, differs in its almost complete shelter from wave action, but probably counteracts this to some extent by the strength of the tidal stream past it. With absence of wave-splash, the general zonation is considerably lower here, but, unlike the sheltered localities in the Isle of Man where there was no tidal current, the lower limit does not rise with increased shelter. The amount of barnacles is less at Misery Point than at Amory Bight—199 gm. compared with 290 gm.—but this is entirely accounted for by the drop in numbers of Chthamalus in the sheltered locality, the amount of Balanus having actually risen from 107 to 155 gm.

The other three stations, Hen Point, Tinside and Drake's Island, form a series with a decreasing amount of sediment in the water, complicated by the increase in amount of wave action in the latter two. In all three there is a slight tidal current.

At Drake's Island *B. balanoides* extends from about mean low water of spring tides to mean high water of neaps, and Chthamalus up to about mean high water of spring tides, the levels here being somewhat raised by the splash. Below low water of spring tides the growth of algæ, etc. both here and at Tinside is too great to allow the survival of this species. Both the total weight of barnacles and the mean individual weight of the adult barnacles are higher than at Misery Point (Figs. 4 and 5). On Drake's Island *B. balanoides* and Chthamalus are represented in almost equal quantities. At Tinside, with about the same wave exposure, and slightly greater amount of sediment in the water, the quantities of both species are less, especially Chthamalus, but the mean weight of the adult Balanus is considerably greater, especially at low water (Fig. 5). Finally, at Hen Point, where conditions are considerably more estuarine, and the water carries a large amount of matter in suspension, Chthamalus is completely absent, and *B. balanoides* present only in much smaller numbers. But here the growth of the Balanus is so enormously greater than at Tinside (again most marked at low water) that the total weight of barnacles is but little less. It seems as if, in these conditions, the spat have considerable difficulty in attaching to the muddy, slimy rocks, but that once attached, food is very abundant and growth correspondingly rapid. In addition they are safe from the attack of the Dog-whelk (*Nucella lapillus*) which does not penetrate into such estuarine waters.

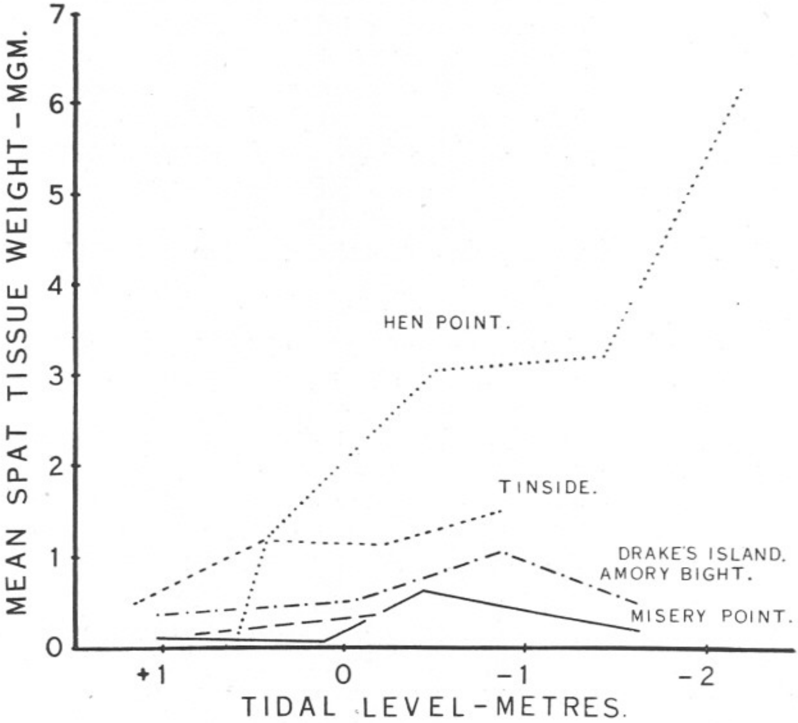

FIG. 6.—The relation of the mean tissue weight of *B. balanoides* spat to tidal level at the various localities.

The mean size of the adult population is not necessarily an index of the rate of growth unless the length of life is the same on the different grounds, which it probably is not. If, however, we can assume that the settlement of the spat takes place at approximately the same time on the different grounds, and there is no reason to think that it does not, then the mean size of the one year group whose age is definitely known, namely, the first year group, can be taken as a safe index of growth rate.

The settlement of the spat takes place at Port Erin in April–May, and probably at about the same time at Plymouth. At Port Erin the maximum growth rate of the spat was observed at low water at first, but moving progressively upwards on the shore with increasing age. With very high wave exposure the optimum level remained at low water.

In Figure 6 are shown the mean weights of the first year Balanus spat in July–August at various levels at the different Plymouth stations. At Amory Bight sufficient samples were not taken to show definite results. At both Misery Point and Drake's Island the level for optimum growth had moved up during the three months since settlement, from low water towards mean sea level, and the general level of growth at Drake's Island was about twice that at Misery Point. At Tinside the rate of growth was considerably higher again, and here the optimum level for growth had remained at low water. While the same was true at Hen Point, here the growth rate was enormously higher, the rate at low water being over thirty times that at Misery Point.

In general, then, conditions at Amory Bight and Misery Point are quite comparable with those observed in the Isle of Man, and show similar distributions and quantities of barnacles except for the inclusion of *Chthamalus stellatus* which does not occur in the Isle of Man. At the other three localities we are dealing with conditions where the great quantity of food material in the water to a large extent outweighs other environmental factors. The effect of this is to reduce the numbers of Balanus present while very greatly increasing their growth rate. And further, this increase is most marked at low water. Since the same effect of increased growth rate was observed to occur at high degrees of wave exposure in the Isle of Man, and particularly at low water, this would seem to support the suggestion already made (Moore, 1935 b, p. 288) that the beneficial effect of water movement on *B. balanoides* was due to the greater quantity of food material which it brought within the barnacle's reach.

SUMMARY.

1. The barnacles at five localities in the Plymouth area were examined as a check on the general application of observations made previously in the Isle of Man.

2. The numbers and weights per square metre, and the mean individual weights, are given for a series of tidal levels for each locality.

3. The two "clean-water" localities agree substantially with the Isle of Man, except for the presence here of *Chthamalus stellatus*.

4. At the three localities where the water is rich in suspended matter first Chthamalus and then Balanus decreases progressively in numbers, but the latter increases very greatly in size, especially at low water.

5. The increased growth rate at low water, where food is abundant, is compared with the similar effect observed in wave-exposed conditions in the Isle of Man.

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TABLE I.

Distribution of Barnacles at Amory Bight, August 1st, 1934.

Numbers in brackets are approximate only. Levels (in metres) refer to mean sea level throughout. Weights per sq. m. are in gm.; mean individual weights are in mgm.; volumes are in mm³. B. bal.=*Balanus balanoides*. Chth.=*Chthamalus stellatus*.

			Number per square metre.				
Level.	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+3·4	0	0	0	0	0	0	0
+2·7	0	0	15,200	9,200	0	24,400	24,400
+1·8	0	400	54,000	38,000	400	92,000	92,400
+0·8	4,000	12,400	55,600	35,200	16,400	90,800	107,000
−0·2	40,400	20,400	400	4,800	60,800	5,200	66,000
−2·1	0	0	0	0	0	0	0

			Weight per square metre.				
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+3·4	0	0	0	0	0	0	0
+2·7	0	0	6·24	0·55	0	6·79	6·79
+1·8	0	0	73·0	3·42	0	76·4	76·4
+0·8	(5·1)	1·86	95·6	8·45	6·96	104	111
−0·2	51·6	7·55	–	1·01	59·2	1·01	60·2
−2·1	0	0	0	0	0	0	0

	Mean individual weight.				Spat mean volumes.	
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	B. bal.	Chth.
+3·4	–	–	–	–	–	–
+2·7	–	–	0·41	0·06	–	0·43
+1·8	–	–	1·37	0·09	–	0·59
+0·8	–	0·15	1·72	0·24	1·52	1·71
−0·2	1·28	0·37	–	0·21	3·10	1·66
−2·1	–	–	–	–	–	–

TABLE II.

