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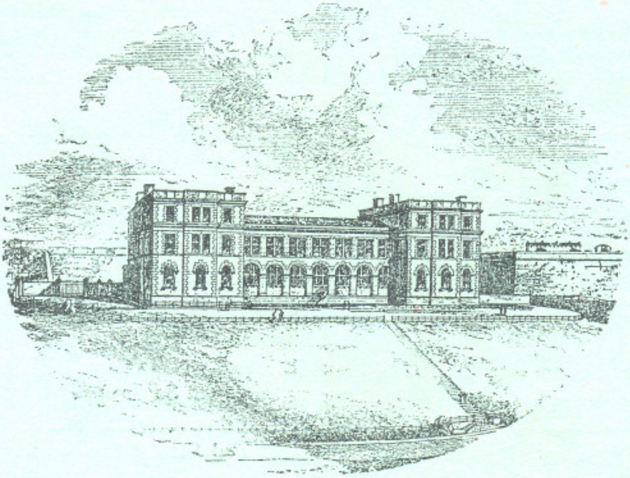

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Edwin Ray Lankester,

1847–1929.

Among the many notable services rendered to Zoological Science by the late Sir Edwin Ray Lankester, probably none is more enduring, certainly none stood higher in his own estimation, than the part he played in the foundation of the Marine Biological Association of the United Kingdom. For he was indeed its Founder. It is true that the conception of a Marine Laboratory, with an Aquarium attached to it, staffed and equipped for the concurrent study of Zoological Science and the practical investigation of problems bearing upon the maintenance and improvement of our sea fisheries, was borrowed, partly from Dr. Anton Dohrn's famous Zoological Station at Naples, partly from the Marine Station established by Professor McIntosh at St. Andrews and the Scottish Marine Station at Granton. It is also true that from the moment of its inception the Marine Biological Association had the cordial support of and received invaluable assistance from all the leading British Zoologists of the day, but such considerations serve only to emphasize the fact that it was due to Sir Ray Lankester's initiative that the Association was planned upon a scale that made it of national and not merely local importance, and that it was through his influence, persuasiveness, and perseverance that the funds for the building and maintenance of the Laboratory were raised. If he received generous help from others it was because he put forward his proposals in so well-thought out and concrete a form as to give assurance of success and because he was willing and competent to take upon himself the burden of overcoming difficulties which might well have deterred a less resolute character.

In retrospect it is sufficiently remarkable that so young a man—he was only thirty-six years old when the project of a Marine Biological Station was first mooted—should have commanded so much influence, not only among his scientific colleagues but among persons of all ranks and callings, as to be able to bring a scheme conceived on such generous lines to a successful issue. The truth is that this relatively young Professor had already made for himself a European reputation and was universally recognized as the only possible successor to Huxley in the leadership of Zoological Science in Great Britain. His lectures in

University College, London, were famous and were attended by many besides those who were preparing themselves for examinations, and he was the author of many scientific memoirs of first-rate importance. He had begun young, for when, at the age of thirteen, he was required in the course of his studies to dissect an earthworm, he was so dissatisfied with the existing accounts of the anatomy of that animal that he published an account of his own observations on the subject in a treatise which, if it bears the marks of immaturity, testifies to his remarkable powers of observation and analysis of morphological fact.

The eldest son of Dr. Edwin Lankester, Coroner for Central Middlesex and Founder and Editor of the *Quarterly Journal of Microscopical Science,* Ray Lankester was brought up in scientific surroundings from his earliest years and as a boy became acquainted with many of the leading zoologists of the day. He was educated at St. Paul's School and at the age of eighteen matriculated at Downing College, Cambridge, where, among his other activities, he represented his College on the river. After two years' residence at Cambridge he entered for and was elected to a Junior Studentship at Christ Church, Oxford, and finished his scientific education in Professor Rolleston's laboratory. There he met and became a close friend of Henry Nottidge Moseley, who was destined to succeed Rolleston as Linacre Professor of Comparative Anatomy at Oxford. The two friends were inseparable; they were placed together in the first class in the Honour School of Natural Science in 1868; both gained Radcliffe Travelling Fellowships and went abroad together, to Vienna in 1870 and to Leipzig in 1871. On his return from Leipzig Lankester was elected to a Fellowship and Lectureship at Exeter College, Oxford, and in 1874 he was appointed to the Professorship of Zoology and Comparative Anatomy at University College, London, a chair which he filled with great distinction, and the years in which he occupied it, 1874 to 1890, were perhaps the most active in his busy life. On the death of his friend, Professor Moseley, in 1891, he succeeded him in the Linacre Professorship of Comparative Anatomy at Oxford, but held the chair for only seven years, as in 1898 he was promoted to the Directorship of the British Museum of Natural History. He became a Knight Companion of the Bath (Civil Division) in 1907 and retired in 1908, after which year, though without an official post, he continued for a long time to exercise a guiding influence in zoological thought and did much to awaken general interest in biological problems by a series of essays entitled "Science from an Easy Chair." In 1919 he completed the fiftieth year of his editorship of the *Quarterly Journal of Microscopical Science* and received the congratulations of his many colleagues and pupils in a special number of the *Journal* dedicated to himself.

The honours bestowed upon Lankester by various Universities and

Scientific Institutions at home and abroad are too numerous to recapitulate here, but it may be recorded that he was awarded the Royal Medal of the Royal Society in 1885 and the Copley Medal in 1913, and he was President of the British Association for the advancement of Science in 1906.

This is hardly the place to survey or to attempt to write an appreciation of Lankester's numerous contributions to Zoological Science, but it will not be out of place to mention a single example as an illustration of his method of treating a zoological problem. The so-called King-Crab, *Limulus polyphemus*, is an example of a persistent type which appeared in triassic times and survives to the present day. Being an aquatic form, with respiratory organs attached to certain of its limbs, it came under the definition of a Crustacean and was classed as such by the leading authorities of the nineteenth century, although Straus-Durckheim had drawn attention to its many resemblances to Arachnida as long ago as 1829. An examination of such specimens as he had in his museum convinced Lankester that Straus-Durckheim was right, and he set out to prove it much in the same way as an eminent counsel accumulates and marshals his evidence until he leaves no loop-hole for doubt in the minds of the jury he is addressing. He obtained a consignment of Limulus from America (it is common enough on the Atlantic coast of N. America, but is not found in our seas) and submitted its anatomy to an exhaustive analysis, the results of which were published in a famous treatise entitled "Limulus an Arachnid" (*Q.J.M.S.*, Vol, XXI, 1881). Of this, and subsequent memoirs on the same subject, it has been well said that he and his pupils compared the King-Crab with the Scorpion, segment with segment, organ with organ, tissue with tissue, almost cell with cell, until he had established the connection between them beyond all possible doubt. For thoroughness, exactitude, and morphological insight this work cannot be surpassed, and we mention it here as a characteristic example of the close attention to detail and the clarity of exposition which are the hall-mark of all his scientific work. He himself regarded this essay as the best he had produced, and in the well-known portrait by Collier he is represented as lecturing on Limulus, with a specimen lying on the table and diagrams of its appendages on the blackboard.

The story of the foundation of the Marine Biological Association is told in the first number of the Journal of the Association, now out of print and difficult to obtain. A leading article in *The Times* of March 1st, 1884, announced that a meeting would be held on that day in the rooms of the Linnean Society to consider a proposal to found a Marine Station for the joint purpose of encouraging the study of marine zoology and making a scientific study of questions relating to sea fisheries. The article was written by Ray Lankester. The time was propitious, for public attention had been attracted to our sea fisheries by the successful Fisheries Exhibition recently held in South Kensington, and the meeting was largely attended. Professor Huxley was in the chair, and among those who spoke in favour of the proposal were the Duke of Argyll, Sir Lyon Playfair, Sir John Lubbock (afterwards Lord Avebury), the Earl of Dalhousie, Professor H. N. Moseley, and Professor (afterwards Sir William) Flower. The ground had been carefully prepared; the proposals submitted to the meeting were of a kind to appeal with equal force to scientists, statesmen, and men of business, and were adopted unanimously. The Association was launched on its career with Professor Huxley as President and E. Ray Lankester as Honorary Secretary. The first step had been taken, but much remained to be done, in particular it was necessary to raise a large sum of money to build and provide for the maintenance of the projected Laboratory and aquarium. The burden of this work fell upon the Honorary Secretary, and so successful was he in his appeal to various interests that at the first Annual Meeting held in June, 1885, he was able to announce that the subscriptions amounted to £8000 and a year later this sum was increased to £15,000. After much discussion and enquiry it was resolved that the Laboratory should be built at Plymouth, the deciding factors in the choice being the generous contributions made by Messrs. John and Robert Bayly, who were deeply interested in the welfare of the fishermen of the district, and the richness of the marine fauna testified to by Mr. C. Spence-Bate, F.R.S., a resident in the city, and there was the additional advantage that the War Office offered on very favourable terms the site on which the Laboratory now stands. No time was lost in getting to work. Mr. Walter Heape was appointed Director of the Laboratory and Assistant Secretary, and Mr. J. T. Cunningham, who had been for three years Superintendent of the Scottish Marine Laboratory at Granton, was appointed Naturalist in charge of fishery investigations. In spite of great difficulties, due to lack of accommodation and equipment, work was begun almost before the commencement of the building of the Laboratory, and in spite of the unfavourable conditions a large amount of research was got through in the two years before the Laboratory was ready for occupation. After the many delays apparently inseparable from a building contract, the Laboratory was formally opened on June 30th, 1888, when the large and distinguished company present was entertained at lunch by the Prime Warden of the Fishmongers' Company who had been, and continue to be, generous patrons of the Association.

Though the Association was fairly launched on its career, the difficulties confronting it were great. So much had been spent on building that only a small sum remained for maintenance. The income amounted to less than £900 per annum, and this had to provide for the salaries of a

Director, a Naturalist, a caretaker and engineer, a fisherman and his assistant, and a Laboratory servant, in addition to the upkeep of the Laboratory and library, the hire of boats, and the publication of the Journal. The work of the naturalists was restricted for want of sea-going boats and fishing-gear. At first the only boat available for daily use was a half-decked 4-ton hook-and-line fishing-smack, to which a rowing boat and a small and not very seaworthy steam-launch were subsequently added, but none of these could venture far outside Plymouth Sound except in settled fine weather, and much time was cut to waste in beating against unfavourable winds and in the calms so frequent at Plymouth in the summer months. At times it seemed impossible to achieve the ends proposed by the Association, but Lankester was not to be deterred by difficulties and had the gift of imparting a large share of his own resolution to those who worked under him. In those early days, also, the work of the Association was largely assisted by voluntary helpers, notably by the late Professor W. F. R. Weldon and Dr. G. H. Fowler, who were inspired by Lankester's enthusiasm to take up their residence at Plymouth and to work whole-heartedly for the success of his venture.

In the difficult years following the opening of the Laboratory, Lankester was a frequent visitor to Plymouth and entered with great care and minuteness into all the details of its organisation. In those days the scientific staff spent a large part of their time at sea, sometimes in trawlers, more often in the little fishing-smack belonging to the Association; sometimes in a tug hired for the purpose of a more distant expedition. This aspect of the work had a great attraction for Lankester and he took as full a share in it as his constitutional inability to find his sea-legs would admit. He would sail across the Sound and make long expeditions on foot for the purpose of shore collecting, but only on rare occasions, usually when Canon A. M. Norman was staying at Plymouth, would he venture outside the Breakwater. In most respects there was little in common between the Professor and the dignitary of the Church, but the latter's knowledge of the British marine fauna was unrivalled and Lankester held him in great respect on this account. The Canon was no better a sailor than the Professor, and united as they were in their love of marine zoology they were equally at one in their sufferings when the dredge was brought aboard and its contents had to be examined whilst the little vessel was pitching heavily in a lively sea.

Though there were changes in the staff of the Laboratory Lankester's unremitting exertions, backed by the goodwill of his friends, maintained the work of the Association in such a state of efficiency that when in 1899–1901 the Government was asked to co-operate in an International Investigation of the North Sea, he could claim successfully that the only organisation in England with a staff trained to undertake the particular kind of work required was to be found in the Marine Biological Association. From that date it has received the steady support of successive Governments and its activities have increased until it has arrived at its present position, a tribute to the energy and foresight of its Founder and President for the last thirty-nine years.

It is difficult to estimate how much of the success of Lankester's undertakings, including the Marine Biological Association, was due to his pre-eminent ability as a zoologist and how much to the influence he exercised over men in all stations of life who were not primarily interested in any branch of science. It cannot be said that his influence extended over all sorts and manners of men, for it was his foible that he was called upon to detect and wage war upon imposture in whatsoever form it might present itself. On one occasion at least his exposure of a spiritualistic impostor was a subject for much merriment and won general approval. But as he was equally intolerant of pedantry and pretentiousness, and did not always discriminate sufficiently clearly between these weaknesses and imposture, he incurred a good deal of hostility by carrying his war into the camps of people who took themselves and their opinions and conventions very seriously. But his too great readiness to scent out imposture was balanced by an unerring faculty for discovering real talent, and he was cordial in his appreciation of those in whom he discerned it. By the exercise of this faculty he surrounded himself with a devoted band of pupils and colleagues to whom he was at once master and *bon camarade*. To his pupils and assistants he was indeed something of a hard master, expecting from them attainments commensurate with his own. But if exacting he was appreciative, never withholding a generous meed of praise for good work ; praise that was the more esteemed because the recipients knew well that it was bestowed only where it was deserved. If he made his assistants slave for him, he was ever mindful of their interest and exerted himself to obtain for them the promotion that he considered their due. His manner with young men was charming. Once he was assured of their worth he admitted them to terms of close though always respectful intimacy, and those who had the privilege of being included among his protégés can recall many an evening's gathering in which wit and wisdom were blended in discussions that lasted well into the small hours of the morning.

Though much of his earlier experience had been gained in Vienna and Leipzig, and he had been largely influenced in his youth by the writings of Ernst Häckel, in later years Lankester attached himself to the French school of zoologists rather than to the German. For him Paris was a more congenial city than a German university town, and he liked serious discussion to be salted with humour and gaiety. Not that he confined his appreciation to Gallic wit, for he reckoned among his most intimate friends such kindred spirits as Professor A. A. W. Hubrecht of Utrecht and Professor Ed. van Beneden of Liége.

Born in the tenth year of Queen Victoria's long reign, Lankester must be counted among the great scientific figures of the late Victorian period. It is now the fashion, among such as think to increase their own stature by belittling the giants of a former age, to depreciate that period. But should we not rather say, in the words and the spirit of the University bidding-prayer, "let us praise great men"? For not only did they add largely to our knowledge, but they also fought for and won the freedom of scientific thought which is our inheritance.

G. C. B.

Experiments in the Sea on the Growth-Inhibitive and Preservative Value of Poisonous Paints and other Substances.

By

J. H. Orton, D.Sc.,

Chief Naturalist at the Plymouth Laboratory.

With Some Chemical Analyses by the Government Chemist.

With 20 Figures in the Text.

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PART I. BIOLOGICAL INVESTIGATIONS.

INTRODUCTION.

OBSERVATIONS on breeding (**1**, 1914 ; **2**, **3**, 1920) and experiments on the rate of growth of marine invertebrates (**4**, 1914 ; **5** to **9**) have been carried out since 1911 (excepting the war period).

The particular objects of these researches were stated (**1**, 1914, p. 312) to be :—

> " (1) to establish the age of common marine invertebrates.
>
> (2) to determine the minimum age at which these forms begin to breed.
>
> (3) to examine the rate of growth at different seasons of the year and *under different conditions.*
>
> (4) to investigate the fecundity of different forms so far as possible.
>
> (5) to collect the scattered literature on these subjects."

During the course of that work it was realised that the general observations being made would form an invaluable control and basis for experiments, particularly for investigating the fundamental properties and the efficacy of anti-fouling paints, i.e. paints having usually poisonous properties. These paints, as is well known, are used on the bottoms of ships to prevent marine organisms from settling and growing there. Slight growths on the bottom of a ship seriously reduce the speed of the vessel and increase the time of making a given passage in proportion to the amount of such growth, i.e. fouling. The debasement of the immense amount of capital involved in the loss of time in passage due to the fouling of vessels, and in their docking for scraping and repainting the bottom, is a sufficient indication of the great economic importance of methods for maintaining the bottoms of ships free from growths. In this pioneer research, which was begun in 1919, it was found that certain so-called anti-fouling paints had only a slight anti-fouling value (even on stationary objects), while others retained a poisoning property up to 3½ years. Publication of the work has been delayed by unavoidable circumstances.

OBJECT OF THE RESEARCH.

The object of the research was to compare growths on anti-fouling paints (A.F.P.) on experimental material composed of painted shells and painted boards and controls placed in the sea in a number of different situations, while observing normal general growth in the same and similar situations in the locality at the same time. By observing the experimental material over a period of years it was possible to determine the age at which particular paints lost their anti-fouling property, and to investigate by chemical analyses the concentration of the poisonous ingredients left in the paints when the poisonous property was lost, or near the point of being lost.

It is known that marine organisms grow more abundantly in certain localities or at certain tidal levels than in others (**10**, **11**). Therefore to test the value of anti-fouling paints in the sea it is advisable to expose these to as great a variety of conditions—to ensure as great a variety of infection from the larvæ or young of different marine organisms—as is possible, since some marine organisms (e.g. certain algæ and Tubularia) are undoubtedly less affected by anti-fouling paints than are others. Moreover, in English waters there is undoubtedly on the whole a seasonal variation in growth and reproduction (see **1** and p. 399), and it is a fact that *all growths on the bottom of floating ships begin by young or larval free-swimming forms settling on the bottom of the ship.* Thus the seasonal variation in reproduction in England and other temperate waters renders surfaces covered by anti-fouling paints liable to infection (and therefore testing) by larvæ less in the winter period than at any other. All these considerations—in addition to the probability of infection in the infective period—are important in testing the value of an anti-fouling paint. To realise the efficacy of the poisonous paints and other substances the reader is directed especially to the records of normal growth given in **1**, 1914 ; and pp. 396–399, 416, 420, and 424 herein.

THE SUBSTANCES TESTED EXPERIMENTALLY.

The following paints and other materials were tested in one or more experiments : numbers I to VI and number XI being proprietary compositions the same as, or similar to, those placed on the market ; No. IX, ship-chandlers' black varnish, being coal tar diluted to the required thinness by naphtha :—

LIST (I) OF THE SUBSTANCES TESTED EXPERIMENTALLY.

No. of Paint or other substance.	Designation.	Colour.	Property.*
I	Anti-fouling composition	Reddish brown	A–F
II	,, ,,	Dark green	A–F
III	Anti-corrosive only, composition	Black	A–C
IV	Anti-fouling composition	Reddish brown	A–F
V	Anti-corrosive only	Black-bronze	A–C
VI	Anti-fouling composition	Red	A–C & A–F
VII	Clean surface (Control)	White or greyish white	
VIII	Red oxide of iron	Red	
IX	Black varnish	Black	
X	Tar	Black	
XI	Anti-fouling composition	Light green	A–F
XII	Aluminium paint	Silvery	
XIII	Copper sheets	Reddish brown	
XIV	Zinc sheets	Metallic grey	
XV	A Grey paint	Grey (opaque)	

DISPOSAL OF THE EXPERIMENTAL MATERIAL IN THE SEA.

In order to expose the anti-fouling paints and other substances to different conditions in the sea, experiments were carried out in three situations in Plymouth Sound, namely :—

(1) on an experimental raft submerged in Cawsand Bay.

(2) on the piles of the West Wharf, Great Western Railway, in Millbay Docks, Plymouth, at the level of low-water spring tides.

(3) on the piles of the Promenade Pier, at the level of low-water spring tides.

---

* A–F signifies anti-fouling ; A–C anti-corrosive.

In these three situations the general conditions are somewhat different.

(1) In Cawsand Bay the water is relatively clean, clear, and usually of high salinity, but the tidal current is slight. In this situation the experimental material was constantly immersed on a wooden raft (20×5×2 feet) at a depth of 1 to 2 feet below the surface. One of the experiments was carried out in direct exposure to light, but the three others were in shade or subdued light. Wave-action is strong only with easterly winds, but the experimental material would be almost continuously in motion due to the roll and pitch and up-and-down movement of the raft.

(2) At the Great Western Railway Wharf the water conditions are more foul than at the Promenade Pier, for besides pollution from the adjacent city sewer, fouling occurs from (*a*) occasional discharges of foul water from the inner dry dock, (*b*) occasional discharges of warm and foul water from vessels unloading alongside the wharf, and (*c*) the loss of grain and china clay from vessels loading and unloading alongside. Tidal currents are negligible in this situation; at dead low-water spring tides the experimental material would be exposed only to diffuse daylight. The salinity in this locality is estimated as being not very different from that prevailing at the Promenade Pier (**2, 29**).

(3) At the Promenade Pier the water must be regarded as mostly heavily charged with bacteria derived from the adjacent sewer outfall, but relatively pure on the latter part of the flood of spring tides. The salinity is variable and of a lower mean than in Cawsand Bay, but, as in Cawsand Bay, the tidal current is slight. The material was mostly in a subdued light (under water under the Pier), but would be exposed to air, wind, and daylight (but not to direct sunlight) at the middle of the day (**11,** p. 280) at spring tides which were slightly lower than the average. Wave-action is fairly strong with south to east winds.

Description of the Experimental Material.

The anti-fouling properties of the paint compositions and the materials were tested by painting them on scallop shells (*Pecten maximus*) and on test-pieces of wood (Elm and Deal). The painted shells were previously bored with holes of a distinctive size or position, and either strung with tarred or clean yacht manilla around piles in the sea and inside or underneath the raft. Other shells were nailed on the bottom of the Cawsand Bay raft; test pieces of wood were nailed on to old Jarra wood piles at the Great Western Railway Wharf (G.W.W.), and some were tied with tarred rope to cement piles in the same wharf.

Two good coats of paint composition (or other material) were given to all shells and test-pieces of wood, i.e. battens. In all cases the application was made as thoroughly as it can be by brushing the paints well in on to dry surfaces and with rare exceptions *the painted surfaces were well dried before being immersed in the sea.* Thirty shells and five wooden test-pieces were used to test each proprietary anti-fouling paint and other substance at Cawsand Bay; and ten shells and one batten to test each of them at the Great Western Wharf, Millbay Docks. One anti-fouling paint was tested by sixteen shells—as were several other materials—at the Promenade Pier, but complete details of the tests are best given with each experiment. In all experiments with shells a number of clean shells equal to or greater than the number of the painted shells was put out with the latter as a control experiment; untreated test-boards were also used as controls alongside treated battens.

LIST (II) OF EXPERIMENTS.

The following list of the experiments carried out will be useful for reference:—

Series I.—Cawsand Bay. Experiments on and in a submerged but floating raft* (see Figs. 19 and 20, pp. 426 and 427) put out in the sea on July 16th, 1919, and moored in 3 fathoms of water about 150 yards N.W. by N. from the end of the pier at Pier Cove (Pier Cellars). The raft was stoutly made of a wooden frame 20 feet by 5 feet by 2 feet deep, on which were nailed 4 by 1-inch battens of wood on the bottom and sides, so as to leave about 1 inch of space between adjacent battens. It was divided into three compartments, over which lids—having the same structure as the bottom and sides—were fitted. Mooring was effected by a central swivelled attachment at the bottom of the raft, and sufficient slack mooring chain was allowed to permit of the raft being turned over completely.

EXPERIMENT.

Designation of experiment.	Duration.	No. of times visited.	Situation on raft.
A. Wooden ladder	Aug. 18th, 1919– Oct. 9th, 1920	9	on bottom and outside
B. Board of squares	,,	9	,,
C. Foot battens exposed to light	,,	9	at sides and outside
D. Shells under raft (1) fixed (2) enstrung	Aug. 18th, 1919– Oct. 23rd, 1920	9	at bottom and outside
E. Shells inside raft (1) fixed (2) enstrung	,,	9	inside

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* This raft was originally designed by Dr. E. J. Allen for acclimatising marine animals (to low pressures) prior to transferring them from the sea to the Plymouth Aquarium tanks. By a modification of the structural parts by the writer, similar smaller rafts were designed for the study of the bionomics of Teredo by Potts (**12**, 1923) and the Institute of Civil Engineers (**13**, 1924).

Series II.—West Wharf, Millbay Docks, Plymouth. Shells were strung on tarred rope and secured around cement piles at low-water spring tide level. Boards were nailed to old Jarra piles at about low-water spring tide level.

Experiment.	Duration.	No. of inspections.	Situation.
F. Three-feet boards (red pine)	Aug. 27th–28th, 1919–March 7th, 1923	15	L.W. spr.
G. Shells on rope	Aug. 28th, 1919–April 23, 1921	8	,,

Series III.—Promenade Pier, Plymouth. Shells and sheets of copper and zinc were strung on tarred and clean rope around the inner piles under the Pier at low-water spring tide level.

Experiment.	Duration.	No. of inspections.	Situation.
H. Shells and metal sheets on rope	June 18th, 1919–Feb. 21st, 1920	8	L.W. spr.
J. Raft, Cawsand Bay	March–Oct., 1912	–	within the battens
K. Bathing rafts, Plymouth Sound	April–Oct., 1912–28	–	on lower surface

LIST (III) OF THE CHIEF* ORGANISMS GROWING ON OR IN THE EXPERIMENTAL MATERIAL AND CONTROLS.

PROTOZOA.

Folliculina ampulla, **20**, p. 257

PORIFERA.

Sycon coronatum, 185
Leucandra fistulosa
Leucosolenia sp., *185*
Halichondria panicea, 186
Halichondria sp.
Hymeniacidon sanguineum, 186

CŒLENTERATA.

TUBULARIA LARYNX, 190
Plumularia pinnata, 199
OBELIA GENICULATA, 193
Bougainvillea ramosa, 189
Clytia Johnstoni, 193
Gonothyræa Loveni, 194
Actinoloba dianthus, 205
(=*Metridium senile*)
Sagartia viduata Gosse, **18**, p. 111
(=*S. anguicoma* [Price])

POLYCHÆTA.

POMATOCEROS TRIQUETER, 232
HYDROIDES NORVEGICA, 232
Serpula vermicularis, 232
Sabella pavonina, 231
Polydora ciliata, 227
Sabella sp., small unidentified

POLYZOA.

Umbonula verrucosa, 262
BUGULA FLABELLATA, 260
Membranipora sp., *260*
CELLULARIA sp., prob. *neritina*

ECHINODERMATA.

Antedon rosacea, 207
Echinus miliaris, 210

MOLLUSCA.

Tergipes despectus, 279
Galvina exigua, 279
Galvina picta, 279

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* The names given in capitals are the predominant organisms in each group causing the fouling of the ships' bottoms and buoys. The figures in italics refer to pages in reference **10.**

Facelina Drummondi, 280
Dendronotus frondosus, 282
TEREDO NORVEGICUS
Pecten opercularis, 287
ANOMIA ACULEATA
MYTILUS EDULIS, 286
Helcion pellucida, 268
Patella vulgata, 268
Concholepas peruviana

CRUSTACEA.

BALANUS sp., probably *crenatus, 237*
B. perforatus, 237
B. TINTINNABULUM, **19**, p. 212
LIMNORIA LIGNORIUM, 243
CHELURA TEREBRANS, 241
JASSA sp., probably *falcata, 241*
CONCHODERMA VIRGATUM, **19**, 144
C. AURITUM, **19**, p. 144
LEPAS HILLI, **19**, p. 110
L. ANATIFERA, **19**, 108
Nautilograpsus minutus (=*Planes*), **22**, p. 135
Pilumnoides perlatus, **23**, p. 544, Plate 50
Cancer pagurus juv., *256*
Porcellana longicornis, 254
Carcinus mænas, 257
Leander serratus, 249

TUNICATA.

DIPLOSOMA GELATINOSUM, **27**, p. 87 (=*Leptoclinum* Hartmeyer, **28**, p. 1455)
BOTRYLLUS VIOLACEUS, 298
Botrylloides rubrum, 298
Morchellium argus, 297
ASCIDIELLA ASPERSA, 296
CIONA INTESTINALIS, 296
Molgula ampulloides

ALGÆ.*

LAMINARIA SACCHARINA
L. digitata
Ulva latissima
ENTEROMORPHA INTESTINALIS

DETAILED ACCOUNT OF THE COURSE OF THE EXPERIMENTS.

SERIES I. CAWSAND BAY RAFT.

Experiment A. Wooden ladder experiment.

In this experiment a ladder was made 3 feet long with eight rungs and fixed across the bottom of the raft. The side pieces of this ladder consisted of two battens of elm, 3 feet by 4 inches by 1 inch, while the rungs were made of smaller battens of elm, 1 foot by 2 inches by 1 inch. Six of the rungs were painted with the proprietary paints I to VI, noted on page

FIG. 1.—Showing the arrangement of the test-pieces treated with substances I to VI and VIII in the ladder experiment (A) on the Cawsand Bay Raft, begun August 18th, 1919 (reduced ca. $\frac{2}{17}$).

Each rung of the ladder was painted with the substance designated by the number (see p. 376) as well as the rectangular areas opposite the end of each rung. No. VII was left untreated as a control.

FIG. 2.—Same as Fig. 1, and showing the distribution of the growths of *Tubularia larynx* found on the test-pieces on September 30th, 1919, after 6 weeks' exposure in the sea.

I, II, and IV are clean and VI has a little growth; all the other test-pieces have acquired heavy growth.

FIG. 3.—Same as Fig. 1, and showing the distribution of various growths on October 9th, 1920, after about 14 months' exposure in the sea.

The growths shown are chiefly Ciona and Diplosoma with some Pomatoceros, Anomia, and colonies of hydroids.

I, II, and IV are still almost clean, but all the other test-pieces have a luxuriant growth.

Figs. 2 and 3 are reproduced from field sketches and notes. The taking of photographs at a later stage (as intended) was prevented by loss of the raft in a gale.

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* Many unidentified, including a brown filamentous Alga and a Polysiphonia sp.

FIG. 1 AUG. 18 1919

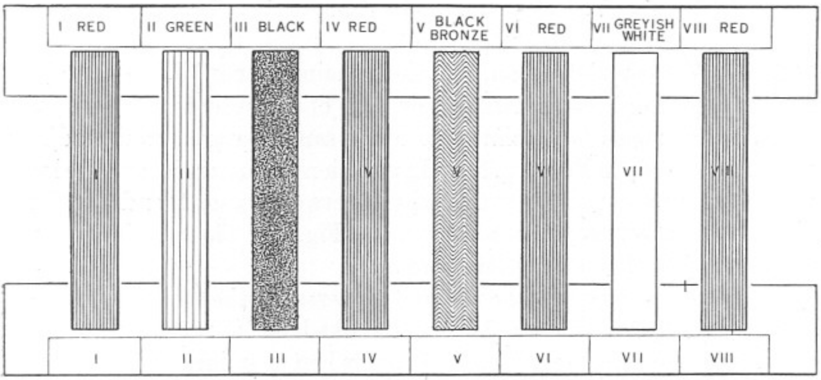


FIG. 2 SEPT 30 1919

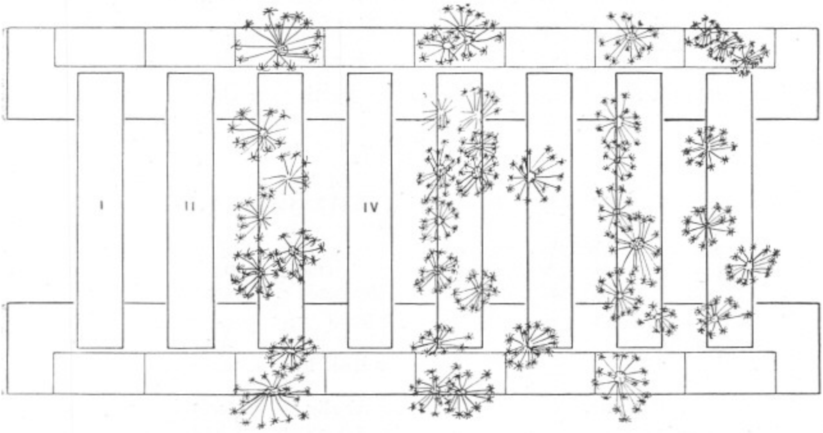
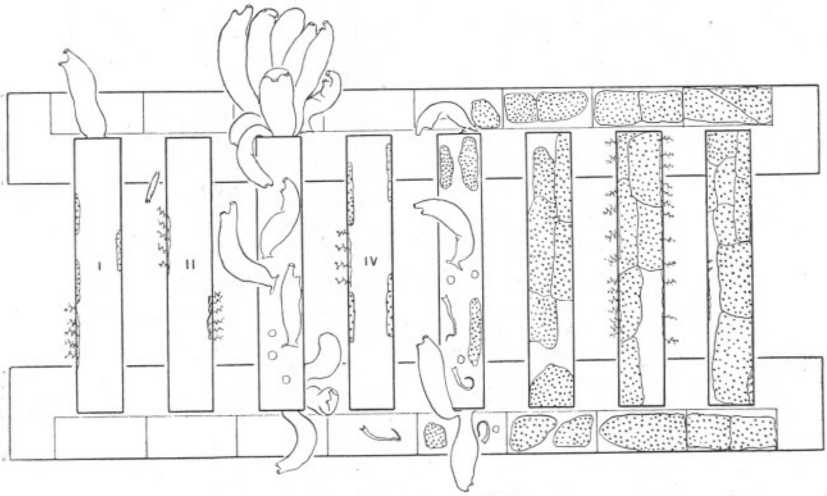


FIG. 3 OCT. 9 1920



376, one (VII) was left clean, and the remaining one (VIII) painted with red oxide (of iron) paint. An area on each of the outer sides of the ladder opposite the rungs was painted with the same material as the adjacent rung, as is shown in Fig. 1, p. 381. In addition the inner sides of the ladder were painted respectively with coal-tar between rungs 2 and 3 and with black varnish between rungs 5 and 6 (see Fig. 1). The remaining part of the sides of the ladder was left clean.

The ladder was fixed to the raft and immersed in the sea on August 18th, 1919. On September 30th, 1919, six weeks later, it was examined, with the result shown in Fig. 2, page 381, and when examined on the last occasion, on October 9th, 1920, it showed the growths depicted in Fig. 3, page 381. This experiment was not reported on again after October 9th, 1920, and the experiment, and indeed all the experiments on the raft, were lost after a gale on December 25th–26th, 1920.

In Table I below are given reports on the growths found on the two visits recorded and the condition of the paints on October 9th, 1920.

TABLE I.

REPORTS ON LADDER EXPERIMENT (A).

Designation and colour of surface.	Growths found on Sept. 30th, 1919 (exposed 6 weeks).	Growths found on Oct. 9th, 1920 (exposed *c.* 14 months).	Condition of paint on Oct. 9th, 1920.
I Reddish brown A–F	None	A little Diplosoma, a few small hydroid colonies, and a little Podoceros	Nearly all gone
II Green, A–F	None	Practically clean: only a few small colonies of hydroids	Very soft
III Black A–C	Large growth of Tubularia and some small Pomatoceros	Enormous Ciona and some Anomia	Apparently good
IV Reddish brown A–F	None	A little Diplosoma and hydroids and one large Pomatoceros	Fairly good
V Blackish bronze A–C	Large growth of Tubularia and some small Pomatoceros	Large Ciona, some Anomia, Pomatoceros, Diplosoma and hydroids	Apparently good
VI Reddish brown A–F	Slight growth of colonies of Tubularia	Covered with Diplosoma which also extends in parts over the paint	Mostly washed off
VII Greyish white untreated	Large growth of Tubularia and some small Pomatoceros rather less than in III and V	Covered with Diplosoma and hydroids	Originally clean
VIII Red, A–C	Same as on VII	Covered with Diplosoma	Mostly washed off

Results of Experiment A.

In this situation and under the conditions described the poisonous paints I, II, and IV retained their growth-inhibiting properties during about fourteen months and only permitted slight growth on parts where the paint had probably washed off more rapidly than in others. The anti-corrosive paints III and V, as well as the clean board VII and the red oxide board VIII, all developed extensive or very extensive growth, within as short a period as six weeks, and developed heavy growths subsequently. The anti-fouling paint VI also developed a slight growth in six weeks and a heavy covering of growth later, and is therefore inefficient as an anti-fouling paint under these conditions. At the end of the experiment, however, paints III and V were in a better condition than any of the others. It is of interest to note that the red oxide was mostly washed away in just over a year. The anti-fouling paints II, IV, and I were efficient in this order after about fourteen months in the sea under these conditions.

Experiment B. Board of Squares.

In this experiment a single piece of wood, 3 feet by 4 inches by 1 inch, was prepared by painting 4 inch squares with each of the paints I to VI and VIII, and leaving one square (VII) and a strip of 2 inches at each end clean (see Fig. 4, p. 385). This board was screwed on the bottom of the Cawsand Bay raft in the same way as in the ladder experiment (p. 380) and at a little distance from it. The board was screwed to the bottom of the raft and exposed to the sea on August 18th, 1919; it was examined on September 30th, 1919, after being in the sea six weeks, and last seen on October 9th, 1920. On September 30th, 1919, the growth found on the board is shown in Fig. 5, p. 385, and is described as follows :—

TABLE II. REPORT ON BOARD OF SQUARES EXPERIMENT, SEPTEMBER 30TH, 1919.

	Designation and colour of surface.		Growths found on Sept. 30th, 1919 (exposed 6 weeks).
I	Reddish brown ;	A–F	None.
II	Green ;	A–F	None.
III	Black ;	A–C	Three colonies of Tubularia.
IV	Reddish brown ;	A–F	None.
V	Black bronze ;	A–C	Three colonies of Tubularia ; some Obelia *with Nudibranchs and spawn.*
VI	Reddish brown ;	A–F	None.
VII	Greyish white ;	untreated	One colony of Tubularia and some small Pomatoceros.
VIII	Red ;	A–C	Also one colony of Tubularia and some small Pomatoceros.
Ends	Greyish white ;	untreated	One colony of Tubularia on one end.

On October 9th, 1920, this board was seen for the last time, and found at that time to have similar growths on each paint or surface as was shown on the rungs of the ladder experiment (see Table I, p. 382). No special report on this board was written down on this day at the moment of observation owing to the advent of bad weather conditions.

Results of Experiment B.

The results from Experiment B were in all respects similar to those obtained from Experiment A (see p. 383).

Experiment C.

On boards 1 foot by 2 inches by 1 inch, treated in the same way as the rungs in the ladder experiment (see p. 380) *and exposed to light.*

These boards were placed vertically on the outside at the ends of the sides of the raft with the bottom end of each board flush with the bottom of the raft. The boards were thus placed 1 to 2 feet below the surface of the water and were exposed to direct water-filtered sunlight, and possibly at times for an instant to direct light.

As in the case of experiments A and B, this experiment was begun on August 18th, 1919, examined on September 30th, 1919, and last seen on October 9th, 1920. The reports given in Table III show the varying degrees to which growth was inhibited in this habitat.

Results of Experiment C.

After six weeks in the sea the same four substances, namely I, II, IV (and VI), resisted growths of seaweed as they did of animals in the contemporaneous experiments A and B (see pp. 383–4). In the same period, i.e. August 18th to September 30th, 1919, the remaining boards III, V, VII, and VIII all became covered with a growth of seaweed, probably mainly of Enteromorpha. Contrary to experiments A and B, however, slight growths of other seaweeds manifested themselves on the former (and poisonous) compositions already on March 2nd, 1920, only seven months after immersion. After about fourteen months in the water the compositions II, IV, and I had definite growths of a short filamentous brown Alga, in contrast with the slight growths on these compositions in situations exposed only or mainly to animal growth, i.e. under the raft, while the remaining boards after fourteen months all had Laminaria as well as other growths. The paint compositions II and IV were the only ones not permitting growth of Laminaria, and there can be little doubt that they were exposed to the same or a similar degree of "infection" as the others.

FIG. 4

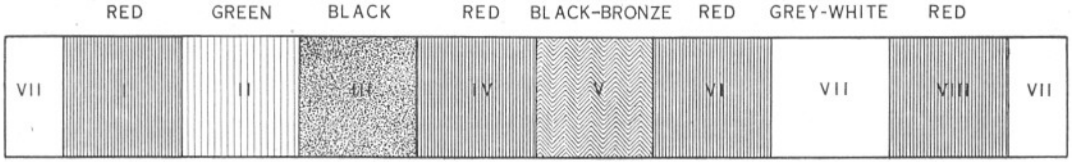


FIG. 5

FIG. 6

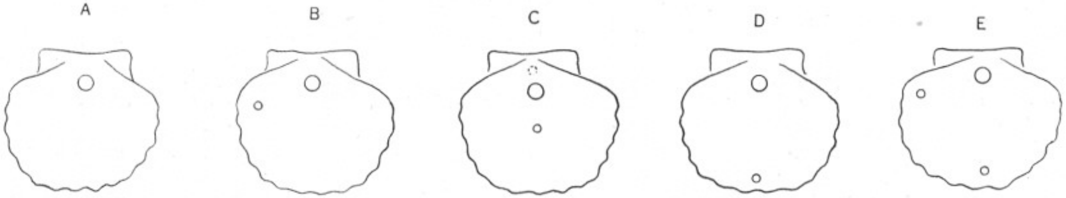


FIG. 4.—Showing the arrangement of the areas painted with substances I to VI and VIII in the Board of Squares experiment (B) begun August 18th, 1919, on the Cawsand Bay Raft.

FIG. 5.—Same as Fig. 4, showing the distribution of colonies of Tubularia on the Board of Squares experiment (B) on September 30th, 1919, after 6 weeks' exposure in the sea.

I, II, IV, and VI are clean, while all the other test-areas have acquired and permitted luxuriant growths of Tubularia.

FIG. 6.—Scheme of the borings made in the painted scallop shells to serve for their identification while exposed in the sea.

A.	One sub-central hole	III Black; I Red; II Dark green; III Aluminium.
B.	.. and a lateral hole.	IX Black; IV Red; XI Light Green.
C.	.. and a central or umbonal hole.	VIII Red.
D.	.. and a ventral hole.	V Black-bronze; VI Red.
E.	.. and a lateral and a ventral hole.	X Black.

The untreated shells (VII) had also in most experiments only one hole, sub-central.

Table III.

Reports on Growths on Test-pieces Exposed to Light on the Cawsand Bay Raft.

Designation and colour of surface	Growth on Sept. 30th, 1919 (exposed 6 weeks).	Growth on March 2nd, 1920 (exposed 7 mths.).	Growth* on Oct. 9th, 1920 (exposed *c.* 14 mths.).
I Reddish brown A–F	None	All with some growth of weed.	Small Laminaria and scum of a brown Alga
II Green A–F	None		Scum of brown Alga only
III Black A–C	Large growth of seaweeds (probably mainly Enteromorpha)		Small Laminaria, Balanus and a scum of brown Alga
IV Reddish brown A–F	None	The Green board appears† to have relatively little growth on it.	Scum of brown Alga only
V Black-bronze	Large growth of seaweed (probably mainly Enteromorpha)		Small Laminaria, small Ulva, good colony of red weed and Anomia
VI Reddish brown A–F	None		Laminaria of medium size, Enteromorpha and Ulva
VII Greyish white untreated	Covered with a growth of weed (probably mainly Enteromorpha)		Laminaria of medium size, Enteromorpha and Ulva
VIII Red A–C	Covered with a growth of weed (probably mainly Enteromorpha)		do.

The boards were fixed on one side of the raft in groups of four near each end in the following order and relation to the ends of the raft :—

(*a*) One end, IV, III, I, II—middle—V, VIII, VI, VII, the other end (*b*).

At the (*a*) end I and III grew Laminaria, as well as those at the (*b*) end, and Laminaria was growing over most of the lower sides of the raft. On the other hand, all the boards at the end (*a*) had a brown scum and no green weeds (Enteromorpha and Ulva), while the boards at the (*b*) end all grew green weeds ; the examination of these four boards had to be performed rapidly, and it is not now certain that these boards had not also a growth of the brown algal scum.

---

* All the painted boards had more or less paint remaining, but a careful examination could not be made on this date owing to the onset of bad weather.

† There was too much wind and wash of the waves to examine the boards thoroughly on this visit.

Thus, although it is unlikely, it is possible that the general conditions were not favourable for the settling and growth of the green weeds at the (*a*) end of the raft. There was a good general growth of the green weeds on the top and sides of the raft, but the detailed distribution was not recorded at the time, and in future experiments it is clear that periodical observations of this kind should be made. Under the conditions of the experiments A, B, and C there are distinct indications that the better toxic paints II, IV, and I are less toxic to marine algæ than to marine animals, but in order to confirm this indication it will be necessary to know whether light itself affects the toxicity of the paints.