Distribution of Barnacles at Misery Point, July 30th, 1934.

Figures as in Table I.

Level.	Number per square metre. B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+1·59	0	0	0	0	0	0	0
+1·39	0	0	7,700	1,900	0	9,600	9,600
+1·02	10,000	2,800	54,400	15,600	12,800	70,000	82,800
+0·70	34,000	7,200	26,800	8,000	41,200	34,800	76,000
+0·11	52,800	28,000	7,200	4,400	80,800	11,600	92,400
−0·46	32,800	59,600	2,400	3,600	92,400	6,000	98,400
−0·56	–	–	0	0	–	0	–
−1·66	3,600	57,200	0	0	60,800	0	60,800
−3·16	0	0	0	0	0	0	0

	Weight per square metre. B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+1·59	0	0	0	0	0	0	0
+1·39	0	0	10·3	2·55	0	12·9	12·0
+1·02	(11·7)	0·28	56·0	1·72	(12·0)	57·7	(69·7)
+0·70	39·8	0·58	31·1	0·96	40·4	32·1	72·5
+0·11	46·0	2·24	6·60	0·66	48·2	7·26	55·5
−0·46	53·8	38·1	2·88	0·47	91·9	3·35	95·3
−0·56	–	–	0	0	–	0	–
−1·66	5·65	11·4	0	0	17·1	0	17·1
−3·16	0	0	0	0	0	0	0

	Mean individual weight.				Spat mean volumes.	
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	B. bal.	Chth.
+1·59	–	–	–	–	–	–
+1·39	–	–	1·34	–	–	–
+1·02	–	0·10	1·03	0·11	0·58	0·64
+0·70	1·17	0·08	1·16	0·12	0·73	0·83
+0·11	0·87	0·08	0·93	0·15	0·76	1·14
−0·46	1·64	0·64	1·20	0·13	1·27	1·32
−0·56	–	–	–	–	–	–
−1·66	1·57	0·20	–	–	3·91	–
−3·16	–	–	–	–	–	–

TABLE III.

Distribution of Barnacles at Drake's Island, July 27th, 1934.

Figures as in Table I.

	Number per square metre.						
Level.	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+2·04	0	0	0	0	0	0	0
+1·81	0	0	20,800	0	0	20,800	20,800
+1·51	0	0	46,400	4,800	0	51,200	51,200
+1·01	3,200	7,600	61,600	13,600	10,800	75,200	86,000
−0·09	31,600	42,400	0	1,200	74,000	1,200	75,200
−0·89	19,600	67,600	0	0	87,200	0	*87,200
−1·64	20,800	44,000	0	0	64,800	0	64,800
−2·24	0	0	0	0	0	0	0

	Weight per square metre.						
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+2·04	0	0	0	0	0	0	0
+1·81	0	0	65·1	0	0	65·1	65·1
+1·51	0	0	145	1·30	0	146	146
+1·01	7·04	2·73	181	3·13	9·77	184	194
−0·09	75·2	22·9	0	0·09	98·1	0·09	98·2
−0·89	51·9	71·6	0	0	123	0	123†
−1·64	44·3	22·5	0	0	66·7	0	66·7
−2·24	0	0	0	0	0	0	0

	Mean individual weight.				Spat mean volumes.	
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	B. bal.	Chth.
+2·04	–	–	–	–	–	–
+1·81	–	–	3·13	–	–	–
+1·51	–	–	3·13	0·27	–	1·40
+1·01	2·20	0·36	2·94	0·23	2·96	1·14
−0·09	2·38	0·54	–	0·08	3·91	1·24
−0·89	2·65	1·06	–	–	5·55	–
−1·64	2·13	0·51	–	–	3·56	–
−2·24	–	–	–	–	–	–

* Together with 400 *B. perforatus* per square metre, with a mean weight of 69·9 mgm.

† Together with 28·0 gm. of *B. perforatus*.

TABLE IV.

Distribution of Barnacles at Tinside, July 7–14th, 1934.

Figures as in Table I.

	Number per square metre.						
Level.	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+2·48	0	0	0	0	0	0	0
+2·28	0	0	500	0	0	500	500
+1·64	0	0	12,800	5,200	0	18,000	18,000
+1·14	1,600	800	31,200	7,200	2,400	38,400	40,800
+0·43	12,000	32,000	10,000	2,400	44,000	12,400	56,400
−0·24	21,200	28,400	0	0	49,600	0	49,600
−0·89	8,000	48,000	0	0	56,400	0	56,400
−1·21	1,200	0	0	0	1,200	0	1,200
−1·31	0	0	0	0	0	0	0

	Weight per square metre.						
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	Total B. bal.	Total Chth.	Total both spp.
+2·48	0	0	0	0	0	0	0
+2·28	0	0	0·94	0	0	0·94	0·94
+1·64	0	0	17·3	2·90	0	20·2	20·2
+1·14	6·37	0·40	154	2·33	6·77	156	163
+0·43	56·5	38·1	17·3	1·46	94·6	18·8	112
−0·24	76·7	32·4	0	0	109	0	109
−0·89	38·3	7·26	0	0	45·6	0	45·6
−1·21	9·71	0	0	0	9·71	0	9·71
−1·31	0	0	0	0	0	0	0

	Mean individual weight.				Spat mean volumes.	
	B. bal. adult.	B. bal. spat.	Chth. adult.	Chth. spat.	B. bal.	Chth.
+2·48	–	–	–	–	–	–
+2·28	–	–	1·88	–	–	0·54
+1·64	–	–	1·35	0·56	–	0·73
+1·14	6·37	0·50	4·94	0·31	5·93	2·28
+0·43	4·71	1·19	1·73	0·61	10·4	3·88
−0·24	3·62	1·14	–	–	10·5	–
−0·89	4·79	1·50	–	–	8·96	–
−1·21	8·09	–	–	–	7·52	–
−1·31	–	–	–	–	–	–

TABLE V.

DISTRIBUTION OF BARNACLES AT HEN POINT, JULY 16–17TH, 1934.

Figures as in Table I. B. cren. = *Balanus crenatus*.

	Number per square metre.						
Level.	B. bal. adult.	B. bal. spat.	B. cren. adult.	B. cren. spat.	Total B. bal.	Total B. cren.	Total both spp.
+1·72	0	0	0	0	0	0	0
+1·27	540	0	0	0	540	0	540
+0·57	13,200	13,600	0	0	26,800	0	26,800
+0·42	7,300	11,200	0	0	18,500	0	18,500
−0·51	6,300	1,100	0	0	7,400	0	7,400
−1·43	2,100	900	30	0	3,000	30	3,030
−2·18	1,300	200	460	150	1,500	610	2,100
−2·43	0	0	?*	?*	0	?*	?*

	Weights per square metre.						
	B. bal. adult.	B. bal. spat.	B. cren. adult.	B. cren. spat.	Total B. bal.	Total B. cren.	Total both spp.
+1·72	0	0	0	0	0	0	0
+1·27	2·59	0	0	0	2·59	0	2·59
+0·57	56·2	2·18	0	0	58·4	0	58·4
+0·42	78·8	13·9	0	0	92·7	0	92·7
−0·51	63·0	3·37	0	0	66·4	0	66·4
−1·43	51·5	2·90	–	0	54·4	–	–
−2·18	51·4	1·24	21·9	0·23	52·6	22·1	74·7
−2·43	0	0	?*	?*	0	?*	?*

	Mean individual weights.				Spat mean volume.	
	B. bal. adult.	B. bal. spat.	B. cren. adult.	B. cren. spat.	B. bal.	B. cren.
+1·72	–	–	–	–	–	–
+1·27	4·79	–	–	–	–	–
+0·57	4·26	0·16	–	–	1·35	–
+0·42	10·8	1·24	–	–	7·38	–
−0·51	10·0	3·06	–	–	13·9	–
−1·43	24·5	3·22	–	–	17·6	–
−2·18	39·5	6·20	47·7	1·52	24·5	23·2
−2·43	–	–	?	?	?	?