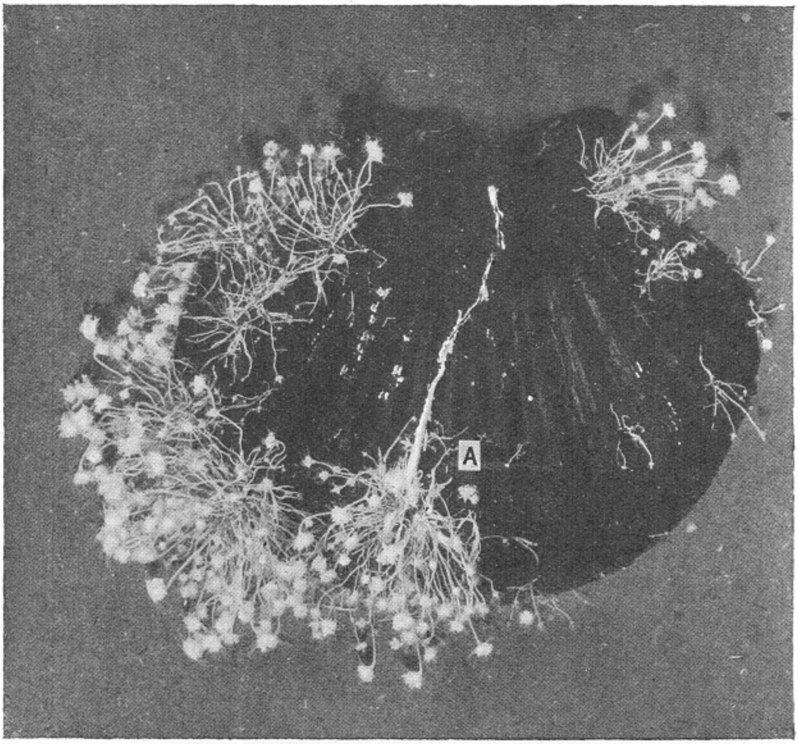


FIG. 7.—Photo of shell with a heavy growth of *Tubularia larynx* from Experiment D, Cawsand Bay raft, coated with substance No. V; exposed in the sea from August 18th, 1919, to September 30th, 1919. (Photo by D. P. Wilson.)

The distinguishing mark of the shell, a small hole ventral, is shown below A, near the lower margin of the shell to the right of the white vertical line in the middle of the shell. The shell was broken into two parts to permit the preservation of the Tubularia in a bottle. A large colony of this hydroid has been taken from the shell in order to expose the distinguishing hole.

In this respect a chemical analysis of painted surfaces exposed contemporaneously in strongly lighted and diffusely lighted, but otherwise equivalent, situations respectively would probably yield significant information.

Experiment D.

Shells of the scallop, Pecten maximus, *were painted with a variety of substances, strung on tarred rope, and secured to the bottom of the outside of the raft in Cawsand Bay.*

Each of the substances (I to VI and VIII, see p. 376) being tested was painted on to a variable number, about ten, scallop shells, which were marked by a boring in a particular place for identification in the manner shown in Fig. 6, p. 385. The painted shells with clean control shells were put out on August 18th, 1919, and examined on September 30th, 1919, October 9th, 1920, and brought in and preserved October 23rd, 1920.

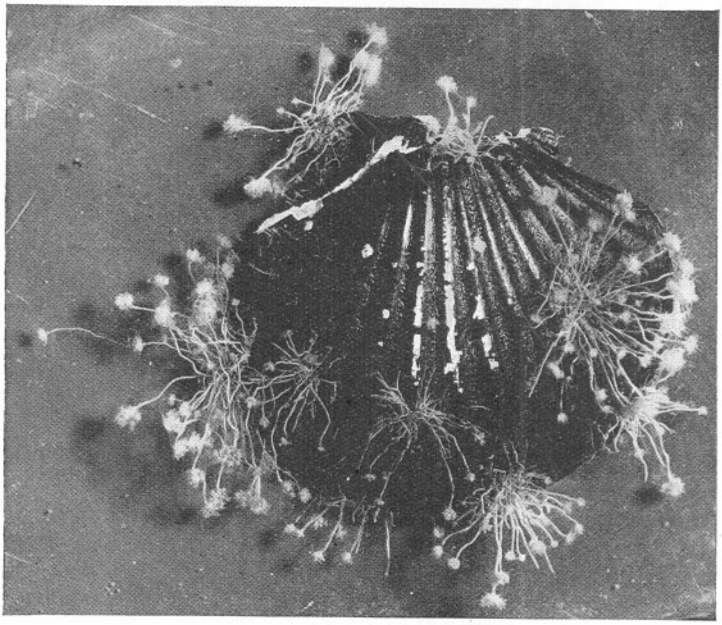


FIG. 8.—Photo of scallop shell from Experiment D_1, Cawsand Bay raft, painted with No. III substance (Black) showing the growth of *Tubularia larynx* on September 30th, 1919, after 6 weeks' exposure in the sea. (× ca. $\frac{3}{5}$.) (Photo by D. P. Wilson.)

Compare Fig. 2, p. 381, and Fig. 5, p. 385. The shell was broken at one corner of the hinge to permit entry into a bottle for preservation. The shell is viewed from the rough outer surface and now shows signs of rubbing on the radiating ridges

The following note was written at the time the shells were put out, and as it is of importance in interpreting the results obtained it is given as written :—

"Two good coats of the paints were given to each shell. Unfortunately, some shells of all paints showed signs of rubbing on the smooth surface when the shells were put out. This was due to the necessity of carrying the shells to the wharf in baskets, during which time the jolting rubbed small patches of paint off the smooth surface of the shells. No case was seen of the paint on the rougher surface being broken. It is, therefore, obvious that paints of this kind chip or rub off very readily on a smooth surface, a fact of importance to be remembered in working with it, and drawing deductions from experiments. On recording subsequent growth on these shells, it is therefore necessary to take into account the condition of the paint at the time an observation is made. These rubbed shells may give valuable information regarding the arrest (or otherwise) of growths by paint if the rubbed areas permit growth and the paint composition inhibits such."

It will be shown later that marine growths were frequently observed on areas of shells denuded of paint, and confined to such areas by the inhibiting (i.e. poisoning) action of the adjacent painted area. Moreover, a painted shell might give an erroneous indication of permitting growth if denuded areas occur and fail to be observed ; and indeed in all experiments of this kind such a possibility must be constantly borne in mind.

The growth observed on these shells is shown in Table IV below and in Table V, p. 390, and Figs. 7, p. 387, and 8, p. 388.

It is noteworthy that *some* of the suspended shells in this experiment grew Laminaria, and were doubtless exposed to dim light.

TABLE IV. EXPERIMENT D_1.

REPORTS ON GROWTHS ON TREATED SHELLS SUSPENDED OUTSIDE THE BOTTOM OF THE RAFT IN CAWSAND BAY ON AUGUST 18TH, 1919.

Designation and colour of surface.	Growth observed on Sept. 30th, 1919 (exposed 6 weeks).	Growth observed on Oct. 9th, 1920 (exposed *c.* 14 months).
I. Reddish brown, A–F	None, except small Tubularia at edges of one shell	
II. Green, A–F	None	All shells except No. II, green, with more or less growth similar to that on the boards in Experiment A (see Table I, Oct. 9th, 1920, p. 382)
III. Black, A–C	Large growth of Tubularia and some Pomatoceros	
IV. Reddish brown, A–F	None	
V. Black-bronze, A–C	Not observed. See Table VI, p. 392	
VI. Reddish brown, A–F	None, except a little Tubularia on edge of one shell	
VII. Greyish white untreated	Large growth of Tubularia on shells at one end of raft, very little growth at the other end	
VIII. Red, A–C	Fair growth of Tubularia	

Table V. Experiment D_1.

Report on Growths and condition of the Paint on Treated Shells suspended outside the bottom of the Cawsand Bay Raft on October 23rd, 1920, when the Shells were brought to the Laboratory and Examined and Preserved. (See Fig. 9, p. 393 and Fig. 10, p. 395.)

Designation and colour of the surface and the number of shells.	Condition of the paint on the (a) smooth and (b) rough outside surface of the shells.	Growth on the shells on (a) smooth (inside) and (b) rough (outside) surface.
I Reddish brown A–F 7 shells.	(a) *Smooth inside surface.* Almost all washed off.	(a) Almost all covered with Tubularia and other hydroids. Some Balanus, Pomatoceros, Anomia, much Diplosoma, Ciona (9·5 cm. contracted).
	(b) *Rough outside surface.* Almost all washed off except in the hollows.	(b) Organisms overgrowing paint in parts, but restricted in some, but not in others, by the paint. Some Balanus, Pomatoceros, many Anomia, much Diplosoma and extensive growth of Tubularia and other hydroids.
II Green A–F 6 shells.	(a) *Smooth inside surface.* Nearly all washed off in all but one, which is still half-covered with paint.	(a) Practically no growth on the paint. Diplosoma and Pomatoceros are overgrowing the paint a little in parts, but on the whole the growth of Diplosoma is obviously still limited to the area of clean (i.e. denuded) shell, and shows little inclination to extend over the paint. Some Balanus, Anomia, Umbonula, Mytilus, as well as Diplosoma and Pomatoceros on the clean parts, and also Tubularia and other hydroids.
	(b) *Rough outside surface.* The paint is about half washed off on the crests, but entire in the hollows on all shells but one, which is still covered by paint.	(b) Growth nil.
III Black A–C 8 shells	(a) *Smooth inside surface.* Washing off all more or less.	(a) Covered with an abundant growth. Some Ciona up to 12 cm. (con.), some Ascidiella up to 7·5 cm. (con.). Actinoloba (greeny brown) 6 cm. at base (con.) with column 3 cm. high (con.). Some Anomia, Pomatoceros, Hydroides, Serpula, Diplosoma, Umbonula, Tubularia and other hydroids, many small Sycon on Ascidiella, large Balanus and many small tubicolous Sabellid worms.
	(b) *Rough outside surface.* None of the paint washed off.	(b) Growths entirely covered 3 shells and almost covered the remaining 5. Some Anomia, Pomatoceros, Hydroides, Umbonula, Diplosoma, many colonies of hydroids and also the seaweed Laminaria, and a red seaweed.

Designation and colour of the surface and the number of shells.	Condition of the paint on the (a) smooth and (b) rough outside surface of the shells.	Growth on the shells on (a) smooth (inside) and (b) rough (outside) surface.
IV Reddish brown A–F 6 shells	(a) *Smooth inside surface.* More than half the paint is washed off 5 shells; one with five-sixths of the paint still adhering.	(a) Some shells are covered with growth even where the paint has remained: in others Diplosoma shows restriction by the paint. Much Diplosoma and Tubularia, 1 Anomia, 2 Hydroides, 2 Balanus and 2 Mytilus.
	(b) *Rough outside surface.* The paint is almost entire on 5 shells.	(b) Three shells (one covered still with paint) have no growth. Tubularia only is present on one shell. Diplosoma is overgrowing half to one-third of the two other shells, which have also 2 Balanus and one Sabellid polychæte.
V Black-bronze A–C 5 shells	(a) *Smooth inside surface.* A very little washed off some, more than half off others.	(a) Mostly well-covered with growth of Serpula, Pomatoceros, Hydroides, Tubularia, and other hydroids, Anomia, Balanus, Membranipora, Diplosoma, and Bicellaria.
	(b) *Rough outside surface.* Three shells with paint entire but washed off one, and probably rubbing off another.	(b) The same as in (a) above with, in addition, Ascidiella and Umbonula.
VI Reddish brown A–F 7 shells	(a) *Smooth inside surface.* Almost all washed off.	(a) Covered with growth: comprising:— Many Pomatoceros, some Hydroides, Anomia, Balanus, Ascidiella 7 cm. (con.), Sabella (10·8-cm. tube), much Diplosoma, Tubularia, and other hydroids, Membranipora, small tubicolous Polychætes, *Laminaria saccharina* with roots growing around the edge.
	(b) *Rough outside surface.* A fair amount of paint left on some, but little on other shells.	(b) All shells practically covered with growth, which is obvious even over the paint. About 20 plants of *Laminaria saccharina* on one shell, and 3 other shells with 1 to 5 plants: fronds up to 96 cm. long by 15 cm. wide. Many Hydroides, few Pomatoceros, Balanus, and Anomia, much Tubularia and other hydroids, and Diplosoma overgrowing many shells. Mytilus up to 22 mm. in length.
VII Greyish white untreated 6 shells	(a) *Smooth inside surface.* Untreated.	(a) Covered with growth. Ascidiella up to 7 cm. (con.); Ciona up to 6·5 cm. (con.). Tubularia and other hydroids, many Anomia, Balanus 2 species, Umbonula, Pomatoceros, Sabella, and other tubicolous Polychætes, young Actinoloba (?), and seedlings of Laminaria.
	(b) *Rough outside surface.* Untreated.	(b) Covered with growth. Ascidiella up to 6·3 cm. (con.), Balanus, Anomia, Pomatoceros, Tubularia, and other hydroids, Actinoloba 3 × 4·5 cm. at base and column 1 to 1·5 cm. high (con.), 12 small seedlings of Laminaria.

Designation and colour of the surface and the number of shells.	Condition of the paint on the (a) smooth and (b) rough outside surface of the shells.	Growth on the shells on (a) smooth (inside) and (b) rough (outside) surface.
VIII Red A–C 5 shells	(a) *Smooth inside surface.* Almost all washed off.	(a) All covered with growth: 4 Ciona up to 11 cm. long (con.); 3 Ascidiella up to 8 cm., many Anomia, several Pomatoceros, much Tubularia, and other hydroid growth, 3 Balanus and one tubicolous Polychæte.
	(b) *Rough outside surface.* Almost all washed off.	(b) All covered with growth: *Laminaria saccharina* frond 105 cm. slightly broken × 14 cm. wide. *Laminaria Digitata* (?) 60 cm. broken × 13 cm. wide. Many Balanus, Anomia, Hydroides, some Pomatoceros, Serpula, and many colonies of Tubularia with other hydroids. (See Fig. 11, p. 397.)

Experiment D_2.

Shells of the scallop, Pecten maximus, *were painted with a variety of substances and fixed to the outside of the bottom of the raft in Cawsand Bay on August* 18*th,* 1919.

In addition to substances I to VI and VIII, black varnish, No. IX substance, p. 376, was also painted on to five shells in this experiment. These shells permitted growth in the same way as those strung under the raft (see Table V), except that the Nudibranch, *Facelina drummondi,* crawled on to and deposited spawn on the colonies of *Tubularia larynx* which were growing on some of the painted substances (as is shown in Table VI below) on September 30, 1919.

TABLE VI.

REPORT ON GROWTH AND CONDITIONS OF PAINT ON SHELLS NAILED TO THE OUTSIDE OF THE BOTTOM OF THE CAWSAND BAY RAFT.

	Growth Sept. 30th, 1919* (exposed 6 weeks).	Growth Oct. 9th, 1920 (exposed *c.* 14 mths.).
I. Reddish brown A–F	None	All shells except No. II with more or less growth similar to that on the boards on Oct. 9th, 1920, in Experiment A. (See Table I, p. 382.) No. II has no growth on 5 shells. No. IV has only slight growth. No. IX has large Ciona.
II. Green, A–F	None	
III. Black, A–C	Large colonies of Tubularia and Pomatoceros	
IV. Reddish brown A–F	None	
V. Black-bronze, A–C	Large colonies of Tubularia with Nudibranch spawn and two shells with Pomatoceros	
VI. Reddish brown A–F	None	
VII. Greyish white untreated	Large colonies of Tubularia with Nudibranch spawn and Pomatoceros	
VIII. Red, A–C	Large colonies of Tubularia and Nudibranch spawn	

* Tubularia observed growing on the heads of the iron nails used for the experiment.

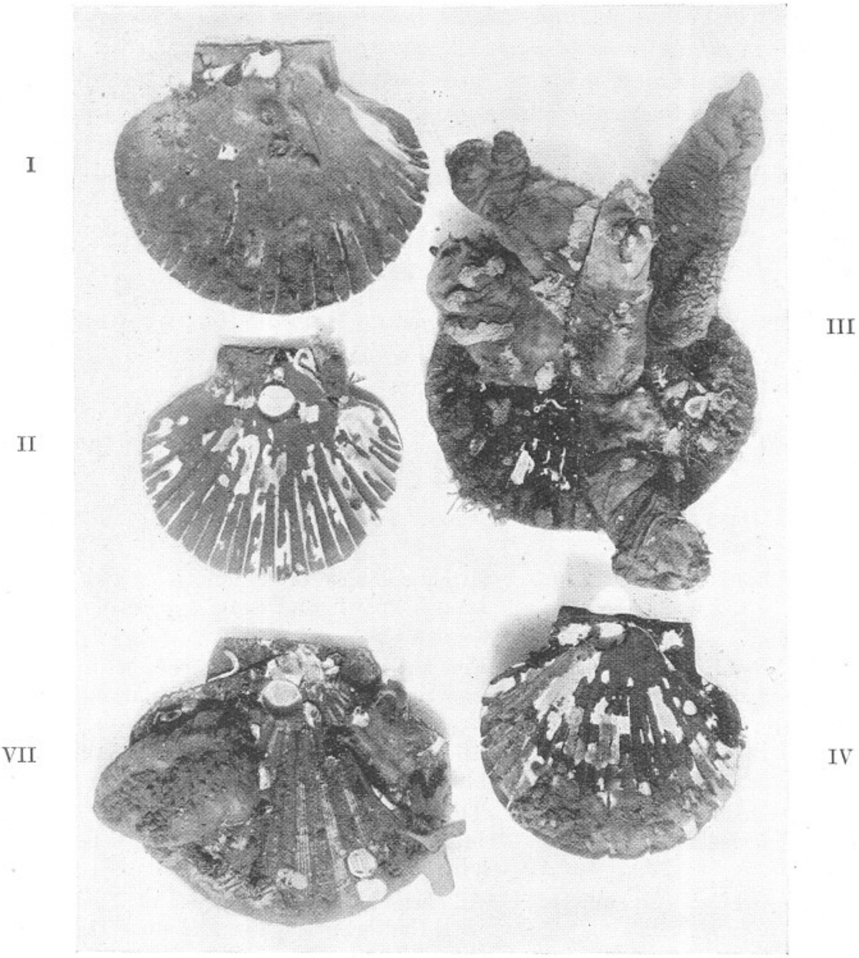


FIG. 9.—Photo of shells from Experiment D_1, Cawsand Bay Raft, October 9th, 1920 ; exposed to the sea on August 18th, 1919. See Table V, p. 390. (× ca. $\frac{2}{5}$.) (Photo by D. P. Wilson.)

I Red : with much Diplosoma and also Balanus and Hydroides, Anomia and a little Tubularia. Very little paint is left on this, the smoother, surface of the shell.

II Dark green : with Diplosoma and Hydroides growing on the hinge-line, but no growth elsewhere. The paint is shown to be washing off badly : smooth surface view of shell.

III Black : with Ciona and Diplosoma mainly, but also with Hydroides, Anomia, and Tubularia : smooth surface view of shell.

IV Red : with Diplosoma mainly and mostly confined to areas denuded of paint. The paint is washing off badly from the smoother surface of the shell as shown.

VII An untreated shell with Ascidiella, Anomia, Pomatoceros, Balanus, and Laminaria : the rougher surface of the shell is shown.

Experiment E.

Shells of Pecten maximus *treated and strung on tarred ropes or nailed inside the raft at Cawsand Bay on August* 18*th,* 1919.

Observations were made on these shells at various times, and growth and resistance to growth found to occur in the order shown in experiments A to D.

One full report of the hanging shells was made on October 22nd, 1919, as in Table VII.

TABLE VII.

REPORT ON SHELLS STRUNG ON TARRED ROPE INSIDE THE MIDDLE COMPARTMENT OF THE CAWSAND BAY RAFT.

		Growth on October 22nd, 1919 (exposed *c.* 9 weeks).
I	Reddish brown ; A–F 5 to 8 shells	None.
II	Green ; A–F 8 shells	None : 2 shells peeling.
III	Black ; A–C 5 to 8 shells	Large colonies of Tubularia with Nudibranch spawn and some Pomatoceros on all shells.
IV	Reddish brown ; A–F 8 shells	Five shells no growth : 2 shells with small growth and one with fair growth of Tubularia.
V	Black-bronze ; A–C 5 to 8 shells	All shells with large colonies of Tubularia and some Pomatoceros.
VI	Reddish brown ; A–F 5 shells	Three shells with only spawn of the Nudibranch *Facelina drummondi :* 2 shells with a little Tubularia.
VII	Greyish white untreated 5 to 8 shells	All shells have large colonies of Tubularia with Nudibranch spawn and some Pomatoceros.
VIII	Red ; A–C 8 shells	Seven shells with Tubularia and one clean : the paint is peeling off 3 shells.

HISTORY OF THE GENERAL GROWTH ON THE RAFT IN CAWSAND BAY.

The history of the growth observed on and in the raft from time to time is important in relation to the growth found on the adjacent treated and untreated shells, and is best shown in a condensed form as follows in Table VIII.

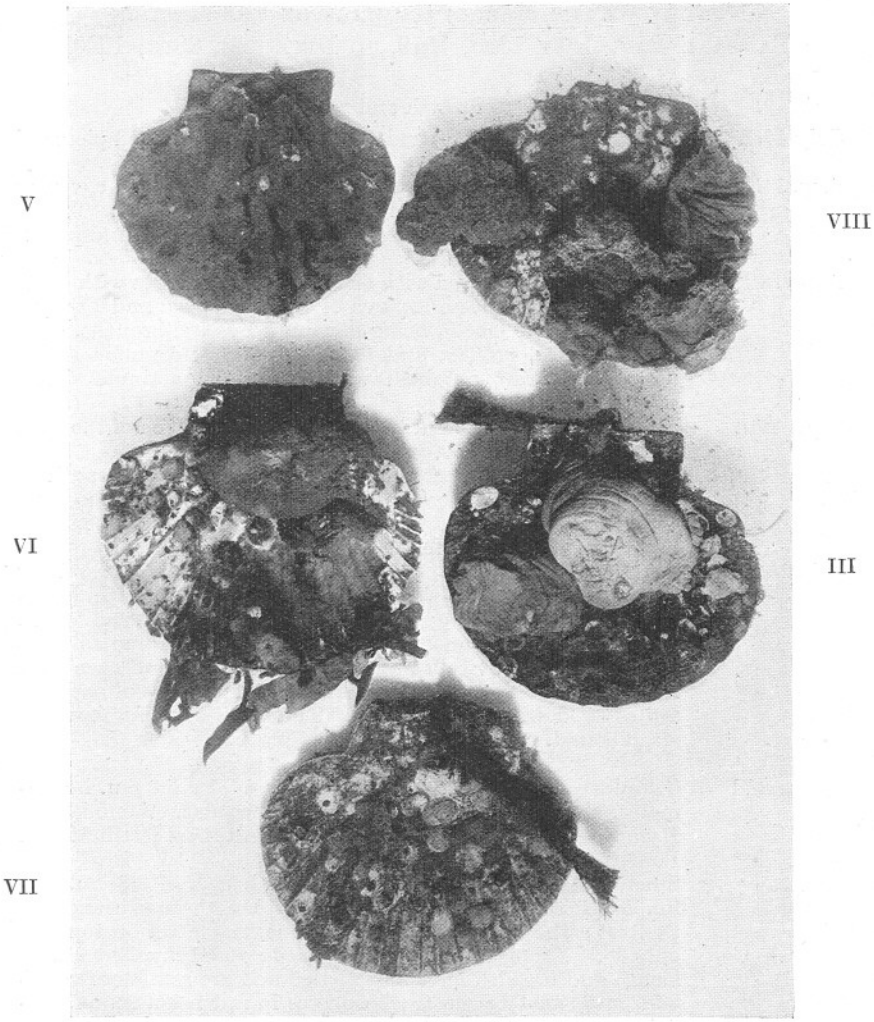


FIG. 10.—Photo of shells from Experiment D_1, Cawsand Bay Raft, October 9th, 1920. See Table V, p. 390. (× ca. $\frac{2}{5}$.) (Photo by D. P. Wilson.)

V Black. Outer (rough) surface of a convex valve with the paint still almost entire, but with Balanus, Anomia, Pomatoceros all becoming overgrown with Diplosoma.

VI Red : view of inner (smooth) surface of a convex valve almost denuded of paint, with a large Ascidiella, Dasychone, 15 individuals of Anomia, some Diplosoma, and several roots of Laminaria.

VIII Red : smooth surface of a flat valve now denuded of paint : with four large Ciona, 13 Anomia, one Balanus, some Diplosoma, and Tubularia.

III Black : inner surface (smooth) of a convex valve ; with one large and one small Actinoloba, one large Ciona, several Hydroides, and Balanus, one Pomatoceros, one Anomia, and a little Diplosoma and Tubularia. The paint is almost entire and is being telescoped on the shells of the Balanus.

VII Untreated : inner smooth surface view : with Balanus, Pomatoceros, numerous Anomia, all becoming overgrown with Diplosoma, some Botryllus, Hydroids and a root of Laminaria.

TABLE VIII.

HISTORY OF THE MARINE GROWTHS ON THE RAFT IN CAWSAND BAY, JULY 16TH, 1919, TO DECEMBER 28TH, 1920.

1919.	Growth and remarks.
July 16th	Raft put in the sea, tarred and dried, with attached pieces of untreated wood.
Aug. 7th	Obelia with spawn of Tergipes and *Galvina exigua* covering the bottom of the raft. Veligers already in the spawn. Teredo in borings about $\frac{1}{2}$ inch long (perforated zinc crab-and-prawn cage put inside the raft).
Aug. 18th	Bottom of raft covered with dense growth of Obelia with great abundance of adult and spawn of *Galvina exigua* and *Tergipes despectus*. The Obelia being devoured by Nudibranchs. *Galvina picta, pallida,* and *farrani* types all common and a little Tubularia[*] obtained which extruded actinula larvæ overnight.
Sept. 30th	Large colonies of Tubularia common on the bottom of the raft, with abundant Pomatoceros and Nudibranchs.
Oct. 10th[†]	*Facelina drummondi* common on the raft up to a length of 3·6 cm. extended : numerous masses of its spawn on the large colonies of Tubularia, which at one end of the raft mostly have the "heads" eaten off.
Oct. 28th	The prawn *Leander* (=Palæmon) *serratus* has settled in numbers and grown *in situ* to a length of 4·3 cm. inside the perforated cage along with young *Cancer pagurus* which have a carapace diameter of 7 to 10 mm. Two fine colonies of Bugula (with ovicells and ova) in the perforated cage with Anomia, Tubularia, and Nudibranchs. The sides of the raft are covered with young Ciona. Tubularia and Nudibranchs still abound.
1920.	
March 2nd	Colonies of Membranipora sub-circular 4·5 by 5·0 cm. in diameter, and of Umbonula 2·2 cm. sub-circular. Anomia and Hydroides mature, and gave successful artificial fertilisations. Pomatoceros mature.
Oct. 9th	Small *Antedon rosacea* with arms to a length of 3·8 cm. and limpets, *Patella vulgata,* 8 to 13 mm. in length have settled on the raft ; the former below and inside, the latter on top and outside. Young *Pecten opercularis* up to 31 by 29 mm. in length and breadth have also settled and are sexually mature and gave good brown trochospheres in fair numbers on artificial fertilisation (a cross fertilisation was made in this case, *P. opercularis* is hermaphrodite). *Sabella pavonina* with tubes up to 17 cm. long by 4·5 mm. wide fairly common, and abundant adult Sycon and some Leucandra. The top of the raft is covered with Enteromorpha and some Ulva. (Put out on the raft fresh clean pieces of wood.)

[*] Tubularia was specially searched for on August 7th, and not seen : it is probable, therefore, that these small colonies grew in about eleven days.

[†] On this day a remarkable Galvina was taken : it had the characteristics of all three types—*picta, pallida, farrani*—in one individual. The lateral cerata were orange tipped ; the median, brown tipped, and the dorsal part of the body was splashed with reddish brown patches as is the case in *picta*.

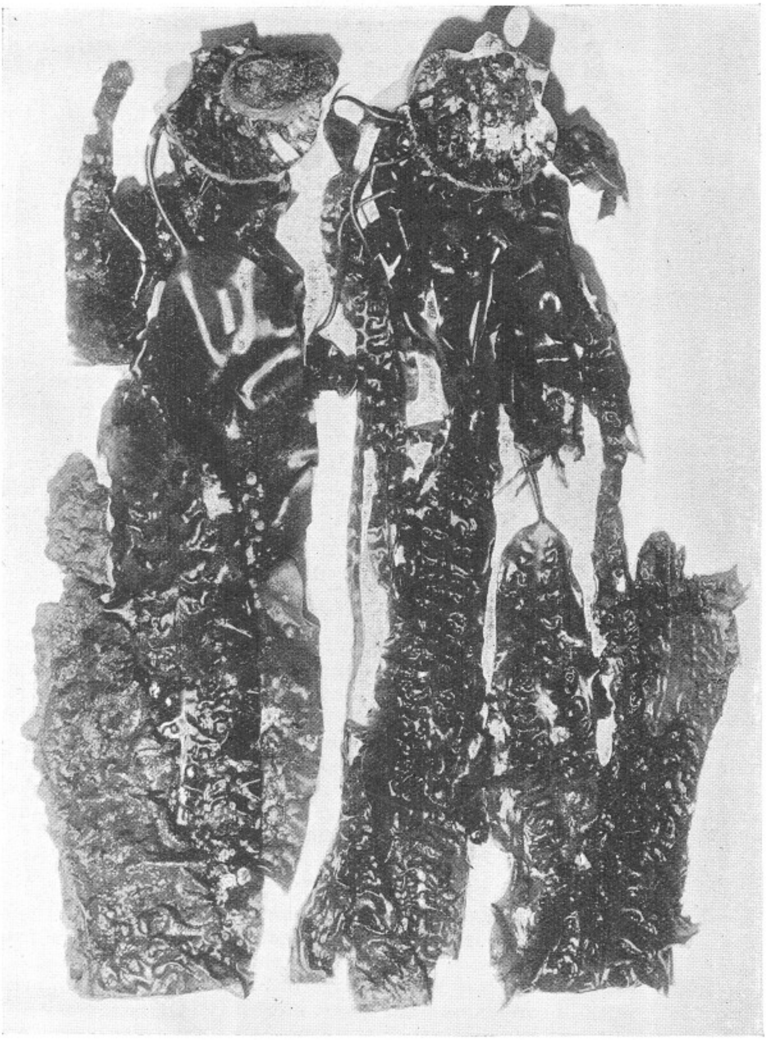


FIG. 11.—Two shells from Experiment D_1, Cawsand Bay Raft, October 9th, 1920, with many large Laminaria fronds. (× ca. $\frac{1}{5}$.) (Photo by D. P. Wilson.)

The convex shell on the left was painted with No. VIII substance, red, which was almost all washed away from the inner (smooth) surface shown. On this shell, besides the Laminaria fronds, which have been folded, are one large Ascidiella, 13 Anomia, Pomatoceros, Hydroides, and Tubularia.

The convex shell on the right was painted with No. V substance, red, which remains only in traces on the smooth inner surface shown. Besides Laminaria, there are shown in this view of the shell, 4 large Balanus, 23 Anomia, one *Sycon coronatum*, and much Diplosoma. The larger fronds of Laminaria are folded along about half their length, and are themselves covered with numerous colonies of Diplosoma, some Botryllus and Obelia.

1920. Growth and remarks.

Oct. 23rd The raft is covered with Laminaria, and red weeds on the sides and green weeds on the top, but underneath and inside with animal growths. Samples of the growths were brought in to the Laboratory and examined as follows :—

Species.	Length of plant in cm.	Width of frond in cm.	Width of stipes in mm.	Remarks.
Laminaria saccharina	95	14	4	Frond frayed at end.
,, ,,	102	12	4	,, ,, ,, a little.
,, ,,	88	10	3·5	,, ,, ,,
,, ,,	110	16	4 to 6	Broken: possibly twice as long in uninjured condition.
,, ,,	143	15·6	8·5	Slightly broken.
,, ,, young	12·5	2·6 to 2·8	2 to 3	Entire.
,, ,, young	60	4·6	4 to 6	Entire.
L. digitata	83	32	8	Broken and covered with Membranipora on both sides.
L. digitata stipes and root	16	—	—	
,,	88	21	8·5	Frond broken.
,,	59	—	6·5	Frond broken with a colony of *M. membranacea* 25 × 5·5 cm. sub-rectangular.
,, young	23	—	3·8	Frond entire.
	29	—	5·5	,,

Helcion pellucida 6·8 mm. long was taken from the stipes of Laminaria and *Mytilus edulis* up to 24 mm. long were common among the roots of the same plants. There was a heavy growth of animals inside and at the bottom outside, the dominant forms being Pomatoceros, Anomia, Hydroides, Ciona, Ascidiella, Diplosoma, Balanus, Sycon, Podoceros (=Jassa), Tubularia, and other hydroids with various Nudibranchs and various Polyzoans. Among the less abundant and occasional forms were Sabella and other smaller Sabellids, Serpula, Pecten, Patella, Mytilus, Helcion, Antedon, Leucandra, Actinoloba *juv.*, Leander, Cancer *juv.*, Porcellana, and Carcinus *juv.*

1920.

Nov. 11th On this day the mooring chain and shackles were overhauled and made secure, as it was probable that it would be many months before observations on these experiments could be resumed owing to the investigator being called away on urgent work in connexion with oyster mortality (**4**).

Dec. 28th The raft broke adrift in a strong gale some time between the nights of December 25th and 27th, and was washed ashore ; it was badly smashed and rubbed. The whole of the top was missing and also many battens from the sides as well as all the experimental material. A reward was vainly offered for the discovery and return, especially of the experimental boards and the lid (for Patella). Apparently one of the main vertical bolts had broken in the wood, and its fellow had been broken off where it emerged from the wood. For this reason a stouter iron basic frame was introduced into future designs.

The battens on the bottom and sides were bored to a great extent by Teredo. Most of the borings were unoccupied and contained putrefying matter. Probably most of those belonged to infections in previous seasons. A few borings of living animals were however found up to a length of 25 cm. with a mean diameter of about 1 cm. and a diameter of 12 mm. at the inner boring end. A few Actinoloba, Mytilus, Balanus, and Sycon remained on the raft. The Actinoloba are of interest as follows :—

Actinoloba dianthus.	Diameter of flower in cm.	Diameter of column in cm.	Diameter of base in cm.	Height of column.
(a) Pink and extended	9·5	4·3	5·5	—
(b) White contracted	—	3·8	3·2	2·7
(c) White partly extended	—	5·0	5·0	7·0
(d, e, f) Pink, 3 about same size as (a)				

THE EXPOSURE OF THE RAFT AND EXPERIMENTAL MATERIAL TO "INFECTION."

The history of the growths on the raft and the experimental material in Cawsand Bay along with a knowledge of the breeding periods of the dominant organisms concerned render it possible to follow the exposure of the raft and experimental material to infection by potential growths.

When the raft was moored in the sea in Cawsand Bay it immediately became infected with Obelia planulæ and spores of Enteromorpha. Almost simultaneously Nudibranch post-veligers (of Tergipes and Galvina) attacked the young Obelia and established themselves. About August 7th, 1919, *Tubularia larynx* actinulæ settled on the raft and established a recurring source of infection which was maintained until the close of the experiment. Thus when the experimental material was put in the sea on August 18th, 1919, it became subject at once to infection by Tubularia from at least a local source. The larval form of Tubularia, the actinula, is highly adhesive; and it will adhere firmly to a clean glass pipette or dish, or to the frond of Laminaria, and very easily to rougher surfaces than these. This larva is moreover virtually a passive floating organism, it is devoid of light-sensitive organs, and is thus one of the most efficient larvæ for testing the value of a poisonous surface. Indeed, both the efficiency of the poisonous paints and of the larva as well as that of the infection is demonstrated in experiments A to E by the fact that this larva established itself on all the non-poisonous surfaces and on small rubbed areas of the shells painted with proven poisonous paints.

During August numerous Pomatoceros and Diplosoma larvæ settled on the raft and on the shells treated with non-toxic paints. Diplosoma, like Tubularia, produces larvæ, in this case, however, tadpoles, which are adhesive and settle at once on objects adhered to. It is probable that the tadpole of Diplosoma is only light-sensitive for a short space of time, if it is at all light-sensitive. Diplosoma can attain maturity in six weeks and breeds during most of the year, so that once this organism is established on a locality it can reinfect the locality over the greater part of the year, excepting the winter period.

In this month, August, and in September the larvæ of Ascidiella and Ciona settled in numbers on the raft along with the larvæ of Balanus, Teredo, Sponges, Polyzoa, and Polychætes, and the spores of many seaweeds.

There is little doubt that infection from all the sources would continue during October and at least part of November (**2**).

After November general infection would diminish until about March–April, when a fresh infection of Balanids and Hydroids especially would begin, and from April–May onwards all the dominant forms mentioned above would continue to infect the raft from outside and some from local sources during the ensuing summer. There can be no doubt, therefore, that the experimental material on the raft was well tested by a succession of larvæ during the greater part of the time that the raft was in the sea, as is shown by the general growth on the raft itself.

Results of Experiments A to E.

Under the conditions of these experiments, which are in some respects severe (but see general discussion on p. 428), it is seen that only the substances II, IV, and I have an effective anti-fouling action. During the period of these experiments, i.e. about fourteen months (August to October), so long as these paints remained on the experimental material, animal growth was almost entirely inhibited by these three substances, but where they were exposed to light growth occurred in about six months. The substances II, IV, and I adhered to the test material approximately in this experiment in the order of their value for inhibiting animal growths, so that it is probable that the paints were eroded before losing their toxic value.

It is thus manifest that a fundamental property of an anti-fouling paint is the capacity for resisting rapid erosion or dissolution in the sea. In these tests all the experimental material was subject to the constant movement produced on the raft by wind and waves.

The anti-corrosive paints III and V remained in the best condition on October 23rd, 1920, and may therefore be said to fulfil a preservative function (for non-wooden structures) satisfactorily for the period and conditions of the experiments.

Red oxide of iron, No. VIII substance, which is commonly used as an anti-corrosive paint on iron buoys, was found to be useless as an anti-fouler; and since it became eroded almost entirely in fourteen months, or less, must be deemed less valuable as an anti-corrosive paint than substances III and V for the conditions of these experiments which are similar to those affecting buoys.

SERIES II. GREAT WESTERN RAILWAY, WEST WHARF, MILLBAY DOCKS, PLYMOUTH.

Experiment F.

On 3-feet test-boards fixed at low-water mark.

In this experiment eleven boards 3 feet by 4 inches by 1 inch were treated with substances I to XII (see p. 376)—excepting No. VII board, which was again untreated—and put in the sea on August 27th, 1919. These boards were affixed vertically to old Jarra piles at low-water mark at the West Wharf, Millbay Docks, Plymouth. The lower ends of the boards (except No. II, which was slightly higher than the others) were fixed about 6 inches below ordinary spring-tide level so that about 2 feet 6 inches of the board would be above the mean spring-tide level. Four additional untreated pieces of wood were put out as additional controls of growth on August 28th, 1919, and five more pieces of untreated wood were put out on February 23rd, 1920, alongside the experimentally treated boards in Bays 3 to 7 inclusive, i.e. alongside boards VIII and XII, V, IV, IX, and XI. These untreated boards were soon lost, but they served the purpose of demonstrating growth on untreated surfaces alongside the treated surfaces. Substances VIII, red oxide of iron, and XII, aluminium paint, were painted on to one board on vertical halves (36 by 2 by 1 inches). The 3-feet boards were of red pine, except No. VII, which was of elm, the additional pieces of wood being ordinary deal.

Numerous visits were made to the West Wharf in studies on the low-water fauna, and the records made on ten inspections of the experimental material from September 25th, 1919, to March 7th, 1923, are given in Table IX, pp. 402–3. In this table is shown the history of the growths which occurred on each of the boards and the condition of the paint. The growths on the experimental substances and on untreated wood (VII) can be readily and easily compared at successive periods of the experiment. The condition of the surviving boards at the end of the experiment is shown in Figs. 12, p. 404, 13 and 14, pp. 405 and 408.

Summary of Results from Experiment F.

The board with the green poisonous paint, No. II, remained almost intact during the course of the experiment, i.e. about 3½ years. All the remaining surviving boards were badly eaten by gribble at the close of the experiment, and of the two boards which were lost, one (No. XI) was nearly eaten away on December 16th, 1921, but the other (No. IX) on this latter date was in good condition and might have remained so for a longer period.

Growth began first on boards V and IX. It is a noticeable fact that

TABLE IX. EXPERIMENT F.

REPORTS ON GROWTHS (AND CONDITION OF PAINTED SUBSTANCE) ON 3-FEET TEST-BOARDS (TREATED AND UNTREATED) PUT OUT ON AUGUST 27TH, 1919, AT LOW WATER SPRING-TIDE LEVEL AT THE WEST WHARF, MILLBAY DOCKS, PLYMOUTH.

No., colour, and designation of paint and position of board.	Sept. 25, 1919 (exposed *c.* 1 month).	Dec. 8, 1919 (exposed *c.* 15 weeks).	Feb. 7, 1920 (exposed *c.* 6 months).	May 19, 1920 (exposed *c.* 9 months).	Aug. 16, 1920 (exposed *c.* 12 months).	April 22, 1921 (exposed *c.* 20 months).	Dec. 16, 1921 (exposed *c.* 28 months).	March 17, 1922 (exposed *c.* 31 months).	March 7, 1923 (exposed *c.* 42½ months).
I Reddish brown A–F 10 Bay	No growth	No growth, paint good	No growth, but an untreated board alongside has Diplosoma and Botryllus	No growth, paint good	Slight growth of a few barnacles: paint washing off. (Untreated board alongside covered with growth and riddled with gribble)	Slight growth on bottom of board; on the lead label and on a nail head; no gribble seen	A little growth only on the bottom of the board	Not reported on	Good piece of board still left and *brought in*. One-third eaten away by gribble: bored by Teredo. The faces of board mostly eaten also by gribble, but the little paint left is overgrown by Botryllus and other organisms. See fig. 13
II Green A–F 11 Bay, outer	No growth	No growth, paint good	No growth, paint good	No growth, paint hard and in good condition	No growth: paint good but soft and rubs off on the finger; washed off a little in a few places at the sides	No growth: a little on a nail head, no gribble seen	No growth	Not reported on	Slight growth only in places, and attacked by gribble isolated parts and at edges. *Board brought in* still covered with some paint on most of surface. See fig. 13
III Black A–C 11 Bay, inner	No growth	No growth, paint good	No growth, but has spawn of Eulalia on it	Good growth, covered at bottom: paint very good and hard (Clean board alongside covered with growth and riddled with gribble)	Covered with growth	Extensive growths all over, no gribble seen	Not examined	Not reported on	Good piece of board left, but covered by by growth. Board *brought in*. See fig. 13, p. 405
IV Reddish brown A–F 5 Bay	No growth	No growth, paint good	No growth	A few barnacles on the bottom of the board; paint very good (Untreated board alongside covered with growth and riddled with gribble)	Slight growth of a few barnacles; a little Diplosoma and Bugula Sept. 30, 1920. Botryllus on lead label, and a few colonies of Botryllus on the board	Slight growth of hydroids, Balanus and Sycon No gribble seen	A good growth now present	Not reported on	Good piece of board left, but covered by growth. *Board brought in*, paint still covering part of surface. See fig. 13, p. 405
V Black-bronze A–C 4 Bay	Growth begun, small colonies of Diplosoma and a growth of Obelia	Good growth, fewer Diplosoma; Botryllus, Ficulina, and much hydroid growth, paint good	Good growth of Diplosoma and Halichondria on the bottom of the board	Covered with growth of small colonies of Diplosoma and Obelia: paint very good (Untreated board alongside as in III and IV)	Covered with growth of Diplosoma, Botryllus, Balanus, Bugula. Untreated board alongside riddled by gribble	Extensive growth: board eaten by gribble about ½ inch at the sides	With a good growth, nearly eaten away by gribble	*Now eaten away to a small remnant and brought in.* See fig. 14, p. 407	

VI Reddish brown A–F 12 Bay	No growth	Not examined, tide too high	No growth, paint rubbing badly and apparently brighter red in colour	Growth of hydroids and Ascidians	Covered with growth everywhere: paint washing off and very soft	Heavy growth of Balanus: moderately eaten by gribble on the face as well as at edges	Now partly eaten away and covered with growth	Not reported on, but on April 29, 1922, found to be *nearly eaten away by gribble and brought in.* See fig. 14, p. 407	
VII Greyish white untreated 14 Bay 8 Bay outer and inner 3 to 7 Bays	No growth	Good growth on two boards, three boards not seen. Diplosoma, Botryllus, Umbonula and hydroids	All untreated boards with Diplosoma and Botryllus and gribble, especially on the bottom of the boards	Covered with growth, and board becoming riddled with gribble. Teredo probably also present	Covered with growth and riddled with gribble	*Nearly eaten away and brought back to laboratory.* Two additional untreated boards previously riddled with gribble are now missing, doubtless having broken away after being reduced to a remnant. See fig. 14			
VIII Red A–C 3 Bay	No growth	No growth, paint now washing off	No growth visible	Covered with spat of Balanus: paint very soft	Covered with growth of Diplosoma, Botryllus, Bugula, Balanus, and Limnoria, and on July 15 had also some brown algæ	Extensive growth: one half of the board eaten (north side) by gribble	With a good growth and nearly eaten away	*Now eaten away to a small remnant and brought in*	
IX Black A–C ? 6 Bay	Growth begun by a young colony of Halichondria sp.	Much Diplosoma on bottom of board and some Ascidians, paint good	Much growth of Diplosoma and Botryllus on the bottom of the board	Good growth covered with spat of Balanus, hydroids and Ascidiella: paint very good	Covered with growth as on VIII and also medium Ascidiella	Extensive growth: slight attack by gribble in one corner only	Covered with growth; not much eaten by gribble	Not reported on	LOST
X Black A–C 9 Bay	No growth	Slight growth, paint good	Growth of Diplosoma and Botryllus	Covered with growth and spat of Balanus at higher level: paint very good	Covered with growth, paint in good condition	Extensive growth: not attacked by gribble except in one top corner	Covered with growth, gribble is beginning to eat away the top part of the board	Not reported on	Most of the board still left, and paint remains on nearly half of outer and most of inner face. Covered with growth and *brought in.* See fig. 13, p. 405
XI Green A–F 7 Bay	No growth	No growth, paint good, Halichondria near board apparently unable to overgrow on to it	No growth, Halichondria in juxtaposition to board in places but is unable to grow on to board	Much spat of Balanus, but no hydroids seen: paint very good. (clean board alongside, put out Feb. 23, covered with growth and riddled with gribble)	No paint left; growths extending all over board (July 15 paint nearly all washed off, fair growth on bottom of board)	Fair amount of growth: moderately eaten by gribble in patches	Nearly eaten away by gribble	Not reported on	LOST
XII Silvery grey 3 Bay	No growth, paint cracking	No growth visible: paint good except for cracks	No growth visible	Covered with spat of Balanus: paint still fairly hard	Covered with growth	Extensive growth: one half of the board eaten by gribble	Nearly eaten away by gribble	*Now eaten away to a small remnant and brought in*	

NOTES TO TABLE IX. EXPERIMENT F.