* *B. crenatus* continues down below low water, but no counts were possible there.

TABLE VI.

Amounts of Barnacles on a One Metre Wide Vertical Strip of Shore.

Locality.	Balanus adult.	Balanus spat.	Chthamalus adult.	Chthamalus spat.	Total Balanus	Total Chthamalus.	Total all species.	Total adult.	Total spat.
	Total numbers								
Hen Point	18,000*	18,800†	–	–	36,900‡	–	37,500	18,600	1,900
Misery Point	83,200	150,000	38,100	13,400	233,000	52,000	285,000	121,000	163,000
Drake's Island	61,800	129,000	75,700	14,400	191,000	90,000	281,000	138,000	143,000
Tinside	26,700	58,900	33,900	9,130	85,600	43,000	129,000	60,600	68,000
Amory Bight	72,700	47,500	120,000	86,800	120,000	207,000	327,000	193,000	134,000
	Weights in gm.								
Hen Point	195§	14·6‖	–	–	210††	–	232	217	14·8
Misery Point	104	51·0	41·2	2·33	155	43·5	199	145	53·0
Drake's Island	140	92·8	228	3·22	233	231	464	368	96·0
Tinside	111	52·2	117	4·15	163	121	284	228	56·4
Amory Bight	92·7	14·7	170	12·6	107	183	290	263	27·3

* 494 *B. crenatus.*
† 153 *B. crenatus.*
‡ 647 *B. crenatus.*
§ 22·3 ,,
‖ 0·23 ,,
†† 22·5 ,,

Summary of Tees Estuary Investigations.

With 7 Figures in the Text
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Survey of the River Tees. Part II. The Estuary, Chemical and Biological.

By W. B. Alexander, B. A. Southgate, and R. Bassindale,

Department of Scientific and Industrial Research. Water Pollution Research, Technical Paper No. 5. *London,* 1935. *H.M. Stationery Office. Price* 9/–.

IN 1929 the Marine Biological Association began a survey of the River Tees Estuary, to study the various physical and chemical conditions and the types and distribution of animal and plant life. At the same time a tidal stream survey was carried out by the Hydrographic Department of the Admiralty. Later, for purposes of comparison, the scope of the enquiry was extended to a survey of the River Tay, but on a less extensive scale.

The investigation was made for the Department of Scientific and Industrial Research and occupied four years. Many facts of general interest to marine biologists emerged. The following is a brief account of some of the main findings and does not purport to summarise the results of the survey, for which the original report should be consulted.

The estuary of the Tees is deep and runs far into the country. For 11 miles, from the sea to Stockton, the channel is dredged to a depth of 18 feet below low water. The incoming tide is free to flow with less turbulence and vertical mixing of the water than in tidal estuaries with an uneven bed. In this respect the Tees falls into a distinctive, but not uncommon, class. Above Stockton the incoming tide flows over an uneven bottom having only a few inches of water over it at low water, and fairly complete vertical mixing is the rule. Salt water extends upstream to Stockton at low water, and penetrates a further 3 to 4 miles at high water, while the rise and fall of the tide has been observed some 9 miles beyond this, the fresh water being banked up by the tide.

Animals or plants living at any particular position in the estuary are regularly subjected to a considerable range of salinity every tidal period.

After heavy rains the fresh water tends to run seaward on the surface above the salter water below, and even under normal condition the net movement of the surface waters over a complete period of ebb and flood is seaward. This surface water picks up salt water from below, with the result that the net movement of the deeper layers is upstream. As a result of this circulatory system, which occurs in this class of estuary where the upper layers are less salt than the deeper layers, the effect of a moderate flood of fresh water from the river is to decrease the salinity in the surface layers and increase the salinity near the bottom.

Water entering the tidal reaches moves relatively slowly seawards, especially if the volume of fresh water coming in from the upper river is small. The mean time taken for all layers of a body of water to travel through the estuary has been estimated to vary from about 6 days under dry weather conditions to about $2\frac{1}{2}$ days under average weather conditions. Substances carried in the upper layers will reach the sea more rapidly and substances in the deeper layers less rapidly than the calculated mean time.

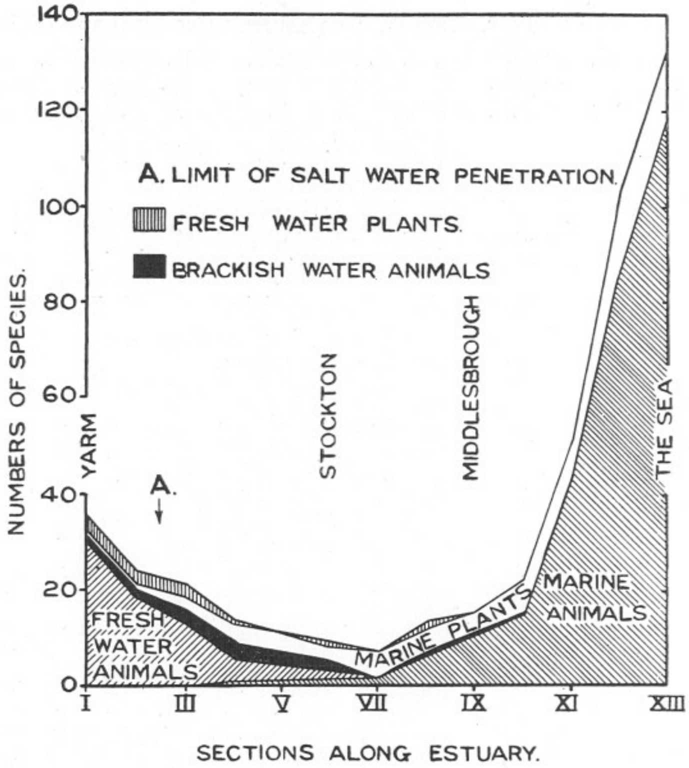

FIG. 1.—Composition of the Flora and Fauna along the Tees Estuary.

At the mouth of the estuary the marine fauna is varied and abundant; above the limit of salt water, fresh water animals and plants are very numerous; in the central portion of the estuary where the greatest

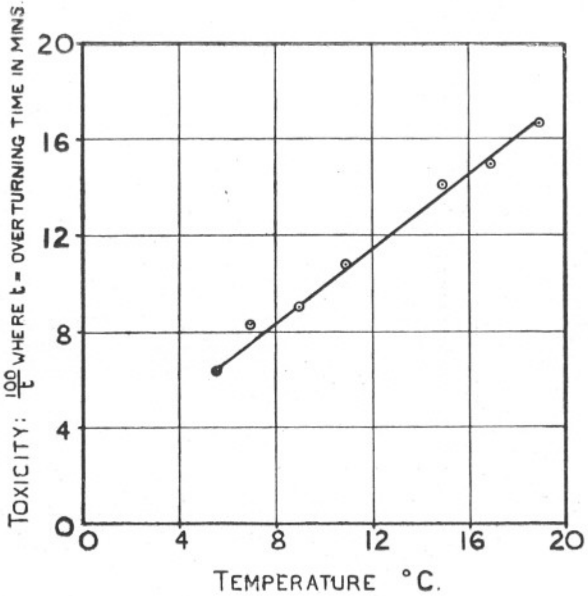

FIG. 2.—Relation between toxicity to trout of a solution of KCN (0·3 gm. CN per litre) and the temperature.