The Bays in which the boards were put out are reckoned from the south end of the West Wharf.

On December 16th, 1921, the examination of the boards was made in my absence by my assistant in this work, Mr. William Searle.

Paints VIII and XII were painted on the same board, half of the board on the long axis and 36 × 2 × 1 inches being painted with red oxide and the corresponding half with aluminium paint.

"Gribble" is a seaman's term for both *Limnoria lignorum* and *Chelura terebrans.* Both these animals were taken from the experimental material, but Limnoria was by far the most abundant, and appears to live at a slightly higher level in the inter-tidal zone than Chelura.

As the boards were nailed on to and against Jarra piles, it was not possible to examine the back parts of the boards during the course of the experiments

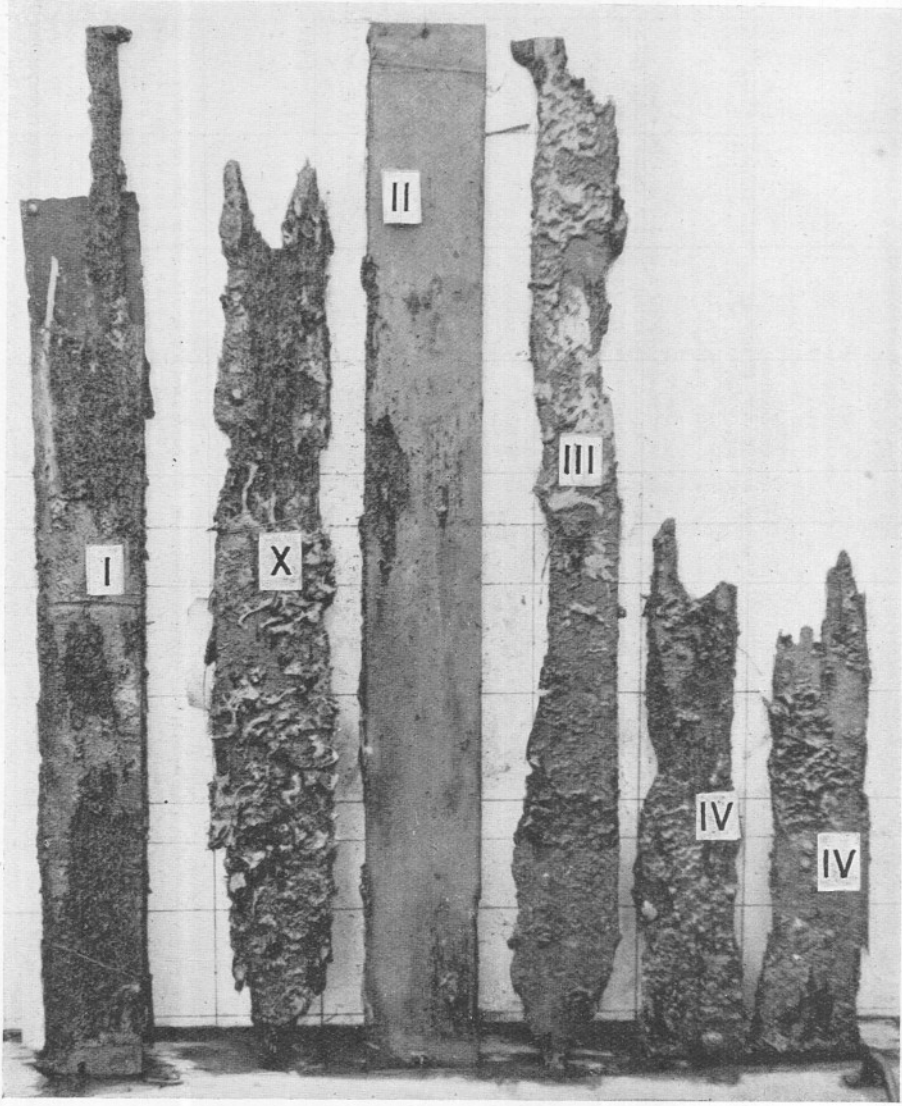


Fig. 12.—Photo of test-boards from Experiment F, Great Western Railway Wharf, Millbay Docks, Plymouth, with living growths on March 7th, 1923, after 3½ years' exposure in the sea. ($\times \frac{2}{13}$.) (Photo by A. J. Smith.)

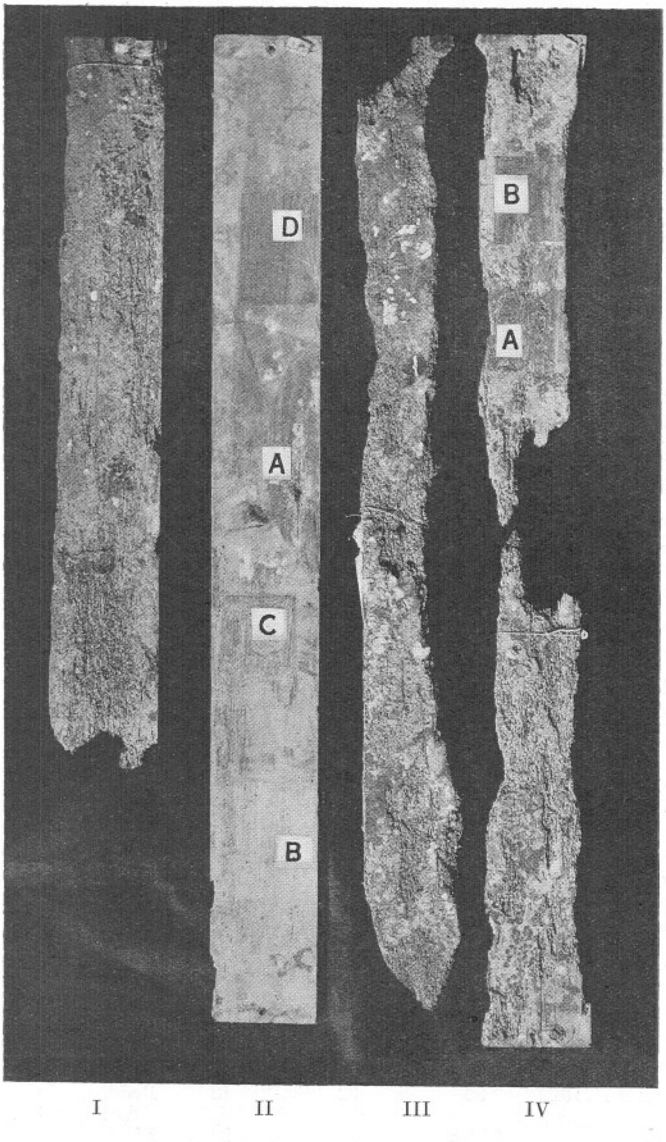


FIG. 13.—Photo of test-pieces from Experiment F, Great Western Railway Wharf, Millbay Docks, Plymouth, dried after exposure in the sea for 3½ years from August 27th, 1919, to March 7th, 1923. (× ca. ⅐.) (Photo by D. P. Wilson.)

Test-piece No. I has had a small portion and the end of a Teredo tube broken off (see Fig. 12, p. 404).

Test-piece No. II shows the four areas B, C, A, and D (in order from below upwards) from which samples of paint were scraped for chemical analysis.

Test-piece III is shown from the side opposite to that shown in Fig. 12, p. 404.

Test-piece IV shows the two areas, A and B, from which samples of paint were scraped for chemical analysis (compare IV, fig. 12, p. 404).

this growth occurred while the untreated board remained devoid of growth. There is little doubt that all kinds of wood are liable to be slightly inimical to growths (and perhaps toxic) for a short period (i.e. a few weeks) after being put into the sea. The untreated board No. VII —comparable with the experimental boards—however, became covered with growth (after 15 weeks in the sea) and was eaten away to a remnant in 20 months. Four other boards, V, VI, (VIII and XII) and XI were eaten away to a remnant in 31 to 32 months, and four others, IV, I, III and IX became badly eaten away—though not reduced to a remnant—in 42½ months, while as stated above No. II board remained almost intact at the end of the period of 42½ months. (See Figs. 12, 13, and 14.) It is therefore possible to estimate the *preserving* action on wood of the substances which were tested by taking as a basis for comparison the length of time required for the destruction of the untreated test-piece of wood, namely No. VII. In this way are derived the estimates of the preserving action shown in Table X, below. The value of each substance for inhibiting growth can be deduced from Table IX in a similar way, and is best shown in tabular form as in Table XI, p. 409.

TABLE X.

RATE OF DESTRUCTION OF THE TEST-BOARDS AND THE DEDUCED PRESERVATIVE VALUE OF THE SUBSTANCES TESTED ON WOOD IN EXPERIMENT F, MILLBAY DOCKS, PLYMOUTH.

No. of test-board and substance.	Date eaten to remnant or brought in.	Months in which test-piece eaten to a remnant (approx.).	Actual and estimated* periods for reduction of all test-boards to a remnant in months (approx.).	Value of preservative action in months (approx.).	Experimental poisonous or other substance.
VII	April 22nd, 1921	20	20	—	Untreated.
V	March 17th, 1922	31	31	11	Black-bronze : anti-corrosive.
VIII	,,	31	31	11	Red oxide of iron : anti-corrosive on iron.
XI	,,	31	31	11	Green : anti-fouling paint.
XII	,,	31	31	11	Aluminium paint experimental.
VI	April 29th, 1922	32	32	12	Reddish brown anti-fouling paint.
IX	Lost	28+a	*49*	29	Black : ordinary black varnish.
IV	March 7th, 1923	42½+b	*49*	29	Reddish brown anti-fouling paint.
X	,,	42½+c	*49*	29	Black : ordinary coal tar.
I	,,	42½+d	*49*	29	Reddish brown anti-fouling paint.
III	,,	42½+e	*49*	29	Black : anti-corrosive paint.
II	,,	42½+f	*65*	45	Green : anti-fouling paint.

* Estimated periods are given in italics.

An inspection of Table X brings out the somewhat surprising fact that the black-bronze anti-corrosive paint (V), the green anti-fouling paint (XI), red oxide of iron (VIII), and aluminium paint (XII) all have an approximately equal value as preservative substances under the condition of the experiment. The red anti-fouling paint (VI) was only a little better than the preceding substances. The failure of these substances to preserve the test-boards is undoubtedly due to the readiness in which they become eroded off the test-boards, while the similarity in the rate of erosion suggests that the body used in these paints was essentially similar.

The substances IX, IV, X, I, and III were approximately equal in preserving value, and owed their increased value undoubtedly to their property of resisting erosion. It is a striking fact that ordinary coal-tar (X) and ordinary black varnish (IX, i.e. coal-tar diluted with naphtha) are as good preservatives as the more expensive paints III, IV, and I under the conditions of these experiments.

The green anti-fouling paint (No. II) stands out in these experiments as a very efficient preservative and—as will be shown later—also a very valuable anti-fouling substance. A similar preservative value to that deduced above would be obtained by taking the relative condition of the boards on December 16th, 1921, after 28 months in the sea (see Table IX, p. 402).

The relative anti-fouling value of the substances tested in this experiment can be estimated approximately from the data given in Table IX. The dates at which general growth was first observed on each test-board gives the approximate time at which the anti-fouling value (if any) of each substance was lost. The intervals of observation are too widely spaced to give in most cases the date at which slight general growth occurred, but in the period between observations recording no growth (or slight growth) and general growth must have occurred the onset of general growth. This period in the case of each test-board is shown in Column 3, Table XI, p. 409. By taking the middle of this period, i.e. between the occurrence of no—or slight—growth and general growth, an approximate date is obtained for the onset of general growth, and this is given in column 4, Table XI. Since substances V and IX showed slight growth in one month, these may be safely stated to have no anti-fouling value (confirmed in other experiments), and the period required in the case of these two substances for the onset of general growth may be taken as the zero for the determination of the relative anti-fouling value of each substance. The relative values obtained in this way are given in Table XI, column 5. A detailed description of the boards recovered from the sea on March 7th, 1923, is given on pages 410–13.

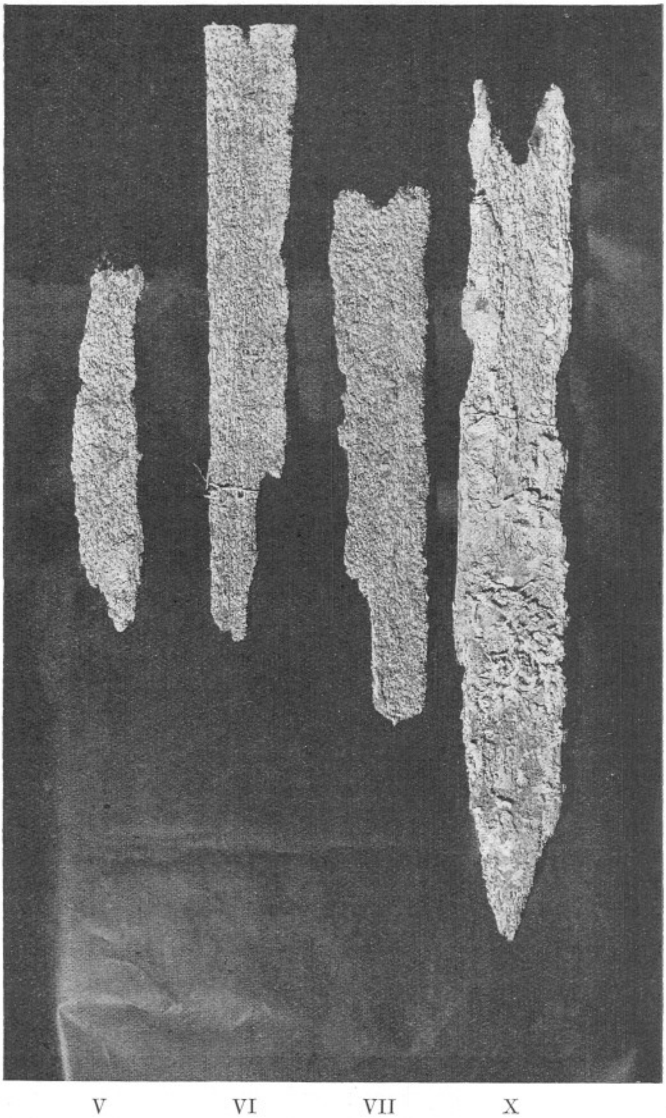


FIG. 14.—Photo of remnants of test-pieces from Experiment F, Great Western Railway Wharf, Millbay Docks, Plymouth, dried after various periods of exposure in the sea.($\times \frac{1}{7}$.) (Photo by D. P. Wilson.)

All the test-pieces were first exposed in the sea on August 27th, 1919. No. V test-piece remnant was taken out of the sea in March, 1922; No. VI in April, 1922; No. VII in April, 1921, and No. X in March, 1923.

TABLE XI.

RATE OF INFECTION OF THE TEST-BOARDS IN EXPERIMENT F WITH GENERAL GROWTH; AND THE DEDUCED ANTI-FOULING VALUE OF THE SUBSTANCES TESTED (ON WOOD).

(1) No. of test-board and substance.	(2) Incidence of slight growth in months (approx.).	(3) Incidence of general growth in months (approx.).	(4) Time taken to establish general growth in months (approx.).	(5) Relative anti-fouling value in months (approx.).
V	1	1–2¾	1½	0
IX	1	1–2¾	1½	0
VII	—	1–2¾	1½	1
X	2¾	2¾–6	4½	3 (0)†
III	—	6–9	7½	6 (0)‡
VI	—	6–9	7½	6
VIII	—	9–12	10½	9
XI	—	9–12	10½	9
XII	—	9–12	10½	9
IV	12–20	20–28	24	22½
I	12–28	28–_36_*	32	30½
II	28 nil	_36_–42½**	39	37½

TABLE XII.

COMPARATIVE ANTI-FOULING AND PRESERVATIVE VALUES DEDUCED FROM EXPERIMENT F.

No. of sub-stance.	Colour and property.	Deduced anti-fouling value (in months).	Deduced preservative value (in months).	Property found in Experiment F.
CLASS A.				
II	Green: anti-fouling	37½	45	A.F. and pres.
I	Reddish brown: anti-fouling	30½	29	A.F. and pres.
IV	Reddish brown: anti-fouling	22½	29	A.F. and pres.
CLASS B.				
IX	Black (varnish): experimental	0	29	non A.F. but pres.
X	Black (coal-tar): experimental	3 (0)	29	non A.F.† but pres.
III	Black: (anti-corrosive and preservative paint)	6 (0)	29	non A.F.‡ but pres.
CLASS C.				
V	Black-bronze: anti-corrosive	0	11	non A.F.: sl. pres.
VI	Reddish brown: anti-fouling	6	12	sl. A.F.: sl. pres.
VIII	Red (oxide of iron): experimental	9	11	sl. A.F.: sl. pres.
XI	Green: anti-fouling	9	11	sl. A.F.: sl. pres.
XII	Aluminium paint: experimental	9	11	sl. A.F.: sl. pres.
CLASS D.				
VII	Untreated wood: greyish white	1	0	very sl. A.F. non pres.

* The figures in italics are estimated. ** General growth on bottom of board only.

† See Experiment G, p. 415, and fig. 16, p. 414, for rapid overgrowth.

‡ See Experiment G, p. 415, and fig. 15, p. 412. No. III substance was tested in No. II inner bay, all the others being placed in outer bays, and was doubtless subjected to a lesser degree of infection in this situation. See also Table XV, p. 422, for rapid overgrowth.

THE ANTI-FOULING AND PRESERVATIVE VALUES DEDUCED FROM EXPERIMENT F.

The estimated anti-fouling values (in months) deduced from Experiment F in Table XI, p. 409, and of the deduced preservative value (in months) in Table X, p. 406, for the various substances tested in this experiment are presented together in Table XII, p. 409. From this table it is seen that the substances fall naturally into four groups or classes as shown.

The results shown in Table XII are discussed on p. 426, after the consideration of experiments on painted shells, which were put out in the sea near the test-boards of Experiment F.

BIOLOGICAL (AND CHEMICAL) OBSERVATIONS ON THE TEST-BOARDS IN EXPERIMENT F AFTER 3½ YEARS' EXPOSURE IN THE SEA.

After the test-pieces in Experiment F had been in the sea for 3½ years the remaining boards were brought in to the Laboratory and photographed. Two of the boards, Nos. II and IV, were sent to the Government Chemist, London, for chemical analysis of samples of the paint in the condition of (*a*) permitting over-growth, and (*b*) apparently in the last stage of inhibiting growth. A report of these and other chemical analyses are given in Part II on pp. 430 to 437, and a discussion of the results obtained is given on pp. 438 to 441.

BIOLOGICAL OBSERVATIONS

No. II. Dark green anti-fouling paint.

The board retained its original size (see Fig. 12, p. 404). The front *face* of the test-board had a slight growth of hydroids in a small area (area A, Fig. 13) around the fixing nail in the middle and at one side. There was also a growth of hydroids on the lead (identifying) label on the top of the board. More or less paint was present on all the face except the lower six inches where were colonies of Diplosoma, Umbonula, and hydroids. There was no other growth on this face (Areas C and D, Fig. 13), but about 8 inches from the bottom in the middle of the face (Area B, Fig. 13) were four recent isolated borings of Limnoria (or Chelura). A few gribble borings were also present on the bottom of the board and around the middle fixing nail.

On the back *face* of the board paint still remained on the major part, but was missing from the lower 6 inches where Diplosoma and Halichondria were growing, and a few places where it had rubbed against the jarra pile. An area near the bottom of the board was eaten out by gribble over a surface of about 2×1 inches and to a depth of 1 cm., and another area 5½ by 1½ inches was similarly eaten out on the back of the board around the middle fixing nail. But there was no other growth on the face.

At one *side* (36×1×1 inches) of the board the paint had almost disappeared and gribble had attacked most of one edge, but little of the other except at the bottom.

On the other *side* some paint remained except on the bottom 5½ inches.

On the upper part of both the *sides* hydroids were growing abundantly with some Botryllus and Polydora; while Diplosoma, Botryllus, Halichondria, and Polydora and gribble occurred on the lower parts. Limnoria and Chelura were taken from many places, but only in the lower three-fourths of these sides of the board. The top and bottom faces (4 × 1 × 1 inches) of the boards were intact.

No. I. Reddish brown anti-fouling paint.

The lower 9 inches of the board were missing, having probably been eaten away. The upper portion (see Fig. 12, p. 404) had only patches of paint left on either the front or back face. In places where traces of the paint remained it was distinctly overgrown with Botryllus, Umbonula, and Polydora tubes. A specimen of Teredo, with a tube 18 cm. long (slightly broken), remained projecting from the test-piece; the wood originally surrounding this tube having been eaten away by gribble. A large part of the face of both the front and back had been eaten away by gribble, and on the front face now were growing in abundance Polydora, Botryllus, Diplosoma, Balanus, and hydroids; on the back were present the same organisms excepting Balanus. From the bottom of the board a sample of 50 gribble was examined and found to be *Chelura terebrans*, and at the top, among about 20 to 30 specimens, only a few were Limnoria.

No. IV. Reddish brown anti-fouling paint.

The test-board was eaten away in the middle, leaving two pieces (see Fig. 12, p. 404). The upper portion, 16–17 inches long, was eaten away at the sides to a width of $3\frac{1}{4}$ inches. There was a good covering of paint over the outer face of the wood (of which Areas A and B were scraped and analysed chemically, see p. 434). The painted surface was unbroken in Area B, but perforated by Limnoria (or Chelura) in Area A, see p. 405, but was covered with a growth of Botryllus, Balanus, Umbonula, and Polydora, Pomatoceros and hydroids, especially a species of Obelia. The wood had been attacked by gribble in such a way as to leave in places a thin surface lamina covered by paint, a fact demonstrating the persistent, poisonous nature of the paint. The back surface of the wood (adjacent to the jarra pile to which it was fixed; and also remote from light) was eaten away over nearly the whole extent, probably having been undermined more quickly than on the front surface. The same kind of growth was found on the back as on the front.

The lower portion of the board also had a covering of paint still remaining over a good part of the front surface, but very little over the back. The paint on the front face was, however, overgrown very much with Botryllus and Diplosoma, several individuals of Balanus, and some Leucosolenia, Botrylloides, Polydora, and hydroids, and a pink sponge, probably a small colony of Hymeniacidon sp. Similar growth occurred at the back face, namely, Botryllus, Botrylloides, Diplosoma, but also Anomia and Umbonula.

No. X. Ordinary coal tar.

The board was almost entire, but eaten away by gribble around most of the original edges (see Fig. 12, p. 404). Paint still remained on nearly half of the outer—and mostly upper—face, and was in excellent condition on most of the back face. On the outer face the lower half was eaten away by gribble on the surface and almost to a point from the lower sides. Growing on the paint in the upper part of this face were Halichondria, Botryllus, Diplosoma, Hymeniacidon, Morchellium, Actinoloba (brown), and a fair amount of worms. On the back face were growing Halichondria, Botryllus, Diplosoma, Umbonula, Pomatoceros, Balanus, Anomia, hydroids, and a few Sabellid worms.

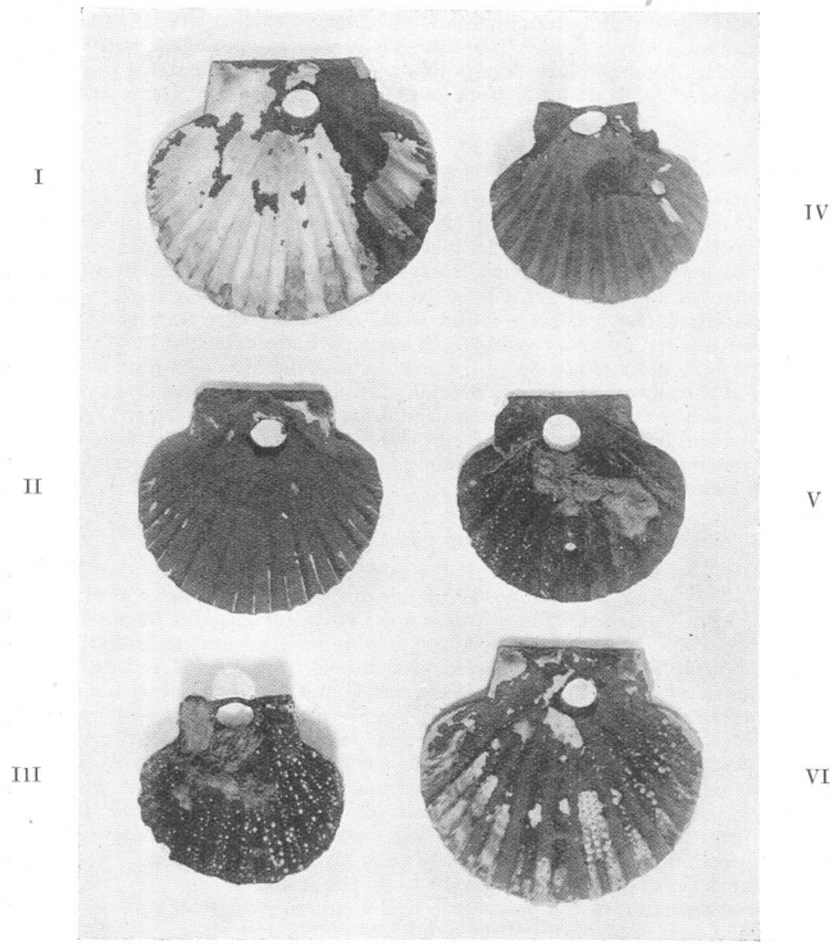


FIG. 15.—Photo of shells exposed at the Great Western Railway Wharf, Millbay Docks, Plymouth, Experiment G, from August 28th, 1919, to May 4th, 1920. (× ca. $\frac{2}{5}$.) (Photo by D. P. Wilson.)

I Red: view of inner smooth surface of a flat shell showing the paint washing away but devoid of growth. (The paint on rough surface—not seen—is almost entire.)

II Dark green: view of inner smooth surface of a flat shell, which is losing paint only at the right-hand upper corner and on certain ridges. There is no growth on this shell. (The paint on the rough surface —not seen—is almost entire.)

III Black: view of inner smooth surface of a convex shell showing the layer of paint to be entire. There is a growth of Halichondria, Leucosolenia, and a hydroid, and a good spatting of Balanus. (The paint on the reverse surface is also entire.)

IV Red: view of inner smooth surface of a convex shell showing the layer of paint to be almost entire. There is no growth on this shell. (The paint on the reverse surface is also almost entire.)

V Black-bronze: view of outer rough surface of a flat shell showing the paint entire and a growth of Ascidians, hydroids, Balanus, and young polychætes. (The inner smooth (reverse) surface shows a slight denudation of paint.)

VI Red: view of inner smooth surface of a flat shell showing the paint denuded from considerable areas and the spatting of Balanus on the bare shell and on the areas still retaining paint. (The paint on the reverse rough surface is almost entire.)

No. III. Black : anti-corrosive and preserving paint.

The test-piece retained the original length of about 3 feet, but was badly eaten away from one edge. An original edge on half of one side remained with paint on it and was only slightly bored by gribble (see Fig. 12, p. 404). The front face along the middle of its length had paint still adhering in very good condition, but was covered everywhere with growth. At the top of the face was much Diplosoma and Botryllus, a few Ascidiella and Botrylloides and a fair amount of encrusting Polyzoan : in the middle was very much Halichondria and Umbonula and a fair amount of Botryllus and Diplosoma, one Pomatoceros, and hydroid colonies : on the bottom of the front face was a lot of Botryllus and Umbonula, a little Diplosoma and a fair amount of the small Sabellid.

On the back face of the board, which was much more eaten by gribble than the front, where the paint remained, it was in good condition ; there was a growth of Sabellid tubes everywhere, eight Balanids, one Anomia, one Pomatoceros, and a little Botryllus and Halichondria.

Experiment G.

Shells of the scallop, *Pecten maximus*, were painted (in lots of ten) with the substances I to XII (see p. 376) (except No. VII, which is—as in all the experiments—untreated material) and put out on tarred rope around the cement supporting piles of the West Wharf, Millbay Docks, Plymouth, on August 28th, 1919, at low water spring-tide level. Two shells of each of the twelve kinds were strung round each of the following piles, counting from the south end of the south division of the wharf :—4th row 2nd pile (=4 R 2 P), 5 R 2 P, 6 R 2 P, 7 R 2 P, 8 R 2 P ; while on 9 R 2 P were strung a number of shells, all of which were clean, or rather untreated. The 4th row of piles separates the 3rd from the 4th bays, and the 5th row separates the 4th and 5th bays, and so on. The experimental material in Experiment F was put out on jarra piles in bays 3 to 14 adjacent to the cement piles (about 2 yards distant) used for this experiment. Thus the sites in the two experiments were essentially similar though the upper half of each test-board would be above the level of the shells ; the shells would be also rather more shaded from light than the boards, and about 1 yard further from the small beach, which is exposed at low water at the back, i.e. inner part, of the wharf.

Observations on this experiment were only carried out over a period of 19 months (owing to the absence of the investigator on other work), but the period was sufficient to discover most of the results obtainable from an experiment of this kind. An examination of and report on individual shells was made on four inspections and general observations made on others. These observations are summarised in Table XIII, p. 415, and the results of the experiments are shown on Figs. 15 and 16, pp. 412 and 414.

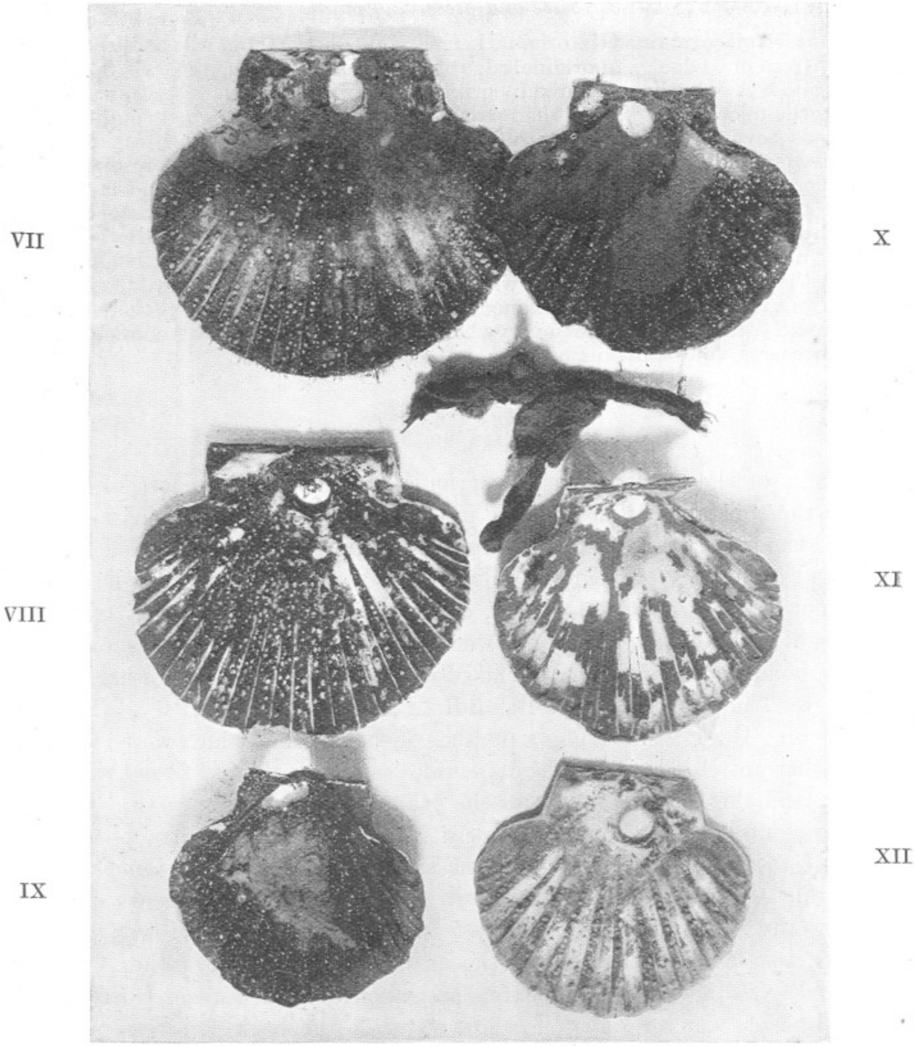


FIG. 16.—Photo of shells exposed at the Great Western Railway Wharf, Millbay Docks, Plymouth, Experiment G, from August 28th, 1919, to May 4th, 1920. (× ca. $\frac{2}{5}$.) (Photo by D. P. Wilson.)

VII Untreated shell: view of inner smooth surface of a flat valve with a slight growth of Halichondria, much hydroid growth and spat of Balanus with also young tubicolous Sabellid polychætes. The growth on the reverse rougher side is similar.

VIII Red: view of inner smooth surface of a flat shell showing areas denuded of paint, Balanus spat on the paint, and a slight growth of tubicolous polychætes around the larger hole. On the rougher reverse side the paint is practically entire, but with similar growth.

IX Black: view of inner smooth surface of convex valve showing the paint almost entire, a good growth of Halichondria, hydroids and Balanus, and a few tubicolous polychætes. The reverse side is similar.

X Black: view of inner smooth surface of a convex valve showing the paint almost entire, a good growth of Botryllus, Diplosoma, and Balanus. The reverse side is similar without Diplosoma.

XI Light Green: view of inner smooth surface of convex valve showing large areas denuded of paint and no growth. On the reverse side the paint is denuded, but to a smaller extent.

XII Silvery: view of inner smooth surface of a flat valve, showing the almost complete absence of paint, a good spatting of Balanus, and a nest of tubicolous polychætes around the large hole. The reverse side is similar, but more paint remains in the roughened hollows.

The T-shaped black object between shells X and XI consists of a horizontal piece of tarred rope on which is growing a large mass of Botryllus and a little Leucosolenia.

TABLE XIII. EXPERIMENT G.

OBSERVATIONS ON GROWTHS (AND CONDITION OF PAINT) ON UNTREATED SHELLS AND SHELLS TREATED WITH VARIOUS SUBSTANCES (I TO VI, AND VIII TO XII, SEE P. 376) AND PUT IN THE SEA ON AUGUST 28TH, 1919, AT THE WEST WHARF, MILLBAY DOCKS, PLYMOUTH.

	Sept. 25, 1919 (exposed 4 weeks).	Dec. 8, 1919 (exposed 14½ weeks).	Feb. 7, 1920 (exposed *c.* 6 months).	May 19, 1920 (exposed *c.* 9½ months (see notes 1–3 below)
I Reddish brown anti-fouling	No growth	No growths; paint good, chipping a little on smooth faces	No growth; paint eroding	Paint entire on some shells, slightly washed off on others Balanus spat on bare shell and a few also on paint
II Green anti-fouling	No growth	No growth; paint good	No growth; paint slimy but still good coat	Paint mostly entire, slight growth only on naked shell
III Black anti-corrosive	Halichondria and a Polyzoan on 2 shells, other shells no growth	Heavy growth on all shells but one; paint in good to very good condition (see Table XIV)	Covered with Diplosoma, Botryllus, Halichondria mainly	Covered with growths, paint not examined
IV Reddish brown anti-fouling	No growth	No growth; paint good	No growth	Paint eroding, but still entire on some shells. A few Balanus spat actually on the paint. No growth on one shell
V Black-bronze anti-corrosive	Three shells with a little growth of Halichondria and young organisms	All but two shells with little to much growth (see Table XIV): paint good on most shells	Some shells without growth, paint not reported on	Shells covered with growth of various kinds: paint good
VI Reddish brown anti-fouling	No growth	No growth, paint already eroding easily	No growth; paint spongy; nearly all off on some sides	Paint good on a few shells, but is mostly badly eroded. A few Balanus on paint as well as on naked shell
VII Greyish white untreated shells	Three shells without growth. Halichondria, Hydroids, Botryllus, Hymeniacidon juv., and Amphipod nests, Diplosoma juv., on the others	Growth on all shells but one (see Table XIV)	Some shells now devoid of growth	All shells covered with good growths mainly of Botryllus, Balanus, and Diplosoma
VIII Red anti-corrosive	No growth, paint already sticky	Much Diplosoma on one shell, others no growth, but paint eroding fast	One shell covered with Diplosoma, others with paint spongy and eroding fast	Some shells still covered with paint but washed off others. Spat chiefly of Balanus is now established on the paint also (see note 4 below)
IX Black (varnish) experimental	Seven shells covered with growth of Halichondria, Hymeniacidon, Botryllus, Pomatoceros, Hydroids, and Amphipod (?) nests	All shells with growth: paint good on most shells (see Table XIV)	Some shells now without growth: paint good	All shells covered with growth: paint good
X Black coal-tar experimental	Four shells with growth of Halichondria, Ascidiella spat, and other unknown spat	Six shells with, 4 without growth: paint good on most shells (see Table XIV)	Good growth on shells	All shells covered with growth: paint good
XI Green anti-fouling	No growth	No growth; paint eroding easily	No growth; paint washing off	Some shells with paint entire but with little to much growth, chiefly of Balanus, on the paint as well as on the bare shell
XII Aluminium paint Silvery and experimental	No growth	Growth on 6 shells, but paint nearly all washed off all	Not observed	No paint or only a trace left. All shells covered with growth

1. August 16th, 1920. (Exposed about 12 months.) All the shells were restrung with tarred twine in the hope of further extended observations. On this date all the shells were found to be overgrown with marine animals of different kinds except the reds IV and I and the green No. II. In the case of No. II the paint was washed off most of the shells to some extent, and growths were found on the naked shell, but not on the paint.

2. September 30th, 1920. (Exposed about 13 months.) IV Red: Paint still good in parts on the rough side of the shell, there was little other growth than a few Balanus on the paint, but much on the denuded parts of the shell. II Green: Paint only good on the rough side of the shell where there is no growth: fair growth on those parts of the smooth side where paint is now washed off. Only 6 and 8 row sets of shells remained, the others having been lost.

3. April 23rd, 1921. (Exposed about 19 months.) Three shells of each of the paints I, II, and IV were collected and sent to the Government Chemist for chemical analysis of the parts. Only slight growth present on the paint, but shells otherwise with abundant growth.

4. Balanus spat have bored through the red oxide which is being pushed up on to the sides of the shell as the shell grows. The same phenomenon occurs when Balanus settles on red oxide on the bottoms of ships, and especially on surfaces covered with coal-tar, pitch, or varnish.

THE GROWTH ON INDIVIDUAL SHELLS IN EXPERIMENT G ON DECEMBER 8TH, 1919. (AFTER 14½ WEEKS IN THE SEA.)

The growths found on the individual shells in experiment G on December 8th, 1919, (i.e. after 14½ weeks' exposure in the sea), treated with substances III, V, IX, X, and the untreated shells (VII) are conveniently shown in Table XIV, below. It is noteworthy that the condition of the paints III, V, IX, and X, which are all black, was at this time very good; only occasional flaking occurred on the smoother side of the shells. The growths found on the painted shells therefore occurred actually on the paint and not on parts of the shell denuded of paint, as was the case, for example, with No. XII shells on this date and others later.

TABLE XIV.

GROWTHS FOUND ON DECEMBER 8TH, 1919, (AFTER 14½ WEEKS IN THE SEA), ON THE SEPARATE SHELLS TREATED WITH SUBSTANCES III, V, IX, AND X, AND THE UNTREATED SHELLS IN EXPERIMENT G, WEST WHARF, MILLBAY DOCKS, PLYMOUTH.

	VII	III	V	IX	X
No. of shell.	Untreated shells.	Black anti-corrosive.	Black-bronze anti-corrosive.	Black varnish experimental.	Black coal-tar experimental.
1	Halichondria 4 colonies	Botryllus	None	Diplosoma	Diplosoma abundant
2	Ascidiella young	Diplosoma Botryllus	Polydora	Halichondria	Halichondria 5 colonies Diplosoma
3	Halichondria Diplosoma Umbonula	Diplosoma Ascidiella young	Diplosoma Ascidiella young	Diplosoma Halichondria	None
4	Hydroids	Diplosoma	Diplosoma	Halichondria	Diplosoma Ascidiella juv. Polydora
5	Halichondria Botryllus Diplosoma	Diplosoma Pomatoceros Anomia	Halichondria	Halichondria 5 colonies	Diplosoma Polydora
6	None, dirty	Ascidiella Polydora Umbonula Anomia	Ascidiella young	Hydroids	None
7	Diplosoma Anomia Umbonula	None	Diplosoma Ascidiella young	Diplosoma	Diplosoma Botryllus
8	Botryllus	Anomia	None	Pomatoceros young	None
9	Botryllus Diplosoma	Botryllus Diplosoma Halichondria Hydroids	Diplosoma abundant	Pomatoceros Halichondria	Diplosoma Botryllus Halichondria a little
10	Diplosoma a little	None	Anomia Nudibranch spawn	Botryllus Diplosoma Halichondria Polydora	None

Summary of Results from Experiment G.

The most important results obtained from Experiment G are (1) the capacity of the different substances tested for resisting or permitting growth in the first few months of exposure in sea-water, and (2) the capacity of the different substances tested for resisting erosion from—or adhering to—rough and smooth surfaces.

The observations made on December 8th, 1919, and recorded in Table XIV, show that all the black paints, i.e. III, V, IX, and X, while remaining in good condition, permitted extensive growth to occur, while the observations made on September 25th, 1919 (see Table XIII), show that even in four weeks the same substances already had slight growths on them of the same kind as occurred on the untreated shells (VII) at that time. These substances must, therefore, be regarded as non-toxic, or at the most only slightly toxic, to the kinds of organisms shown in Table XIV. After nine months' exposure in the sea these paints remained in good condition and adhered to the shells better than the other paints, and were not again reported on. These paints need not be further considered in this experiment.

After 14½ weeks in the sea, paints VI, VIII, XI, and XII were found to be eroding fast, while I, II, and IV remained mostly in good condition, except for slight flaking on the smoother faces of the shell. At this time growths occurred on VIII and XII, but as the paint was already nearly all washed off the latter (XII), growth may have begun originally on the denuded parts of the shell. No. XII paint, therefore, was eroded in so short a period as 14½ weeks in this experiment and need not be further considered, except that it could be regarded as preventing marine growths for one month (see Table XIII).

After 6 *months in the sea* the following paints remain to be considered, namely I, II, IV, VI, VIII, and XI. Of these No. VI was spongy and washed almost completely off some of the shell-faces ; Nos. VIII and XI were soft and also being rapidly eroded ; the other paints remained good, but No. I was washing away to some extent.

After 9 *months in the sea* the paints VI, VIII, and XI were washed off most shells, and even where they remained permitted growths of Balanus. Nos. IV and I were also washing off to some extent and permitted Balanus to settle on the paint. No. II remained in the best condition, being washed off the shell in small areas in a few cases. In some of such cases growth had occurred on the denuded shell area.

After 12 *months in the sea* all shells were covered with growths except those painted with Nos. IV, I, and II ; of these Nos. IV and I permitted growths of Balanus on the paint itself, but no growth occurred actually on No. II paint, although occurring on clean denuded areas of shell adjacent to the paint.

After 13 *months in the sea* the condition was almost the same as after 12 months. The paints II and IV still adhered well to the rougher faces of the shell, but was more or less washed off the smoother faces. No. IV still only permitted the growth of a few Balanus, while No. II still inhibited all kinds of growth, although not preventing such on adjacent clean shell area. No. I paint was not reported on on this examination.

After 19 *months in the sea*, shells, still covered with the paints IV, I, and II, and permitting little or no growth, were taken out of the sea and sent immediately to the Government Chemist for separate chemical analyses of the paints at this stage.

The results of this experiment confirm those in Experiment D especially, in which the paints were found to wash off the smooth side of the shells to a great extent in about 13–14 months. This period is not long enough to test fully the anti-fouling value of the more efficient kinds of poisonous paints, e.g. II, IV, and I, but serves to demonstrate the fundamental importance of the capacity of a paint of this kind (*a*) to withstand erosion and (*b*) to adhere to the surface to which it is applied. This and the other experiments with shells fully prove that all the paints adhere better to, and erode less quickly from, a rough than a smooth surface. In this experiment the anti-fouling paint VI eroded more quickly than VIII, and was, therefore, of less value for keeping down growth from this fact alone, whatever poisonous properties that paint may have had before erosion. It is obvious that an anti-fouling paint has lost its value as such as soon as it is washed away, therefore *the degree to which an anti-fouling paint resists erosion while retaining its growth-inhibiting properties is a fundamental property of such paints.*

SERIES III. PROMENADE PIER, PLYMOUTH.

Experiment H.

In this experiment the following substances only were tested, namely IV, anti-fouling paint; VIII, red oxide of iron paint; IX, black varnish; XV, a common grey paint; along with VII, untreated shells; XIII, sheets of copper 4 inches square; and XIV, sheets of zinc of the same size. The tarred rope (tarred with coal-tar and well dried) provided an additional experiment with No. X substance. The shells were painted with each paint, in lots of sixteen, and strung on tarred rope around the piles of the Promenade Pier at the level of low-water spring tides. Twenty shells were put out around each pile in two horizontal rows each containing ten shells, and in such a way that a clean shell alternated

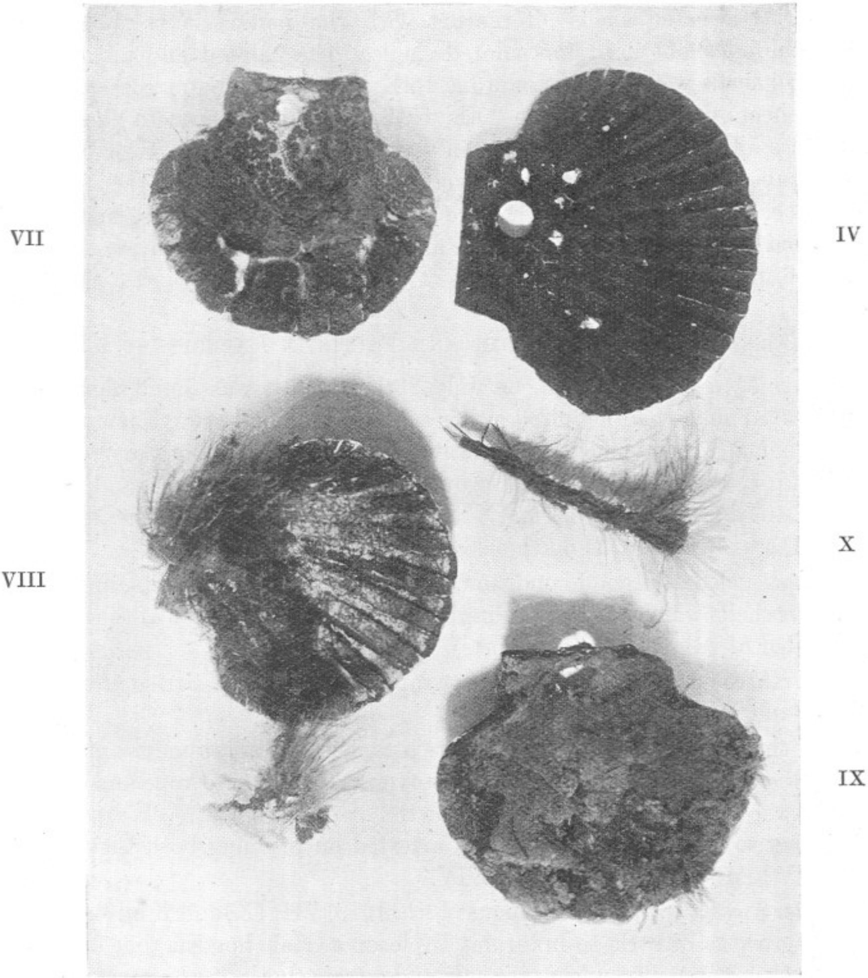


FIG. 17.—Photo of shells from Experiment H, Promenade Pier, Plymouth, exposed in the sea from June 18th, 1919, to September 13th, 1919. (× ca. $\frac{2}{5}$.) (Photo by D. P. Wilson.)

VII Untreated shell covered with a growth of six or seven distinct colonies of Botryllus, and with a slight growth of hydroids.

VIII Red: view of smooth inner surface of shell showing the paint washed off to a great extent and with mature Plumularia and Clytia overgrowing both the paint and the denuded shell. The reverse surface showed denudation of paint to a smaller extent, but hydroid growth both on paint and naked shell. The tarred rope still attached to this shell showed a luxuriant growth of Halichondria, Diplosoma, and ripe Plumularia.

IV Red: view of smooth inner surface of a flat valve, showing only slight loss of paint and no growth; the reverse side showed no loss of paint and no growth.

IX Black: view of smooth inner surface of a convex valve covered with colonies of Botryllus overgrowing the paint and ripe Plumularia and Clytia. The reverse side showed slight loss of paint on the ridges and similar luxuriant growth.

The piece of tarred rope between IX and X shells shows also a heavy growth of ripe Plumularia.

with a treated shell (with rare exceptions) both vertically and horizontally. Untreated shells alternating with the metal sheets were put out on piles not used for painted shells. The painted and untreated control shells were put out on June 18th, 1919, and the untreated shells and sheets of metal on June 20th, 1919. In this experiment the substances VIII, IX, and XV were only painted on the shells in one coat, but substance IV was given two coats. In all the other experiments two coats of each substance were applied. The shells were suitably marked by borings differing in size and position for identification. (See Fig. 6, p. 385.)

OBSERVATIONS ON GROWTHS AND PAINTS IN EXPERIMENT H.

After $5\frac{1}{2}$ *weeks in the sea*, on July 26th, 1919, it was found that the untreated shells had acquired either a little or a good growth mainly of Diplosoma (which yielded living active tadpoles in the Laboratory), Halichrondria, Plumularia (ca. half-grown colonies in abundance), and some Mytilus spat. Shells with No. IX substance and the tarred rope, X, had growths as luxuriant as on the clean shells.

IV was clean, in good condition, and without growth, except in three or four shells which showed slight growth (doubtless on parts of the shells denuded of paint, see later reports).

On XV the paint was washing away rapidly and already carried growths. XIII and XIV showed no growth.

On the pile to which the shells were attached was an abundant growth of *Halichondria panicea* which rapidly overgrew the tarred rope and crept on to the clean shells. Creeping growths of this kind were observed *on this day* to have been undoubtedly arrested on reaching both the paint No. IV and the zinc sheets No. XIV.

After 8 *weeks in the sea*, on August 12th, 1919, VII, IX, and X all showed good growths of little to luxuriant Diplosoma, Halichondria (one colony $3{\cdot}2 \times 2 \times 1$ cms.), *Plumularia pinnata* and *setacea* (both of which extruded planulæ), Clytia (which yielded medusæ), Botryllus (one colony with fifteen whole and three half-systems), and other hydroids. XIII showed no growth, but of XIV (zinc) one sheet had a small colony 10×3 mm. of Halichondria which had almost certainly grown from a larva.

XV had fair growths and VIII a little growth on two shells, but none visible on others.

After $12\frac{1}{2}$ *weeks in the sea* (see Fig. 17, p. 419), on September 13th, 1919, a detailed report on the shells was made which may be summarised as follows :—

VII, untreated shells : four shells with little growth, others (ca. 70) mostly covered with growths of Botryllus, Diplosoma, Plumularia, Clytia, Bougainvillea, and other hydroids. One shell placed between two sheets of copper had no visible growth on this day.

IV, reddish brown anti-fouling paint. All shells without growth and the paint in good condition and entire on nearly all the shells.

VIII, red oxide ; the paint is washed off the inside (smooth face) of most shells. Five shells with no growth, others with small growth of hydroids, others with young colonies of a compound Ascidian (probably Morchellium) and Botryllus and Diplosoma overgrowing the paint.

IX, black varnish shells covered with same growth as on others, and paint still good.

X, tarred rope with luxuriant growths and overgrowths.

XIII, copper sheets ; all without growth.

XIV, zinc sheets ; thirteen no growth, two with slight hydroid growth, one with a small colony of Halichondria now 12×5 mm.

XV, the grey paint is almost all washed away on all shells, which have now acquired little to luxuriant growths. On this day tadpoles of Botryllus and Diplosoma were obtained from samples of the growth on the material, and medusæ of Clytia from isolated colonies. On September 15th numerous *Folliculina ampullaria* were obtained in a bowl from material isolated September 13th. This species had passed through a reproductive phase in the Laboratory. On October 24th three sets of shells were missing. *Bougainvillea ramosa* collected from the experimental material gave off medusæ.

After 25 *weeks in the sea*, on December 9th, 1919, the shells, No. IV, showed no growth, but the paint was washing off badly on the smoother side of the shells. Bougainvillea colonies and Sycon were now abundant on most of the other material, in addition to the organisms already recorded.

After 8½ *months in the sea* all the No. IV shells had lost a large amount of paint ; one shell had no paint at all left. There was, however, no growth on the residual paint itself.

Many of the untreated shells, No. VII, were being washed clean by the wave-action resulting from heavy gales ; colonies of Botryllus were found just hanging on to the shells.

On February 21st, 1920, the shells were restrung with fresh rope or trawl twine.

On August 18th, 1920, many strings of shells were missing. Four sheets of copper were found to be very thin, but there occurred a luxuriant growth of organisms all around the copper sheets which obviously have no effect on keeping down growth to within a distance of even a few millimetres. There was, however, no growth on the copper itself.

On this day Halichondria from the shells yielded embryos. No further observations were made.

TABLE XV.

SUMMARY OF RESULTS FROM ALL EXPERIMENTS, SHOWING INCIDENCE OF GROWTHS* AND FINAL CONDITION OF THE SUBSTANCES TESTED.

		Cawsand Bay				West Wharf			Prom. Pier	
Experiment		A and B on wood	C on wood	D and E on shells		F§ on wood	G on shells		H on shells	
Observations				smooth surface	rough surface		smooth surface	rough surface	smooth surface	rough surface
I	Growth	little	fair amount	*abundant*	*abundant*	little	little	little		
	in period	14 months	14 months	14 months	14 months	12 to 28 months	9½ months	9½ months	—	—
	paint	nearly done	some†	trace	trace	fair amount	eroding slightly	eroding slightly		
	in period	14 months	14 months	14 months	14 months	28 months trace 42½ months	9½ months	9½ months		
II	Growth	trace	little	*abundant*	none	none	none	none		
	in period	14 months	14 months	14 months	14 months	28 months	13 months	13 months	—	—
	paint	entire	some	trace	partly washed away	fair amount	much eroded	slightly eroded		
	in period	14 months	14 months	14 months	14 months	42½ months	13 months	13 months		
III	Growth	fair amount	abundant	abundant	abundant	abundant	slight	slight		
	in period	6 weeks	6 weeks	from 6 weeks	6 weeks	from 6–9 months	4 weeks	4 weeks	—	—
	paint	good	some	partly washed off	entire	good where not	not recorded	not recorded		
	in period	14 months	14 months	14 months	14 months	eaten, 42½ mths.	13 months	13 months		
IV	Growth	little	little	fair amount and *abundant*	none to little	little	little	little	none	none
	in period	14 months	14 months	14 months	14 months	12–20 months	13 months	13 months	8½ months	8½ months
	paint	fairly good	some	partly washed off	almost entire	fair amount	badly eroded	slightly eroded	badly eroded	badly eroded
	in period	14 months	14 months	14 months	14 months	42½ months	13 months	13 months	6 to 8½ months	9 months
V	Growth	fair amount	abundant	abundant	abundant	slight	little to much	little to much		
	in period	6 weeks	6 weeks	from 6 weeks	from 6 weeks	from one month	4 to 14½ weeks	4 to 14½ weeks	—	—
	paint	good	some	little to ½ eroded	almost entire	eaten away	good	good		
	in period	14 months	14 months	14 months	14 months	20–28 months	9½ months	9½ months		
VI	Growth	slight	much	slight	abundant	abundant	slight	slight		
	in period	6 weeks	14 months	9 weeks	14 months	6–9 months	9½ months	9½ months	—	—
	paint	little left	some	almost all eroded	trace to ⅓ eroded	eroding in 12	eroded	mostly eroded		
	in period	14 months	14 months	14 months	14 months	none left 28–31 months	6–9 months	9 months		
VII	Growth	fair amount	abundant	abundant	abundant	almost eaten away	abundant	abundant	fair amount	fair amount
	in period	6 weeks	6 weeks	6 weeks	6 weeks	20 months	4–14½ weeks	4–14½ weeks	5½ weeks	5½ weeks

VIII	Growth	fair amount	abundant	fair amount	fair amount	abundant	slight	slight	fair amount	fair amount
	in period	6 weeks	6 weeks	from 6 weeks	from 6 weeks	1 to 2¾ months	3½ to 6 months	3½ to 6 months	12½ weeks	12½ weeks
	paint	little left	some	trace	trace	eroded or eaten	mostly eroded	eroding badly	badly eroded	somewhat eroded
	in period	14 months	14 months	14 months	14 months	12–20 months	3½ to 6 months	9 months	12½ weeks	12½ weeks
IX	Growth	—	—	—	—	fair amount	much	much	fair amount	fair amount
	in period					one month	one month	one month	5½ weeks	5½ weeks
	paint					almost entire	good	good	good	good
	in period					28 months	9½ months	9½ months	25 weeks	25 weeks
X	Growth	—	—	—	—	abundant	fair amount	fair amount		fair amount‡
	in period					2¾ to 6 months	one month	one month	—	5½ weeks
	paint					almost entire	slightly eroded	good		good
	in period					28 months: good where not eaten 42½ months	3½ to 9 months	9 months		8 months
XI	Growth	—	—	—	—	*abundant*	slight	slight		
	in period					9–12 months	9 months	9 months	—	—
	paint					washed away	badly eroded	eroded badly		
	in period					12 months	3½ to 9 months	9 months		
XII	Growth	—	—	—	—	abundant	slight	slight		
	in period					9–12 months	14½ weeks	14½ weeks	—	—
	paint					entirely eroded	badly eroded	badly eroded		
	in period					20–28 months	14½ weeks.	14½ weeks		
XV	Growth	—	—	—	—	—	—	—	slight	slight
	in period								5½ weeks	5½ weeks
	paint								badly eroded	badly eroded
	in period								5½ to 12½ weeks	5½ to 12½ weeks

XIII and XIV XIII acquired no growth but became thin in 14 months
XIV acquired a slight growth in 8 weeks on one sheet only and on 3 sheets in 12½ weeks.

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* If the records of growth are given in italics, they refer to growth on the shell or surface denuded of paint; otherwise they refer to growth on the paint.

† The condition of the paint in this experiment after 14 months' exposure could not be determined accurately owing to bad weather, but it was easily seen that all the boards had some paint remaining.

‡ In this experiment No. X, coal-tar, was only tested on tarred rope, which must be regarded as having a rough surface.

§ The erosive influences operating in this experiment (F) must be considered: (1) water erosion, (2) attrition of the paint by gribble either by ingestion or undermining the underlying wood, and (3) possibly also unusual chemical action with the substances involved in typical dock-side water-pollution.

Results of Experiment H.

It was found that the anti-fouling paint No. IV resisted growths so long as the paint remained on the shells, that is, during 8½ months only, in this experiment. This paint washed off the smoother faces of the shells much more rapidly than the rough face.

No. XIII, sheet copper, resisted growths so long as observed, i.e. ca. 14 months, but did not prevent marine growths occurring within even a few millimetres' distance.

No. XIV, sheet zinc,* inhibited growth for only a short period; after only 8 to 12½ weeks in the sea a small proportion of the sheets used acquired a slight growth of Halichondria or hydroids.

No. IX, black varnish, became overgrown as soon as, and as much as, untreated shells, but remained in good condition longer than the other paints.

No. X, coal-tar on the rope, acquired growth as soon as, and apparently more profuse than, the clean shells.

No. XV, an ordinary grey paint, became washed off the shells to a great extent in only 5½ weeks and had disappeared after 12½ weeks.

No. VIII, red oxide, inhibited growth during 8 weeks so long as it remained on the shells. This paint was washed off the smoother faces of the shells more rapidly (ca. 12½ weeks) than off the rougher faces, and began to be overgrown (where it still adhered) after 12½ weeks.

In this situation erosion was more rapid than in corresponding experiments at the West Wharf and Cawsand Bay.

Experiment J.

This experiment has previously been partially recorded (**1**, 1914), but is included here briefly for comparison with others. The Cawsand Bay raft (see p. 380) was moored in the sea after being well coated with coal-tar on March 12th, 1912. Thirty-one weeks later, on October 15th, 1912, the raft was brought in and beached above high-water mark. Living *Teredo norvegicus* (not *navalis* as previously recorded) were taken from the boards of the raft on October 15th, and a re-examination was made for others on October 31st and November 2nd after the raft had been a fortnight out of water. On November 2nd four large individuals were taken out of the wood and one was found to have cilia on the gill beating quite actively; the other three had recently died.

The largest specimen measured, fresh out of its burrow, was 19·8 cm. long. The largest boring was 28 cm. long, and had a mean diameter of

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* Zinc-coated buoys acquire a heavy growth of many kinds of organisms after only a relatively short period in the sea, namely, one to two years. The zinc, however, becomes coated with a white substance, probably a zinc salt which has not been investigated and is apparently non-toxic or only slightly toxic.

about 1 cm. (see Fig. 18, below). The raft was made of common wood and was presumably pine. The general growth on the raft during 1912 was similar to that recorded in 1919 (see p. 396), and similar growth has been repeated during many seasons, therefore there is no doubt that coal-tar is of no value whatever for preventing marine growths or for preserving wood from the attacks of Teredo. On the other hand, Experiment G proves that coal-tar is a valuable agent for preserving wood from the attacks of gribble, i.e. *Limnoria lignorum* and *Chelura terebrans*, in English waters.

Experiment K.

A number of bathing rafts (usually three, sometimes four) are put out in the sea each year off Plymouth Hoe about the end of April and taken in again about the middle of the following October. It has been possible to make observations on these rafts over a number of years, owing to the courtesy of Mr. A. L. Bennetts of the Plymouth Corporation. The bottoms of these rafts are either well coated with two good coats of coal-tar or are thickly covered with pitch. Growth occurs quickly and luxuriantly on the bottoms and on the sides, comparable with that obtained on the Cawsand Bay raft; for example, Mytilus settles on the bottom and grows *in situ* each year to a size of

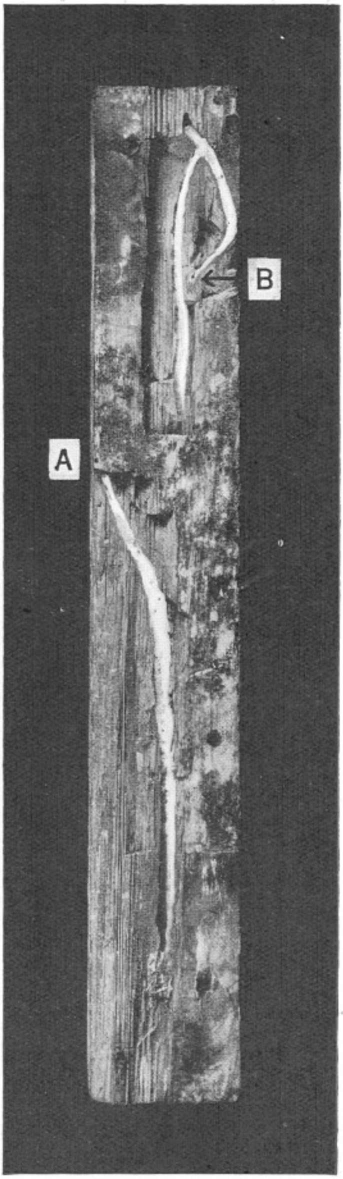

FIG. 18.—Photo of a piece of wood carved to expose two large Teredo borings from Experiment J, Cawsand Bay Raft, after 31 weeks' immersion in the sea. (× ca. $\frac{2}{3}$.) (Photo by D. P. Wilson.)

A. The point of entry of one Teredo which bored to the middle of the wood and then continued its course in the middle. The end of the boring is not quite exposed.

B. The point of entry of another Teredo which, in order to avoid a nail, bored at first towards the side and then turned inwards, but found itself approaching the wetter and more external wood ; whereupon it abandoned the last part of the burrow, sealed it with a calcareous partition from the main burrow, and changed direction completely to bore down the middle. The end of the burrow is not lined with calcareous matter and is not completely exposed.

3 to 4 cm. approximately; and in 1914 mature *Ciona intestinalis* grew up to 10·5 cm. long, mature *Ascidiella aspersa* up to 5·9 cm., *Sycon coronatum* to 8·2 cm. long, carrying embryos; and other growths occurred comparable in general to that obtained on the Cawsand Bay raft (see p. 396). It is clear therefore that coal-tar and pitch are not deterrents to growth *in the sea,* and indeed when well-dried favour growth by offering at once a clean non-toxic surface for the organisms.

SUMMARY OF RESULTS FROM ALL EXPERIMENTS.

The results obtained in all the experiments are collected together in Table XV, p. 422, and can now be considered. Experiments may be referred to conveniently by letter to save repetition of the word "experiment."

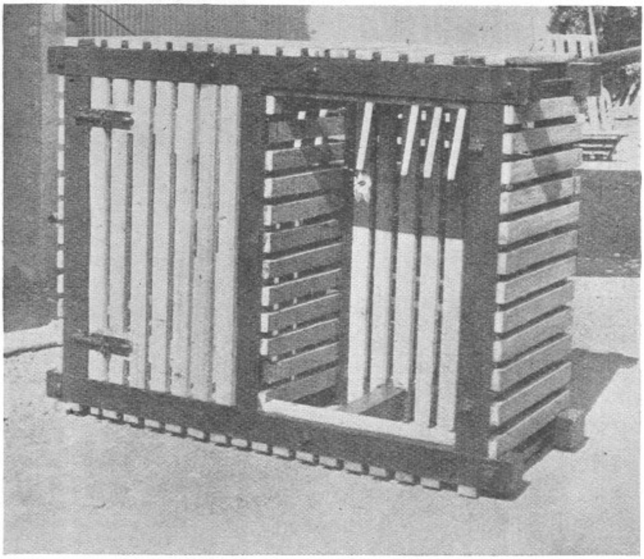

FIG. 19.—Photo of an upper view of a raft similar to, but three times as small as, the one used in Cawsand Bay.

One lid has been removed to show the internal structure. Every piece of wood can be removed for observation of growth and can be replaced by a new piece without interfering with the structural basis of the raft. See Fig. 20 for under-surface view. This raft was used for experiments on rate of growth at Spitzbergen in 1921 (**30**). (Photo by A. J. Smith.)

It is clear from Table XV that the only paints having effective anti-fouling values are I, II, and IV. It is also manifest that the anti-fouling value depends upon the retention of the paint on a substratum (see especially the series of experiments on paints Nos. II, I, and XI).

All the paints are retained better on wood than on shells (compare F and G) and better on the rougher face of the shells than on the smooth face (see D and E, G and H). On wood the paint was eroded less quickly in a situation subject to less erosion, as in F, than in one subject to greater erosive influence as in A, B and C (compare also Table I, p. 382, and Table IX, p. 402, especially with regard to No. I paint). On shells there is an indication that erosion occurred roughly in proportion to the erosive effect of the sea-water in the different situations. Compare G in a relatively quiet situation with D and E where motion was continuous.

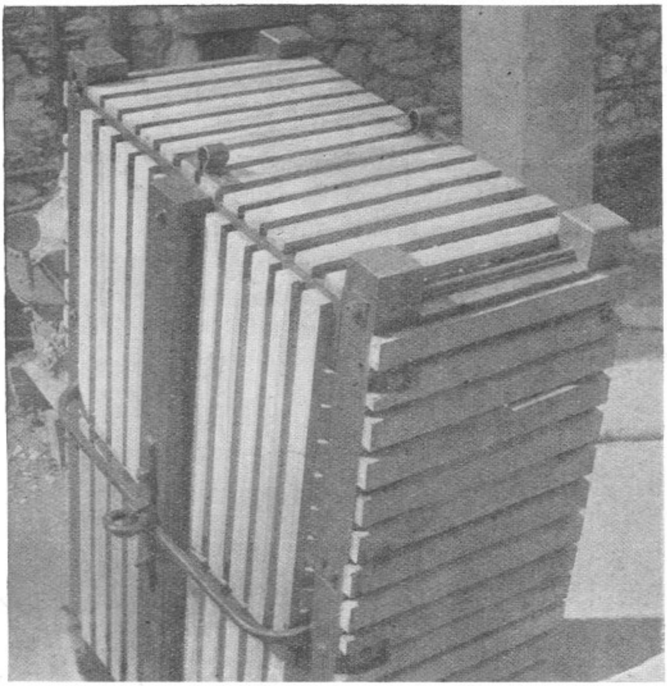

FIG. 20.—Photo of a raft similar to, but much smaller than, the one used in Cawsand Bay to show the under surface and side construction.

The bar of iron with loop for the swivelled shackle of the mooring-chain is also looped around the middle of each of the stout side-pieces which form a part of the basic skeletal structure of the raft. See also Fig. 19. The bolting of the basic parts is also shown. (Photo by A. J. Smith.)

In H, however, No. IV paint eroded badly on the rougher face of the shells in 9 months, but it is possible that in this situation wave action at about the time of low water is exceptionally severe in winter, while it is probable that some rubbing occurred as well as water erosion.

It is significant that the proprietary anti-fouling paints VI and XI eroded rapidly and also permitted growth early, even when not eroded. See especially A and B, VI, for growth ; and F, XI, for erosion.

The anti-corrosive substances III, V, and VIII all permit early growths, but while the latter eroded rapidly both on wood and shells the two former adhered to shells (and would presumably also adhere to iron) better than the best anti-fouling paint. On wood, however, No. V was rapidly eroded probably partly by gribble, whereas No. III remained in good condition and preserved the wood as long as any of the anti-fouling paints except No. II.

In its property of preserving wood (and probably also iron) coal-tar No. X was as efficient as the proprietary paint No. III, and more efficient than No. V, while so far as the observations were continued black varnish No. IX was shown to be equal in value as a preservative on wood to No. III and better than V.

Common paints such as XII and XV were shown to be rapidly eroded and to have only a slight preservative and anti-fouling value. Zinc, it was shown, might soon lose its toxic effect in the sea, but copper retained its anti-fouling property during the period of the experiment, but dissolved somewhat rapidly in the sea-water.

The most critical situation from an anti-fouling point of view is where a strong light plays on the paint, for No. II paint, which remained free from growth during at least 28 months in Experiment F, acquired some algal growth in 7 to 14 months in Experiment C.

LIMITATIONS OF THE EXPERIMENTS.

In order to compare the results obtained from the experiments herein recorded with those likely to be obtained in actual practice, i.e. on the bottoms of ships or other structures, it is necessary to compare the conditions under which the experiments were carried out with those occurring in actual practice.

The Nature of the Surface covered by the Experimental Substance.

In practice, iron ships, after being scraped and cleaned, are usually painted first with red oxide paint (such as No. VIII in the experiments), which is used as an (iron) anti-corrosive agent. When this coat is dry it is painted over sometimes with one or two coats of quick-drying anti-fouling paint, such as Nos. I, II, IV, VI, and XI in the foregoing experiments. Wooden ships after being scraped and cleaned—and more or less dried—are painted with the anti-fouling paint at once.

In the experiments the test-boards and shells were painted with two coats of anti-fouling paint, which were well dried on the same day or the day before the material was put in the sea. The treatment in the experiments with regard to painting is therefore comparable to, but better than, that given to iron vessels. With iron vessels the anti-fouling paint is usually directly applied on red oxide; and it is possible, and indeed probable, that the behaviour of the anti-fouling paints in the sea differs according to the nature of the underlying surface. In this respect there are three conditions to be considered, namely :—

(*a*) Anti-fouling paint on iron oxide over iron.
(*b*) Anti-fouling paint directly painted on to wood.
(*c*) Anti-fouling paint directly painted on to shells.

Experiments A, B, C, and F are of the (*b*) type and the remaining experiments of the (*c*) type. No experiments of the (*a*) type were tried.

CONDITIONS CONDUCIVE TO EROSION.

The paint on the bottom of a ship is subjected to erosive effects in proportion to the speed of the ship and the period of time the boat is in motion. In Experiments A to E the experimental material was in effect buoyed and would be subject to almost continuous motion by the lifting motion of the waves as well as the slight pitch and roll of the buoy (i.e. the parallelopiped-shaped raft, 20 × 5 × 2 feet). In Experiment F the test-boards were fixed and experienced no subjective motion. In Experiments G and H the material was also fixed with tarred rope, but in these cases the shells were liable to be, and were in instances, worked loose by wave action.

In Experiments A to E in Cawsand Bay the experimental material would be liable to erosion by slight tidal currents, and H at the Promenade Pier by similar tidal currents and wave action, especially at low water, while F and G at the West Wharf would only experience slight erosion due to the rise and fall of the tide and that due to slight wave action (in this protected situation) at low water.

Experiments A to E were therefore subject to relatively great erosive influences, but probably not so great as that experienced by even a 10-knot vessel; the painted surfaces in the other experiments would experience proportionately milder erosive action.

CONDITION AND DRYNESS OF THE SURFACES PAINTED.

The surface of the bottom of an iron vessel which has been cleaned and scraped will vary from smooth to roughly pitted according to the number of times the bottom has been scraped and the degree of fouling experienced. The surface of the bottom of a wooden vessel will vary in a similar way, but will become more uneven than that of an iron ship.

In Experiments A, B, C, and F the wood was glass-papered to a smooth but not polished surface; and in the shell experiments the inner face of each shell is of a polished smoothness, while the outer face is roughened with fine decussations, except in some of the convex valves which might be smooth-worn on the crown of the shell.

In all the experiments the experimental material was in a dry condition when painted, whereas when ships are painted under economic conditions the bottom is liable to be wet or damp in rainy or damp weather, or when docking is carried out hastily.

Thus on the whole the experimental paints would be applied more efficiently than under economic conditions, and to a variety of surfaces roughly comparable to those occurring on the bottoms of ships, but would be subject to less water erosion than on even slow-moving vessels (say, 10 knots) if such vessels are in fairly continuous translation.

PART II. CHEMICAL INVESTIGATIONS.

During the course of these experiments and observations the question arose during the concurrent investigation by the writer of the cause of unusual oyster mortality (**14** and **15**, 1921, 1923–24) as to what order of concentration of arsenic and copper particularly was likely to be poisonous to oysters and other marine animals. Fortunately, samples of paints which had been in the sea a considerable time while remaining poisonous were still available from the experiments herein described.

As it was possible to derive valuable information regarding the resistance of marine animals to poisons from chemical analyses of paints which (*a*) retained their poisonous properties in the sea and (*b*) were just losing their poisonous properties and beginning to be overgrown, the assistance of the Government Chemist was asked for and happily obtained for making a few critical analyses.

It is necessary to point out that a thorough chemical and biological study of the question was not contemplated in this research. In order to study the problem in such a way it would be necessary to know all the chemical ingredients used in the manufacture of the paints, but as the chief substances tested were proprietary articles, which are of great economic value, it was manifestly impossible to obtain the information.

The chemical investigations in these experiments are therefore limited to :—

(1) The analyses of three anti-fouling paints after exposure to sea-water and retention of anti-fouling property for 19 months.

(2) The analyses of two of the same paints as in (1) after exposure to sea-water on test-boards for 42½ months, when the paints had either lost, or were apparently just about to lose, toxicity to marine animals.

(3) The analyses of samples of two original paints (the same as in (2)) from the original paint-can.

These analyses were made in the Government Laboratory by the Government Chemist and his staff, to all of whom we are indebted for the resultant general information.

ANALYSES OF THREE PAINTS WHICH RETAINED POISONOUS PROPERTIES AFTER REMAINING 19 MONTHS IN THE SEA.

Three of the shells used in Experiment G put out in the sea on August 28th, 1919, were collected from the West Wharf, Millbay Docks, Plymouth, on April 22nd, 1921, and forwarded the same day to the Government Chemist for chemical analysis of the paint remaining on the shells. At this time most of the paint on the smoother face of the shells had been washed away, but where the paint remained there was little growth other than Balanus in I and IV, but none on II, although good growth occurred on adjacent areas of the shell denuded of paint. (See notes to Table XIII, p. 415.)

Thus on this date paints I and IV were still toxic to most marine animals, and paint No. II was still poisonous. The Government Chemist reported (**15**, 1924, p. 41) that "The paints were scraped off with as little of the shell matter as possible and give the following results :—

Lab. No.	Paint.	Colour.	Lead.	Zinc. per cent.	Copper per cent.	Arsenic as As $_4O_6$ per cent.
32	IV	Red	Absent	0·95	5·79 (cuprous)	0·01
33	I	Red	Absent	0·85	7·91 (cuprous)	0·01
34	II	Green	Absent	0·04	16·56 (cupric)	2·60

No evidence of Mercury nor of Barium was obtained in any of the paints, but Nos. 32 and 33 contained large proportions of iron."

It is clear from these analyses that the paints I and IV are very much alike in constitution as in behaviour (see Table XV, p. 422) but contain very much less copper and arsenic than No. II. The combination of the metals zinc, copper, and arsenic in these paints with the respective percentages of approximately 1·0 zinc, 6 to 8 (cuprous) copper, and 0·01 per cent arsenic is one which is just approaching the limit of toxicity in sea-water. This is a valuable result, even though the actual chemical constitution of the original materials is unknown.

The high percentage of cupric copper and arsenic remaining in paint II is sufficient explanation of the retained toxicity and a tribute to the efficiency of the matrix in this paint after 19 months' exposure on a shell surface in the sea.

ANALYSES OF PAINTS ON TEST-BOARDS AFTER ABOUT $3\frac{1}{2}$ YEARS IN THE SEA.

The paints II and IV on the test-boards used in Experiment F were analysed after remaining in the sea about $3\frac{1}{2}$ years. The condition of these two test-boards with regard to overgrowth is given in detail in the section beginning on p. 410, and is depicted in Fig. 12, p. 404, and Fig. 13, p. 405.

In the case of No. IV test-board, two areas of paint were scraped off and analysed. Both these areas had undoubtedly lost toxicity and were covered with living organisms when taken from the sea (see Fig. 12). The zinc-copper-arsenic percentage in these two samples of paint had been reduced greatly below that found to be near the limit of toxicity in the preceding sample, and had doubtless been non-toxic for some time, as may be also adjudged especially from the size of the barnacles (Balanus) which were growing on the analysed paint.

The condition with regard to overgrowths on the areas of paint, A to D, analysed from the front face of test-board II were as follows, but see also Fig. 12, p. 404.

	Site.	Region.	Growth.
Area A	Around the fixing nail 10 to 18·4 inches from the top.	In the upper middle region of the board.	Covered in part with a growth of the hydroid Obelia and with a few borings of gribble in a crack in the wood.
Area B	4·5 to 8·8 inches from	the bottom of the board	with 3 large and a few small borings of gribble, i.e. Limnoria or Chelura.
Area C	10·5 to 14·7 inches from	the bottom of the board, i.e. in the lower half.	No growth observable.
Area D	5·6 to 9·8 inches from	the top of the board.	No growth observable.

The bottom of the board was covered with a growth of Diplosoma, Umbonula, and Halichondria up to a height of 5 or 6 inches from the lower edge; this growth probably encroached slightly on the lower part of area B, which was scraped for chemical analysis.

The results of the analyses of the samples of paints scraped from areas A to D are given in the following report by the Government Chemist with a discussion on the significance of the figures obtained, together with analyses of the original paints from the paint-can.

THE GOVERNMENT CHEMIST'S REPORT ON CHEMICAL ANALYSES.

"REPORT ON THE EXAMINATION OF TWO SAMPLES OF ANTIFOULING PAINT RECEIVED FROM DR. ORTON ON 15TH MARCH, 1923, AND OF THE PAINT REMAINING ON AREAS OF TWO WOODEN BOARDS TO WHICH THESE PAINTS HAD BEEN APPLIED WITH DIFFERING TOXIC EFFECTS AFTER 3½ YEARS IMMERSION IN SEA-WATER.

The paints were described as :—

Lab. No. 323. 1. (Green paint)
Lab. No. 324. 2. (Brown paint)
and gave the following results on analysis :—

TABLE 1.

ANALYSES OF NO. II AND NO. IV ORIGINAL PAINTS.

	Green per cent.	(Reddish) brown per cent.
Volatile matter (turpentine substitute)	22·4	21·6
Oil	18·7	15·9
Oxidised oil and varnish gums	8·6	10·5
Silica and silicates	1·2	5·6
Lead oxide	0·1	nil
Arsenious oxide	5·0	0·2
Cupric oxide	14·8	*nil*
Cuprous oxide	*nil*	11·8
Iron oxide	0·4	15·4
Zinc oxide	0·8	0·5
Calcium oxide	8·6	9·3
Carbon dioxide	4·6	8·3
Phosphoric pentoxide	0·2	nil
Magnesium oxide	0·2	0·9
Sulphuric anhydride	8·6	nil
Acetic acid and a little undetermined organic matter (by difference)	5·8	nil
	100·0	100·0

In the green paint the copper appears to be present partly as insoluble basic sulphate (and some of the lime might also be linked up with this) and partly as aceto-arsenite of copper (Scheeles green). The calcium-oxide is in combination with the carbon dioxide and with part of the sulphuric anhydride. It is impossible to give the exact composition of such a mixture.

In the case of the brown paint the copper is present in the form of red cuprous oxide and the calcium and magnesium oxides are in combination with the carbon dioxide forming carbonates.

The paint on the boards was very thin and only small quantities were obtained from the areas scraped. There was not sufficient material, therefore, for complete analyses. The most important constituents have been determined but the results are complicated by the fact that silicious material, carbonates, sodium salts, etc., have been deposited in the paint. Before scraping off the samples all organic growth was removed together with any incrustation that obviously did not belong to the paint. In the case of the brown board sample A was taken from a place competely overgrown, while the area sampled for B was fairly clean except for five or six barnacles.

Four areas of the green-painted board were marked A, B, C, and D by Dr. Orton, who stated that 'the part A has a growth of hydroids roughly within the circle,' and 'parts B, C, and D are apparently all just losing toxicity.'

The results of the analysis are as follows :—

Table 2.

Analyses of Paint Scrapings from Test-Boards II and IV. Experiment F.

(a) *Green board* (II)

		Partly covered by a growth of hydroid. A %	Bored by gribble and slightly overgrown. B %	No growth. C %	No growth. D %
Insoluble in acid.	Oxidised oil, wood and organic matter	14·1	14·5	12·1	14·4
	Mineral matter, silica and silicates	30·8	34·8	28·8	11·2
Cupric oxide		4·0	2·2	7·5	15·2
Iron oxide		4·5	6·3	5·0	2·4
Zinc oxide		0·2	0·3	0·4	0·2
Calcium oxide		22·6	30·4	11·2	8·5
Magnesium oxide		1·4	1·6	1·8	0·9
Arsenious oxide		0·4	trace	0·7	0·7
Phosphorous pentoxide		0·6	0·5	0·3	0·3
Undetermined—CO_2, chlorides, sulphates, moisture, soluble organic matter, and sodium salts		21·4	9·4	32·2	46·2
		100·0	100·0	100·0	100·0

(b) *Brown board* (IV)

		Overgrown with marine organisms and non-toxic. A %	B %
Insoluble in acid.	Oxidised oil, wood and organic matter	17·5	16·5
	Mineral matter, silica and silicates	16·9	19·3
Cuprous oxide		0·2	0·6
Iron oxide		16·4	16·0
Zinc oxide		0·5	0·6
Calcium oxide		24·2	19·2
Magnesium oxide		2·6	2·2
Arsenious oxide		nil	0·05
Phosphorous pentoxide		0·4	0·3
Undetermined — CO_2, chlorides, sulphates, moisture, soluble organic matter and sodium salts		21·3	25·3
		100·0	100·0

It will be seen that in both sets of samples there are notable increases in the proportions of silicious material and calcium oxide while in the samples from the green board the iron has unaccountably increased.

In order to obtain a better comparison of the main inorganic constituents of the scrapings with those of the original paints the basic constituents (including silica and silicates and arsenic) have been added together and worked out on a 100 per cent basis. The figures are as follows :—

Table 3.

Percentage of Basic Constituents (including Silica, Silicates, and Arsenious Oxide) in the Original Paints II and IV and in Samples exposed in the Sea for 3½ Years.

(*a*) *Green board* (II)

		Areas after 3½ years exposure in the sea.			
	Original paint. %	With Hydroid growth. A %	With gribble borings. B %	No growth. C %	No growth. D %
Basic constituents (including silica and silicates)	31·1	63·9	75·5	55·4	39·0
Silica and silicates	3·9	48·2	46·1	52·1	28·7
Lead oxide	0·3	nil	nil	nil	nil
Arsenious oxide	16·1	0·6	tce.	1·2	1·7
Cupric oxide	47·5	6·3	2·9	13·5	39·0
Iron oxide	1·3	7·0	8·3	9·1	6·0
Zinc oxide	2·6	0·3	0·4	0·7	0·6
Calcium oxide	27·6	35·4	40·2	20·1	21·7
Magnesium oxide	0·7	2·2	2·1	3·3	2·3
	100·0	100·0	100·0	100·0	100·0

(*b*) *Brown board* (IV)

	Original paint. %	Overgrown area. A %	Overgrown area. B %
Basic constituents (including silica and silicates)	43·7	60·9	57·9
Silica and silicates	12·8	27·8	33·2
Arsenious oxide	0·5	nil	0·1
Cuprous oxide	27·0	0·4	1·0
Iron oxide	35·2	26·9	27·7
Zinc oxide	1·1	0·8	1·1
Calcium oxide	21·3	39·8	33·1
Magnesium oxide	2·1	4·3	3·8
	100·0	100·0	100·0

The results from the green (arsenic) board are peculiar. Sample B contained the largest proportion of basic constituents and silica, i.e. 75·5 per cent, the bulk of this consisting of silica and silicates and calcium oxide.* Since practically all the arsenic and most of the copper have been washed out, this paint should have lost its toxicity to a greater extent than A which still contains 0·6 and 6·3 per cent respectively of arsenious oxide and copper oxide. Samples C and D should be more toxic than A and it will be seen that whereas in A and B there is an increase in the proportion of calcium oxide which is presumably due to shells* of minute organisms, the proportion in C and D is less than in the original paint, pointing to the paint surface still being obnoxious to the organisms. The proportion of basic constituents and silica in D is only 39·0 per cent as compared with 63·9 per cent in A.

The apparent increase in the iron content of the scrapings may have been caused by deposition of rust or some insoluble iron deposit from the sea water, or it may be due to the ferric oxide in the original paint being very much more resistant to the sea water than all the other constituents of the paint.

In the case of the brown (copper) board it can be said that the cuprous oxide has been almost completely washed out and there is little difference in the copper content on the area completely overgrown (A) and on the area only partially overgrown (B).

It is, however, practically impossible from the limited number of results to trace the changes which have occurred in the paints during exposure. The composition of the paint is affected on the one hand by *removal* of constituents, organic and inorganic, and on the other by *addition* of inorganic matter in the form of calcium carbonate and silicious material derived either from the sea water or from organisms inseparable from the surface of the paint, or of organic matter, from the organisms or from the underlying wood, which could not be separated from the scraped paint.

The results of the analysis of the paints on three shells which were given in the oyster mortality investigation report of 14th July, 1921, in terms of metallic copper and zinc may be stated, for comparison in terms of the compounds found in the original paints as follows :—

Lab. No.	No. of paint.	Cuprous oxide. %	Cupric oxide. %	Zinc oxide. %	Arsenious oxide. %
32 (red)	IV	6·52	—	1·18	0·01
33 (red)	I	8·91	—	1·06	0·01
34 (green)	II	—	20·71	0·05	2·60

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* The excess of calcium oxide in this sample was probably derived from the encrusting Polyzoan on the lower part of area B (see p. 432). J. H. O.

about 1 cm. (see Fig. 18, below). The raft was made of common wood and was presumably pine. The general growth on the raft during 1912 was similar to that recorded in 1919 (see p. 396), and similar growth has been repeated during many seasons, therefore there is no doubt that coal-tar is of no value whatever for preventing marine growths or for preserving wood from the attacks of Teredo. On the other hand, Experiment G proves that coal-tar is a valuable agent for preserving wood from the attacks of gribble, i.e. *Limnoria lignorum* and *Chelura terebrans*, in English waters.

Experiment K.

A number of bathing rafts (usually three, sometimes four) are put out in the sea each year off Plymouth Hoe about the end of April and taken in again about the middle of the following October. It has been possible to make observations on these rafts over a number of years, owing to the courtesy of Mr. A. L. Bennetts of the Plymouth Corporation. The bottoms of these rafts are either well coated with two good coats of coal-tar or are thickly covered with pitch. Growth occurs quickly and luxuriantly on the bottoms and on the sides, comparable with that obtained on the Cawsand Bay raft; for example, Mytilus settles on the bottom and grows *in situ* each year to a size of

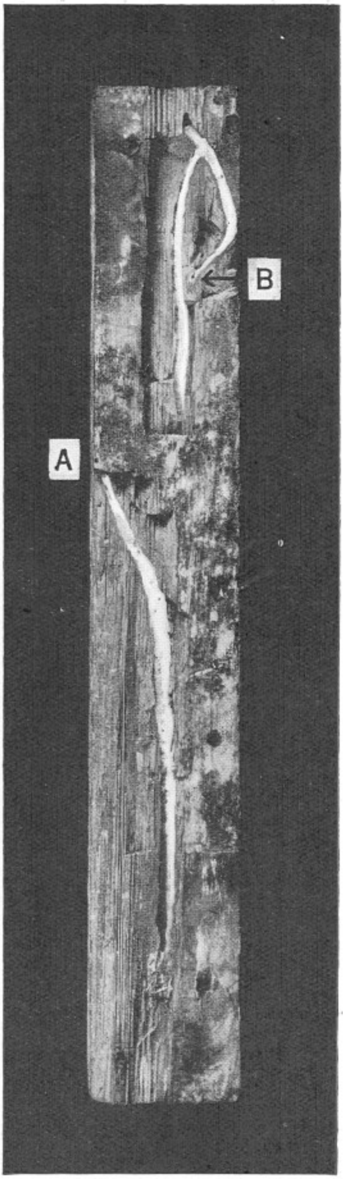

FIG. 18.—Photo of a piece of wood carved to expose two large Teredo borings from Experiment J, Cawsand Bay Raft, after 31 weeks' immersion in the sea. (× ca. $\frac{2}{3}$.) (Photo by D. P. Wilson.)