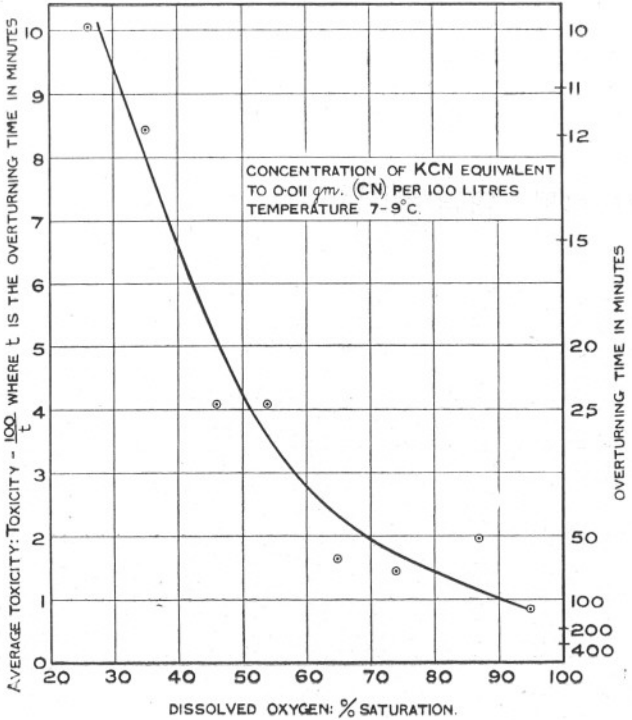

FIG. 3.—Toxicity to Rainbow trout of cyanide in solutions of different dissolved oxygen concentrations.

changes in salinity occur there is little variety or abundance of either marine or fresh water organisms. A similar general distribution had been found in the estuary of the Tamar (Percival) and in Randers Fjord (Johansen), and a similar distribution was found in the sandy estuary of the Tay.

From the extensive salinity data collected in the Tees Estuary, and less extensive data in the Tay, it was possible to divide both into thirteen sections between sea and fresh water. The sections in each case were roughly comparable in having similar ranges of salinity. Collections of animals and plants were made in each section and the numbers and kinds of each species found compared.

In the sandy estuary of the Tay, and also in the muddy estuary of the Tamar, the marine species whilst progressively reduced as the head of the estuary is approached do not die out quite so quickly as in the Tees. In all three estuaries it is evident that the scarcity of marine and fresh water organisms in the central stretch is due mainly to unsuitable tidal and salinity conditions.

Tidal sand and mud banks at the mouths of the Tees and the Tay contain roughly the same number of organisms per unit area. The height above low water of the intertidal areas of mud in the central part of the Tees estuary varies considerably owing to the presence of wharves and retaining walls. Since the abundance of burrowing animals depends largely on the level of the available habitat in the tidal stretch it is difficult to determine the true causes of local fluctuations in their numbers. On the whole the fauna of the Tees estuary is similar both in variety and abundance to that of unpolluted estuaries, except that in the Tees there are few, if any, fish living permanently in the central reaches and the numbers of certain shrimps are much smaller.

The plankton or free floating organisms of the estuary consist of fresh water species, mainly diatoms, washed down from the upper river and marine organisms carried into the estuary mainly in the sub-surface current. In addition *Eurytemora hirundoides*, a brackish water variety of a small crustacean, is found. During the summer this copepod occurs in abundance and is distributed over the greater part of the estuary; in the winter it is not nearly so abundant and its range is restricted to a short stretch in the central portion (Fig. 4).

In the Tees estuary death of migratory fish is common. Salmon are often seen floundering near the surface or floating dead, while salmon and sea-trout smolts die in great numbers during their passage to the sea in the spring.

Various industrial effluents, many of them containing substances highly toxic to fish, are discharged into the estuary—approximately 4400 lb. of tar acids and 1800 lb. of cyanide were discharged daily. In addition, the

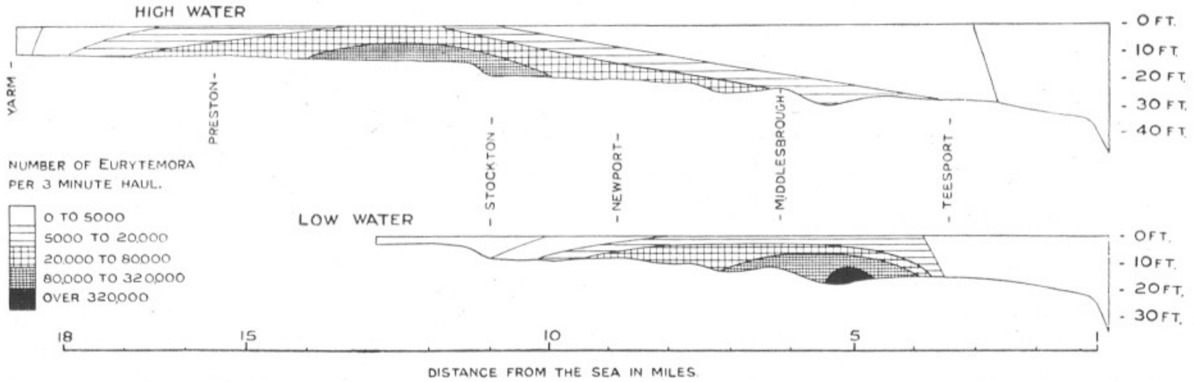

FIG. 4.—Average distribution of Eurytemora at high and low water in the Tees Estuary.

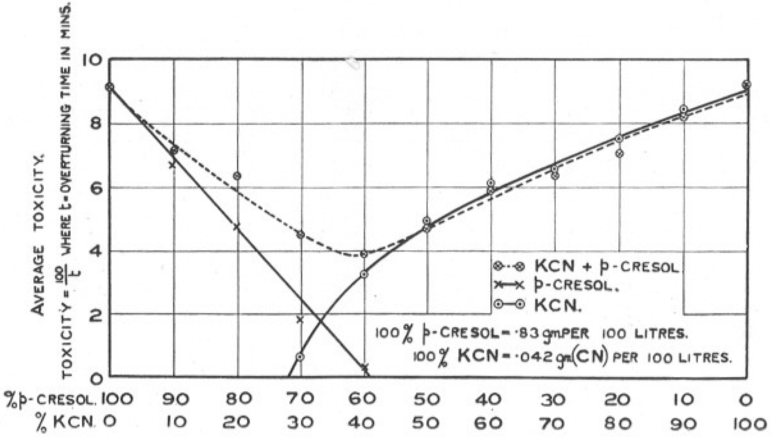

FIG. 5.—Toxicity of mixtures of potassium cyanide and p-Cresol to Rainbow trout.

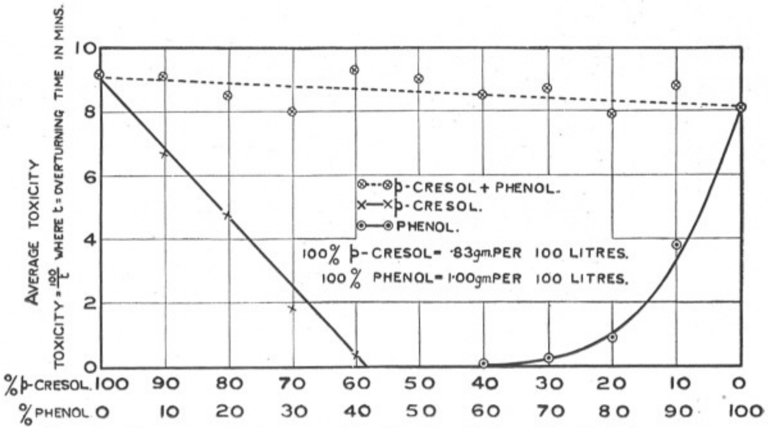

FIG. 6.—Toxicity of mixtures of p-Cresol and phenol to Rainbow trout.

untreated sewage from a considerable population flows into the central part of the estuary and its decay causes partial deoxidation of the water. The extent of this deoxidation is controlled mostly by the prevailing temperature.