A. The point of entry of one Teredo which bored to the middle of the wood and then continued its course in the middle. The end of the boring is not quite exposed.

B. The point of entry of another Teredo which, in order to avoid a nail, bored at first towards the side and then turned inwards, but found itself approaching the wetter and more external wood; whereupon it abandoned the last part of the burrow, sealed it with a calcareous partition from the main burrow, and changed direction completely to bore down the middle. The end of the burrow is not lined with calcareous matter and is not completely exposed.

3 to 4 cm. approximately; and in 1914 mature *Ciona intestinalis* grew up to 10·5 cm. long, mature *Ascidiella aspersa* up to 5·9 cm., *Sycon coronatum* to 8·2 cm. long, carrying embryos; and other growths occurred comparable in general to that obtained on the Cawsand Bay raft (see p. 396). It is clear therefore that coal-tar and pitch are not deterrents to growth *in the sea,* and indeed when well-dried favour growth by offering at once a clean non-toxic surface for the organisms.

SUMMARY OF RESULTS FROM ALL EXPERIMENTS.

The results obtained in all the experiments are collected together in Table XV, p. 422, and can now be considered. Experiments may be referred to conveniently by letter to save repetition of the word "experiment."

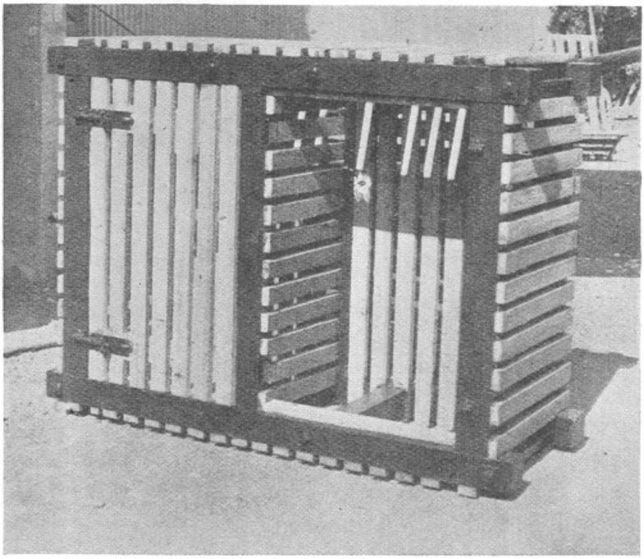

FIG. 19.—Photo of an upper view of a raft similar to, but three times as small as, the one used in Cawsand Bay.

One lid has been removed to show the internal structure. Every piece of wood can be removed for observation of growth and can be replaced by a new piece without interfering with the structural basis of the raft. See Fig. 20 for under-surface view. This raft was used for experiments on rate of growth at Spitzbergen in 1921 (**30**). (Photo by A. J. Smith.)

It is clear from Table XV that the only paints having effective anti-fouling values are I, II, and IV. It is also manifest that the anti-fouling value depends upon the retention of the paint on a substratum (see especially the series of experiments on paints Nos. II, I, and XI).

All the paints are retained better on wood than on shells (compare F and G) and better on the rougher face of the shells than on the smooth face (see D and E, G and H). On wood the paint was eroded less quickly in a situation subject to less erosion, as in F, than in one subject to greater erosive influence as in A, B and C (compare also Table I, p. 382, and Table IX, p. 402, especially with regard to No. I paint). On shells there is an indication that erosion occurred roughly in proportion to the erosive effect of the sea-water in the different situations. Compare G in a relatively quiet situation with D and E where motion was continuous.

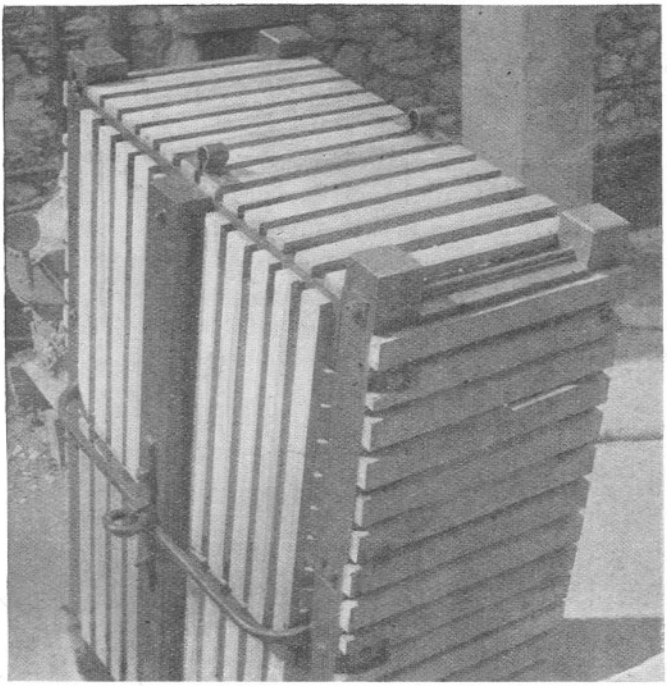

FIG. 20.—Photo of a raft similar to, but much smaller than, the one used in Cawsand Bay to show the under surface and side construction.

The bar of iron with loop for the swivelled shackle of the mooring-chain is also looped around the middle of each of the stout side-pieces which form a part of the basic skeletal structure of the raft. See also Fig. 19. The bolting of the basic parts is also shown. (Photo by A. J. Smith.)

In H, however, No. IV paint eroded badly on the rougher face of the shells in 9 months, but it is possible that in this situation wave action at about the time of low water is exceptionally severe in winter, while it is probable that some rubbing occurred as well as water erosion.

It is significant that the proprietary anti-fouling paints VI and XI eroded rapidly and also permitted growth early, even when not eroded. See especially A and B, VI, for growth; and F, XI, for erosion.

The anti-corrosive substances III, V, and VIII all permit early growths, but while the latter eroded rapidly both on wood and shells the two former adhered to shells (and would presumably also adhere to iron) better than the best anti-fouling paint. On wood, however, No. V was rapidly eroded probably partly by gribble, whereas No. III remained in good condition and preserved the wood as long as any of the anti-fouling paints except No. II.

In its property of preserving wood (and probably also iron) coal-tar No. X was as efficient as the proprietary paint No. III, and more efficient than No. V, while so far as the observations were continued black varnish No. IX was shown to be equal in value as a preservative on wood to No. III and better than V.

Common paints such as XII and XV were shown to be rapidly eroded and to have only a slight preservative and anti-fouling value. Zinc, it was shown, might soon lose its toxic effect in the sea, but copper retained its anti-fouling property during the period of the experiment, but dissolved somewhat rapidly in the sea-water.

The most critical situation from an anti-fouling point of view is where a strong light plays on the paint, for No. II paint, which remained free from growth during at least 28 months in Experiment F, acquired some algal growth in 7 to 14 months in Experiment C.

LIMITATIONS OF THE EXPERIMENTS.

In order to compare the results obtained from the experiments herein recorded with those likely to be obtained in actual practice, i.e. on the bottoms of ships or other structures, it is necessary to compare the conditions under which the experiments were carried out with those occurring in actual practice.

THE NATURE OF THE SURFACE COVERED BY THE EXPERIMENTAL SUBSTANCE.

In practice, iron ships, after being scraped and cleaned, are usually painted first with red oxide paint (such as No. VIII in the experiments), which is used as an (iron) anti-corrosive agent. When this coat is dry it is painted over sometimes with one or two coats of quick-drying anti-fouling paint, such as Nos. I, II, IV, VI, and XI in the foregoing experiments. Wooden ships after being scraped and cleaned—and more or less dried—are painted with the anti-fouling paint at once.

In the experiments the test-boards and shells were painted with two coats of anti-fouling paint, which were well dried on the same day or the day before the material was put in the sea. The treatment in the experiments with regard to painting is therefore comparable to, but better than, that given to iron vessels. With iron vessels the anti-fouling paint is usually directly applied on red oxide; and it is possible, and indeed probable, that the behaviour of the anti-fouling paints in the sea differs according to the nature of the underlying surface. In this respect there are three conditions to be considered, namely :—

(*a*) Anti-fouling paint on iron oxide over iron.
(*b*) Anti-fouling paint directly painted on to wood.
(*c*) Anti-fouling paint directly painted on to shells.

Experiments A, B, C, and F are of the (*b*) type and the remaining experiments of the (*c*) type. No experiments of the (*a*) type were tried.

Conditions Conducive to Erosion.

The paint on the bottom of a ship is subjected to erosive effects in proportion to the speed of the ship and the period of time the boat is in motion. In Experiments A to E the experimental material was in effect buoyed and would be subject to almost continuous motion by the lifting motion of the waves as well as the slight pitch and roll of the buoy (i.e. the parallelopiped-shaped raft, 20×5×2 feet). In Experiment F the test-boards were fixed and experienced no subjective motion. In Experiments G and H the material was also fixed with tarred rope, but in these cases the shells were liable to be, and were in instances, worked loose by wave action.

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Experiments A to E were therefore subject to relatively great erosive influences, but probably not so great as that experienced by even a 10-knot vessel; the painted surfaces in the other experiments would experience proportionately milder erosive action.

Condition and Dryness of the Surfaces Painted.

The surface of the bottom of an iron vessel which has been cleaned and scraped will vary from smooth to roughly pitted according to the number of times the bottom has been scraped and the degree of fouling experienced. The surface of the bottom of a wooden vessel will vary in a similar way, but will become more uneven than that of an iron ship.

In Experiments A, B, C, and F the wood was glass-papered to a smooth but not polished surface; and in the shell experiments the inner face of each shell is of a polished smoothness, while the outer face is roughened with fine decussations, except in some of the convex valves which might be smooth-worn on the crown of the shell.

In all the experiments the experimental material was in a dry condition when painted, whereas when ships are painted under economic conditions the bottom is liable to be wet or damp in rainy or damp weather, or when docking is carried out hastily.

Thus on the whole the experimental paints would be applied more efficiently than under economic conditions, and to a variety of surfaces roughly comparable to those occurring on the bottoms of ships, but would be subject to less water erosion than on even slow-moving vessels (say, 10 knots) if such vessels are in fairly continuous translation.

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During the course of these experiments and observations the question arose during the concurrent investigation by the writer of the cause of unusual oyster mortality (**14** and **15**, 1921, 1923–24) as to what order of concentration of arsenic and copper particularly was likely to be poisonous to oysters and other marine animals. Fortunately, samples of paints which had been in the sea a considerable time while remaining poisonous were still available from the experiments herein described.

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(1) The analyses of three anti-fouling paints after exposure to sea-water and retention of anti-fouling property for 19 months.

(2) The analyses of two of the same paints as in (1) after exposure to sea-water on test-boards for 42½ months, when the paints had either lost, or were apparently just about to lose, toxicity to marine animals.

(3) The analyses of samples of two original paints (the same as in (2)) from the original paint-can.

These analyses were made in the Government Laboratory by the Government Chemist and his staff, to all of whom we are indebted for the resultant general information.

Analyses of three Paints which Retained Poisonous Properties after remaining 19 Months in the Sea.

Three of the shells used in Experiment G put out in the sea on August 28th, 1919, were collected from the West Wharf, Millbay Docks, Plymouth, on April 22nd, 1921, and forwarded the same day to the Government Chemist for chemical analysis of the paint remaining on the shells. At this time most of the paint on the smoother face of the shells had been washed away, but where the paint remained there was little growth other than Balanus in I and IV, but none on II, although good growth occurred on adjacent areas of the shell denuded of paint. (See notes to Table XIII, p. 415.)

Thus on this date paints I and IV were still toxic to most marine animals, and paint No. II was still poisonous. The Government Chemist reported (**15**, 1924, p. 41) that "The paints were scraped off with as little of the shell matter as possible and give the following results :—

Lab. No.	Paint.	Colour.	Lead.	Zinc. per cent.	Copper per cent.	Arsenic as As_4O_6 per cent.
32	IV	Red	Absent	0·95	5·79 (cuprous)	0·01
33	I	Red	Absent	0·85	7·91 (cuprous)	0·01
34	II	Green	Absent	0·04	16·56 (cupric)	2·60

No evidence of Mercury nor of Barium was obtained in any of the paints, but Nos. 32 and 33 contained large proportions of iron."

It is clear from these analyses that the paints I and IV are very much alike in constitution as in behaviour (see Table XV, p. 422) but contain very much less copper and arsenic than No. II. The combination of the metals zinc, copper, and arsenic in these paints with the respective percentages of approximately 1·0 zinc, 6 to 8 (cuprous) copper, and 0·01 per cent arsenic is one which is just approaching the limit of toxicity in sea-water. This is a valuable result, even though the actual chemical constitution of the original materials is unknown.

The high percentage of cupric copper and arsenic remaining in paint II is sufficient explanation of the retained toxicity and a tribute to the efficiency of the matrix in this paint after 19 months' exposure on a shell surface in the sea.

ANALYSES OF PAINTS ON TEST-BOARDS AFTER ABOUT $3\frac{1}{2}$ YEARS IN THE SEA.

The paints II and IV on the test-boards used in Experiment F were analysed after remaining in the sea about $3\frac{1}{2}$ years. The condition of these two test-boards with regard to overgrowth is given in detail in the section beginning on p. 410, and is depicted in Fig. 12, p. 404, and Fig. 13, p. 405.

In the case of No. IV test-board, two areas of paint were scraped off and analysed. Both these areas had undoubtedly lost toxicity and were covered with living organisms when taken from the sea (see Fig. 12). The zinc-copper-arsenic percentage in these two samples of paint had been reduced greatly below that found to be near the limit of toxicity in the preceding sample, and had doubtless been non-toxic for some time, as may be also adjudged especially from the size of the barnacles (Balanus) which were growing on the analysed paint.

The condition with regard to overgrowths on the areas of paint, A to D, analysed from the front face of test-board II were as follows, but see also Fig. 12, p. 404.

	Site.	Region.	Growth.
Area A	Around the fixing nail 10 to 18·4 inches from the top.	In the upper middle region of the board.	Covered in part with a growth of the hydroid Obelia and with a few borings of gribble in a crack in the wood.
Area B	4·5 to 8·8 inches from	the bottom of the board	with 3 large and a few small borings of gribble, i.e. Limnoria or Chelura.
Area C	10·5 to 14·7 inches from	the bottom of the board, i.e. in the lower half.	No growth observable.
Area D	5·6 to 9·8 inches from	the top of the board.	No growth observable.

The bottom of the board was covered with a growth of Diplosoma, Umbonula, and Halichondria up to a height of 5 or 6 inches from the lower edge ; this growth probably encroached slightly on the lower part of area B, which was scraped for chemical analysis.

The results of the analyses of the samples of paints scraped from areas A to D are given in the following report by the Government Chemist with a discussion on the significance of the figures obtained, together with analyses of the original paints from the paint-can.

THE GOVERNMENT CHEMIST'S REPORT ON CHEMICAL ANALYSES.

"REPORT ON THE EXAMINATION OF TWO SAMPLES OF ANTIFOULING PAINT RECEIVED FROM DR. ORTON ON 15TH MARCH, 1923, AND OF THE PAINT REMAINING ON AREAS OF TWO WOODEN BOARDS TO WHICH THESE PAINTS HAD BEEN APPLIED WITH DIFFERING TOXIC EFFECTS AFTER 3½ YEARS IMMERSION IN SEA-WATER.

The paints were described as :—
Lab. No. 323. 1. (Green paint)
Lab. No. 324. 2. (Brown paint)
and gave the following results on analysis :—

TABLE 1.

ANALYSES OF NO. II AND NO. IV ORIGINAL PAINTS.

	Green per cent.	(Reddish) brown per cent.
Volatile matter (turpentine substitute)	22·4	21·6
Oil	18·7	15·9
Oxidised oil and varnish gums	8·6	10·5
Silica and silicates	1·2	5·6
Lead oxide	0·1	nil
Arsenious oxide	5·0	0·2
Cupric oxide	14·8	*nil*
Cuprous oxide	*nil*	11·8
Iron oxide	0·4	15·4
Zinc oxide	0·8	0·5
Calcium oxide	8·6	9·3
Carbon dioxide	4·6	8·3
Phosphoric pentoxide	0·2	nil
Magnesium oxide	0·2	0·9
Sulphuric anhydride	8·6	nil
Acetic acid and a little undetermined organic matter (by difference)	5·8	nil
	100·0	100·0

In the green paint the copper appears to be present partly as insoluble basic sulphate (and some of the lime might also be linked up with this) and partly as aceto-arsenite of copper (Scheeles green). The calcium-oxide is in combination with the carbon dioxide and with part of the sulphuric anhydride. It is impossible to give the exact composition of such a mixture.

In the case of the brown paint the copper is present in the form of red cuprous oxide and the calcium and magnesium oxides are in combination with the carbon dioxide forming carbonates.

The paint on the boards was very thin and only small quantities were obtained from the areas scraped. There was not sufficient material, therefore, for complete analyses. The most important constituents have been determined but the results are complicated by the fact that silicious material, carbonates, sodium salts, etc., have been deposited in the paint. Before scraping off the samples all organic growth was removed together with any incrustation that obviously did not belong to the paint. In the case of the brown board sample A was taken from a place competely overgrown, while the area sampled for B was fairly clean except for five or six barnacles.

Four areas of the green-painted board were marked A, B, C, and D by Dr. Orton, who stated that 'the part A has a growth of hydroids roughly within the circle,' and 'parts B, C, and D are apparently all just losing toxicity.'

The results of the analysis are as follows :—

TABLE 2.

ANALYSES OF PAINT SCRAPINGS FROM TEST-BOARDS II AND IV. EXPERIMENT F.

(a) *Green board* (II)

		Partly covered by a growth of hydroid. A %	Bored by gribble and slightly overgrown. B %	No growth. C %	No growth. D %
Insoluble in acid.	Oxidised oil, wood and organic matter	14·1	14·5	12·1	14·4
	Mineral matter, silica and silicates	30·8	34·8	28·8	11·2
Cupric oxide		4·0	2·2	7·5	15·2
Iron oxide		4·5	6·3	5·0	2·4
Zinc oxide		0·2	0·3	0·4	0·2
Calcium oxide		22·6	30·4	11·2	8·5
Magnesium oxide		1·4	1·6	1·8	0·9
Arsenious oxide		0·4	trace	0·7	0·7
Phosphorous pentoxide		0·6	0·5	0·3	0·3
Undetermined—CO_2, chlorides, sulphates, moisture, soluble organic matter, and sodium salts		21·4	9·4	32·2	46·2
		100·0	100·0	100·0	100·0

(b) *Brown board* (IV)

		Overgrown with marine organisms and non-toxic. A %	B %
Insoluble in acid.	Oxidised oil, wood and organic matter	17·5	16·5
	Mineral matter, silica and silicates	16·9	19·3
Cuprous oxide		0·2	0·6
Iron oxide		16·4	16·0
Zinc oxide		0·5	0·6
Calcium oxide		24·2	19·2
Magnesium oxide		2·6	2·2
Arsenious oxide		nil	0·05
Phosphorous pentoxide		0·4	0·3
Undetermined — CO_2, chlorides, sulphates, moisture, soluble organic matter and sodium salts		21·3	25·3
		100·0	100·0

It will be seen that in both sets of samples there are notable increases in the proportions of silicious material and calcium oxide while in the samples from the green board the iron has unaccountably increased.

In order to obtain a better comparison of the main inorganic constituents of the scrapings with those of the original paints the basic constituents (including silica and silicates and arsenic) have been added together and worked out on a 100 per cent basis. The figures are as follows :—

TABLE 3.

PERCENTAGE OF BASIC CONSTITUENTS (INCLUDING SILICA, SILICATES, AND ARSENIOUS OXIDE) IN THE ORIGINAL PAINTS II AND IV AND IN SAMPLES EXPOSED IN THE SEA FOR 3½ YEARS.

(*a*) *Green board* (II)

		Areas after 3½ years exposure in the sea.			
	Original paint. %	With Hydroid growth. A %	With gribble borings. B %	No growth. C %	No growth. D %
Basic constituents (including silica and silicates)	31·1	63·9	75·5	55·4	39·0
Silica and silicates	3·9	48·2	46·1	52·1	28·7
Lead oxide	0·3	nil	nil	nil	nil
Arsenious oxide	16·1	0·6	tce.	1·2	1·7
Cupric oxide	47·5	6·3	2·9	13·5	39·0
Iron oxide	1·3	7·0	8·3	9·1	6·0
Zinc oxide	2·6	0·3	0·4	0·7	0·6
Calcium oxide	27·6	35·4	40·2	20·1	21·7
Magnesium oxide	0·7	2·2	2·1	3·3	2·3
	100·0	100·0	100·0	100·0	100·0

(*b*) *Brown board* (IV)

	Original paint. %	Overgrown area. A %	Overgrown area. B %
Basic constituents (including silica and silicates)	43·7	60·9	57·9
Silica and silicates	12·8	27·8	33·2
Arsenious oxide	0·5	nil	0·1
Cuprous oxide	27·0	0·4	1·0
Iron oxide	35·2	26·9	27·7
Zinc oxide	1·1	0·8	1·1
Calcium oxide	21·3	39·8	33·1
Magnesium oxide	2·1	4·3	3·8
	100·0	100·0	100·0

The results from the green (arsenic) board are peculiar. Sample B contained the largest proportion of basic constituents and silica, i.e. 75·5 per cent, the bulk of this consisting of silica and silicates and calcium oxide.* Since practically all the arsenic and most of the copper have been washed out, this paint should have lost its toxicity to a greater extent than A which still contains 0·6 and 6·3 per cent respectively of arsenious oxide and copper oxide. Samples C and D should be more toxic than A and it will be seen that whereas in A and B there is an increase in the proportion of calcium oxide which is presumably due to shells* of minute organisms, the proportion in C and D is less than in the original paint, pointing to the paint surface still being obnoxious to the organisms. The proportion of basic constituents and silica in D is only 39·0 per cent as compared with 63·9 per cent in A.

The apparent increase in the iron content of the scrapings may have been caused by deposition of rust or some insoluble iron deposit from the sea water, or it may be due to the ferric oxide in the original paint being very much more resistant to the sea water than all the other constituents of the paint.

In the case of the brown (copper) board it can be said that the cuprous oxide has been almost completely washed out and there is little difference in the copper content on the area completely overgrown (A) and on the area only partially overgrown (B).

It is, however, practically impossible from the limited number of results to trace the changes which have occurred in the paints during exposure. The composition of the paint is affected on the one hand by *removal* of constituents, organic and inorganic, and on the other by *addition* of inorganic matter in the form of calcium carbonate and silicious material derived either from the sea water or from organisms inseparable from the surface of the paint, or of organic matter, from the organisms or from the underlying wood, which could not be separated from the scraped paint.

The results of the analysis of the paints on three shells which were given in the oyster mortality investigation report of 14th July, 1921, in terms of metallic copper and zinc may be stated, for comparison in terms of the compounds found in the original paints as follows :—

Lab. No.	No. of paint.	Cuprous oxide. %	Cupric oxide. %	Zinc oxide. %	Arsenious oxide. %
32 (red)	IV	6·52	—	1·18	0·01
33 (red)	I	8·91	—	1·06	0·01
34 (green)	II	—	20·71	0·05	2·60

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* The excess of calcium oxide in this sample was probably derived from the encrusting Polyzoan on the lower part of area B (see p. 432). J. H. O.

These results show that the brown paint on the shells had lost cuprous oxide, and the green paint had lost arsenic. The apparent increase of copper oxide in the green paint shows only that during its exposure to the sea the paint had lost less of its copper oxide than of other constituents. In illustration of the apparent increase it may be noted that if the original green paint had lost all its volatile matter and 3 per cent of arsenic, the remaining paint would contain 19·8 per cent of cupric oxide and 2·6 per cent of arsenic." A. MORE.

R.R.

June 14, 1923.

BIOLOGICAL OBSERVATIONS ON THE GOVERNMENT CHEMIST'S REPORT.

It is interesting to compare the biological observations which were made relating to a few points discussed in the preceding report by the Government Chemist. With regard to the sample B in the green test-board (II), the high proportion of basic constituents referred to is almost entirely due to calcium oxide (see Table 2 (a), p. 434). It is certain that this excess is due to the inclusion of the calcareous test of Umbonula (see p. 432) which was growing on the bottom of the board and was included in the scrapings from the lower part of area B.

The low percentage of copper and arsenic in this sample is reflected in the occurrence of borings of gribble in area B; these borings give therefore a biological confirmation to the chemical analyses, for they occur nowhere else on the surface of the areas scraped.

The area A was scraped over a rather greater extent than was intended, and it included a small space where the paint was retained as in area D. Hence the average toxic constituents in area A was slightly higher than would occur where the hydroid growth was well developed.

It is noteworthy that excepting area A—which obviously became more rapidly denuded of paint due to the effect of the fixing nail—the areas B, C, and D form a graded series from bottom to top of the board in loss of arsenic and copper. This series is continued at the bottom of the board by a non-toxic area on which organisms were growing abundantly and where doubtless the arsenic and copper had been washed out to a very great extent. It has already been pointed out that this board was fixed vertically with the bottom a little below the level of low-water mark of spring tides; thus there had occurred a graded erosion of the paint from the region of low water to 3 feet above. As the bottom of the board would be almost constantly in water, it would seem that the erosion of the paint was due either to greater wave action at the bottom of the board or possibly, in this particular situation, to greater chemical interaction with the sea-water in proportion to the longer period of immersion at the different levels of the board. The other test-boards in this experiment also gave indication of maximum erosion at the bottom of the board (see Table IX, p. 402).

It is of interest to note that the reddish-brown paints have cuprous copper as the main toxic ingredient, while the green paint contains a large quantity of arsenious oxide, with a very high proportion of cupric copper, and with also rather more zinc than the aforementioned paints. The probable state of combination of these toxic ingredients is discussed in the Government Chemist's report (see p. 433).

Discussion of the Results.

The experiments herein described show clearly that a poisonous paint will inhibit the growth of marine animals for a period depending upon the retention of the paint on the surface it is desired to protect, and the existence in the paint of substances which maintain a toxic surface on the paint (see Table XV). It has been demonstrated that a dark green arsenic paint (II) remained toxic for a longer period than two red copper (IV and I) and one light green (arsenic) paint (XI), and that the durability of the matrix (oils, etc.) of the paint is a fundamental character of efficient paints. It is also clear that beyond a certain concentration of poison in a paint the durability of the matrix is more important than the nature of the toxic ingredient.

There can be little doubt that the best anti-fouling paints function through ionisation—and therefore loss—of the toxic ingredients.

Chemical analyses revealed the following facts with regard to a certain reddish-brown anti-fouling paint :—

	% Composition (approx.).		
	Arsenious oxide.	Cuprous oxide.	Zinc oxide.
Original paint (IV)	0·2	11·8	0·5
(*a*) Toxicity retained after 19 months' exposure in the sea.	0·01	6 to 8	0·8 to 1·0
(*b*) Toxicity lost (some months previously) after 42½ months' exposure	nil to 0·05	0·2 to 0·6	0·5 to 0·6

Therefore the paint will remain toxic so long as it contains the ingredients of the order shown above in (*a*). Another dark green paint showed on chemical analysis :—

	% Composition (approx.).		
	Arsenious oxide.	Cupric oxide.	Zinc oxide.
Original paint (II)	5·0	14·8	0·8
(*c*) Toxicity retained after 19 months' exposure in the sea.	2·6	16·6	0·04
(*d*) Toxicity retained after 42½ months' exposure (C, fig. 13)	0·7	7·5	0·4
(*e*) Toxicity recently lost after 42½ months in the sea (A, fig. 13)	0·4	4·0	0·2

Thus in order to maintain toxicity a paint of this kind must retain a concentration of the poisonous ingredients not less than the values shown in (*d*) above. In a similar way the combination of toxic ingredients which is necessary to inhibit growth of marine animals can be determined for any paint. The rate and nature of ionisation of the toxic ingredients at about the critical point for loss of toxicity has not been determined, but the non-toxic states of the two paints just noted indicate that a relatively high degree of ionisation of toxic substances is probably necessary to prevent the growth of animals on a surface in the sea. It has been pointed out that the results noted above were obtained under conditions more favourable than occur on the bottom of a ship where erosion plays a much more important rôle. In reviewing the extensive work done recently on this subject in America, Visscher (**16**, 1928) states that "Under optimum conditions vessels foul within 30 days of the time of dry-docking and the application of poisonous anti-fouling paints, indicating the hypothetical value of anti-fouling paints."

The experiment and observations herein described, however, indicate that good anti-fouling paints applied on a slightly roughened surface under dry conditions should give results which are definitely not hypothetical. It has, however, been demonstrated that great differences occur in the erosive value (i.e. degree of resistance to erosion) of anti-fouling paints (see Table XV, p. 422), and that paints such as VI or XI, be they ever so toxic, are probably of little value on the bottom of a ship. Hence the fundamental importance of the matrix of such paints. In the American work (*loc. cit.*) it would seem that the importance of the matrix has not been sufficiently recognised. It has been suggested herein that bacteria may be intimately concerned in breaking down both the matrix and toxic agents of a paint in the sea, and that researches on this subject are needed (see also Hillen, **24**, who found bacteria in the "slime" on ships' bottoms). If bacteria prove to be important destructive agents, then the constituents of these paints should have a low energy potentiality value, as Matthews (**17**) showed in analogous work on bacteria in soils.

The nature of the surface to which paint will adhere best has been shown to be a slightly roughened surface (see Table XV, p. 422). A rough surface is, however, undesirable on the bottoms of ships owing to the increase of frictional effect, but it may be possible to devise a method of coating a roughened surface with paint so as to leave a finished smooth surface. Paints applied to a very smooth surface are eroded or flaked off very easily (see Table XV). On non-toxic surfaces little difference has been found in these and other experiments in the *gross* growth, whether the surface be smooth or rough (see *passim* herein the growth on black varnish, IX, and the white smooth inner surface of scallop shells on the one hand, and the growth on untreated wood and the outer rough surface of scallop shells on the other). I am, therefore, unable to agree with Visscher's remarks on this subject (**16**, p. 236), and consider that an alternative explanation is probable for each instance therein cited. It is obvious that the flaking of an anti-fouling paint will leave an area where organisms can and do settle (see especially Experiment H) and form a *point d'appui* for still other organisms. This is no doubt what has occurred in the case cited by Visscher (*loc. cit.*, Fig. 33B), and may be considered a silent tribute actually to the efficiency of the anti-fouling paint used in this particular case. The experiments described in these pages do, however, indicate that some hydroids—but not Tubularia—appear to grow better on a rough surface, but the evidence is not critical.

The effect of the nature of the light reflected from anti-fouling paints and other material has not been critically tested in these experiments, but in Experiments A to E heavy growths of Tubularia occurred within 6 weeks on greyish-white, red and black surfaces in subdued light. The correlated absence of growth on dark green and red poisonous surfaces is adequately proved to be due to the poisonous nature of these surfaces from the results of all the experiments. There can be little doubt that Tubularia will stick to any kind or colour of non-toxic surface in a subdued light, but the intensity of the light with regard to general growth is doubtless an important factor. In Experiment C, a growth of Algæ occurred on each of the green, red, and black painted and greyish-white untreated surfaces after 7 months' exposure (see Table III, p. 386), and a growth of Balanus occurred on a green paint in Experiment G after 9 months' exposure (see p. 415, and Holzapfel **25** and Visscher **16**, p. 240). It is probable, however, that light colours in well-lighted situations prevent such larvæ as Pomatoceros, Hydroides, and allied Polychaetes, most Polyzoan larvæ, the cypris of Balanids and the tadpoles of Ascidians from settling on them readily, but the actinulæ of Tubularia and the planulæ of hydroids appear to stick to any surface with which they come in contact; while the spores of Algæ prefer and require some degree of light (see raft observation, p. 398); it is, moreover, probable that although the tadpoles of tunicates undoubtedly fix in the darker places on experimental material in the sea they probably meet sufficiently dark places to induce settlement in the microscopic shade afforded by such growths as hydroids at even moderate depths on light-coloured surfaces (see Table XIV, p. 416). It is therefore probable that—other things being equal, an equality difficult to obtain—a light-coloured anti-fouling paint may inhibit the growth of marine animals *to a greater degree* than a darker paint, but may be expected to acquire a relatively greater fouling from algæ.

The surface of the paints exposed in the sea was observed and recorded. It was found that the best anti-fouling paints became eventually soft or powdery. The poorest paints became rapidly soft and easily eroded away, while the best paint, the dark green No. II, " powdered " very slowly and rubbed off slightly on the finger. Nos. IV and I paints remained hard—and clean—for many months but eventually became soft and eroded slowly. No. I eroded rather more quickly than IV. It is probable that the virtue in paint No. II lay in its capacity for powdering slowly and that the property is related mainly to the nature of the matrix, but possibly also to the interaction of the matrix and the toxic constituents. Any paint which relies on rapid erosion—and some are apparently constructed on this principle—is manifestly of little use on a vessel because of the rapid erosion (see Table XV, p. 422) to extinction.

It would appear that a soft or even slimy surface on a good durable anti-fouling paint is a necessity from the nature of the paint and its mode of functioning, and that it is therefore incompatible to strive for a hard and at the same time efficient poisonous paint. Visscher (*loc. cit.*) discusses the point from a different angle. He states that " the beneficial effects of the paints now used very probably can be attributed far more to the nature of the surface (when in water) than to any peculiarly poisonous property that they may possess. It seems that undue emphasis has been placed upon the use of poisons in paints on steel ships, which is probably a hold over from their use on wooden vessels, and that the proper nature of the surface film is the desired goal."

There can, however, be little doubt that the chemical analyses given of sea-exposed paints (at the beginning of this section, p. 438) at a point just before losing the power of inhibiting growth, and just after or at the instant of losing this power, is a demonstration of the dependence of these paints on toxicity for inhibiting growth. Therefore Visscher's conclusion is erroneous. The nature of the surface film of a paint may, however, be readily acknowledged as a property of primary importance.

ON THE FUNDAMENTAL PROPERTIES OF AN IDEAL ANTI-FOULING PAINT.

The experiments described in the foregoing pages have shown clearly that in order to maintain a painted surface free from marine growths it must be painted with a substance which requires to have three fundamental properties, namely :—

(1) It must adhere strongly to a surface which may be damp.
(2) It must present such a surface that marine organisms cannot exist on it (whether the surface be poisonous or otherwise).
(3) It must have the power of resisting erosion for a long period while retaining its inimical surface.

The power of resisting erosion for a long period will depend to a great extent upon the nature of the matrix, but also on the value of the other ingredients for preserving the matrix while maintaining a (toxic) surface on which marine organisms cannot exist. It may be presumed that marine bacteria are significant organisms in the disintegration of the matrix (researches on the bacterial infection of anti-fouling paints at different epochs of exposure have, however, not been made) of a paint, and that therefore the best matrix would be one highly resistive to bacterial action, while at the same time resisting chemical interaction with sea-water.

It would therefore appear that *beyond a certain concentration* the toxicity of an anti-fouling paint is less important than the property of resisting erosion, that is the longevity of the matrix. A paint may be intensely poisonous, but it is of little value if the matrix is such that easy disintegration and/or erosion occurs in the sea. If, as is suggested, bacteria are primarily concerned in breaking down the matrix of a good paint in the sea, then it appears that a fundamental property of the matrix must be a low-energy potentiality value, as Matthews (**17**) found to be necessary in the case of substances capable of resisting bacteria in soils.

The review of the results of the experiments given in Table XV, p. 422, affords an opportunity to see how the fundamental properties of an ideal anti-fouling paint are distributed among the substances tested. But as the life of any paint in the sea must necessarily be short—in terms of years—being dependent upon the longevity of the matrix, it would appear that—failing the discovery of a permanent matrix—the problem of maintaining the bottom of ships clean and free from growths, for periods reckoned in years, must be solved by some other method than the application of paint.

PART III. OBSERVATIONS ON THE GROWTHS ON THE BOTTOMS OF OCEAN-GOING AND LOCAL SHIPS.

The following observations on the growth of marine organisms on the bottom of ocean-going and local ships within relatively short periods after being painted are useful as a practical indication of the inefficiency or efficiency of the paints used. In most of these cases the kind of paint used on the bottom of the ship was not known, but all were red in colour. If allowance be made, however, for the anti-fouling value of even inefficient paints the observations on the rapid growth of oceanic marine organisms and the transport of foreign organisms are well worth recording. Information regarding the duration and itinerary of the voyages and the last dates of repainting were obtained from the masters of the ships, to whom acknowledgment is gladly and warmly tendered.

S.V. *Jarstein*. Master, A. B. Axelsen. Examined at Plymouth September 2nd, 1913.

Painted with tar and a copper paint at Pelotas, South-east Brazil, May 16th, 1913, but only passed into salt water June 17th, 1913, on crossing the bar of Rio Grande (see the South American Pilot, Part I, p. 354, Admiralty).*

The following growths on the bottom of this ship were collected at Plymouth on September 2nd, 1913; the maximum age of this growth is therefore only eleven weeks :—

Species.	Length of peduncle.	Breadth of capitulum.	Sex condition.
Lepas Hilli	35–60 mm.	13–20 mm.	Mostly with ova or embryos.
Lepas anatifera	29–55 ,,	11–18 ,,	do.
Conchoderma virgatum	25–33 ,,	9–10 ,,	Mostly with ova or embryos and some with nauplii.

A specimen of *Nautilograpsus minutus* was taken on the stern of this ship, having a carapace width 11 mm. and length 10·5 mm., but may have either settled on the boat as a larva or at a later stage.

S.S. *War Viceroy*. 2nd Officer, G. Bryant. Examined at Plymouth, September 25th, 1919.

Docked and painted March, 1919, at Cardiff; left Venice for Australia end of April, 1919; left Geelong for Plymouth, July, 1919, via Albany, Durban, Cape Town, St. Vincent, Cape de Verde Is., and arrived Plymouth, September, 1919. Average speed 8·2 knots, maximum $10\frac{1}{2}$ and minimum $5\frac{1}{2}$ knots.

The maximum age of the following is, therefore, about 5 months, i.e. May to September :—

			Peduncle.
Lepas Hilli, length and breadth of capitulum		27×16 mm.	ca. 22
Conchoderma virginatum	do.	22×15 ,,	ca. 25
,, *auritum*	do.	23×14 ,,	ca. 36

Balanus sp. probably *tintinabulum* with test 20×19 mm., subcircular at base and height 18 mm.

Tubularia sp. abundant.

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* For this reference I am indebted to Commander Campbell Hepworth, the then Marine Superintendent of the Meteorological Office.

Lepas and C. *virginatum* had embryos in the brood pouch, but *C. auritum* had only ova, which are apparently attached to the lining of the mantle cavity.

s.v. *Miefield*, Liverpool. Capt. Drummond. Examined at Plymouth, April 7–14th, 1913.

After spending about 6 weeks in fresh water at Buenos Aires and directly afterwards about 2 months in fresh water at Newcastle, N.S. Wales, this vessel returned to Plymouth via Anto-Fagasta, Chili, and Falmouth with only short periods at each of the ports. The ship was last painted on the bottom at Fiume, Austria, in June, 1911.

The age of the material cannot be given, but it is certainly not more than 4 or 5 months; growth doubtless began soon after leaving Australia on a bottom probably denuded of paint. The vessel was steel, not wood.

Conchoderma virgatum, some with embryos and nauplii with capitulum only 15×10 mm. and others much larger.

Conchoderma auritum, eggs in peduncle and apparently in the mantle lining (capitulum 25×16 mm., peduncle 50 mm.)

Lepas anatifera, some with nauplii (capitulum 35×21 mm., peduncle 20 mm.).

Lepas Hilli, some with nauplii (capitulum 30×18 mm.). Cellularia sp., Tubularia sp., and Amphipods in nests covered the bottom of the ship.

Nautilograpsus minutus, the Sargasso seaweed crab; three specimens; two escaped; one male with carapace width 10·5×10 mm. long.

Pilumnoides perlatus, a South American crab; twenty-one specimens; some were soft and some were moulting in April; the four largest specimens were males with carapace width 9 mm.; seven others were males, seven others females, and three of undetermined sex. These specimens were exhibited at the Royal Society Soirées in 1913, and on August 26th, 1913, the remaining females had grown to carapace breadth 12 to 14 mm. ×9 to 11 mm. in length, and a male 9×7 mm.

Concholepas peruviana, a Chilean Gastropod, was taken (one specimen) creeping on the bottom of the vessel.

By adding powdered carmine to the water in which *C. auritum* was kept it was observed that water was drawn in at the auriculæ when the animal exserts its cirri, and expelled when the animal retracts into its shell. There can be no doubt therefore (as Darwin suggested, **26** II, p. 145) that one function of the auriculæ is connected with respiration. Observations are, however, required on the orientation of the auriculæ in relation to the direction of motion of the vessel and on the feeding mechanism, before the function of these peculiar organs can be understood.

S.V. *MacMahon*, Nantes. Capt. Guteguiz.

This vessel was painted on April 15th, 1913, and examined for growth at Plymouth, October 17th to 20th, 1913, so that the maximum age of growths on the bottom is about 6 months, but as the paint would have some anti-fouling value, the actual age must be much less than this period. Lepas and Conchoderma, hydroids and spawning Nudibranchs were collected from the bottom of this vessel.

S.S. *Penolver*. Capt. Bradshaw.

This vessel was painted with a well-known red anti-fouling paint and left Barry Dock at the end of January, 1920. It arrived at Rio de Janeiro, February 25th, and left March 3rd, 1920; arrived Buenos Aires 9.3.20 and left 10.4.20; arrived St. Vincent 29.4.20 and left same day, reaching Plymouth May 12th, 1920. A few pedunculate barnacles were collected from this ship at Plymouth, May 19th, 1920, only 3½ months after being painted with an anti-fouling paint.

S.S. *Wotan*. Master, Fred Hancock.

This vessel was dry-docked and received two coats of anti-fouling paint at Glasgow, December, 1919, and proceeded to Barry, Malta, Constantinople, Sevastapol, Odessa, Salonica, Gibraltar, and thence to the River Plate, arriving there April 10th, 1920, and loaded up the River *in fresh water*. The ship sailed for Plymouth, May 1st, arriving June 7th, 1920.

A number of Lepas and Conchoderma, the latter of which were carrying embryos, as well as some South American crabs, were taken from the bottom of this vessel. These barnacles had undoubtedly grown since May 1st, that is in only 5 weeks and 2 days, and attained sexual maturity on a bottom painted so recently as 5½ months.

S.S. *London City*.

This vessel was docked and painted at West Hartlepool, April, 1910, towed round the coast to Brixham, and used there as a coal hulk. The bottom of this vessel was examined at Plymouth on August 1st, 1911, and an exceedingly luxuriant growth found of Tubularia, Pomatoceros, and other worms, numerous *Echinus miliaris* up to a diameter of 3 cm.; abundant *Sagartia viduata* (=*anguicoma*) with a column uniformly ca. 20 mm. in diameter and 4·5 cm. high (preserved); numerous *Dendronotus frondosus* upwards to 40 mm. long (preserved) were found feeding on the *Tubularia larynx*.

The maximum age of growth on the bottom of this vessel was 16 months, but the actual age must have been very much less for most of the growth, such as Echinus, Sagartia, and Dendronotus. For information regarding this vessel I am indebted to Mr. T. E. Gullett.

s.s. *Smeaton*. Master, J. J. B. Hambley.

This vessel cruised only locally and was observed over three docking and painting periods.

It was scraped and painted April 18th, 1912, and examined in dock on November 25th, 1912, only 7 months later. On the latter date a heavy growth was found of Balanus, mature Pomatoceros, larvigerous Bugula, Ciona up to 3·3 cm. (extended) which gave larvæ on artificial fertilisation, Molgula which gave some segmenting eggs, and Anomia which gave some larvæ on artificial fertilisation.

On November 27th, 1912, the vessel was refloated and redocked April 23rd, 1913. On this date only a few patches of hydroids occurred on the bottom along with a few small Mytilus.

The contrast in these two periods, one summer and one winter, is very marked. The actual paint used is not known, but believed to be red oxide.

s.s. *Sir Walter Raleigh*.

Docking and painting occurred November 12th, 1912, and a subsequent redocking for painting May 14th, 1913, that is after 25 weeks. Only a very slight growth was again found, as occurred in the winter period with s.s. *Smeaton*. Two patches only of Tubularia occurred, a few Balanus, one colony of Bugula, two or three specimens of Pomatoceros, but many patches of a hydroid, probably Gonothyræa, up to 9 inches in diameter. The paint used in this case was probably also red oxide.

No. 1 *buoy*, timber with zinc, G.W.R. Docks, Plymouth.

The date this buoy was put out is uncertain, but on the zinc and timber were numerous clear-tested Ascidiella up to 6·5 cm. long, living and expanded, Ciona up to 8·6 and numerous smaller ones (expanded), much Botryllus, and fine long colonies of a hydroid, probably *Obelia longissima*. Similar zinc buoys exposed for two or more years acquire luxuriant growths similar to those described on the Cawsand Bay raft (see p. 398).

No. 10 *buoy* (iron), G.W.R. Docks, Plymouth, newly painted with red oxide, May 14th, 1913, was examined May 8th, 1914, and found to have only small Ascidiella, a few Mytilus, but large colonies of Botryllus and Diplosoma and a heavy growth of seaweeds. Heavy growths have been found on many similar buoys after exposure of the paint from 1 to 2 years.

ACKNOWLEDGMENTS.

In the prosecution of the large amount of experimental field-work herein described, I am greatly indebted to Mr. Wm. Searle for valuable advice and willing assistance in many ways.

The chemical analyses undertaken by the Government Chemist and his staff in connexion with this work served the dual purpose of providing valuable additional data for these and other investigations. In so far as the chemical results obtained assist my own work, I owe and gladly tender thanks to those workers, and especially to Sir Robert Robertson.

For the photographs which illustrate the paper I have pleasure in thanking Mr. D. P. Wilson, who took most of his photos by flashlight, and Mr. A. J. Smith, and for other assistance in photography I gladly acknowledge help by Prof. J. S. Dunkerley and Dr. R. S. Clark. I am also indebted to Mr. F. S. Russell and Miss M. Lewis for assistance in reading the proofs.

SUMMARY.

Contemporaneously with extensive researches on the rate of growth and breeding in marine Invertebrates, observations were made on experimental material exposed in the sea for periods varying from 14 months to 3½ years to test the power of a number of paints and other substances (1) for inhibiting the growth of marine organisms, (2) for their preservation value, and (3) for their durability in sea-water. The experimental material was tested simultaneously in seven different habitats in three different localities on wood and on shells, which provided three essentially different types of surface.

The substances tested include proprietary anti-fouling and proprietary anti-corrosive paints, other anti-corrosive and preservation paints, coal-tar, varnish, some common paints, sheet copper, and sheet zinc.

Observations were also made at Plymouth on the growth on the bottoms of ocean-going ships, and on local ships, buoys and rafts.

It was found that certain proprietary anti-fouling paints did not inhibit the growth of marine animals under the conditions of the experiments for more than a few weeks. Other similar paints inhibited the growth of marine animals for about 9 months, while others inhibited such growths for periods varying from 20 to 42½ months.

The so-called anti-fouling paint which inhibited growth only for a few weeks was non-toxic; the paints which inhibited growth for longer periods were toxic, and their toxic property depends upon the maintenance in the paint of toxic ingredients of a certain concentration.

Some of the toxic paints eroded so rapidly that the prepared surfaces

became denuded of paint before the toxic properties were lost : in other paints erosion occurred sufficiently slowly in some situations for the toxic effect to be lost before the paint was completely eroded. Chemical analysis of two paints which had been in the sea for 19 months without permitting overgrowth on the paint, and of the same two paints at a later epoch when overgrowth had occurred, or was just beginning, gave the following results :—

		Poisonous constituents. Percentage composition.		
		Arsenious oxide.	Cuprous oxide.	Zinc oxide.
No. IV.	Paint exposed 19 months without overgrowth	0·01	6 to 8	0·8 to 1·0
No. IV.	Paint exposed $42\frac{1}{2}$ months with overgrowth aged some months	nil to 0·05	0.2 to 0·6	0.5 to 0·6

		Percentage composition.		
		Arsenious oxide.	Cupric oxide.	Zinc oxide.
No. II.	Paint exposed 19 months without overgrowth	2·6	16·6	0·04
No. II.	Paint exposed $42\frac{1}{2}$ months without overgrowth	0·7	7·5	0·4
do.	do. with overgrowth	0·4	4·0	0·2

These analyses fix for these particular paints the approximate limits of the toxic ingredients which are necessary to maintain toxicity, and also prove that these paints inhibit marine growths by maintaining a toxic influence at the surface of the paint.

In the case of the paints No. IV and No. II, which are shown to be good or excellent anti-fouling preparations, these paints, as well as other preparations, adhered well to the rougher surface of scallop shells and to glass-papered dry wood, but very badly to the smoother face of the scallop shells. Anti-fouling paints must therefore possess the following fundamental properties :—

1. Capacity to adhere to a surface, which in practice may be slightly damp.
2. Capacity to resist rapid erosion.
3. Capacity to prevent continuously—whether the vessel be stationary or in motion—the settlement and growth of the larvæ of marine organisms (a capacity usually attained by the incorporation of toxic ingredients).

Some of these fundamental properties may be modified to meet economic conditions, e.g. painting the bottoms of ships in dock in a hurry ; but some of the economic conditions must be modified to meet the inherent deficiences of anti-fouling paints, e.g. a sufficiently thick deposit of the paint must be applied to a dry and rough surface to ensure adherence, to resist erosion, and to maintain a toxic surface for a reasonable period.

It is pointed out that in order to resist erosion the body of the paint must be durable, and that the durability of the body may be largely conditioned by the attacks of marine bacteria and the energy available in that body. The body used in the construction of these paints is highly important, and the experiments described prove that certain proprietary anti-fouling paints are fundamentally deficient in possessing a body incapable of resisting even a moderate amount of exposure to sea water.

Thus the body of a paint may be more important than the toxic ingredients subject to the maintenance of a certain degree of toxicity.

It is shown that marine organisms can live and flourish adjacent to paint residues which give on chemical analysis high percentages of (presumably) toxic substances, but that further investigations are required to give the rate and degree of ionisation of the toxic ingredients at the surface of a paint at various epochs after the date of first exposure in the sea. Anti-fouling paints exposed to strong light permit growths much sooner than in subdued light, but in the former case the growth is marine algæ. It is pointed out that it is not clear whether this phenomenon is due to loss of toxicity in the paint due to the direct action of light, or to a greater resistive power of the spores of marine algæ to toxic agents. It is suggested that all toxic substances before or after combination with organic matter may be attacked by bacteria in the sea, and that such substances may therefore undergo a regular "life-history" of degradation and that in this respect copper may be short-lived.

The preservative properties of the substances (paints, coal-tar, etc.) were investigated on test-boards in one critical situation where wood is rapidly eaten away by gribble (i.e. Limnoria and Chelura). It was found that the substances range themselves into three categories.

A. Definitely anti-fouling and definitely preservative (on wood).
B. Non-anti-fouling but definitely preservative (on wood).
C. Slightly anti-fouling and slightly preservative (on wood).

It is pointed out that the experiments are subject to certain limitations in comparison with economic practice, in that none were carried out on iron. The variety of surface tested, however, permits proximal deductions regarding the behaviour of the substances on iron.

Thus Classes A and B (above) are—when properly applied—probably also good anti-corrosive agents on iron, as well as being valuable preservatives on wood.

Class C, in which occurs Red Oxide (of iron)—the commonest and most widely used of anti-corrosive paints for the bottom of iron ships,—is definitely shown to be of less value than either A or B on wood, and is also probably of less value than these on iron owing to weak resistance to erosion.

Class B includes common coal-tar, and common black varnish, while Class C includes, besides Red Oxide, certain proprietary anti-fouling and anti-corrosive paints and an ordinary aluminium paint.

Preservation is manifestly distinct from anti-fouling, though both may be effected by the same paint. The preservation of wood (by paints) can be ensured against "gribble," but not against Teredo, by common coal-tar and black varnish, to at least as great a degree as by the application of many special paints and "Red Oxide." On the other hand, well-dried coal-tar and black varnish give innocuous surfaces on which marine organisms establish themselves more readily in the sea than on untreated wood, the latter substance being usually slightly inimical to growths for a short period. It was found that all the paints and other substances adhered better to a rough than a smooth surface in all the experiments. Hence the conclusion that the bottoms of ships should be slightly roughened before the application of a paint, and the paint itself applied in such a way as to produce the smooth surface required for the reduction of friction. Coal-tar is proved to be a valuable preservative against gribble, but Teredo bored almost at once into wood which had been covered with two good coats of well-dried coal-tar. In these cases the larvæ of Teredo had either bored through the coal-tar, or not improbably had found spots in the wood imperfectly covered with tar.

The paints in preliminary experiments were found to adhere less well to a damp than a dry surface; it is therefore recommended that after scraping and brushing, *the bottoms of ships should be well hosed with fresh water* and allowed to dry thoroughly (ideally) before the application of a paint.

The composition of an ideal anti-fouling paint is discussed, but the conclusion is reached that if the bottoms of ships are to be maintained free from growths for a period, stated in years, some other method must necessarily be used than the application of paint.

Observations are recorded of the rapid fouling of the bottoms of local ships treated in the spring with red oxide and relatively little after an equivalent period when treated in the autumn with the same material.

Heavy growths are recorded on rafts treated with coal-tar, slighter growths on buoys painted with a red paint, and on zinc buoys, within a period of about a year. A growth of Conchoderma and other barnacles which attained sexual maturity in a minimum period of 5 weeks and 2 days is recorded along with other rapid growths on ocean-going ships inspected at Plymouth. The capture of the Sargasso seaweed crab, *Nautilograpsus minutus* (=Planes), of the South American crab, *Pilumnoides perlatus*, and the Chilean Gastropod, *Concholepas peruviana*, on the bottoms of ships arriving at Plymouth is also recorded.

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The Larva of *Nicothoë astaci* and its Systematic Position.

By

Robert Gurney, D.Sc.

With 6 Figures in the Text.

MR. LEIGH-SHARPE, in his account of the external structure of this interesting Copepod (1926), concludes that it is most nearly related to the Ascomyzontidæ. Having recently obtained a number of larvæ, hatched from adults obtained at Plymouth, and finding that my own conclusion as to the relationship of the genus differs from that of Mr. Leigh-Sharpe, it seems worth while to describe the larvæ and the bearing they seem to have upon the systematic position of the adult.

The larvæ hatch and become active inside the egg-sac.* Immediately after becoming free they swim vigorously for a short time, but very soon sink to the bottom and remain quiescent, with occasional spasms of activity. This quiescence may, of course, not be normal; but, as the larvæ remained alive for over a week, their behaviour during the first days cannot be due to ill-health. One may suggest that this is the normal procedure; the early activity ensures some dispersal and the later rest on the bottom brings them into touch with a new host. I have seen exactly the same thing in the larvæ of *Chondracanthus lophii*. As hatching proceeded the beaker in which they were contained became filled with swimming nauplii; but the next morning all were on the bottom and there remained, apparently perfectly healthy, and readily stirred to sudden spurts of movement, for several days.

The larva hatches as a Cyclopid with two pairs of legs and a rudimentary third pair. (Fig. 1.)

Length: ·28 mm.

The cephalothorax is as long as the rest of the body, and includes the somite of leg 1. The somites of legs 2 and 3 are free, and are followed by two legless somites. Furcal rami short, bearing 6 setæ, 1 dorsal and 5 lateral and terminal. The innermost seta is the longest, and between it and the next one is a delicate sensory seta. No eye is visible.

The antennules are of 3 joints (Fig. 3), the third the longest and bearing numerous setæ. The antennæ are difficult to make out, but appear to

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* This has already been noted by Rathke, 1843.

consist of four joints, the last two flexed upon the second (see Fig. 3). The last joint ends in a spine and bears an inner seta. The mandibles are enclosed within the mouth tube, which has the form of a sucker. The distal part of the sucker consists of a chitinous ring strengthened by radial thickenings. The ring is enclosed by a transparent membrane broken at its outer edge into a very delicate fringe. In the bottom of the conical hollow can be seen the mouth opening through which the tips of the mandibles protrude. While the distal disc is entire, except for an anterior median indentation, the mouth tube itself is made up of an anterior and a posterior part, representing the upper and lower lips, the division between them being marked by a distinct suture visible in side view (Fig. 2). The mandibles, which are hinged to the body close to, and outside, the base of the maxillules, pass into the mouth tube through a gap in the suture.

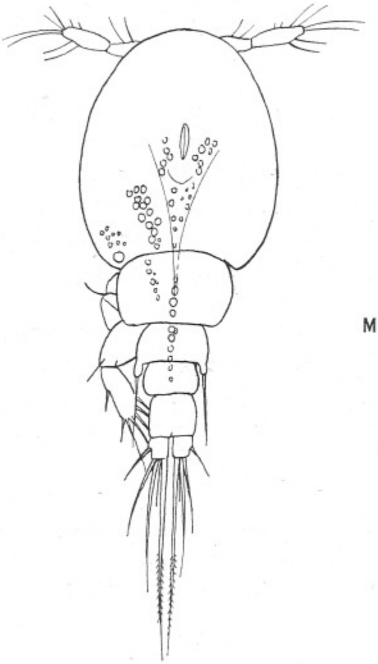

FIG. 1.—Copepodid larva, dorsal view.

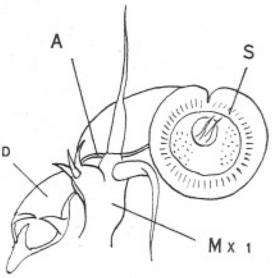

FIG. 2.—Side view of sucker. S. sucker. A. lateral suture of sucker. Md. mandible. Mx. 1. Maxillule.

Close against the antennæ and just behind the sucker is the maxillule. This is made up of two parts. Quite distinct is a small papilla bearing three short spines, and on the inside of this is a cylindrical joint bearing two long flagella.

The maxilla is a strong three-jointed appendage, situated some way behind the maxillule. The basal joint is very broad, and is followed by two simple narrow joints, the distal one with a brush of spines at the end.

The maxillipede is four-jointed, the last joint bearing a strong claw and a seta.

The two pairs of swimming legs are biramous, the branches one-jointed. The third pair is represented by a bilobed rudiment, the outer lobe being a small papilla, visible dorsally, bearing one long seta.

In the adult there is no essential difference in the arrangement and structure of the mouth parts (Fig. 4). The sucker seems to be rather more complicated, and on either side of the mouth, in the sucker-cone, is a pad covered with minute prickles.

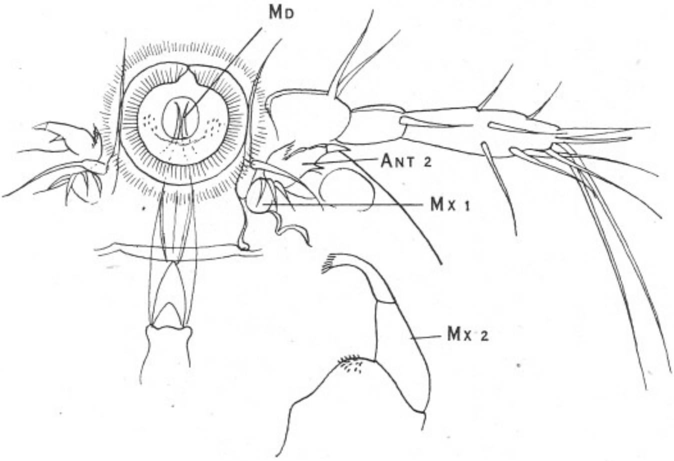

FIG. 3.—Copepodid. Ventral view of head region. Ant. 2. Antenna. Md. Mandible. Mx. 1. Maxillule. Mx. 2. Maxilla.

The maxillule has much the same form, but there is now a third flagellum on the anterior branch of it (Fig. 6).

In Mr. Leigh-Sharpe's figure of the adult there are two structures shown which should be mentioned, namely, the second antenna and the pair of " lunules."

In a specimen cleaned with caustic potash both these structures can be seen and appear to be chitinous bodies enbedded in the carapace. The " lunules " show no resemblance to the lunules of Caligus to which he has compared them.

As regards the systematic position of Nicothoë, Mr. Leigh-Sharpe points out a number of Cyclopoid features and concludes that it is a member of the Ascomyzontidæ.* At the same time he gives as examples of Caligoid features the presence of "lunules," the suctorial mouth, and "a first attempt at the inauguration of a genital segment." I think the "lunules" can be dismissed, and the sucker-like mouth tube has much less resemblance to the mouth tube of Caligus than to that of some other Copepods.

It seems to me that the affinity is not with the Caligidæ nor with the Ascomyzontidæ, but with the Choniostomatidæ.

If a comparison is made between the larva of Nicothoë and that of a Choniostomatid—e.g. Stenothocheres (Hansen, 1897, pl. 1. fig. 1, 1) the agreement is almost startling. Apart from the general Cyclopoid form which in itself means little at this stage, we have a similar three-jointed antennule ; the same form of mouth tube, with the same sucker ; the same form of maxillule, and almost identical maxilla and maxillipede. In both cases there are two pairs of functional legs and a rudiment of leg 3, and the arrangement of setæ on the furcal rami is the same. The detailed structure of the maxillule in the Choniostomatidæ is not very clearly described or

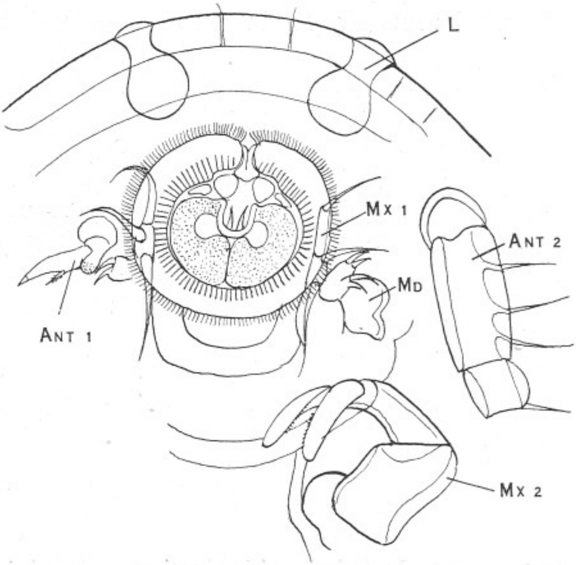

Fig. 4.—Adult female, ventral view of head region.
L. so-called Lunule.

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* Leigh-Sharpe (1926, p. 153) : "I consider it preferable to associate Nicothoë with the genera Pœcilopes and Lophiropes (with which, however, I am not yet acquainted) in the family Ascomyzontidæ (Asterocheridæ)." Compare Audouin and Milne Edwards (1826, p. 351) : "Il n'est pas moins certain qu'il doit être rangé dans l'ordre des Branchiopodes de M. Latreille ; mais il devient assez difficile de lui assigner une place plutôt dans la section des Pœcilopes que dans celle des Lophiropes."

figured by Hansen, but it seems to be built on the same plan and to include two or three flagella as in Nicothoë. The styliform mandible in both cases enters the base of the mouth tube and projects through the small mouth opening.

A further point of agreement is that in both larvæ there is a projecting median ventral ridge just in front of leg 1. This is very much more prominent in the Choniostomatidæ, and is named the "pouch" by Hansen.*

It may be no more than a coincidence that Nicothoë is parasitic in the gill chamber of a Decapod, and that all Choniostomatidæ are parasitic on various Crustacea, including some also in the gill chamber of Decapods; but it is a fact which should at least be thrown into the scale with the other resemblances.

FIG. 5.—Antenna of adult female.

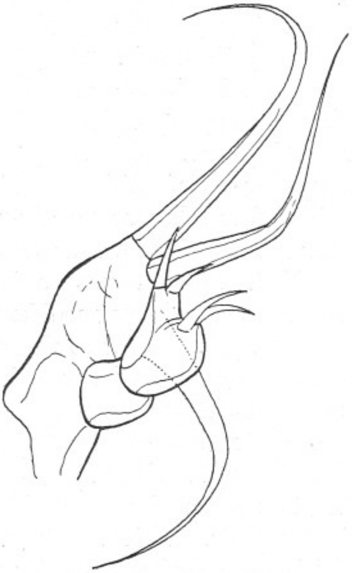

FIG. 6.—Maxillule of adult female.

In the Choniostomatidæ the copepodid larva becomes fixed to a host and moults directly into the degenerate form of the adult. We do not know the course of development in Nicothoë, but there is little degeneration in the adult, which has the full number of normal posterior appendages and the full number of abdominal somites. In the Choniostomatidæ not more than two pairs of legs are developed, and there is rarely in the adult any definite abdominal region. The antennules are of three joints,

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* A similar, very prominent, ridge is found in the larval form known as "Saphirella," which probably belongs to the Clausidiidæ.

the second shortest and the third longest, exactly as in the larva of Nicothoë.

I suggest that Nicothoë represents more or less closely the primitive Choniostomatid form, and that the Choniostomatidæ themselves are really pædogenetic larval forms.

There is a striking tendency among the semi-parasitic and parasitic Crustacea to abbreviation of development, to which attention has already been directed by Canu (1892, p. 91). There may be only one or two nauplius stages, and the larva may seek a host in the first Copepodid stage (Lernæa) or the second (Ascidicolidæ).

Such early attachment to a host, before the development of the full complement of legs, seems to provide a condition most favourable to the occurrence of pædogenesis. There is, one might say, no inducement for the larva to develop legs or an abdomen which will never be of any use, and every advantage in the attainment of sexual maturity without further development. Garstang (1928) has interpreted the Appendicularians as pædogenetic Doliolids, and it is possible that this interpretation may be applied to other apparently " degenerate " animals.

The relationship of the Choniostomatidæ to other groups is a question still undecided. Hansen goes no further than to say that they come " much nearer to the Lernæopodidæ than to any other form of parasitic Copepoda " (p. 86). So far as the structure of the adult is concerned, there seems to be more affinity with the Ergasilidæ and Clausiidæ, but there is no doubt that there are points of resemblance between the larvæ of the Choniostomatidæ and those of the Lernæopodidæ and the Lernæidæ (and through the latter to the Caligidæ). Any real decision on this point involves a complete reconsideration of the parasitic and semi-parasitic Copepods. Such a revision must take into account above all the larval forms, and the possibility of pædogenesis must also be borne in mind.

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The Larval Stages of the Copepod Longipedia.

By

Robert Gurney, D.Sc.

With 10 Figures in the Text.

During a short stay at the Laboratory at Plymouth, with the object of studying the larvæ of Longipedia and Misophria, I was successful in identifying the nauplius of the former, and, as it is of rather exceptional interest from the systematic point of view, the various stages are described here. I did not find the adult of any species of Longipedia and am not able to describe the first nauplius with certainty, but the identity of the series as a whole was settled beyond doubt by the moulting of a late nauplius into a Copepodid which could be definitely identified as a species of Longipedia. It is impossible to say to which species it belonged, but the specific determination is not of serious importance.

All the stages described were taken in the plankton, in which they were common at this time (July 27th–August 7th, 1929). Three species referable to the same genus could be easily recognised by colour and to some extent by size and structure. The commonest form is of a dark green colour, with blue pigment dorsally, and it is from this form that the Copepodid moulted. It was generally to be found in plankton from the Sound, but was extremely common in a sample taken up the Tamar opposite the mouth of the Lynher. On the same day two other samples were taken lower down the Tamar, above and below the Docks, and the numbers of larvæ showed a very marked decline, indicating the upper waters as the home of the adult. Another form distinguished by its pink colour was very common in the Sound, but entirely absent from the Tamar. Isolated larvæ of this form unfortunately all died before the last moult, but in one sample in which the nauplii were unusually abundant a number of Copepodids were found which corresponded so exactly in their colour and the distribution of the pigment to the nauplius that there could be no doubt of their origin. A third form recognisable by its smaller size and yellow colour was also seen, but it was very rare as compared with the other two. It was found with the green form in the upper Tamar plankton. No Copepodid was found which could be referred to it. Only two species of Longipedia—*L. scotti* Sars and *L. minor* T. & A. Scott—have hitherto

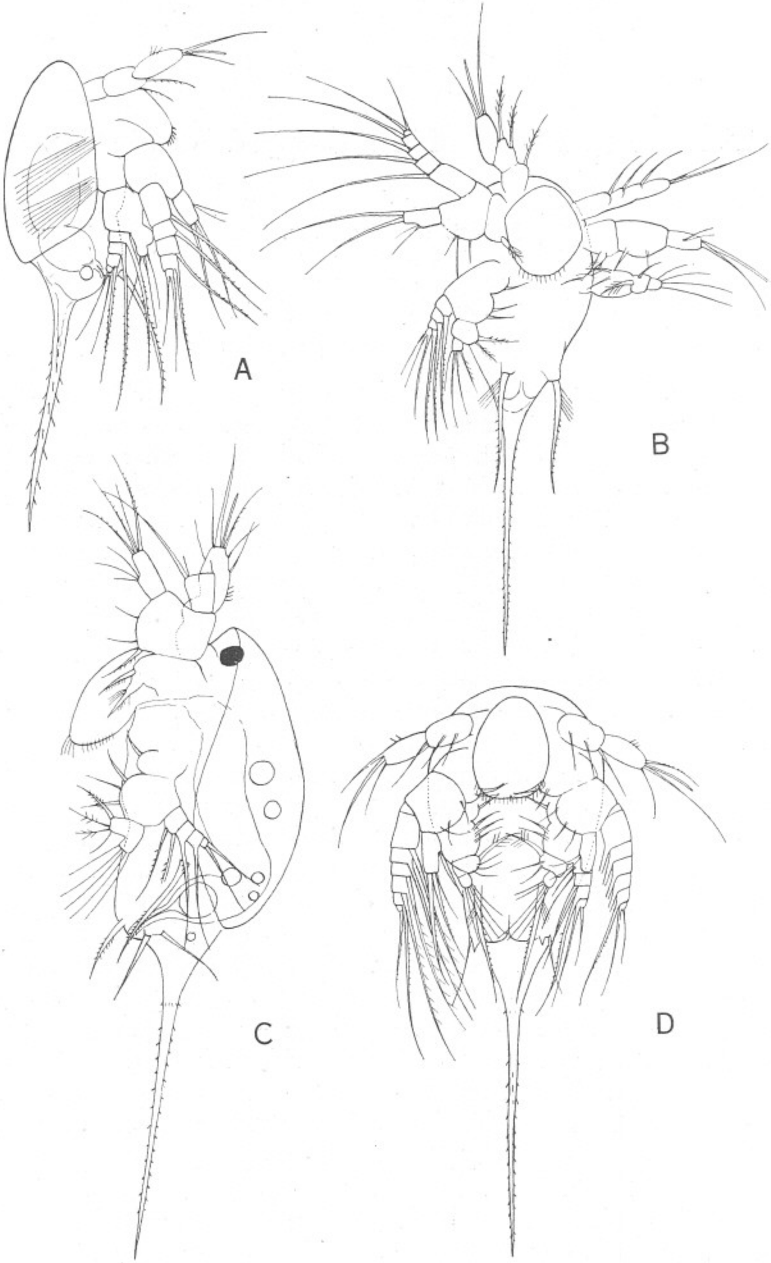

FIG. 1.—A. Longipedia, green form. Stage I, lateral.
B. Longipedia, green form. Stage I, ventral.
C. Longipedia, green form. Stage III, lateral.
D. Longipedia, green form. Stage II, ventral.

been recorded from Plymouth, but four are included by Sars in the fauna of Norway, and it is not unlikely that all of them may actually occur at Plymouth.

LONGIPEDIA SP. (Green form).

Stage I. (Figs. 1, A and B.)

Body pear-shaped, tapering behind into a spine which is longer than the body. In side-view the cephalothoracic shield is conspicuously marked. Labrum very prominent and fringed with short spinules.

Antennule three-jointed. Joint 1 bears one seta and joint 2 bears two, the three about equal in length. Joint 3 bears two setæ and an æsthete at the end but no lateral setæ.

Antenna with a long exopod of 5 joints, bearing 6 setæ, two on the last joint. The endopod is one-jointed, with a pair of lateral and two long terminal setæ.

The coxal joint has a single large swollen seta, and the basis has 4 small setæ.

Mandible with exopod of 4 joints, bearing 5 setæ, the proximal 3 setæ armed with spinules. Endopod of two joints.

Some distance behind the mandible, just in front of the anus, is a pair of very long curved spines, each with a brush of long hairs at its base. These may perhaps represent the future maxillules.

There are no furcal setæ, a very unusual feature.

Length : Body (to anus), ·125–·129 mm. Posterior spine, ·132–·144 mm. Total length, ·257–·273 mm.

Colour : At this stage the body is colourless or slightly greenish, with a conspicuous yellow intestine. Eye red.

Specimens of this stage, which I suppose to be the first, are very rare, and have only been found after much search.

In subsequent stages the general form remains the same, but the posterior spine becomes progressively shorter in proportion to the body, and the colour becomes conspicuously green, but with some blue pigment dorsally. The appendages remain much the same, but at each stage there are some differences in the number of setæ.

Stage II. (Fig. 1, D.)

Antennule—last joint with 3 setæ and æsthete.

Antenna—Exopod of 6 joints. Joints 1–5 with one seta, joint 6 with two. The first 4 setæ are feathered, but setæ 5 and 6 have a row of short spinules on the dorsal side only. Endopod with 3 terminal setæ. Coxa with a strong spine and a seta (fig. 3, A).

Mandible—Exopod of 4 joints, with 6 setæ, joint 1 having now 2 setæ. Setæ 2 and 3 are the strongest, and all except the first have short spinules.

Endopod of 2 joints, joint 1 with 4 setæ of which the basal one is strong with long feathering. Joint 2 with 5 setæ.

In the anal region there is a transverse ridge with a spinous process at each end, and a pair of short slender anal, or furcal, setæ.

The posterior spine has a circlet of spinules near the base which remains a constant feature of later stages.

Length : Body, ·175 mm. Spine, ·173 mm. Total, ·348 mm.

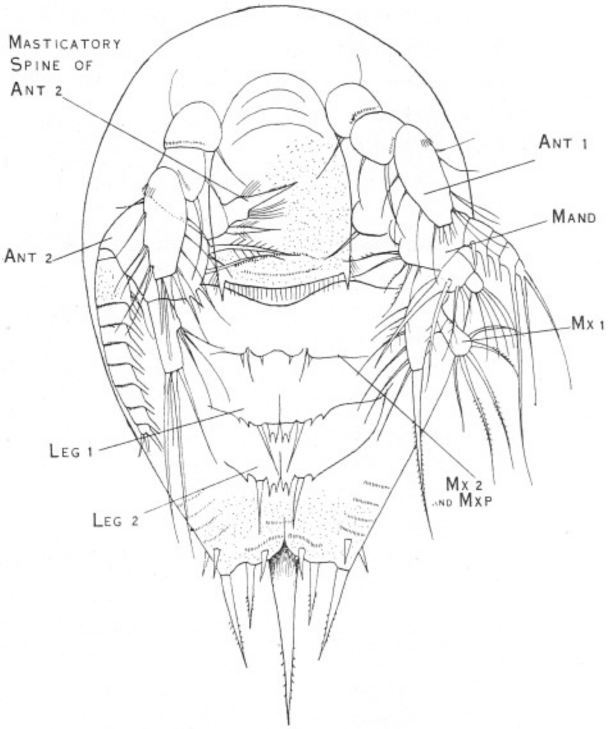

FIG. 2.—Longipedia, pink form. Stage VI, ventral. Antenna omitted on left side, and mandible and maxillule on right. Drawn from a moulted skin.

Stage III. (Fig. 1, C.)

Antennule—as before but with two short setæ on posterior, and one on anterior, edge of last joint.

Antenna—Exopod of 7 joints with 9 setæ. The first joint is divided at its base. This division is sometimes seen in Stage II. Coxa with two strong masticatory spines and a small seta. Basis with 4 setæ. Endopod with 4 terminal and 3 lateral setæ. Mandible almost unchanged.

The maxillule is traceable under the skin at the base of the long maxillular spines.

There are now two pairs of furcal spines in addition to the pair of furcal setæ.

Length : Body, ·188 mm. Spine, ·182 mm. Total, ·370 mm.

Stage IV.

Antennule—last joint with 3 anterior and 4 posterior setæ.

Antenna—Exopod of 8 joints. Endopod, etc., as before.

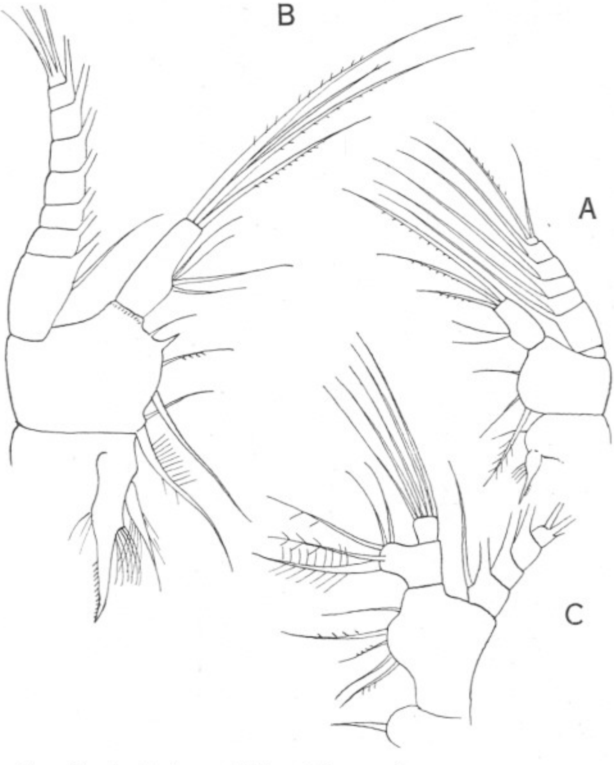

FIG. 3.—A. Antenna of Stage II, green form.
B, C. Antenna and mandible of pink form, Stage VI.

Mandible—Exopod of 4 joints, with 6 setæ. Endopod, joint 1 with 4 setæ, and joint 3 with 5.

Maxillule bilobed, the inner lobe with a strong terminal spine and 4 inner setæ ; the outer lobe with 3 setæ. Furcal region with 3 pairs of spines.

Length : Body, ·22 mm. Spine, ·19 mm. Total, ·41 mm.

This stage differs so little from the next that it is only separable with difficulty. At the same time I believe it does represent a distinct moult.

Stage V.

Antennule—last joint with 4 anterior and 6 posterior setæ.

Antenna—Exopod of 8 joints, with 11 setæ. Joint 1 has 2 and joint 8 has 3 setæ. Coxa with 3 setæ; basis with 5.

Mandible—Exopod unchanged. Endopod, joint 1 large, produced inwards, with 3 strong and 2 slender setæ. Joint 2 with 5 setæ. Maxillule two-branched. Outer branch with 5 setæ; inner with long stout terminal spine and about 6 slender inner setæ. Maxilla, maxillipede and two pairs of legs visible under skin. Three pairs of furcal spines present.

Length: Body, ·26 mm. Spine, ·18 mm. Total, ·44 mm.

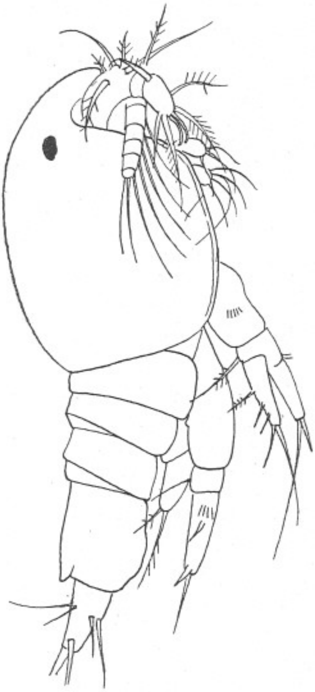

FIG. 4.—Longipedia, green form. Cyclopid I, lateral.

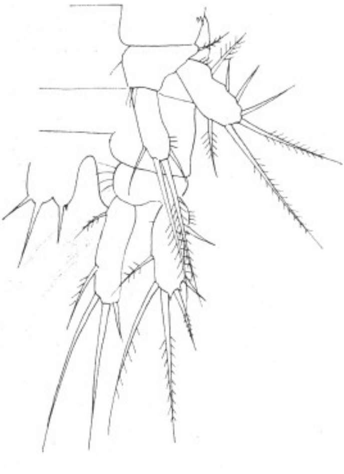

FIG. 5.—Longipedia, green form. Cyclopid I, legs 1–3.

Stage VI. (Figs. 2 and 3, B, C.)

This stage differs only from Stage V in size, in the shorter spine, and in the appearance of the rudiments of the legs. The maxilla and maxillipedes are scarcely defined, their position being simply indicated by a transverse ridge with small spines and a pair of setæ. The two pairs of legs are represented by two ridges with spines, but are not definitely bilobed.

Length: Body, ·29 mm. Spine, ·185 mm. Total, ·475 mm.

The yellow form of nauplius does not appear to differ from the green one in any way except in colour and in being a trifle smaller. The pink form, on the other hand, is not only easily recognisable by its colour, but is also larger, and has a relatively shorter spine. It also differs from the other two species in having the labrum squarely truncated, with a spine at each angle, and in having a tooth on the basis of the antenna in addition to the usual setæ. (See Figs. 2 and 3 B.)

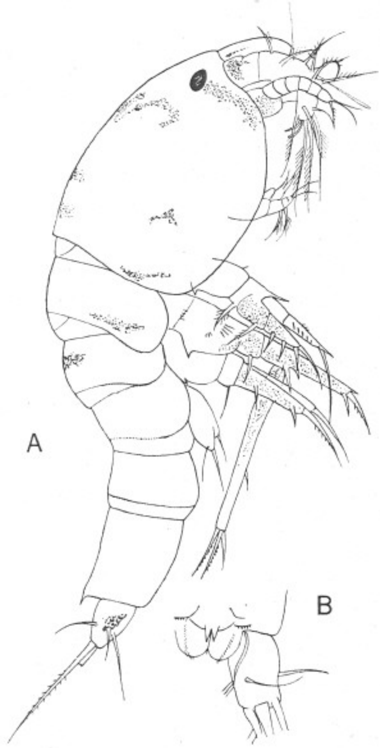

FIG. 6.—Longipedia, pink form. A. Cyclopid II, lateral. B. The operculum and furcal ramus.

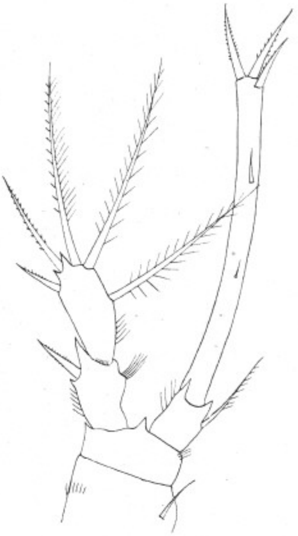

FIG. 7.—Longipedia, pink form. Leg 2.

Cyclopid I. (Green form.) (Figs. 4, 5.)

Cephalothorax longer than rest of body. Rostrum very large and broad. Three free thoracic and one abdominal somite. Furcal rami rather long and narrow, with a pair of outer lateral spines, one long subterminal spine and two long terminal setæ. There is also a dorsal seta and a ventral spine. Anal operculum smooth.

Antennule of 3 or 4 joints, the basal joint indistinctly divided. As in the adult, the antennule bears stiff bristly setæ, but they are relatively few. The last joint bears, in addition to several setæ, a pair of curved æsthetes as in the adult.

Antenna with large exopod of 6 joints, the endopod of 3 joints as in the adult. Mouth parts of the adult form.

Legs 1 and 2 biramous, the branches one-jointed. Leg 2 shows no sign of elongation of the endopod. Leg 3 is a bilobed rudiment.

Length : ·45 mm.

Colour : Thorax blue or blue-green, remainder colourless.

Cyclopid II. (Pink form.) (Figs. 6, 7.)

This stage differs from the preceding in having three pairs of legs well developed and a rudiment of the fourth. The fifth somite is distinct, but the abdomen is still of one somite. Leg 2 has developed the very long endopod characteristic of the adult. The operculum has a pair of median spines.

I have not seen this stage in the green form, but, among a number of cyclopids of the pink form taken in the tow-net on August 6th, one was found which had moulted to Stage II.

OTHER ALLIED NAUPLII.

Besides the three forms mentioned above, which no doubt all belong to the genus Longipedia, two other types of nauplii have been seen which are evidently closely related, but must represent other genera.

Longipediidæ—Genus II. (Fig. 8.)

Only two specimens of this larva have been seen, both taken in the sample from the mouth of the Lynher, one in Stage I and the other in Stage V.

The resemblance to the larva of Longipedia in the structure of the appendages is so close that a near relationship is obvious, and there is also in Stage I the pair of large maxillular spines which is so characteristic.

On the other hand the body lacks altogether the conspicuous posterior median spine, and there is a pair of long furcal setæ in Stage I. The body has, otherwise, the same form as in Longipedia, with a very arched dorsal contour.

In Stage V the resemblance to Longipedia is still more marked. There are now 3 pairs of furcal spines, but no median spine. The larva is in fact simply a Longipedia without a posterior spine.

Length : Stage I, ·13 mm. ; Stage V, ·21 mm.

Longipediidæ—Genus III. (Fig. 9.)

Structure of appendages as in the preceding forms, and agreeing with Longipedia in having a long posterior median spine; but differing from all other forms in the long narrow shape of the body and the remarkable helmet-shaped head. Not only is the head produced forwards and upwards, but it has also a downward beak-like projection. The labrum is very prominent and covered with small spines. Colour, rosy red.

This larva was fairly common in some of the plankton samples from the Sound, but I was unable to find any post-larval stage corresponding to it, or to keep the larva alive until the last moult. I found it almost impossible to isolate specimens alive, since they were almost invariably caught on the surface film. The pink form of Longipedia has also a tendency to be so caught, but by no means so readily as this helmeted form.

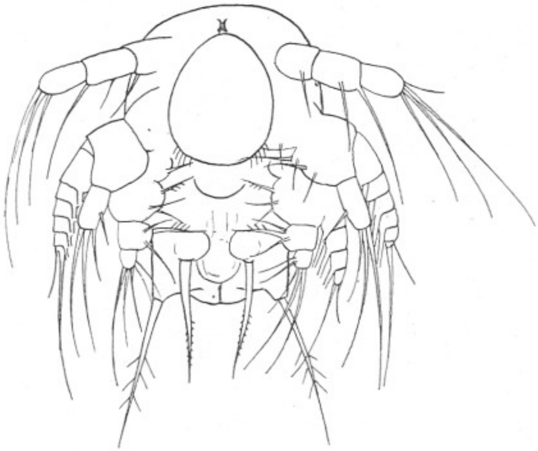

FIG. 8.—Longipediidæ, Genus II. Nauplius, Stage I.

While the identity of the Longipedia larva is beyond question, and the general relationship of all can hardly be doubted, it is impossible to assign the last two larvæ to genera. Prof. Sars includes in the family Longipediidæ the genera Longipedia, Canuella, and Sunaristes, and representatives of all these genera have been taken on the Devonshire coast. It may be no more than a coincidence that I find three generic types of larva; but it is at least probable that "Genera II and III" represent the larvæ of Canuella and Sunaristes.

DISCUSSION.

Prof. Sars, in his *Crustacea of Norway*, divided the Harpacticoida into two sections, the Achirota and Chirognatha, which are separated only according to the structure of the maxillipedes. Within the former are included four families, Misophriidæ, Longipediidæ, Cerviniidæ, and Ectinosomidæ. The validity of this system is doubtful. In the first place a non-prehensile maxillipede is not confined to the Achirota, being found also among Chirognatha in *Stenhelia palustris* (but not in other Stenhelias), Ceylonia, Viguierella, and Tachidiopsis. Secondly, it is difficult, apart from this character, to find within the Achirota anything by which to distinguish them as a whole from the rest of the Harpacticoida, and indeed it is very doubtful if these four families form a natural group at all. The Misophriidæ differ so much from all the Harpacticoida that they

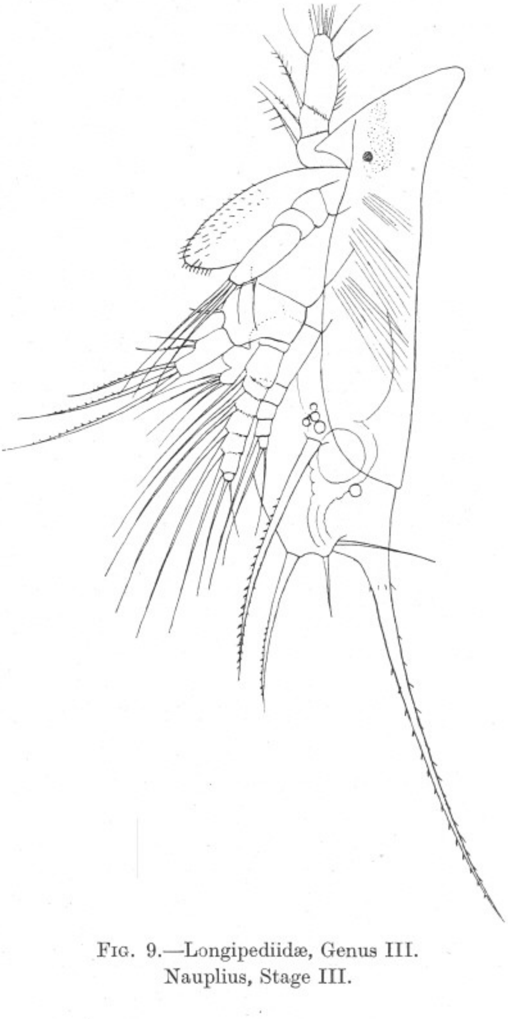

FIG. 9.—Longipediidæ, Genus III.
Nauplius, Stage III.

should be regarded as forming a separate suborder, for they cannot be satisfactorily included either in the Calanoida or the Cyclopoida, though possessing some of the characters of both.*

Again, the relationship of the Longipediidæ to the Cerviniidæ and Ectinosomidæ does not seem to be very close. The Cerviniidæ include, in Sars' classification, the genus Zosime which resembles so closely some forms of the family Tachidiidæ (e.g. Tachidiopsis) that it is impossible to justify its placing in an entirely distinct section. Prof. Sars did not describe or figure the maxilliped of *Z. incrassata*, but it is in all other respects a typical "Chirognath." The Ectinosomidæ are a well-marked family differing greatly both from the Longipediidæ and from typical Chirognatha.