Cyanide is very much more toxic than tar acids, concentrations of the order of 0·01 to 0·02 part per 100,000, calculated as (CN), being sufficient to kill fish in less than an hour. Laboratory experiments showed that the toxicity of a solution of cyanide increases with rise of temperature and as the concentration of dissolved oxygen is reduced (Figs. 2 and 3), but is little affected by additions of sub-lethal concentrations of tar acids. The toxicity of various mixtures of these poisons was tested with the results shown in Figures 5, 6 and 7.

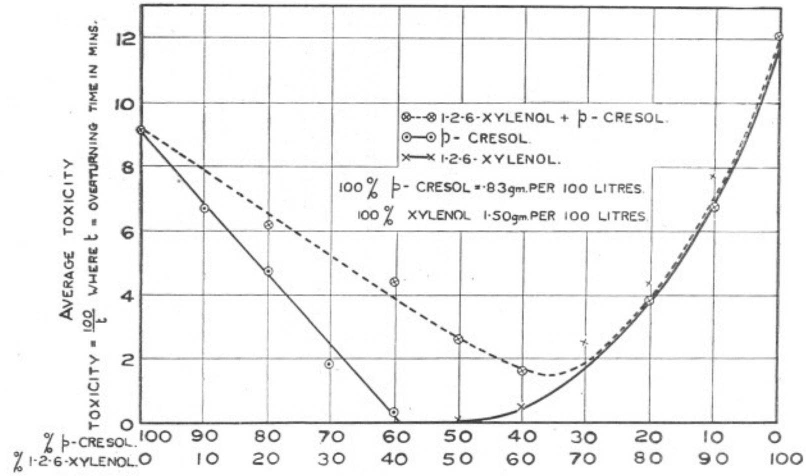

FIG. 7.—Toxicity of mixtures of p-Cresol and 1·2·6 Xylenol to Rainbow trout.

In the spring of 1931 an extensive survey was carried out during the period when salmon and sea-trout smolts were migrating through the estuary to the sea. As in the two previous years, large numbers of fish were killed in the polluted region. With the low prevailing water temperature, the concentration of dissolved oxygen remained at a moderately high level and was more than 50 per cent of the saturation value until the end of the migration period when it fell to between 40 and 50 per cent. In a laboratory experiment Rainbow trout lived comfortably for 35 days in a stream of running water, the oxygen concentration of which varied between 37 and 58 per cent with a mean value of 48 per cent of the saturation value. Over short periods of a few days the minimum oxygen requirements of trout were found to be considerably lower than these concentrations. During the migration tar acids were present in the estuary in concentrations of 0·01 to 0·03, and more rarely in amounts exceeding 0·05 part per 100,000; these are considerably lower than the minimum concentration required to kill fish. On the other hand, cyanides were present on most days during the migration in concentrations as high as, and sometimes exceeding, 0·02 part (CN) per 100,000, which is sufficient to kill fish in a short period. Samples of estuary water taken from the mortality stretch and found to be toxic to trout were rendered innocuous by the removal of cyanide. This was done by adding formaldehyde. Moreover the colour of the gills of smolts found dying in the estuary was brighter than that of normal fish, a characteristic symptom of poisoning by cyanide. All the evidence collected points to the fact that cyanide, discharged as a constituent of effluents from coke-oven gas coolers, was the main cause of the mortality in 1931. It is also possible that in exceptionally warm spring weather the dissolved oxygen content of the water might fall so low as to be insufficient to support fish life.

Smolts were systematically netted, marked and released during the migration in 1931. Some of these marked fish were later recovered and were found to have remained in the estuary for periods up to 9 days. No relationship was found between the numbers netted on any day and the volume of water coming down from the upper river. The dead smolts collected provided information on the size, age, sex and food of the migrating fish. The collection was composed mainly of two-year-old fish, and migration appeared to be dependent on their reaching a size above a certain minimum. Fish which did not grow to this length in two years migrated in the following season.

In view of the mortality of fish brought about in the Tees estuary by cyanide, some experiments were carried out to determine the effect of cyanide on invertebrate animals. Of four crustaceans, the ranges of which are particularly restricted in the Tees, two were apparently unaffected by the maximum concentration normally found in the estuary, while two, the common shrimp and the chameleon shrimp, were susceptible to this concentration. It seems probable that the ranges of these latter animals are restricted by the presence of cyanides.

Both cyanides and tar acids undergo decomposition when diluted with water, and it is probable that a considerable loss of these substances occurs during the period in which they are carried to and fro in the estuary. While the rate of decomposition of tar acids is markedly accelerated by the presence of sewage, that of cyanides is apparently unaffected. The breakdown of cyanides is, however, increased when they are diluted with estuarine water, and it is possible that this water contains a specific bacterial flora capable of bringing about their decomposition.

An examination was made of the methods by which the oxygen demand of the different types of polluting material entering the estuary might be assessed and compared. In determining the rate at which dissolved oxygen is absorbed from solution by sterile industrial effluents it is essential that they should be diluted with water containing an appropriate bacterial flora ; the diluent used was aerated estuary water of a constant salinity. The total oxygen demand of the sewage was estimated from the population served by the sewerage systems, the demand due to spent pickle liquors was calculated from the weight of ferrous iron discharged, and the oxygen demands of other industrial effluents were determined experimentally. It has been estimated that, of the total oxygen demand, nearly 60 per cent is due to sewage, about 3 per cent to spent pickle liquors and nearly 40 per cent to other industrial effluents. The experimental data are given fully in Tables in the Report.

H. W. H.

Abstracts of Memoirs

RECORDING WORK DONE AT THE PLYMOUTH LABORATORY.

The Feeding Mechanism of the Cumacean Crustacean *Diastylis Bradyi.*

By Ralph Dennell.

Trans. Roy. Soc., Edinb., Vol. LVIII, Pt. I, 1934, pp. 125–142.

Diastylis feeds on small food particles abstracted by the maxillary filter from a water current produced by movements of the maxillæ and maxillipeds. This current is secondarily aided by the outgoing respiratory current, and the assistance it gives to the filter current is much greater than in Gnathophausia. The large epipodites cause water to enter the branchial chambers through the mouth-parts, and pass it out anteriorly through the rostral siphon which is provided with a valve. In flowing forwards lateral to the mouth-parts the respiratory currents pass over the maxillary exites and extract water from the filter chamber.

A feature of the mouth-parts not possessed by the typical filtratory Malacostracan is a peculiar median process projecting into the filter chamber, and forming an abutment for the inner margins of maxillæ and maxillipeds.

The ancestral Cumacean probably had features in common with the primitive Lophogastrid Mysids Gnathophausia and Lophogaster, and in an account of the feeding mechanism of Apseudes, now in preparation for the press, an account will be given of the probable evolution of the Peracaridan feeding mechanisms from that possessed by a primitive Mysid-like ancestor which adopted mud-living habits.

R. D.

On the Feeding Mechanism of Certain Marine Ostracoda.

By H. Graham Cannon.

Trans. Roy. Soc., Edinb., Vol. LVII, 1933, *pp.* 739–764.