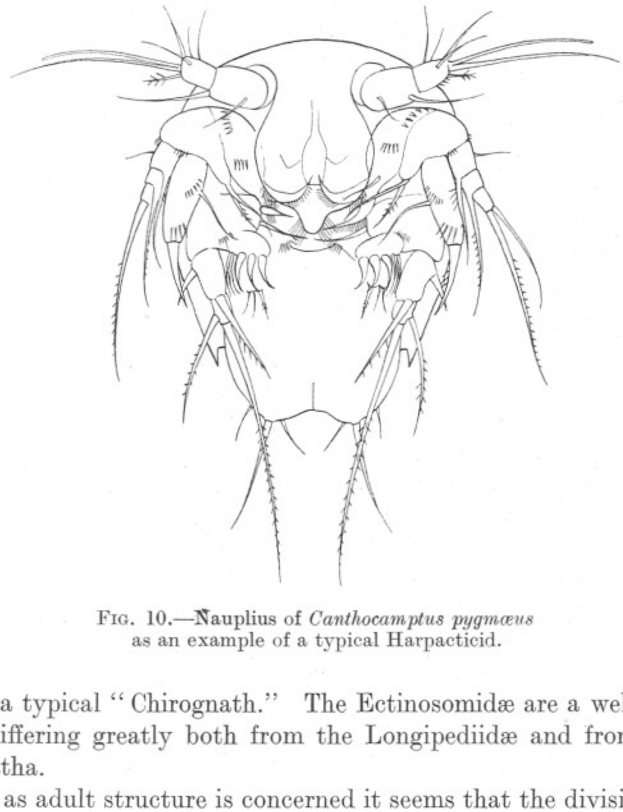
FIG. 10.—Nauplius of *Canthocamptus pygmæus* as an example of a typical Harpacticid.

So far as adult structure is concerned it seems that the division of the Harpacticoida into Achirota and Chirognatha cannot be sustained, and that the families included in the former are not very nearly related. Among them the family Longipediidæ is furthest removed from the Chirognath type.

In order to arrive at any sound grouping of the Copepoda it is certainly necessary that the characters of the nauplii should be taken into account,

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* See Gurney, *Trans. Zool. Soc.*, XXII, p. 454, 1927.

and it is to be expected that a knowledge of the larvæ of the Achirota will throw some light on their relationship. Unfortunately we know at present only the larva of Ectinosoma, and that, while differing considerably from that of a typical Chirognath, is not so different as to justify a fundamental separation.

Having now made known the nauplius of Longipedia and two related genera, it is necessary to determine what evidence, if any, it offers with regard to the relationship of the family.

If we compare the nauplius of Longipedia with that of a typical Chirognath (e.g. Canthocamptus, Fig. 10) we find certain striking differences.

(1) The pear-shaped form of the body resembles that of a Calanoid and not the flattened discoidal form of a Harpacticid.

(2) The posterior median spine is seen in no other Copepod, but recalls that of the Cirripedes.

(3) The flattened form of the antennule is unique among Harpacticids, but exactly paralleled among Calanoida and, to a less extent, among Cyclopoida.

(4) The antenna differs from the typical Harpacticid type in the very long many-jointed exopod. In typical Harpacticids the exopod is relatively short and with not more than 4 joints. Even among the Calanoida and Cyclopoida it is rare to meet with an exopod so well developed, and it is only among the Branchiopoda, Cirripedia, and Penæidea that a parallel can be found. The endopod in most, if not all, Chirognath Harpacticids has become modified into a strong clasping organ, often very much larger than the exopod, while in Longipedia it is a simple one-jointed branch exactly the same, even to the arrangement of the setæ, as in Calanoida and Cyclopoida.

Lastly, there is a difference with regard to the coxa which it is a little difficult at present to take into account. In many, perhaps in all, typical Harpacticids this joint has a very large mandibular process which may be toothed at the end and appears to be a process of the joint rather than a modified spine. In Longipedia, as also is the case in Calanoida and Cyclopoida, this joint bears one, or in later stages two, stout movable spines of very different appearance.

(5) The mandible in typical Harpacticids always has the exopod more or less reduced. It is never so well developed as in Longipedia. The endopod is always more or less modified into a prehensile organ, the first joint bearing from one to three stout hooked spines and the second joint reduced to a small papilla bearing three to five setæ, or even absent, the setæ springing from the outer edge of the apparently single joint. In Longipedia the two joints are clearly distinct and there are no prehensile spines.

In this respect it seems to be more primitive even than the Calanoida where the two joints are usually fused, and to resemble more closely the Cyclopoida where they are distinct. It is in the Cirripedia that these joints are best developed.

In the Harpacticoida the basal joints do not seem to take any large part in mastication, having no mandibular process and only relatively weak spines. In this respect alone the limb of Longipedia resembles that of typical Harpacticids and differs from that of most Calanoida in which a mandibular process is developed very early. At the same time probably no great importance can be attached to this point, since the early development of the mandibular process in Calanoida (and also in Branchiopoda) seems to be a case of the early acquisition of an adult character and not primitive.

(6) With regard to the posterior limbs little can be said, especially as they belong rather to the adult than to the nauplius stage, but there seems to be a difference between the nauplii of Calanoida and all other Copepoda in that in them the maxilla and maxillipede may be quite distinct in the last nauplius whereas in other forms they are scarcely traceable. The appearance of a pair of spines representing the maxillulæ in the first nauplius in Longipedia is, so far as I know, a unique feature.

(7) The strong furcal spines developed in Longipedia are a feature distinguishing the nauplius from that of any Harpacticid yet described. It is only among the Calanoida that such spines are found, but in them there is usually some asymmetry of the furcal setæ which is not seen here.

This comparison makes it clear that, so far as the larvæ are concerned, the difference between Longipedia and such typical Harpacticids as we know the larva of is profound and much greater than it is between Longipedia and the Calanoida or Cyclopoida. In fact, anyone meeting with this nauplius and not knowing its parentage would almost certainly regard it as the larva of a Calanoid. It is true that the most conspicuous differences such as the very large exopodites of the antenna and mandible are such as may be accounted for by adaptation to a pelagic life, the nauplii of typical Harpacticids being creepers on the bottom ; but it seems more reasonable to regard these features as primitive. In Euterpina, a Harpacticid which is pelagic at all stages, the nauplius is a modification of the ordinary Harpacticid type, the exopods being enlarged without increase in the number of the joints. In this case there has probably been a secondary assumption of pelagic life. In the case of the Longipediidæ we have a family which has retained the primitive pelagic larva and has perhaps only comparatively recently become benthic as adults. It is worth noting that I have found species of Longipedia not uncommon in plankton from the Suez Canal and from Samoa, and that it is an exceedingly active swimmer.

The general conclusion seems to be justified that, if there is to be any fundamental division among the Harpacticoida, it must be between the Longipediidæ and the rest. At the same time it is evidently premature to insist on such a conclusion until the larvæ of other forms such as Cervinia are made known and the identity of those here described as probably belonging to Canuella and Sunaristes is established. For the present it seems clear that the divisions Achirota and Chirognatha in Sars' sense should be dropped.

Incubation-habit in a Phyllodocid Polychæte, *Notophyllum foliosum* Sars.

By

Yô K. Okada.

With 1 Figure in the Text.

That a mother worm protects its eggs until the young are hatched is common enough among Polychætes, but not in the family Phyllodocidæ.

McIntosh (1908) mentioned in his *British Annelids*, Vol. II, Pt. I, p. 49, that two female specimens of *Notophyllum foliosum*, procured by his late friend Dr. Howden, at Lamlash, Arran, in August, were laden with mature eggs. Certainly the words " were laden " used here tell us something about the particular habit of the worm, but the sentence is too short and is not emphatic enough to attract attention. Hence his observation has remained without being noticed at all.

Using the opportunity of my stay at Plymouth, I have always paid attention to *Notophyllum* found among dredgings, and have carefully examined the specimens obtained, with the hope of proving McIntosh's statement. I was lucky enough to obtain two female specimens laden with eggs, and I am very glad to be able to prove the incubation habit in this Phyllodocid Polychæte. The accompanying figure shows one of these specimens mounted in Canada balsam.

This specimen was found in September, 1927, in an abandoned tube of *Serpula*, and measured about 12 mm. It consisted of fifty-six setigerous segments succeeded as usual by a pygidium. The dorsal cirri are exceedingly broad, which is a generic character, and they cover almost the entire dorsal surface of the body, overlapping one another on both sides. The lamellæ in the fresh condition are somewhat fleshy, soft, and rather yellowish in colour, with dark brown pigment round the edge.

When these broad dorsal lamellæ were turned forwards (or anteriorly), a mass of cream-like, yellow gelatinous substance came to light near the posterior end of the worm. A piece of this mass was isolated, and then brought under the microscope, which disclosed a large number of developing eggs, agglutinated together in a band or ribbon. The length of the entire band or ribbon extended from the 38th to the 47th setigerous segment or a little beyond these segments, and the band was fixed at both ends to the dorsal surface of segments 41–45 and coiled in between these fixed points (see fig. 1). There was another small mass of the eggs attached near the level of the 15th setigerous segment, but in the second specimen such an anterior mass was not found. In other respects the incubation habit was the same in both cases.

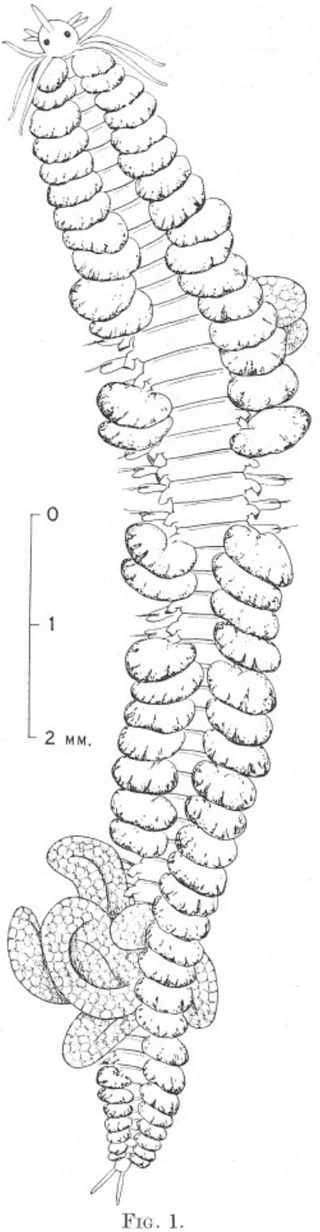

Fig. 1.

Without further description, it is easily understood that the method of incubation is the same or at least closely related to that of Polynoids. *Harmothoë imbricata*, a common Polychæte on both the English and French sides of the Channel, lives also in Japan, and there the worm incubates, protecting the eggs under the broad dorsal cirri or elytra, as they are called. According to A. Izuka (1912, p. 48), the breeding season of the Polychæte (at Misaki ?) is in " the months of March and April " ; " the eggs are agglutinated together by a transparent mucous secretion," but not in the shape of a ribbon, and are carried under the elytra, from the 8th to the penultimate segment. The only difference to be found in this case is that the egg-masses do not form ribbons, and a greater number of segments is concerned in the phenomenon.

P. Fauvel (1916, p. 426) gives another example of a Polynoid showing the incubation habit in *Polynoë antarctica* from the Falklands. (" Sous les élytres, sont accumulés des œufs qui y paraissent incubés.")

The method of incubation in the Polynoids is evidently a special utilization of the space produced between the broadened dorsal cirri and the dorsal surface of the worm, but we are entirely ignorant as to why only a very limited number of species utilize this space for the special purpose of incubation.

In the Falklands collection Fauvel (l.c., p. 448) finds a specimen of *Cirratulus cirratus* in a tube of *Potamilla* buried in the tissues of a sponge, protecting larvæ 2 mm. long. ("Ses branchies et ses filets tentaculaires, rabattus sur le dos et fortement emmelés, y retiennent une masse assez considérable de jeunes larves de 2 mm. de longueur, ne possédant encore que douze sétigères.") According to Ch. Gravier (1923, p. 179), this Polychæte does not incubate its eggs on the French side of the Channel, and I think perhaps not on the English side either. The incubation habit in this case of *Cirratulus* may be due to the low temperature at the Falklands, but the same analogy cannot be extended to the case of Polynoids, since at Misaki, Japan, where *Harmothoë imbricata* incubates, the water is by no means colder than in the English Channel.

If, on the other hand, the habit in question is a chance happening in certain Polynoids to utilize the comparatively wide space between the dorsal lamellæ and the surface of the body for the purpose of protecting the young, it would be little astonishing to find the same or at least a similar habit independently developed in Polychætes of another family having a similar differentiation of the dorsal cirri, and also utilizing the same space for the same purpose. The incubation-habit in Notophyllum would be of this nature, its origin, independent of, but closely related to the same habit of Polynoids. As mentioned by Gravier (l.c.), this method of incubation is the most primitive type among Polychætes.

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A Remark on the Constitution of Larval Syllids.

By

Yô K. Okada.

With 5 Figures in the Text.

THE facts of Polychæte embryology inform us that the change of the trochophore into the perfect worm consists, first of all, in a growing out of the posterior section of its body and a gradual reduction of the anterior part, segmentation appearing at the same time. This phenomenon depends upon a marked change of the mesodermal bands, situated on each side of the intestine. Each of them is separated into two cell-layers, which spread out toward the mid-ventral and mid-dorsal lines. Then a segmentation makes its appearance in them, proceeding from in front backwards, and almost simultaneously the two layers of the bands separate from each other, by the formation of a cavity in each section or segment. That new segments are gradually formed one after the other, and from before backwards, in the hinder part of the growing body, holds true universally, but, at the extreme end a segment has been individualised from the first, or at a very early phase of the segmentation, and this segment does not divide again even to the end of development. In this way the pygidium is formed, and it represents the posterior individual portion of the trochophore. The growth of Polychæte-larvæ is therefore anteanal and entirely in the penultimate segment.

Syllids pass the earliest phases of their development within the egg-capsule, and the larvæ hatch out generally as metatrochophores, or even at the commencement of parapodial formation in the anterior secondary divisions or segments (*nectochætæ*). The origin of these new segments follows, of course, the law of embryonic development mentioned in the last paragraph ; this is, however, after the 9-meric stage in this family of Polychætes.

The larva of this stage has generally the following morphology : the prostomium has three appendages and two pairs of eyes on the dorsal aspect, but very frequently no palpi on the ventral side. In the second segment the dorsal cirri are well marked, but the ventral are either in an early stage of development or are not yet formed. The five following metameres are each provided with a pair of parapodia or those of the hinder part are replaced by bundles of setæ. Generally there are dorsal cirri too. The larvæ of Exogoninæ are without the dorsal cirri in the second setigerous segment, and this fact seems quite constant within this sub-family (see Viguier's pl. V, fig. 52, 1884, or Malaquin's pl. XIV, fig. 32, 1893, for example). The eighth section of the body is the growth zone, and the ninth is the pygidium, which carries the already elongated caudal cirri.

Before this stage the larva, when typical, consists of seven segments, three being setigerous. Most larvæ of the Exogoninæ have this constitution (see Viguier's pl. IV, fig. 33, and Malaquin's pl. XIV, fig. 3).

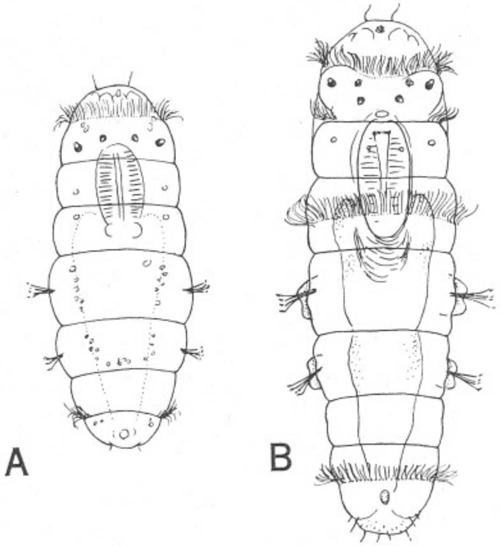

FIG. 1.—Larvæ of *A. longeferiens*, (A) one-day old and (B) four-day old, from Mrs. Sexton's sketches.

The growth zone being always penultimate, it forms here the sixth section of the body. However, a metameric number less than seven is usually normal, especially in the other sub-families, some being bi-setigerous (see Malaquin's pl. XIII, fig. 20 ; Herpin's pl. IV, fig. 92, 1925) and others mono-setigerous (see Malaquin's pl. XIV, fig. 17A ; Herpin's pl. VI, fig. 124 ; Greeff's pl. XIV, fig. 36, 1879). In such cases it is generally stated that the position of the setæ represents the third and fourth segments in the first instance, or the third segment alone in the second. My own view in respect to the position of the setæ in the atypical 7-meric larvæ of Syllids is different.

Dating back to 1914 (Feb. 18th) a Sacconereis of *Autolytus longeferiens* was captured by the tow-net off the Eddystone, S.W. by W., one mile (the Plymouth district). It carried two ovigerous sacs on its mid-ventral surface, from which swimming larvæ were hatched out on March 2nd. Mrs. E. W. Sexton sketched several of them very faithfully from the living specimens. According to these drawings the larva of one day old, which is shown in Fig. 1A, judging from its matameric number, exactly corresponds to the 7-meric stage of the standard development. The larva in question is, however, bi-setigerous, pale yellow in colour and about 0·25 mm. in length. The cephalic section has two pairs of reddish-brown eyes and bears a ring of long cilia (akrotroch) in front of them. The telotroch (paratroch) appears on each side between the last two segments. The fourth section of the body is larger than any other, and this and the next segment are provided with setæ. The stomodeal invagination reaches the middle of the third segment and the intestine also commences from this position. It is almost impossible to doubt, unless we are deceived as to the exactitude of the sketch, that the anterior pair of the setose-bundles is formed in the fourth section, which corresponds to the second setigerous segment of later development, and the same is the case in the adult.

After three days the larva (Fig. 1B) (sketched March 4th) measures naturally more (0·35 mm.) than before, and several important changes have crept into its structure. A band of cilia appears in the middle of the third segment and surrounds it like a girdle (interparatroch). The telotroch is now complete all the way round, its position being between the last two segments as before. Another new feature is a band of cilia on each of the hinder borders of the cephalic section, just behind the position of the eyes (according to my reinvestigation this band is continuous on both sides, on the ventral side certainly, and it is almost without doubt the prototroch), and a new segment appears between the posterior setigerous segment and the penultimate growth zone. The pharynx and the intestine are as before. The setæ of the fourth and fifth segments are now elongate, and a primitive parapodium is beginning to be associated with each bundle of them. But neither of these organs is found in the third segment. This fact finally led us to investigate whether the segment bearing the interparatroch is really the third section of the larva, that gives rise later to the first setigerous segment of the adult worm. There is no sketch of the more advanced stages and no data are available to solve the problem.

Mr. D. P. Wilson has observed similar larvæ of *Autolytus pictus* in earlier phases than those of Mrs. Sexton, and by means of Mr. Wilson's observation we can trace two stages back. At the time of hatching (April 19th, 1927) the larva (Fig. 2A) was 0·25 mm. long and pale green in colour. There were neither appendages nor setæ in the body-segments. The eyes, four in two pairs, were only distinct in the head section, each provided with a prominent lens. The anterior lenses are directed forwards and outwards, while the posterior look outwards and backwards. As a whole the larva is elongate and pyriform, the wider end being anterior, and it is divided into five sections. The prototroch is well marked and is situated behind the eyes. It is transversely straight on the dorsal surface, while, ventrally, it is continuous and arches forwards in front of the mouth opening. There is a band of long cilia on each side of the cephalic section in front of the anterior eyes, as in the older larva of *Autolytus longeferiens*. I think that perhaps each band is connected by a row of shorter cilia, and constitutes a complete ring, the akrotroch. The telotroch marks the boundary of the body and the pygidium. The interparatroch is already distinct in the middle of the second section of the body, and not in the third. It is present on the ventral surface only (gastrotroch). There are a number of sensory hairs at both extremities, and also spine-like tactile hairs on each side behind the prototroch, in the

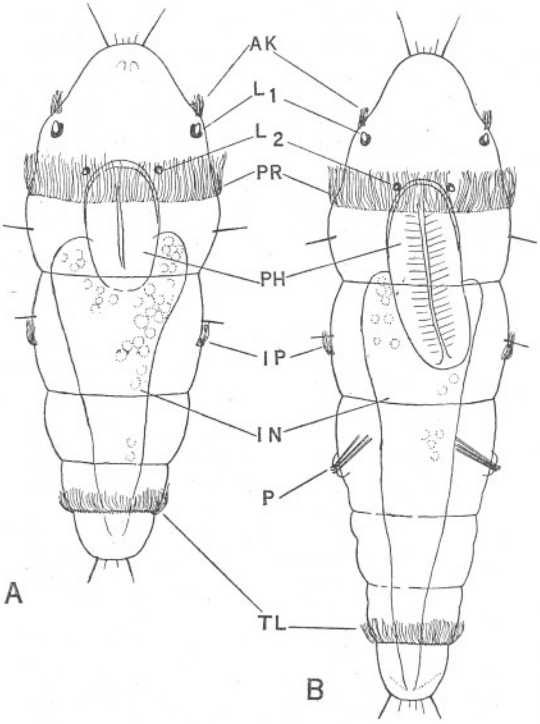

FIG. 2.—Larvæ of *A. pictus,* (A) one-day old and (B) six-day old, from Mr. Wilson's sketches.

AK—akrotroch; L1—anterior pair; L2—posterior pair of eyes; IN—intestine; IP—inter-paratroch; P—parapodium with setæ; PH—pharynx; PR—prototroch; TL—telotroch.

cephalic section and in the middle of the third segment, just in front of the interparatroch. The main portion of the gut consists of an ovoid stomodeal invagination and an intestine, which contains a quantity of yolk. It is important to call attention to the position of the larval pharynx, which is unmistakably within the boundary of the cephalic section. It scarcely extends into the second segment carrying the interparatroch.

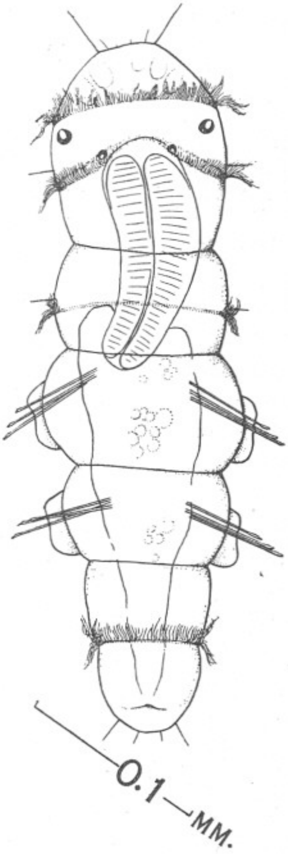

FIG. 3.—6-meric larva of *A. longeferiens*, three-day old, dorsal view.

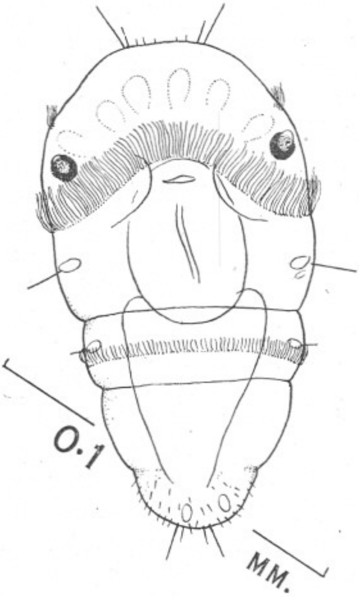

FIG. 4.—3-meric larva of *A. prolifer* (?) just before hatching, ventral view.

After six days, a mono-setigerous larva (0·3 mm. long) results, to which (Fig. 2B) one more segment is added at the hinder section of the body. There is no change in the front part. The first pair of bundles of setæ is now visible. They are formed in the third section of the larva. But we should not fail to notice that this is next to the segment bearing the interparatroch, so that it corresponds to the fourth segment of the *A. longeferiens*—larva figured by Mrs. Sexton. There is another consideration to support this view, in addition to the position of the interparatroch. As mentioned above, the stomodeal invagination comes down from the mid-ventral position of the cephalic section, instead of from the band-bearing segment. According to Malaquin (l.c., p. 392), the stomodeal invagination should have already been complete and the mouth open by this stage of development. The cephalic section is in close connection with the stomodeal invagination, and this invagination takes place both theoretically and actually between the epi- and hypo-sphere of the trochophore, and thus it seems not unreasonable to suppose that we are here dealing with a non-segmented condition of the prostomium and the buccal segment, as in the development of Nereis (see E. B. Wilson, 1892, p. 424). The buccal segment must become individualized at a later period of development (see Fig. 5).

I could not actually find a trace of the division into two segments in the cephalic section of the Syllidian larvæ in the early phases of development. The head (Fig. 3) is always completely marked off from the body by a distinct constriction lying immediately in front of the segment bearing the interparatroch. The buccal segment, therefore, constitutes morphologically an integral part of the head in this case, though, of course, it belongs to the first segment of the "Soma."

Before the stage just discussed, the larvæ are without doubt less segmented and without setæ at all. To them are referred the metatrochophores of *Eusyllis assimilis* drawn by Malaquin (see l.c., pl. XIII, fig. 19) and *Odontosyllis ctenostoma* figured by Herpin (see l.c., pl. V, fig. 87). There are two constrictions and three divisions; these are in *Autolytus prolifer* (Fig. 4) the anterior cephalo-buccal section, the median first setegerous segment and the posterior somato-pygidial section. Herpin (l.c., p. 166) describes the development of the 3-meric body of *Odontosyllis ctenostoma* into the condition of seven segments as follows: "La plus jeune larve observée (pl. IV, fig. 87) possède déjà trois couronnes ciliées inegalement développées, dont une cephalique. Bientôt (pl. IV, fig. 88) une quatrième apparaît, en même temps que les segments s'individualisent. Au maximum de développement (pl. IV, fig. 91), les larves pélagiques *d'O. ctenostoma* présentent six forts couronnes ciliées." The larvæ are then 7-meric and bi-setigerous (pl. IV, fig. 92).

According to the known data, it may be stated that those larvæ in which the early developmental stages are most slowly passed through are polytrochal, cilia appearing very early and, except those of the special bands, being confined to the dorsal surface and disappearing from in front backwards. In other larvæ, in which the early stages are abbreviated, the cilia do not appear until a later period, and then only on the head (akro- and proto-troch) and between the last two segments (telo- or para-troch), (Malaquin, l.c., pp. 389–426, from Gravely, 1909, p. 8) with slight modifications. There is generally an interparatroch (on the ventral surface) in the middle of the future first setigerous segment. The formation of parapodia seems to commence from the second setigerous segment, and not from the first.

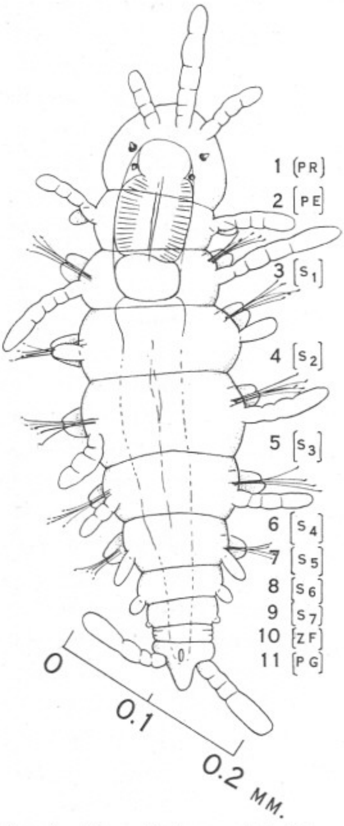

FIG. 5.—11-meric larva of *Syllis* sp. found on the colony of Syncoryne with *Procerastea halleziana*.

1 (PR) prostomium, 2 (PE) peristomium, 3 (S1) first setigerous segment . . . , 10 (ZF) growth zone, 11 (PG) pygidium.

The 9-meric stage is followed by the 11-meric stage (Fig. 5). (The number of segments is not very important and larvæ of ten or twelve segments appear as well.) The morphology of the head is near completion, and the stomodeal invagination is divided into a long anterior pharynx proper, and a short posterior proventricular portion. The ventriculus may be differentiated also. According to Herpin (l.c., p. 166) a mono-pharyngeal condition continues, in *Odontosyllis ctenostoma*, until the 13-meric stage, and it is also at this time that the central cirri of the buccal segment are formed. The palpi may appear quite early in *Syllis armillaris* (according to Malaquin at the 7-meric stage) or their appearance is retarded, in *Odontosyllis ctenostoma*, until the 15-meric stage. In any case a juvenile Syllid is complete at the stage of seventeen segments, thirteen being setigerous. The pharynx then reaches the posterior border of the fifth setigerous segment, and the intestine commences from the sixth segment. In Amblyosyllis, the only further development is to specialize the individual metameres, in each portion of the body parts as already determined, the growth zone being directly transformed into the penultimate tetracirrigerous segment. However, Syllids have generally more segments than seventeen, and growth must be continued. This is but a simple repetition of the same segmentation in the hinder section of the body, the manner of which is well known and requires no description in this place.

The length of Amblyosyllis is by no means the shortest among Syllids, but perhaps of the smallest number of segments. *A. lineata* (=*Pterosyllis formosa*) as well as *A. speciosa* (a Japanese species described by Izuka, 1912, p. 183) consists almost constantly of seventeen segments, thirteen of which, i.e. from the third to fifteenth, are setigerous. The first segment is, of course, the prostomium, the second the peristomium, and the last the pygidium as usual, but the penultimate segment of this peculiar Syllid is also, as mentioned just above, without parapodia and bears instead two pairs of long cirri like the second segment. Malaquin (l.c., p. 423, pl. XIV, fig. 30) has figured a young " Pterosyllis " of eight segments succeeded by a pygidium; he, however, does not draw any segment without setæ between the last two segments, that is between the eighth setigerous one and the pygidium. It is, therefore, quite problematical in this case whether the penultimate, i.e. the eighth setigerous segment, represents the active zone. Malequin (l.c., p. 291), in another place, in describing the development of the Stolons of Myrianida, lays great weight upon the importance of the pygidium, so far as its first appearance in chain-formation is concerned, and Meusch (1900, p. 278) states that a new growth zone which contributes to the elongation of the Stolon, arises in *Autolytus variens* actually from the anal segment and in the course of its development it does not receive any contribution from the setigerous segment preceding it. Such an origin of the growth zone (in stolonisation) is entirely adverse to what I have described so far. Discussion of this problem, however, I shall not enter upon now, but postpone until another occasion, when " the Schizogamy of the Syllidæ " will be particularly considered.

But I should not postpone my acknowledgment to Dr. E. J. Allen, the Director of the Laboratory, and thanking him for help in various ways. Mrs. E. W. Sexton has helped me greatly by her generous permission to copy two larval *Autolytus longeferiens* from her beautiful colour sketches, both shown in Fig. 1, and to Mr. D. P. Wilson I am greatly indebted for two very young stages of *Autolytus pictus* shown in Fig. 2. I thank both for their kind help.

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Additions to the Sponge Fauna at Plymouth.

By

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With 9 Figures in the Text.

During a short visit to Plymouth, in 1928, Dr. M. W. de Laubenfels made a collection of sponges which, with the exception of six, he identified and deposited in the Biological Laboratory at Plymouth. Before leaving England he left these six with me, with the request that they should be identified. This I have now done, and the results have proved extremely interesting, adding six species, *Halichondria bowerbanki*, *Mycale similaris*, *Iophon hyndmani*, *Endectyon delaubenfelsi*, *Hymedesmia stephensi*, and *Pachaxinella subdola*, to the recorded faunal list for Plymouth, of which three are new species.

HALICHONDRIA BOWERBANKI sp. n.

Spongia coalita Lamouroux 1816, p. 80 ; Lamarck 1816, p. 382 ; Grant 1825, pp. 95, 96, 101, 102, 105, 340 ; Id. 1826 *a*, pp. 114, 116–118, 120, 338 ; Id. 1826 ζ, p. 347 ; Id. 1826η, pp. 123, 135.

Halichondria coalita Fleming 1828, p. 522 ; Bellamy 1839, p. 268 ; Johnston 1842, p. 135, pl. xii, fig. 1 ; Bowerbank 1866, p. 238 ; Parfitt 1868, p. 11.

Amorphina coalita Schmidt 1870, p. 77.

Halichondria coalita Bowerbank 1874, p. 102, pl. xli, figs. 18–20 ; Id. 1882, p. 96.

Halichondria panicea (pars) Levinsen 1887*a*, p. 512.

Amorphina coalita Topsent 1888, p. 146.

Halichondria coalita Topsent 1911*a*, pp. i–xv ; Id. 1913, p. 31.

Diagnosis.—Sponge typically repent, and sub-ramose or profusely branched ; branches frequently anastomosing ; surface smooth, slightly uneven ; texture compact, friable ; oscules small, few, or not apparent ; colour, in life, yellowish, dried, white ; oxea ranging from ·2 by ·003 to ·33 by ·012 mm.

(There is little to choose between this species and *Halichondria panicea*. The main differences are that in *H. bowerbanki* the external form is usually ramose, the oscules are inconspicuous, the dermal reticulation more strongly marked, and the oxea slightly stouter. Topsent (1911*a*) has also shown a difference in the larvæ of the two species.)

Remarks.—The species *coalita*, usually ascribed to Bowerbank or Johnston, is first mentioned by Müller (1776), but between the date of its inception and the year in which Johnston gave it an adequate description and illustration, its history is a series of errors and confusions. Müller appears to have taken as his type the specimen figured by Ellis (1755, p. 80, pl. xxxii, fig. F; not p. 95, as quoted by Müller), which is almost certainly a slightly atypical, though fairly common, form of *Chalina oculata*, and to which Ellis gave the name of *Spongia ramosa Britannica*. Thirteen years later Müller (1789) once again refers to *Spongia coalita*, this time giving his own figure, that of a white encrusting sponge growing on a branching Cœlenterate. It is impossible to tell what this sponge was, but it was most probably a specimen of *Halichondria panicea*. Gmelin (1791, p. 3825) described *Spongia coalita* as "Sp. ramosissima mollis tenera flava, ramis compressiusculis. Habitat in mari norwegico." This helps very little, but since Gmelin probably took his ideas from Müller, we may justifiably regard it as a synonym of *Chalina oculata*. In the same way, Bosc (1802, p. 146), in describing the species as "Très-rameuse, molle, tendre, jaune; les rameaux applatis," was probably following Müller's first description, and we may regard his sponge as *Chalina oculata*. Turton (1806, p. 662) appears to have merely translated Bosc's description when he says, "Very much branched, soft, tender, yellow, the branches a little compressed."

Lamouroux (1816), on the other hand, appears to have had before him a sponge similar to that which Johnston and Bowerbank both figure as *Halichondria coalita*. He says ," base étalée en membrane qui enveloppe plusieurs corps et qui se divise en rameaux prolifères, mous, doux au toucher; surface irregulièrement réticulée." At the same time, even this is open to doubt. He quotes *Spongia Lycopodium* Esper as a synonym, which is quite wrong. Lamarck (1816), who appears to be slavishly following Lamouroux, even to the extent of quoting *S. Lycopodium* as a synonym, describes *S. coalita* as "Sp. basi dilatata, corpora aliena obvolvens, ramosissima; ramis tereticompressis, ramulosis; superficie fibris apressis."

Montagu (1818, p. 80) gives as his diagnosis of *S. coalita*, "much branched in an irregular and distorted manner, rather compressed and of brittle corky substance," a description aptly fitting *Chalina oculata* when dried. Gray (1821, p. 355) in describing his "Coalescent Tuphe," uses almost the same words as Montagu, but treats the sponge as an alga.

Grant, from whose papers Johnston quoted extensively in his description of *Halichondria coalita*, and Fleming (1828, p. 522), were evidently dealing with the sponge Bowerbank (1874) so clearly figured. Fleming gives as his diagnosis, "growth very irregular, branches more or less compressed, frequently uniting; substance resembling *H. papillaris* (which we now know to be a synonym of *H. panicea*); tubular processes sometimes occur on the sides of the branches, with small round orifices. It grows on dead shells or invests corallines, beyond low-water mark." Bellamy, in recording the sponge from South Devon, merely remarks that it is "not uncommon on exposed beaches." His sponge is, therefore, clearly not *Chalina oculata*, but is probably *Halichondria coalita* or *H. panicea*.

Blainville (1834, p. 532) merely quotes Müller.

After this date, following the accounts given by Johnston and Bowerbank, the conception of *H. coalita* becomes quite clear and consistent.

Prior to Johnston, therefore, we can divide the references to the species into three groups; those probably synonymous with *Chalina oculata*, with *Halichondria panicea*, and with another species which I shall call *H. bowerbanki* sp. n., as follows :—

Chalina oculata.

Spongia coalita Müller 1776, p. 256.
Spongia coalita Gmelin 1791, p. 3825.
Spongia coalita Bosc 1802, p. 146.
Spongia coalita Turton 1806, p. 662.
Spongia coalita Montagu 1818, p. 80.
Tupha coalita Gray 1821, p. 355.
Spongia coalita Blainville 1834, p. 532.

Halichondria panicea.

Spongia coalita Müller 1789, p. 71, pl. 120.
Halichondria coalita Bellamy 1839, p. 268.

Halichondria bowerbanki sp. n. with synonymy as given at the beginning.

Since Bowerbank's specimen is the only one which has survived, and of which we can have first-hand knowledge, I take this for the holotype of the new species.

Distribution.—Arctic Seas; Norway; British Isles; France.

MYCALE SIMILARIS (Bowerbank).

(See Topsent 1924, p. 109.)

Remarks.—I have re-examined the holotype of *Raphiodesma fallaciosum* Bowerbank and find, as Topsent (l.c., p. 84) tentatively suggests, that it is a synonym of *Mycale similaris*.

Distribution.—Jersey; Westport, Ireland; France, North and East coasts.

IOPHON HYNDMANI (Bowerbank).

Remarks.—As I hope shortly to publish a comprehensive study of the Iophoneæ generally, it is inadvisable to say more concerning this species now.

Distribution.—British Isles generally and, probably, along the whole of the Atlantic coast of Europe.

GENUS **ENDECTYON** Topsent.

Genotype.—*Phakellia tenax* Schmidt.

Diagnosis.—Ectyoninæ of erect, branching habit; branches supported by an axial skeleton composed of a uni- or multispicular reticulation of smooth styli, which may be partially or wholly replaced by acanthostyli; surface of sponge rendered hispid by projecting brushes of long smooth styli, with which a third category of spicule, slender styli, may be associated.

ENDECTYON DELAUBENFELSI sp. n.

(Text figs. 1, 2, 3.)

Holotype.—B.M. 29.8.21.3.

Diagnosis.—Sponge erect, stipitate, branched, composed of a number of irregular branches lying in one plane; surface coarsely hispid; oscules and pores not apparent; colour, in life, golden-yellow; skeleton composed of an axial reticulation of small styli and acanthostyli, which gives off short bundles of spicules on its outer fringes to run vertically to dermis; surface echinated by bundles of long styli; spicules:—(i) long smooth styli, usually straight, almost entirely confined to surface brushes, ·85 by ·007 to ·012 mm.; (ii) short styli, smooth, usually curved, often vermiform, roughly divisible into two categories, ·18 by ·005 mm. and ·225 by ·005 mm.; (iii) acanthostyli, sparingly beset with spines which occasionally form a crown at either base or apex of spicule, ·18 by ·006; microscleres absent.

Remarks.—The species is interesting from many points of view. In the first place, new species of sponges are rarely found in British waters to-day, and it is extremely likely that this one has been overlooked hitherto owing to its extremely close resemblance to *Raspailia ventilabrum* (Bowerbank). Indeed, from external appearance only it is quite impossible to tell the two species apart. This emphasizes, once again, the great need for examining all sponges microscopically in order to be absolutely certain as to their identity.

The present species is the third one recorded for the genus *Endectyon*, the other two, *E. tenax* and *E. demonstrans*, having been found off Florida and the Azores respectively (see Topsent 1920 β, pp. 23–26).

The chief interest attaching to it, however, is that the spiculation shows the manner in which the acanthostyli of the Ectyoninæ may have arisen. The axial skeleton of the branches consists of a multispicular reticulation of triangular meshes, built up of small styli, for the most part curved, and acanthostyli. The latter, however, are of comparatively rare occurrence. The typical form (figs. 1 I, L.) is that of a smooth style bearing a few stout spines. In a few cases, the

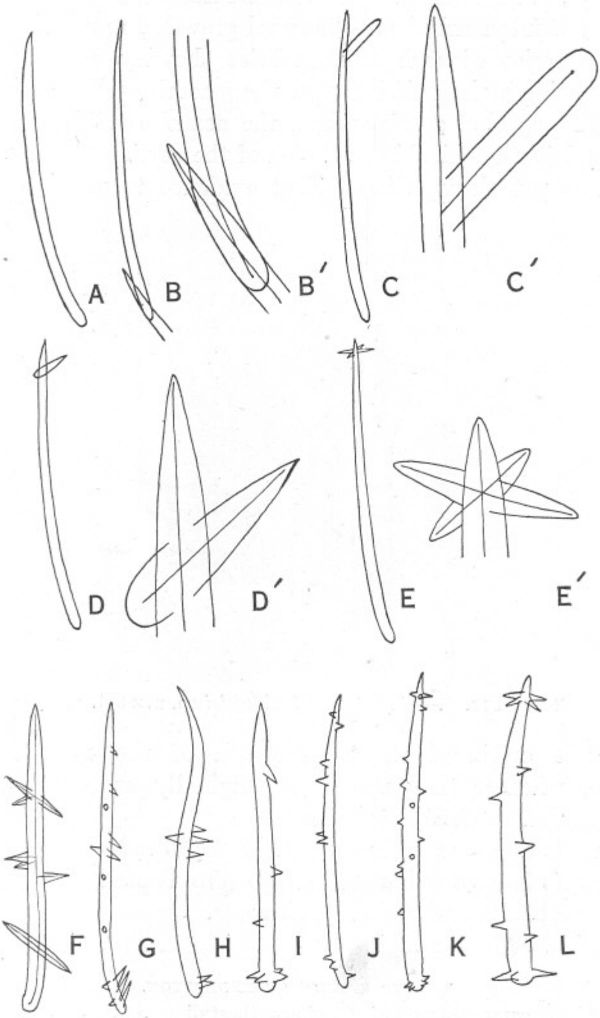

FIG. 1.—*Endectyon delaubenfelsi* sp. n. A. Normal stylus of main skeleton; B–E. abnormal styli (B′–E′. abnormalities enlarged); F–H. abnormal styli showing transitions to normal acanthostyli; I–L. normal acanthostyli. All figures (except B′–E′) × 220.

spines have become so grouped that the spicule is ornamented by crowns of spines, four to six in number, at either end of the spicule. In this condition the spicules closely resemble those of the genotype, *E. tenax* (see Topsent, l.c., p. 24, fig. 4b). On the other hand, the smooth styli of the axial skeleton frequently bear abnormal growths, and it is possible to pick out a series of such abnormalities showing a transition which effectually bridges the gulf between the smooth styli and the acanthostyli. In this species, at all events, the acanthostyli have arisen from an abnormal (pathological ?) condition of the styli. The next question, for which as yet there is insufficient evidence to provide an answer, concerns the origin of the acanthostyli of the remainder of the Ectyoninæ, whether they too arose originally as abnormalities and what factors led to their stabilisation.

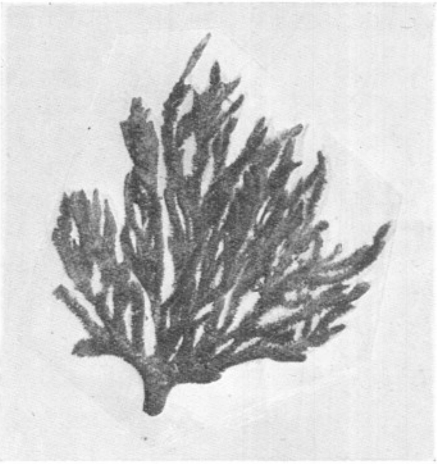

FIG. 2.—*Endectyon delaubenfelsi* sp. n. × 3/4.

Endectyon is apparently closely related to *Hemectyon* Topsent (genotype *Raspailia hamata* Schmidt), *Tethyospira* Topsent (genotype *Tethea spinosa* Bowerbank), and, possibly, *Acarnus*.

Distribution.—Plymouth.

KEY TO SPECIES OF ENDECTYON.

1	Axial skeleton composed exclusively of acanthostyli	*demonstrans*
	Axial skeleton composed of a mixture of smooth styli and acanthostyli	2
2	Acanthostyli invariably with a crown of recurved spines at each end . . .	*tenax*
	Acanthostyli only occasionally bearing a crown of spines at either end .	*delaubenfelsi*

HYMEDESMIA STEPHENSI sp. n.

(Fig. 4.)

Holotype.—B.M. 29.8.21.5.

Diagnosis.—Sponge thinly encrusting; surface uneven, minutely hispid, in places slightly conulose; oscules few, scattered, conspicuous; pores not apparent; colour, in life, brown; texture, in life, " slimy "; megascleres of main skeleton divided into two categories, long acanthostyli, usually slightly curved, sparingly spined and often quite smooth, ·225 by ·007 mm., and small entirely spined acanthostyli, ·048 by ·002 mm.; tornota very variable in shape, straight, smooth, with hastate mucronate, strongylote, or slightly tylote heads, ·165 by ·003 mm.

Remarks.—The species finds its closest ally in *H. mucronella* Lundbeck, from which it differs in many important respects, notably in the size and shape of the acanthostyli and the variability of the ends of the tornota. The small size of the smaller acanthostyli is, indeed, its characteristic feature.