Asterope is a purely filtratory feeder. A current of water is caused to pass through the valves of the shell by the vibratory activity of the maxillary epipodite beating against the first trunk limb. The hinder parts of these two limbs are thin flexible plates and act as a valve, allowing only a passage of water in an antero-posterior direction. The filter is formed by the maxillules. The tips of the filter setæ are supported by the front edge of the first trunk limb. Food residue is scraped off the filter by a row of comb setæ developed on the anterior prolongation of the maxilla, and also by a spinous lobe on the mandible. The mandibular palp can flex back on to its spinous lobe, but cannot reach as far as the mouth. The food is passed on to the long setæ of the maxillulary endites, which curve up into the mouth. Food passed to the mouth by these setæ is transferred into the œsophagus by the scythe-shaped process of the mandible. There is no labral gland secretion to entangle the food particles, and the labrum is correspondingly small.

Cypridina may feed on large food masses or on minute detritus, which it abstracts from a current of water produced through the valves by the same mechanism as in Asterope. Minute particles are retained on a barrage of setæ which converge towards the mouth and arise from the basal part of the maxillules, the maxillæ and first trunk limb. The same setæ transport the collected mass upwards into the mouth. The labrum is very large, and the slimy secretions of the labral gland entangle the suspended matter. The mandibular palps flex so that their clawed tips reach as far as the mouth. The biting jaws consist of the laterally working tips of the maxillules and subsidiary teeth, which work obliquely forwards on the exopodite of the maxilla.

Cytherella is a purely filtratory feeder. The mechanism of its feeding is closely analogous to that of Asterope, but the various processes are carried out by different limbs. A comparison between the two is shown in Table I.

H. G. C.

The Action of Potassium and other Ions on the Injury Potential and Action Current in Maia Nerve.

By S. L. Cowan.

Proc. Roy. Soc., B, 115, 1934, *pp.* 216–260.

Analyses of *Maia squinado* blood serum and nerve show that the potassium concentration per 100 g. of water is at least thirteen times as great in the nerve as in the serum. The observed injury potential of Maia nerve was usually 30 millivolts; at 17°C a ± 5 p.c. reproducibility persisted for about two hours, precautions being taken to eliminate the "crush sealing over" effect (Gerard, 1930).

Potassium chloride rich solutions depressed both the injury potential and action current rapidly and reversibly. The potassium concentration required to abolish the action current was about five times that occurring in Maia serum; the depression of the action current could be partly prevented by the addition of an equimolecular concentration of calcium chloride. Probably the reversible inexcitability which occurs in freshly dissected Maia nerves is due to an abnormal concentration of potassium ions at the external surfaces of the fibres ; the potassium ions may escape either from the nerve or from the surrounding muscle fibres, as a result of small unavoidable injuries inflicted during the dissection.

Rubidium and cæsium ions also produced a reversible abolition of the action current, but 2·0 rubidium or 3·2 cæsium ions were required to give the effect of one potassium ion : the depressant action of these ions could be partly prevented by calcium ions.

Nerves which had been immersed in potassium rich solutions gave an approximately linear relation between the logarithm of the potassium chloride concentration and the depression of the injury potential, although higher concentrations than would be expected from the chemical analyses were required to make the potential zero. Probably the discrepancy is due to the difficulty of isolating for chemical analysis nerves uncontaminated by connective tissue and sea water, although other factors, such as the Donnan effect, may also have been appreciable.

Resting nerves in sea water leaked little potassium salt, but nerves stimulated to fatigue leaked considerable amounts. Assuming that the long-continued recovery heat production of these nerves is due to a " secretory " process whereby ions are restored to their original positions, the thermodynamical efficiency is calculated to be 0·02.

After severe asphyxia the conductivity of Maia nerves was only partly restored by the admission of oxygen ; for more complete recovery, washing in sea water was also necessary. It is suggested that during the later stages of anoxia potassium salts may escape from the interior of the fibres.

S. L. C.

The Effect of Quaternary Ammonium Salts upon Nerve.

(Preliminary communication.)

By S. L. Cowan and H. R. Ing.

J. Physiol., Vol. LXXIX, 1933, *pp.* 75–82.

and

The Action of Quaternary Ammonium Salts on Nerve.

By S. L. Cowan.

Nature, Vol. CXXXI, 1933, *p.* 658.

The action current was abolished in Maia nerves which had been immersed for a minute in sea water to which had been added tetramethyl or tetraethylammonium chloride in a concentration of 0·9 millimol per litre.

Using *Rana esculentia* and concentrations of tetramethylammonium iodide which readily produce a curariform paralysis but do not ordinarily affect either muscle or nerve, it was found that if a nerve was asphyxiated for about an hour after the abolition of the action current, then on the admission of oxygen the action current returned only for a short time if at all. Similar results were obtained with octyltrimethylammonium iodide and with strychnine methiodide, but with tetraethylammonium iodide in a concentration of 10 millimols per litre an increase in the galvanometer deflection due to the action current was observed.

S. L. C.

A Physiological Study of Phosphagen in Plain Muscle.

By M. Grace Eggleton.

J. Physiol., Vol. LXXXII, 1934, *pp.* 79–87.

The phosphagen present in the retractor muscle of *Mytilus edulis* is identical with argininephosphoric acid as regards its rate of hydrolysis in acid. A method for the rapid estimation of argininephosphoric acid is described, based upon its separation from pyro- and orthophosphate before hydrolysis. Both sodium pyrophosphate and muscle " pyrophosphate " are hydrolysed to a slight extent in N/20 acid at 28°C, a fact leading to error in the estimation of argininephosphoric acid by the method at present in general use.

In the resting aerated muscle the ratio of phosphagen to the sum of phosphagen and orthophosphate is 0·8. Fatigue induced by a series of contractions reduces this value to 0·45 and by a tetanus to 0·6. Rest under aerobic conditions restores the phosphagen to its original resting level, full mechanical recovery occurring at the same time. Under anaerobic conditions the ratio remains practically unchanged after the same period of recovery and the power of mechanical response is restored to only a slight extent. It is concluded that phosphagen bears the same close relation to activity in this plain muscle as it has previously been shown to do in skeletal and cardiac muscle.

M. G. E.

The Structure and Relationships of Lamellibranchs possessing a Cruciform Muscle.

By A. Graham.

Proc. Roy. Soc., Edinb., Vol. LIV, 1934, *pp.* 158–187.

A comparative anatomical description of the following species of bivalves belonging to the Tellinacea is given: *Gari tellinella, Tellina crassa, Macoma balthica, Scrobicularia plana* and *Donax vittatus*. All agree in many important points, particularly in possessing a cruciform muscle but no other mantle fusions; a linguiform, byssiferous foot; long, separate, retractile siphons; an anterior retractor pedis muscle with one insertion on each valve and lying internal to the posterior retractor in the foot; a protractor pedis; an outer demibranch with large supra-axial extension; a fused style sac and intestine.

The Solenidæ, of which *Cultellus pellucidus* is described, have no cruciform muscle, but possess other extensive mantle fusions; a cylindrical foot without a byssus; short siphons, not retractile; anterior retractor pedis with two insertions on each valve and external to the posterior retractor in the foot; usually no protractor pedis; no supra-axial extension to the outer demibranch; no fusion of style sac and intestine.

Solecurtus scopula and *S. chamasolen* agree in all main points with the former group. The Solecurtidæ, till now associated with the Solenidæ, must be placed in the tribe Tellinacea.

A. G.

The Development of Certain Parasitic Copepoda of the Families Caligidæ and Clavellidæ.

By Robert Gurney.

Proc. Zool. Soc., London, 1934 (*I*), *pp.* 177–217. 43 *Text-figs.*

In the development of Caligus there are two nauplius and five copepodid stages, of which stage I only is free. The last four are attached by a frontal filament which is extruded from the body of the free copepodid at the moult. This filament remains unchanged, a new basal part being added at each moult. Trebius differs from Caligus in having no frontal filament and no maxillipede in copepodid I. In Clavella there is one nauplius and one free copepodid stage. The latter attaches itself by a frontal filament, and the next stage develops within its skin, the skin being ruptured, but not cast off. The young Clavella clings to the end of the filament by the maxillæ, but the next stage is found attached by a bulla, which has no connection with the filament. There appear to be no further moults, and it is clear that the adult Clavella represents a pædomorphic copepodid of stage I or II.

R. G.

Note on the Effect of Salts in the Determination of Phosphate in Sea Water by Denigès' Method.

By O. Gomez Ibañez.

J. Cons. int. Explor. Mer., Vol. VIII, No. 3, 1933, *pp.* 326–329.

The work was made in order to determine the error due to other salts present in sea water.

A sample of sea water (of 35 °/₀₀ salinity) was found to contain 8·4 mg. P_2O_5/m^3. To portions of this were added varying quantities of phosphate.

The total amount of phosphate was determined by Denigès' method and the colour comparisons were made by Hehner tubes. The correction for the blue colour of the water was applied.

Over a large range of concentration the salt error is independent of the phosphate concentration and is at least approximately proportional to the salinity.

O. G. I.

Preservation of Sea Water Samples with Fluoride for Phosphate Estimation by Denigès' Method.

By O. Gomez Ibañez.

J. Cons. int. Explor. Mer., Vol. VIII, No. 3, 1933, *pp.* 329–330.

The phosphate determination will be in error unless carried out within a short time of collection, or unless planktonic activity is stopped by some method which does not interfere with the analysis. Sodium fluoride has been found to be an excellent preservative for sea water samples for phosphate estimation.

When 1 cm^3 of a one per cent solution of *pure* sodium fluoride was added to 100 cm^3 of the sample, no change in phosphate could be detected. Experiments were made with and without this preservative directly and after adding 30 mgs. P_2O_5 per cubic metre in samples stored during three months.

O. G. I.

The Development of *Ophiocoma nigra*.

By N. Narasimhamurti.

Quart. J. Micr. Sci., Vol. LXXVI, 1933–34, *pp.* 63–88.

This paper is in the nature of a reinvestigation of the development of an Ophiuroid. The material for this work was obtained by artificial fertilization at the Plymouth Laboratory. The paper embodies a complete history of development from fertilization to metamorphosis. Several interesting observations have been recorded and the more important of these are :

1. A right hydrocœle arises in all the larvæ from the anterior coelom, in addition to the left hydrocœle, but does not assume a five lobed form in any case and degenerates as metamorphosis progresses.

2. A pericardial vesicle arises from the dorsal wall of the right anterior coelom as in Echinoids and Asteroids and persists in the adult as a thin-walled pulsating sac, its invaginated ventral wall forming the heart. Pulsations occur once in every 12 seconds in the ventral wall of the newly metamorphosed imago.

3. During metamorphosis the fifth lobe of the hydrocœle, instead of moving across the œsophagus upwards, slightly bends to the right to meet the first which travels down after traversing the œsophagus.

4. All perihæmal spaces are found to arise from the left posterior coelom.

5. The outer ends of the cylindrical cells of the stomach are vacuolated and stained black with Osmic acid owing to the presence of fat in them. The stomach at first appears as a solid mass in post-metamorphic stages, but later sends five projections alternating with the arms.

Reaction of the Smooth Muscle of the Gastro-intestinal Tract of the Skate to Stimulation of Autonomic Nerves in Isolated Nerve-muscle Preparations.

By J. V. V. Nicholls.

J. Physiol., Vol. LXXXIII, 1934, *pp.* 56–67.

Faradic stimulation of the anterior gastric artery stimulates the gastric antrum and fundus ; of the superior mesenteric artery, the spiral intestine and colon ; of the inferior mesenteric artery, the rectum. These effects are not affected by ergotoxine. Ergotoxine alone stimulates the antrum, fundus and pyloric sphincter, but has no effect upon the spiral intestine, colon and rectum. The effect of adrenaline is not antagonized by ergotoxine in the case of the stomach, but is antagonized in the case of the spiral intestine, rectum and colon. Single and multiple break shocks and faradic stimulation of the vagus stimulate the cardiac and fundic regions of the stomach. These last effects are not inhibited even by large doses of atropine.

J. V. V. N.

Formation de têtes dans la stolonisation des Polychètes syllidiens.

By Yô K. Okada.

Bull. Soc. Zool., France, T. LIX, 1934, *pp.* 388–405.

In this paper the mechanism of head development is described in some Syllids, with special reference to the determination of the character of head in stolonization. In *Procerœa picta*, for example, the position of the new head is even indicated on the antero-dorsal side of the 14th setigerous segment before any sign of stolonization. But the irreversible determination of the head waits until indication of stolonization becomes fairly distinct. Even when the worm is cut across at one segment posterior to the position in question, tail regenerates instead. If, however, the plane of section passes through the middle of the 14th segment, heteromorphic head results. In the Syllinæ, where the head of the stolon appears with a wide range of segmental variation in the middle part of the body, the anlage is undifferentiated. In such cases the determination of the tissue in relation to the head is more retarded than in the preceding form. In other respects both agree well, and, after the determination, half anlage produces half head. Only the regulation of symmetry of eyes and appendages is still possible. Finally, pluri-cephalic specimens of *Typosyllis prolifera* are studied.

Yô K. O.

Les possibilités de la régénération de la tête chez le Polychète, *Myxicola æsthetica* (Clap.).

By Yô K. Okada.

Ann. Zool. Jap., Vol. XIII, 1932, *pp.* 535–550.

Régénération de la tête chez le Polychète, *Myxicola æsthetica* (Clap.).

By Yô K. Okada.

Bull. biol. (Franc. et Belg.), LXVIII, 1934, *pp.* 340–381.

Regeneration of the head is investigated in *Myxicola æsthetica* (Clap.). At Plymouth this Polychæte is easily obtainable and provides an excellent material for experiments of this kind. It can be kept alive for a long time in a small glass vessel filled with plain sea-water. The animal, in this condition, easily regenerates the head as well as the tail. Head regeneration is especially pronounced, the power being retained almost as far as the posterior extremity. When the communication of the ventral chain of nerve is severed, without, however, separating the anterior segments from the posterior ones, a lateral head frequently appears at the point of lesion. In the anterior third of the body, the lateral head remains generally under-grown, but in the remaining two-thirds the head develops as well as in the normal case of regeneration on the anterior cut-surface. The lateral head can be induced not only singly but also several at a time, with the resulting production of multicephalic specimens. The head produced at a side can be brought to the posterior end by taking off the segments below that level by an oblique cut passing the base of the new head; thus results a specimen with a head at the anterior as well as the posterior end. Even a single segment gives rise to a worm, forming the head in front and the tail behind. The anterior regeneration is, as a rule, limited to a production of the head and one setigerous segment. (The anterior part will be completed afterwards through metamorphosis of the following segments to form thorax.) Further, segments longitudinally divided into halves can still regenerate the head in so far as these contain the ventral nerve. The intestine and other viscera attached to the septum take no part in the process, and these can be therefore eliminated from the pieces, without interfering with their power of regenerating head. Throughout the whole experiment no tail is regenerated except at the posterior extremity of the body when transversely cut.

Yô K. O.

On the Excitation of Crustacean Muscle—I.

By C. F. A. Pantin.

J. exp. Biol., Vol. XI, 1934, *pp.* 11–27.

By stimulating the nerve in Carcinus leg with alternating currents of increasing intensity a series of varied responses is obtained. Above the threshold a contraction is developed of a comparatively slow type. With increase of intensity of the stimulus the response fails, owing to the excitation of inhibitory nerves. But at still greater intensities contraction reappears. This contraction, however, is very rapid. Tetani developed from the slow contraction are easily inhibited. Tetani developed from the rapid contraction cannot be inhibited by superimposed stimuli.

The relation of the quick and slow contractions is considered. It is not possible to fatigue one without fatiguing the other. Experiments show that on suddenly releasing the tension of the muscle during a tetanus, the tension always redevelops in a manner similar to the development of tension in the quick contraction, even though the tetanus be developed initially by the slow contraction. The same contractile mechanism is involved in both cases.

The latent period of contraction on stimulation of the nerve is very long, and ranges from 300σ at the threshold. That for direct stimulation of the muscle is 7–10σ. Above the threshold the latent period shortens rapidly with increasing stimulus. Over this region the contractions are of the slow type. The latent period becomes asymptotic to 50σ as the intensity is increased. At this value the contractions are of the quick type. Inhibition is effective where the latent period begins to approach its asymptotic value.

It is suggested that all the varied phenomena observed are related to the power of summation of crustacean muscle ; that the slow contraction in response to a battery of stimuli is not due to a different contractile mechanism from the quick one, but that it is a summation effect by which a statistically increasing number of muscle fibres are brought into action as successive impulses pass down the nerve.

C. F. A. P.

On the Nature and Functions of the Amœbocytes of *Ostrea edulis*.

By Shun-ichi Takatsuki.

Quart. J. Micr. Sci., Vol. LXXVI, 1933–34, *pp.* 379–431.

There are two kinds of corpuscles in the blood of the oyster ; one consists of granular, the other of hyaline amœbocytes. The granules are neutrophile with a tendency to become stained by the basic dyes *intra vitam*.

The amœbocytes of the oyster have important functions in connexion with the digestive mechanism and excretion. The phagocytic behaviour of the amœbocytes is prominent and there can be found the sucroclastic, lipoclastic and proteoclastic enzymes in the amœbocytes. These enzymes have an optimum pH quite different from the other digestive enzymes in the digestive tracts of the oyster.

There is no evidence of absorption either of soluble matter or of solid substances by the epithelium of the mantle cavity of the oyster other than by the agency of amœbocytes.

S. T.

Book Notice.

Dana Report No. 1.—Introduction to the Reports from the Carlsberg Foundation's Oceanographical Expedition round the World 1928–30.

Dana Report No. 4.—Untersuchungen über die Verbreitung, Biologie und Variation der Ceratien im Südlichen Stillen Ocean. Von E. Steeman Nielsen.

The Carlsberg Foundation's Oceanographical Expedition round the world 1928–30 *and previous " Dana " Expeditions under the leadership of the late Professor Johannes Schmidt. Copenhagen,* 1934.

Report No. 1 contains an article by Martin Knudsen in Memoriam of Johannes Schmidt, with portrait, a foreword by P. Jespersen and Å. Vedel Tåning, a list of stations with maps and tables of the echo-soundings, with introductory remarks by S. V. Greve. This great expedition, the last and the most important of the many which were personally planned and carried out by Professor Schmidt, has brought back an enormous amount of material of every description, now being described in detail by specialists in many fields and to be published in a series of reports. No. II (*Deep-Sea Angler Fishes* (*Ceratioidea*) by C. Tate-Regan and Ethelwynn Trewavas) was published in 1932. No. III (*Les Poissons apodes appartenant au Sous-Ordres des Lyomères*, by Léon Bertin) is in preparation, and No. IV, now before us, treats of the genus Ceratium as representative of the phyto-plankton.

S. Nielsen covers much ground in his report which embraces material from two " Dana " Expeditions, in January 1922 in the Gulf of Panama, and in September 1928–March 1929, on the present Expedition in which the author took part, through the Pacific Ocean from Panama to New Zealand and Australia. 68 stations were sampled, the Nansen closing net being mainly used and the catches taken at 200–100, 100–50, 50–0 metres.

Most of these Ceratium species are oceanic, only a few being found in numbers in purely neritic regions, although a neritic influence apparently modifies the cells and affects the distribution. The author is of the opinion that the reason for the dearth of species in neritic regions is the fact that the substances formed by the breaking down of the plentiful planktonic organisms act as a kind of poison to the very sensitive oceanic species. He finds that a rising temperature tends to lessen the size of the cell, and, in some cases, tends to lengthen the horns. In neritic waters the cells are large and frequently the horns are lessened also. " Shadow " species are characteristic. These are all oceanic and live in a moderate light intensity where nutrient salts are plentiful. There is found a striking agreement in the Ceratia from the Atlantic and Pacific oceans, very few species being peculiar to one or the other.

M. V. L.

Marine Biological Association of the United Kingdom.

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OF THE

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OF THE UNITED KINGDOM.

THE ASSOCIATION was founded at a Meeting called for the purpose in March, 1884, and held in the Rooms of the Royal Society of London.

Professor HUXLEY, at that time President of the Royal Society, took the chair, and amongst the speakers in support of the project were the Duke of ARGYLL, Sir LYON PLAYFAIR, Lord AVEBURY, Sir JOSEPH HOOKER, Dr. CARPENTER, Dr. GÜNTHER, Lord DALHOUSIE, Professor MOSELEY, Mr. ROMANES, and Sir E. RAY LANKESTER.

The Association owes its existence and its present satisfactory condition to a combination of scientific naturalists, and of gentlemen who, from philanthropic or practical reasons, are specially interested in the great sea fisheries of the United Kingdom. It is universally admitted that our knowledge of the habits and conditions of life of sea fishes is very small, and insufficient to enable either the practical fisherman or the Legislature to take measures calculated to ensure to the country the greatest return from the "harvest of the sea." Naturalists are, on the other hand, anxious to push further our knowledge of marine life and its conditions. Hence the Association has erected at Plymouth a thoroughly efficient Laboratory, where naturalists may study the history of marine animals and plants in general, and where researches on food-fishes and molluscs may be carried out with the best appliances.

The Laboratory and its fittings were completed in June, 1888, at a cost of some £12,000 and from that time until 1933 a sum of over £16,000 has been spent on additional buildings. Throughout this period investigations, practical and scientific, have been constantly pursued at Plymouth. Practical investigations upon matters connected with sea-fishing are carried on under the direction of the Council; in addition, naturalists from England and from abroad have come to the Laboratory, to carry on their own independent researches, and have made valuable additions to zoological and botanical science, at the expense of a small rent for the use of a working table in the Laboratory and other appliances. The number of naturalists who can be employed by the Association in special investigations on fishery questions, and definitely retained for the purpose of carrying on those researches throughout the year, must depend on the funds subscribed by private individuals and public bodies for the purpose. The first charges on the revenue of the Association are the working of the sea-water circulation in the tanks, stocking the tanks with fish and feeding the latter, the payment of servants and fishermen, the maintenance of a research steamer and other collecting boats, and the salaries of the Resident Director and Staff. At the commencement of this number will be found the names of the gentlemen on the Staff.

The purpose of the Association is to aid at the same time both science and industry. It is national in character and constitution, and its affairs are conducted by a representative Council and an Honorary Treasurer, without any charge upon its funds, so that the whole of the subscriptions and donations received are devoted absolutely to the support of the Laboratory and the prosecution of researches by aid of its appliances.

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Members of the Association have the following rights and privileges: they elect annually the Officers and Council; they receive the Journal of the Association free by post; they are admitted to view the Laboratory at Plymouth, and may introduce friends with them; they have the first claim to rent a place in the Laboratory for research, with use of tanks, boats, &c.; and have access to the books in the Library at Plymouth.

All correspondence should be addressed to the Director, The Laboratory, Plymouth.

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NOTICE.