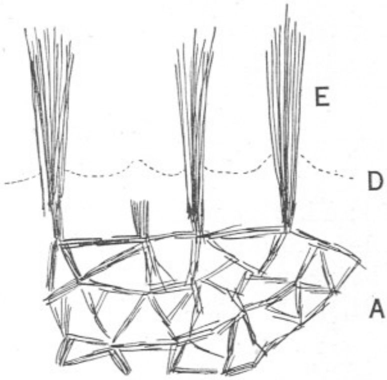

FIG. 3.—*Endectyon delaubenfelsi* sp. n. Section at right angles to surface, showing, A, reticulation of styli and acanthostyli of internal skeleton; D, dermis; and E, echinating tufts of long styli at the surface. (Diagrammatic.)

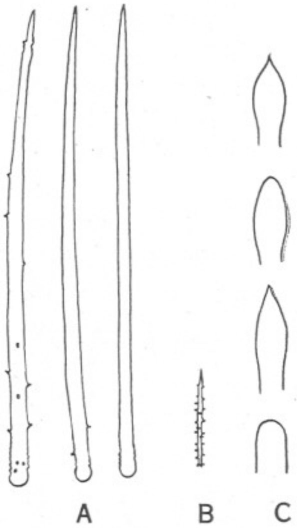

FIG. 4.—*Hymedesmia stephensi* sp. n. A, styli of main skeleton, × 260; B, acanthostyle, × 260; C, heads of tornota, to show variability in form, × 2600.

Dr. de Laubenfels describes this sponge in life as " brown, slimy."

Distribution.—Plymouth.

List of species of Hymedesmia recorded for the British Isles.

The following list of 21 species of *Hymedesmia* represents the complete list recorded for the British Isles. So far, the only species recorded for the Plymouth area is *H. stephensi* sp. n., but since there is no obvious reason why they may not all be found there, in time, I have thought it worth while to give this list. Several of the British species described by Bowerbank have hitherto been only inadequately described. The re-descriptions given here are based on a re-examination of the types.

GENUS **HYMEDESMIA** Bowerbank.

Genotype.—*H. zetlandica* Bowerbank.

Diagnosis.—Ectyoninæ of encrusting habit; main skeleton composed of acanthostyli, of one or more kinds, variable in size, placed vertically with their bases echinating the substratum; dermal skeleton composed of tornota variously disposed, either in bundles running vertically from the apices of the acanthostyli to the surface, in scattered bundles, or in a horizontal layer supporting the dermis; microscleres chelæ, occasionally absent, and/or sigmata.

1. H. ZETLANDICA Bowerbank.

H. zetlandica Bowerbank 1864, p. 190; Id. 1866, p. 152; Gray 1867, p. 537; Id. 1874, p. 73, pl. xxix, figs. 1–7; *Myxilla zetlandica* Vosmaer 1880, p. 126; *Hymedesmia zetlandica* Bowerbank 1882, p. 70; Topsent 1888, p. 142; *Leptosia zetlandica* Id. 1894, p. 31; *Hymedesmia zetlandica* Stephens 1921, p. 32, pl. iv, fig. 3.

Distribution.—Shetland Is.; S.W. coast of Ireland.

2. H. RADIATA Bowerbank.

H. radiata Bowerbank 1866, p. 149; *Epicles radiatus* Gray 1867, p. 521; *Hymedesmia radiata* Bowerbank 1874, p. 71, pl. xxviii, figs. 1–4, pl. xxix, fig. 8; Id. 1882, p. 56; *Myxilla radiata* Topsent 1892, p. 109; *Hymeraphia radiata* Hanitsch 1894, p. 196; Dendy 1921, 84.

Diagnosis.—Megascleres of main skeleton divided into two categories, long, smooth styli, usually straight or nearly so, sometimes slightly subtylostylote, up to 1·8 by ·012 mm., and entirely spined acanthostyli, with somewhat pronounced head, from ·075 by ·004 to ·24 by ·009 mm.; tornota, sometimes inclined to be slightly vermiform, arranged for most part in stellate groups in dermis, with strongylote ends, ·27 by ·003 mm.

Remarks.—The specimen described by Dendy under this name evidently represents a totally different species which I propose to call *Hymedesmia dendyi* sp. n. The suggestion made by Dendy, that Topsent's *Myxilla radiata* differs specifically from *Hymedesmia radiata*, is almost certainly wrong.

Distribution.—Shetland Is., and the Minch, Scotland; Azores.

3. H. PAUPERTAS (Bowerbank).

Hymeniacidon paupertas Bowerbank 1866, p. 223; Id. 1874, p. 93, pl. xxxvii, figs. 4–8; *Myxilla paupertas* Vosmaer 1880, p. 127; *Hymeniacidon paupertas* Bowerbank 1882, p. 92; *Myxilla paupertas* Ridley and Dendy 1887, p. 143; *Hymeraphia paupertas* Hanitsch 1894, p. 177; Topsent 1894 β, p. 18; *Hymedesmia paupertas* Stephens 1912, p. 28; Id. 1921, p. 31, pl. iv, fig. 1.

Remarks.—Contrary to the assertion of Ridley and Dendy (l.c.), Bowerbank's preparations show that the species is, quite unmistakably, a *Hymedesmia*. *Myxilla paupertas* Topsent (1904, p. 168) is obviously different to Bowerbank's species and, since it is almost certainly a true *Myxilla*, I propose for it the name *M. topsenti* sp. n.

Distribution.—Greenland; Shetland Is.; W. and S.W. coasts of Ireland.

4. H. BRONDSTEDI sp. n.

Hymeniacidon dujardinii Bowerbank 1866, p. 224; Id. 1874, p. 95, pl. xxxviii, figs. 1–4; Id. 1882, p. 92; *Stylopus dujardini* Levinsen 1887*a*, p. 512; *Dendoryx dujardini* Topsent 1888, p. 146; Id. 1890, p. 201; Id. 1891, p. 528; Id. 1892, p. 99; *Myxilla radiata* Id. l.c., p. 109; *Leptosia dujardini* Id. 1894*a*, p. 37; Id. 1896 β, p. 275; Id. 1902 β, p. 353; Id. 1904*a*, p. 185, pl. i, fig. 5; *Hymedesmia dujardinii* Lundbeck 1909, p. 444; Id. 1910, p. 101, pl. x, fig. 5; *Hymedesmia dujardini* Arndt 1912, p. 119; Stephens 1917, p. 11; Id. 1921, p. 40.

Remarks.—In describing his *Hymeniacidon dujardinii*, Bowerbank was under the impression that it was specifically identical with Johnson's *Halisarca dujardinii*. Since this is clearly a case of wrong identification, the name *dujardinii* as applied to *Hymeniacidon* and, since Bowerbank's time, to *Hymedesmia*, cannot stand. I propose, therefore, the name *brondstedi*.

Distribution.—N.E., S.E., and W. coasts of Ireland; Greenland; Norway.

5. H. OCCULTA Bowerbank.

H. occulta Bowerbank [in] Norman 1869*a*, p. 331; Id. 1874, p. 250, pl. lxxix, figs. 9–11; *Myxilla occulta* Vosmaer 1880, p. 129; *Hymedesmia occulta* Bowerbank 1882, p. 56; *Desmacidon occultum* Hanitsch 1894, p. 180; *Hymeraphia occulta* Topsent 1894 β, p. 12; *Leptosia occulta* Id. 1904*a*, p. 186, pl. xv, fig. 1; *Hymedesmia occulta* Lundbeck 1910, p. 67, pl. iii, fig. 6, pl. vii, fig. 8; Stephens 1921, p. 37.

Distribution.—Greenland; Shetland Is.; W. and S.W. coast of Ireland; Azores.

6. H. CRUX (Schmidt).

Desmacidon crux Schmidt 1875, p. 118, pl. i, figs. 10–11 ; *Hymedesmia crux* Thiele 1903*a*, p. 392, pl. xxi, fig. 26 ; Lundbeck 1910, p. 83, pl. iii, fig. 11, pl. viii, fig. 10 ; Stephens 1921, p. 38.

Distribution.—Greenland ; Norway ; Faröes ; S.W. coast of Ireland.

FIG. 5.—*Hymedesmia pilata* Bowerbank. A–C, acanthostyli, showing three typical sizes, × 260 ; D, ends of a typical tornote, × 2600 ; E, sigmata, × 650.

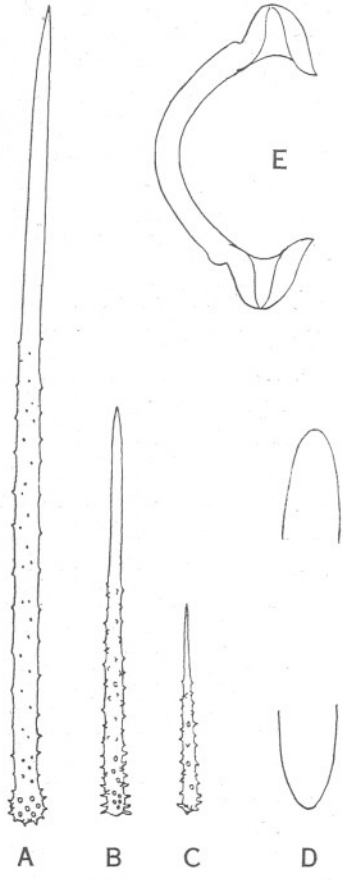

FIG. 6.—*Hymedesmia peachii* Bowerbank. A–C, acanthostyli of main skeleton, × 260 ; D, ends of tornota, × 2600 ; E, isochela arcuata, × 1300.

7. H. PANSA Bowerbank.

H. pansa Bowerbank 1882, p. 56, pl. i, figs. 1–4 ; *H. pulchella* Id. l.c., p. 61, pl. ii, figs. 5–8 ; *H. pansa* Stephens 1912, p. 29 ; Id. 1917, p. 11 ; Id. 1921, p. 36, pl. iv, fig. 4.

Remarks.—*H. pulchella* differs from *H. pansa* in the smaller size of its spicules only. The following are the maximum dimensions of the spicules of *H. pulchella* : large acanthostyli, ·22 by ·006 mm. ; small acanthostyli, ·09 by ·007 mm. ; tornota, ·18 by ·003 mm. ; isochelæ, ·019 mm.

Distribution.—W. coast of Ireland ; Roscoff, France (*fide* Stephens 1912, p. 300).

8. H. PILATA Bowerbank. (Fig. 5.)

H. pilata Bowerbank 1882, p. 59, pl. ii, figs. 1–4.

Diagnosis.—Acanthostyli not divisible into two categories, spined for the greater part of length but smooth in distal portion, spining particularly pronounced at base, varying from ·078 by ·009 to ·24 by ·008 mm., including spines ; tornota extremely slender, straight, with strongylote ends, ·12 by ·0015 mm. ; microscleres sigmata of two sorts, ·015 and ·03 mm. long respectively.

Distribution.—Birterbuy Bay, W. coast of Ireland.

9. H. PEACHII Bowerbank. (Fig. 6.)

H. peachii Bowerbank 1882, p. 64, pl. xiii, figs. 5–12.

Diagnosis.—Acanthostyli not divisible into two categories, spined for greater part of length but smooth in distal portion, spining particularly strong near base, varying from ·105 by ·012 to ·39 by ·022 mm., including spines ; tornota slender, straight, with bluntly oxeote ends, ·195 by ·003 mm. ; isochelæ arcuatæ, ·03 mm. long.

Remarks.—The chelæ vary considerably in shape. The one figured probably represents the typical form, but large numbers may be found in which the shaft is more strongly curved.

Distribution.—Wick, North Britain.

10. H. ARMIGER (Bowerbank).

Hymeniacidon armiger Bowerbank 1882, p. 73, pl. iv, figs. 10–17.

Remarks.—The species undoubtedly belongs to Hymedesmia and Bowerbank's figures show this clearly. The reason for its having been so long ignored is probably to be found in the fact that his figures are misleading in regard to the size of the spicules. The megascleres are faithfully portrayed, the acanthostyli measuring from ·075 to ·22 mm. in length, and the tornota ·175 by ·003 mm. The microscleres are chelæ arcuatæ, chiefly remarkable for their small size, ·012 mm. long, and form the characteristic feature of the species.

Distribution.—Roundstone Bay, Ireland.

11. H. KŒHLERI (Topsent).

Leptosia kœhleri Topsent 1896β, p. 284, pl. viii, figs. 7–9 ; Id. 1904*a*, p. 188 ; Lundbeck 1910, p. 42, pl. v, fig. 5 ; Stephens 1921, p. 34.

Distribution.—Greenland ; Iceland ; Faröes ; W. and S.W. coasts of Ireland ; Bay of Biscay ; Azores.

12. H. MUCRONATA (Topsent).

Hymeraphia mucronata Topsent 1904*a*, p. 165, pl. xiv, fig. 4 ; *Hymedesmia mucronata* Lundbeck 1910, p. 98, pl. x, fig. 3 ; Stephens 1921, p. 39.

Distribution.—Greenland ; S.W. coast of Ireland ; Azores.

13. H. MUTABILIS (Topsent).

Hymeraphia mutabilis Topsent 1904*a*, p. 166, pl. xiv, fig. 3 ; *Hymedesmia mutabilis* Stephens 1921, p. 38.

Distribution.—S.W. coast of Ireland ; Azores.

14. H. BACULIFERA (Topsent).

H. baculifera Topsent 1902β, p. 354 ; Id. 1904*a*, p. 191, pl. xv, fig. 2 ; Lundbeck 1910, p. 71, pl. viii, fig. 1 ; Stephens 1915*a*, p. 440 ; Id. 1921, p. 37.

Distribution.—Greenland ; Iceland ; Faröes ; S.W. Ireland ; Mediterranean coast of Algeria ; Azores ; Saldanha Bay, S. Africa.

15. H. CURVICHELA Lundbeck.

H. curvichela Lundbeck 1910, p. 48, pl. vi, fig. 2 ; Stephens 1921, p. 34.

Distribution.—Greenland ; S.W. coast of Ireland.

16. H. TRUNCATA Lundbeck.

H. truncata Lundbeck 1910, p. 77, pl. iii, fig. 9, pl. viii, fig. 6 ; Stephens 1921, p. 33.

Distribution.—Greenland ; Iceland ; Faröes ; S.W. coast of Ireland.

17. H. DIGITATA Lundbeck.

H. digitata Lundbeck 1910, p. 90, pl. iii, fig. 15, pl. ix, fig. 4 ; Stephens 1921, p. 39.

Distribution.—Greenland ; S.W. coast of Ireland.

18. H. TENUISIGMA Lundbeck.

H. tenuisigma Lundbeck 1910, p. 100, pl. x, fig. 4 ; Stephens 1921, p. 39.

Distribution.—Greenland ; W. coast of Ireland.

19. H. HELGÆ Stephens.

H. helgæ Stephens 1915, p. 236; Id. 1921, p. 40, pl. iv, fig. 6.
Distribution.—S.W. coast of Ireland.

20. H. SPINOSA Stephens.

H. spinosa Stephens 1916, p. 237; Id. 1921, p. 41, pl. iv, fig. 5.
Distribution.—S.W. coast of Ireland.

21. H. HIBERNICA Stephens.

H. hibernica Stephens 1916, p. 237; Id. 1921, p. 42, pl. iv, fig. 2.
Distribution.—S.W. coast of Ireland.

22. H. STEPHENSI sp. n.

Distribution.—Plymouth.

KEY TO BRITISH SPECIES OF HYMEDESMIA.

1	With spicules of main skeleton divided into two categories, long, usually basally-spined, and short, entirely-spined, acanthostyli	2
	With spicules of main skeleton of one sort only, but of varying size and, usually, entirely-spined	12
2	With larger spicules of main skeleton spined for some part of length	3
	With larger spicules of main skeleton entirely smooth styli	*radiata*
3	With microscleres	5
	Without microscleres	4
4	With smaller acanthostyli never less than one-third the length of larger acanthostyli	*hibernica*
	With smaller acanthostyli less than one-fifth of larger acanthostyli	*stephensi*
5	Microscleres sigmata only	6
	Microscleres chelæ to which sigmata may be added	7
6	With microscleres less than ·04 mm. long	*pilata*
	With microscleres more than ·04 mm. long	*tenuisigma*
7	Microscleres ancoræ spatuliferæ and sigmata	*mutabilis*
	Microscleres chelæ arcuatæ	8
8	With sigmata	*digitata*
	Without sigmata	9
9	With larger megascleres of main skeleton spined throughout length, strongly in lower, feebly along distal portion	*helgæ*
	With larger megascleres of main skeleton spined in basal portion only	10
10	With chelæ less than ·025 mm. long	*pansa*
	With chelæ more than ·025 mm. long	11
11	With oxeote tornota	*occulta*
	With strongylote, to slightly tylote, tornota	*paupertas*
12	With microscleres	13
	Without microscleres	*brondstedi*
13	Microscleres chelæ and sigmata	14
	Microscleres chelæ only	15
14	With chelæ of one sort only	*zetlandica*
	With chelæ of two sorts	*mucronata*
15	With shaft of chelæ smooth	16
	With shaft of chelæ spined	*crux*

16	With strongylote tornota	**17**
	With oxeote tornota	**19**
	With tylote tornota	*truncata*
17	With polytylote tornota	**18**
	With simple tornota, not polytylote	*baculifera*
18	With shaft of chelæ strongly curved and teeth small	*curvichela*
	With chelæ of normal shape	*kœhleri*
19	With chelæ more than ·02 mm. long	**20**
	With chelæ less than ·02 mm. long	*armiger*
20	With all acanthostyli strongly and entirely spined	*spinosa*
	With larger acanthostyli smooth in distal half	*peachii*

BRITISH SPECIES OF HYMEDESMIA NOW REMOVED TO OTHER GENERA.

H. stellata Bowerbank 1866, p. 150=*Timea stellata*.

H. simplicima Id. 1874, p. 253, pl. lxxx, fig. 1=*Pseudosuberites simplicima*.

The skeleton of *Hymedesmia simplicima* is composed of tylostyles (fig. 7) only disposed with no apparent order. They measure, on an average, ·6 by ·009 mm. The sponge itself is so small that it is difficult to be certain of its systematic position, but it is extremely possible that it is nothing more than the immediate post-fixation stage of a species of *Pseudosuberites*.

FIG. 7.—*Hymedesmia simplicima* Bowerbank. Head of a tylostyle, × 250.

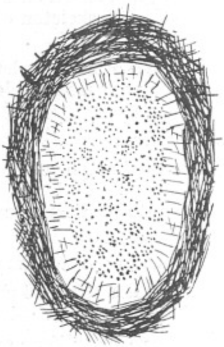

FIG. 8.—*Pachaxinella subdola* Bowerbank. Transverse section of a branch, showing internal axial skeleton of longitudinally-disposed spicules and outer, dermal layer. (Diagrammatic.)

H. inflata Id. 1874, p. 245, pl. lxxix, figs. 5–8=*Crella inflata*.

The spiculation of this species consists of acanthoxea, ·096–·12 by ·006 mm., and long, slender tornota, measuring, on an average, ·5 by ·003 mm. The acanthoxea are for the most part slightly curved or sharply angulated and, usually, centrotylote. The tornota have oxeote ends and are quite straight and smooth. The species closely resembles *C. carnosa* (Topsent), but differs from it in the dimensions of the spicules, the centrotylote character of the acanthoxea, and the absence of polytylote markings on the tornota.

H. acuto-stellata Hanitsch 1894, p. 203.

The original description of this species is quite inadequate, but, so far as one may judge, it is probably an encrusting form, perhaps even the immediate post-fixation stage, of *Dictyocylindrus stuposus*. It is certainly not a *Hymedesmia*.

GENUS **PACHAXINELLA** gen. n.

Genotype.—Halichondria subdola Bowerbank.

Diagnosis.—Axinellidæ of erect, branching habit; skeleton composed of an axial core of loose bundles of spicules surrounded by a dense layer in which spicules are irregularly disposed, sometimes at right angles, sometimes tangential to the surface; spicules smooth styli of varying size.

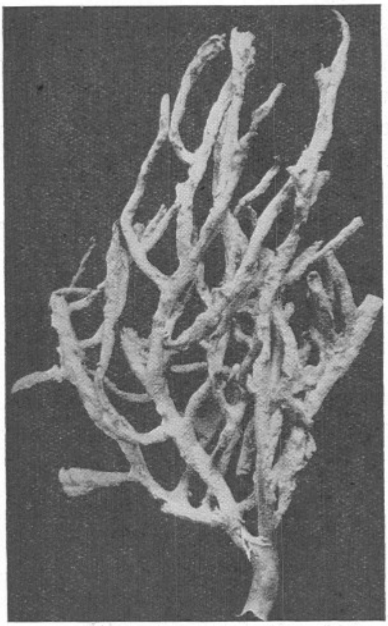

FIG. 9.—*Pachaxinella subdola* Bowerbank. × 3/4.

Remarks.—The genus is closely allied to *Homaxinella*, but differs from it in the arrangement of the skeleton. The usual order of the Axinellidæ, with a dense axial skeleton and a diffuse extra-axial skeleton, is reversed.

PACHAXINELLA SUBDOLA (Bowerbank).

(Figs. 8, 9.)

Holotype.—B.M.—29.11.27.1.

Halichondria subdola Bowerbank 1866, p. 247 ; Id. 1874, p. 106, pl. xliii, figs. 14–16.

Diagnosis.—Sponge erect, copiously branched, stipitate ; surface even, minutely hispid ; oscules and pores not apparent ; texture firm, brittle when dry ; colour, in dried state, creamy-white, alive golden-yellow ; axial skeleton composed of loose bundles of spicules running longitudinally through branches, united by moderate quantity of spongin ; extra-axial skeleton a dense layer of spicules, very irregularly arranged, sometimes horizontal to surface, sometimes at right angles to it, with all positions between these two ; spicules smooth styli, usually straight, varying in size, ·22 by ·003 to ·51 by ·006 mm.

Remarks.—The present specimen, a complete sponge, is practically identical in all essential features with Bowerbank's fragmentary holotype.

The junction between the axial and extra-axial skeletons is marked by a thin, almost imperceptible, zone of loose tissue supported by spicules which emerge from the axial skeleton, almost at right angles to it, and project into the extra-axial zone.

Previously known distribution.—Guernsey.

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The Photo-chemical and Photo-electric Measurement of Submarine Illumination.

By

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Accounts have been given in previous papers (1925, 1926, 1928) of measurements of submarine illumination carried out near Plymouth by means of photo-electric cells. A further paper (1929, 3) recorded the results so obtained during 1928. An account is now given of photo-chemical measurements made in that year, simultaneously with the photo-electric measurements.

Adaptation of the Uranyl Oxalate Method for Submarine Measurements.

We have elsewhere (1929, 5) described the use, in daylight photometry, of a 0·1 N solution of oxalic acid approximately 0·01 M with respect to uranyl sulphate $UO_2SO_4{\cdot}3H_2O$. The concentration of uranyl sulphate actually used was 4·27 g. per litre, following the practice of other workers, but the rate of decomposition of oxalic acid is independent of the concentration of uranyl sulphate within fairly wide limits.

After exposure of the solution in quartz, or glass, test tubes the oxalic acid remaining was titrated with potassium permanganate. As the amounts used in the deeper submarine measurements were very small, it was necessary to titrate with the greatest care, and an allowance was made colorimetrically for any excess of permanganate added in the final drop.

It was especially desired to obtain information concerning the penetration of the ultra-violet portion of the spectrum. Uranyl oxalate is sensitive to this region, and also to the violet and blue of the visible spectrum, but the sensitivity decreases as the wave-length increases. Quartz tubes were used so that the full effect of the shorter waves should be registered, but the decomposition in both air and water is mainly due to the visible rays and to the glass-passing portion of the ultra-violet. Using tubes of quartz and of Monax resistance glass suspended vertically in air, it was found that the rate of reaction was 1·14 times as great in the former as in the latter. In other words, only one-eighth part of the decomposition was due to the ultra-violet cut out by the glass. This is very nearly a measure of the portion which is physiologically active in producing erythema, and in activating ergosterol, as explained elsewhere (1929, 6).

Since the decomposition results in the liberation of gas, the rubber corks inserted in the tubes were, at first, provided with narrow glass tubes closed by rubber tubing with a small slit and terminating in a piece of glass rod. The arrangement permits of the escape of gas, while the pressure of the water effects a seal by causing the walls of the rubber tubing to collapse. It was found, however, that the valves often leaked, and, since the rate of decomposition is much reduced under water, the method adopted in all the measurements recorded here was to secure the stoppers with copper wire. The tubes were then attached by copper wire to a weighted line marked in metres. Care was taken to avoid exposing the tubes before they were lowered, and, on hauling up, the wires were snipped and the tubes placed in a light-tight box.

So far as we are aware there is no evidence that the small excess pressure due to the decomposition products in any way affects the rate of reaction ; in other words, it is not a reversible reaction.

Marshall and Orr (1928) state, however, that " there are two objections to the use of the method in the sea. As decomposition goes on, gases are evolved, causing an increase in pressure which inhibits the reaction, and in addition there is superimposed the pressure of the column of sea-water overlying the tube. In the second place absorption of light of very short wave-length by sea-water is rapid, and the results obtained below the surface are low." No experimental evidence is adduced for the statement that the excess pressure (of carbon monoxide and carbon dioxide) inhibits the reaction, which implies that the exertion of pressure upon these gases results in the synthesis of oxalic acid in the presence of water and uranyl sulphate under the action of light. The pressure of the column of sea-water is immaterial, being entirely supported by the walls of the tube and stopper. It remains to be proved that light of short wave-length is rapidly absorbed.

A possible error due to the shading of the tubes by the ship was avoided by attaching the end of the line, to which the tubes had been tied, to the middle of a spar with cork floats at each end. This was then lowered into the sea, and the ship drifted away from it to the full length of the rope, about 20 metres. This method could not be used with the photo-electric photometers owing to their weight. Thus the latter readings are somewhat reduced by shading, though, owing to the precautions taken to lessen this as much as possible, the effect is not important.

AERIAL AND SUBMARINE RATES OF DECOMPOSITION.

For comparison with the tubes lowered into the water, similar tubes, each with 10 c.c. of the reaction mixture, were suspended from the topping lift running from the mizen-mast to the end of the boom. These were uncorked, and swung about a mean vertical position, so that they registered the effect of horizontal light. The tubes lowered into the water also took up a vertical position in a flat calm, when there was no drift. Their angle with the vertical became greater and greater the faster the drift, so that no real comparison could be made between the submarine and aerial rates of decomposition. Table I shows the rates in air and in water. The former may be seen to be from about two up to nearly four times as great as the rates at one metre depth, but no exact comparison is permissible owing to changes in the angular distribution of the light in passing through the water surface, and to the reduction in reflection losses at the surface of the tube when immersed.

TABLE I.

DECOMPOSITION OF URANYL OXALATE SOLUTIONS, 0·1 N WITH RESPECT TO OXALIC ACID, EXPOSED IN CLOSED QUARTZ TUBES 13×1·3 CM. (INTERNAL DIAMETER) AND LOWERED IN THE SEA TO THE DEPTHS SHOWN.

The angle with the horizontal varied according to rate of drift of the ship. Work at Station E1, bottom at 72 m.

RATES OF DECOMPOSITION IN C.C. OF 0·1 N OXALIC ACID PER HOUR.

m.	July 11	July 23	Aug. 9	Aug. 29	Sept. 18	Sept. 18	Oct. 2	Nov. 30
0 (air)	10·22	10·67	5·46	9·72	7·31	5·91*	8·07	0·98
1	4·03	4·83	1·51	3·57	1·94	1·87	2·17	0·42
5	2·26	3·38	0·67	2·11	1·43	1·44	1·12	0·21
10	1·29	2·05	0·24	1·09	0·80	0·875	0·54	0·12
15	0·69	1·07	0·103	0·39	0·45	0·53	0·25	0·055
20	—	0·34	0·027	—	0·28	0·365	—	—
25	—	—	0·020	—	0·15	—	—	—
40	—	—	0·000	—	0·095	—	—	—
Exposure, minutes	120	92	180	93	114	114	136	130

PERCENTAGE RATES OF DECOMPOSITION.

m.								
1	100·0	100·0	100·0	100·0	100·0	100*	100·0	100·0
5	56·1	70·0	44·4	59·1	73·8	77·1	51·7	50·0
10	32·4	42·5	15·9	30·5	41·2	46·8	24·9	28·6
15	17·1	22·2	6·8	10·9	23·2	28·4	11·5	13·0
20	—	7·0	1·8	—	14·4	19·5	—	—
25	—	—	1·3	—	7·7	—	—	—
40	—	—	—	—	4·9	—	—	—

* In Monax resistance glass tubes of approximately the same dimensions as the quartz tubes. In air on this date rate in quartz tube was 1·24 times that in glass tube at time of experiment. Asterisk refers to all depths.

At 1 m. the rate varies from 30·4 to 2·65 mg. of crystalline oxalic acid decomposed per hour. The values are, however, recorded in cubic centimetres rather than in milligrams, as this enables the degree of accuracy of the titration to be judged better. The second column for September 18 contains the results obtained using glass tubes instead of quartz. In air and at 1 m. the rates in quartz exceed those in glass, at 5 m. the two are equal, and beyond that the rate for glass is the greater. The values in quartz in air are naturally the greater, since the effect of the shorter waves is added on, but as the proportion of shorter waves becomes reduced, this effect diminishes. The fact that the glass tube rates become the greater below 5 m. can only be attributed to a difference in the angle at which the tubes were riding owing to the unequal weights in water of the closed tubes, the quartz being the greater.

TABLE II.

Under C and E are Tabulated the Absorption Coefficients, μ_v, Calculated on the Actual Mean Depths, as Determined Photo-chemically by Uranyl Oxalate and by Vacuum and Gas-filled Potassium Photo-electric Cells. Under C M are Shown Values of μ_v Obtained using Monax Resistance Glass Tubes Instead of Quartz.

	July 11		July 23		August 9		August 29	
m.	C	E	C	E	C	E	C	E
5	0·125	0·101*	0·095	0·075*	0·204	0·183*	0·132	0·123*
10	0·129	0·100	0·115	0·083	0·187	0·181	0·169	0·107
15	—	—	0·180	0·109	0·217	0·192	—	—
20	—	—	—	—	0·165	0·178	—	—
C/E	1·26	—	1·46†	—	1·05	—	1·31	—

	September 18			October 2		November 30	
m.	C	E	CM	C	E	C	E
5	0·098	0·086*	0·084	0·154	0·166*	0·139	0·156*
10	0·116	0·076	0·100	0·150	0·129	0·134	0·125
15	0·105	0·084	0·087	—	—	—	—
20	0·110	0·092	—	—	—	—	—
C/E	1·37	—	1·10‡	1·02	—	0·97	—

* Taking surface losses as 15 per cent.
† Or 1·33 excluding probably erroneous value for 15 m.
‡ CM/E.
Note.—Mean value of C/E = 1·21, and CM/E = 1·10.

In Table II are shown the values of the vertical absorption coefficient, μ_v, calculated as usual from $\mu_v = \frac{2\cdot3}{\delta}(\log_{10}p_1 - \log_{10}p_2)$ where δ is the difference in depth and p_1 and p_2 the percentages of the light at the two depths, as given in Table I; the depths shown are the mean depths for the values there recorded. Beside the photo-chemically determined (C) values of μ_v, those obtained photo-electrically (E) are tabulated; the values of the latter are the mean of two series, made with photometers L and K while the tubes were being exposed, for the first four dates, and are the values obtained with photometers L, K, and J, respectively, for the final three. As previously shown (1928), L has its maximum sensitivity at 4000 Å.U. and K at 4400 Å.U. J, being also a potassium gas-filled photometer, probably resembles K.

Taking the mean of the same number of values of μ_v, determined by each method, over approximately the same depth, it may be seen that the ratio C/E varies from 0·97–1·46, mean of seven series 1·21. Using glass tubes the ratio is 1·10. We may conclude that the photo-electric measurements and the photo-chemical in glass tubes cover approximately the same spectral region, viz. 4800 Å.U. to 3400 Å.U., so that they measure substantially the same degree of absorption and scattering by the water. The quartz tubes, however, permit of the passage of the shortest wavelengths found in sunlight reaching the earth, namely, down to about 3000 Å.U. The scattering of these shorter waves by the water must be considerably greater than that of the longer. In the air their relative activities are 14 : 100, as deduced from the quartz to glass ratio 1·14. In water, however, the shortest waves are cut out more rapidly than the longer ones, as shown by the higher value of the absorption coefficient, which may be regarded as compounded of the coefficients for the portion that passes glass and for the portion that is stopped by glass.

SUMMARY.

1. The uranyl oxalate method of daylight photometry has been used to determine the absorption coefficient of water at depths down to 40 metres at International Hydrographic Station E1, about 10 miles S.W. of the Eddystone in the English Channel off Plymouth. Using quartz tubes on seven days from July to November inclusive the absorption coefficient varied 0·095 for 5 m. on July 23rd to 0·217 for 15 m. on August 9th; no seasonal variation was shown. The interpretation of the coefficients has been discussed in the paper dealing with the photo-electric measurements.

2. The ratio of the photo-chemically determined coefficients (using quartz tubes) to the photo-electrically determined values (obtained with potassium vacuum and gas-filled glass cells) varied from 1·02 to 1·46 or to 1·37, omitting a probably erroneous value from a series. Using glass tubes the same ratio was 1·10. The ratios are based upon mean values for the various depth series.

3. The higher absorption coefficient determined photo-chemically may indicate a greater absorption of the shortest wave-lengths, in which case one would expect the ratio of the coefficients to decrease with depth; of this there is, however, no evidence.

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Seasonal Changes in the Nitrite Content of Sea-Water.

By

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Brandt (1927) has summarised and reviewed our knowledge of the nitrogen compounds existing in sea-water, including nitrites. In general, estimations of nitrite in sea-water have been made colorimetrically, using the Griess-Ilosvay reagent, which has also been used in the present work. Usually the amount of nitrite found, recorded as milligrams of nitrogen per cubic metre, was small. Raben's results have been grouped by Brandt as follows, 0 mg., 48 cases; under 1 mg., 53 cases; 1–4 mg., 21 cases; 5–9 mg., 6 cases. Orr (1926) in the Clyde Area, found from under 1 mg. to about 10 mg. in June 1925, the deeper water having more than the upper layers. Harvey (1926) states that, " in a number of water samples from the English Channel, examined either on board ship or immediately after landing, no definitely detectable traces of nitrites could be found either by the Griess-Ilosvay reagent or with the strychnine reagent without sulphuric acid, except in the case of inshore water subject to pollution. After storage an appreciable quantity of nitrite has been detected in several instances. In water from 830 metres in the Bay of Biscay, preserved with mercuric chloride when collected, and in water at various depths up to 3000 metres, similarly preserved, collected by the R.R.S. *Discovery* some 200 miles west of Portugal, no nitrite could be definitely detected."

It may be added that dilute standard solutions of nitrite lose strength by the production of nitrate from nitrite, so the same process must take place in sea-water on storing, as well as the converse.

As is well known, ammonium salts are converted to nitrites by bacterial action, and the latter is oxidised to nitrate by another micro-organism or by air. It seemed probable, therefore, that when ammonium salts were being converted into nitrite, a considerable amount of nitrite must exist temporarily in the sea. Harvey (1928) showed that at International Hydrographic Station E1 there was a rapid production of nitrate* in early

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* The reduced strychnine reagent used by Harvey reacts both with nitrites and nitrates. The values have been referred to as nitrate for brevity, since that is normally the major constituent.

autumn, which accompanies the phosphate regeneration found by the writer to take place at E1 simultaneously. The analyses shown in Table I make it clear that this nitrate production is preceded and accompanied by nitrite production. The nitrite test is easier to carry out than is that for nitrate on account of the difficulty of preparing the reduced strychnine reagent required for the latter. The presence of nitrite, moreover, indicates, in sea-water, that nitrate is being produced. Whereas by the nitrate test alone it would require two consecutive samples to establish this. Furthermore, the absence of nitrite in the deep oceanic samples examined by Harvey shows that nitrification has, in them, run its full course to nitrate. Table I contains analyses for E1, E2 mid-Channel, and E3 off Ushant. The dates of analysis are shown opposite A in the bottom line of the table. The values found for the surface waters, even in the warmest period of the year, show conclusively that there has been no significant error due to storage.

TABLE I

NITRITE NITROGEN AS MG. PER CUBIC METRE AT STATIONS E1, E2, E3 DURING 1928–1929.

m.	Aug. 16 E1	Aug. 16 E2	Aug. 17 E3	Aug. 29 E1	Sept. 18 E1	Oct. 2 E1	Nov. 30 E1	Jan. 2 E1	Mar. 4 E1	Mar. 26 E1	Mar. 26 E2	Mar. 27 E3
0	0·2	0·2	0·2	0·0	<1	13·3	1·4	3·1	11·0	2·7	4·3	3·2
5	—	—	—	0·0	—	12·8	—	—	—	—	—	—
10	—	0·2	—	0·0	—	—	—	—	—	—	—	—
15	0·2	—	0·2	4·3	<1	—	1·4	—	—	—	—	—
20	0·2	—	0·2	38·9	2·0	—	—	—	—	—	—	—
25	38·3	—	0·2	—	14·6	14·2	—	3·4	—	—	—	—
30	—	—	—	—	13·6	—	—	—	—	—	—	—
40	—	—	—	28·9	—	—	—	—	—	—	—	—
50	23·5	—	0·2	—	—	—	—	—	—	—	—	—
60	—	5·6	—	—	—	—	—	—	—	—	—	—
70	31·0	—	—	37·4	16·1	15·6	1·4	3·9	8·9	3·1	—	—
80	*	—	—	*	*	*	*	*	*	*	—	—
85		5·4	—								4·0	—
90		*	—								*	—
100			0·2									—
105			*									3·1
A	20/8	20/8	20/8	30/8	19/9	4/10	1/12	3/1	6/3	28/3	28/3	28/3

* Denotes that the bottom has been reached before the depth indicated.

From the analyses it may be judged that there is a rapid nitrification in the hypothalassa during August at E1, a less rapid production at E2, and very little at E3. The blank estimation with the reagents usually amounted to only 0·1 mg. per m^3. According to Harvey's (1926, 1928) values for nitrate at E3 for July 1925 and 1926, the available supplies had been depleted to a greater extent at E1 than at E3, E2 being intermediate.

In October at E1 nitrite production was rapid, but by November 30th nitrite had almost all been converted, as shown by the small amount found and Harvey's high nitrate values for this season. Following, apparently, a late autumn or early winter plankton outburst, the existence of which is quite in keeping with Harvey's 1926 nitrate figures, we find a prolonged nitrite production in early spring, with a peak early in March.

It remains to be considered to what extent the nitrite values found are affected by the discharge of sewage from Plymouth, 22 miles N.W. of E1, or from the coast generally. Table II shows clearly that such an effect is negligible or non-existent, inasmuch as not even at L1, which is only about 300 metres from a large sewage outfall and less than 500 m. from the main outfall, are values found at all as high as at E1 during August. We may conclude, therefore, that, as in the case of phosphate and nitrate, the nitrite content of E1 is due to the operation of cyclic processes occurring at that spot.

TABLE II.

Nitrite Nitrogen as mg. per m.^{3}, in Surface Samples, 1928–1929. Station L1, below Laboratory in Plymouth Sound; L2, at Breakwater; L3, off Rame Head; L4, half-way to Eddystone; L5, at Eddystone; L6, 5 miles S.W. of Eddystone, viz. midway between L5 and E1.

Station.	Sept. 18.	Nov. 30.	Jan. 2.	Mar. 1.	Mar. 26.
L1	3·1	6·0	9·5	9·1	4·8
L2	3·0	3·9	9·5	7·2	—
L3	3·5	3·3	9·2	6·0	3·4
L4	0·0	3·3	7·7	7·9	—
L5	1·0	—	5·6	7·3	—
L6	0·0	1·3	3·5	9·1	—
E1	0·0	1·4	3·1	11·0	2·7
A	19/9	1/12	3/1	6/3	28/3

SUMMARY.

1. The nitrite content of sea-water is a useful indication of the rapid transformation of ammonium salts into nitrates.

2. In August the upper 20 m. of water at Station E1, in the English Channel, were devoid of nitrite, from 0·0 to 0·2 mg. of nitrite nitrogen per m.^{3} being found. At and below 25 m. as much as 38 mg. per m.^{3} was found; off Ushant, at E3, the whole water column was devoid of nitrite.

3. In October at E1 the whole water column contained about 14 mg. per m.^{3}, which had fallen to 1·4 mg. by the end of November. From January to March from 3–11 mg. per m.^{3} was found at E1, and at E3 on March 27th 3 mg. was recorded for the whole isothermal water column.

4. The values given for nitrite nitrogen are unaffected by transport from the shore, since inshore waters and even Plymouth Sound are poorer in nitrite than the lower layers at E1 in August, and the shore effect ceases to be appreciable beyond the Eddystone Lighthouse at the most, usually nearer shore.

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Apparatus for Rapid Electrometric Titration.

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With 4 Figures in the Text.

CONTENTS.

I. Introduction.

This apparatus was assembled at Millport for the electrometric titration of solutions which, being highly coloured, cannot well be titrated with an indicator. It may be used also for highly dilute solutions, unless they are so slightly buffered that their pH value is appreciably changed by the addition of a small quantity of quinhydrone. Measurement of hydrogen-ion concentrations at the quinhydrone electrode has also been attempted with the apparatus. The apparatus is suitable for use at sea.

II. Outline of a Titration Method.

Biilmann (**1**) has described a method of measuring hydrogen-ion concentrations at what he terms the quinhydrone electrode. Quinhydrone may be considered as an equimolecular compound of quinone, $C_6H_4O_2$, and hydroquinone, $C_6H_4O_2H_2$. In acid aqueous solution there is an equilibrium which may be represented by :—

$$\left[H_2\right] \rightleftarrows K_1 \frac{[C_6H_4O_2]}{[C_6H_4O_2H_2]}$$

(It is necessary to specify that the solution shall be acid, because in solutions with a pH value of 8·0 or more, weak acids are formed by oxidation.)

The square brackets denote molar concentrations ; and in this case of an equimolecular compound, the concentrations of quinone and of hydroquinone must always be equal, so that there is, in the solution, a concentration of free hydrogen, equal to the constant, K_1. The half-cell formed by the immersion of a gold or platinum electrode in the solution, alters its potential with the hydrogen-ion concentration exactly as does the "hydrogen electrode" half-cell, and may therefore be used for the

TABLE I.

Alkali added. (c.c.)	E.M.F. (m.v.)	Increment of E.M.F.	dE/dx.
0	−64		
		5	0·5
10·0	−59		
		7	1·4
15·0	−52		
		14	3·5
19·0	−38		
		19	6·3
22·0	−19		
		11	11
23·0	− 8		
		19	19
24·0	+11		
		16	40
24·4	+27		
		10	50
24·6	+37		
		6	60
24·7	+43		
		11	110
24·8	+54		
		15	150
24·9	+69		
		45	450
25·0	+114		
		134	**1340**
25·1	+248		
		62	620
25·2	+310		
		32	320
25·3	+342		
		14	140
25·4	+356		

measurement of hydrogen-ion concentrations. It is connected to a standard half-cell (usually a calomel half-cell) by an electrically conducting " bridge " of potassium chloride and agar-agar, and the E.M.F. of the complete cell is measured with a potentiometer.

Now the rapid change in hydrogen-ion concentration which occurs at the " end-point " of a titration may be detected by this method as a rapid change in potential. And that point in the titration where this change in potential is most rapid, is the end-point. This, the Potentiometric method of titration, has been discussed in detail by Kolthoff and Furman (**2**), and a number of practical applications of it are excellently summarised by Callan and Horrobin (**3**).

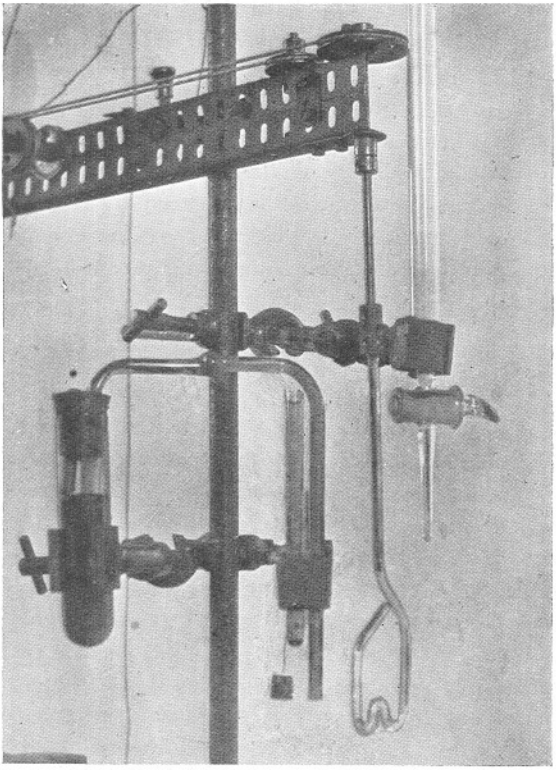

FIG. 1.—The electrodes, etc., the mechanical stirrer and the burette. The titration beaker, into which the stirrer and the exposed electrode dip, is placed in position and supported by a wooden block.

The most usual method is to measure the E.M.F. by potentiometer and galvanometer, at intervals as the titration proceeds, and to express increment of E.M.F. as millivolts per c.c. of alkali added. This factor, termed "dE/dx" by Callan and Horrobin, is greatest at the end-point. The increments of alkali are, of course, made progressively smaller as the end-point is approached. Table I represents the titration of 25 c.c. of N/10 HCl with N/10 NaOH.

The end-point is read from the table as 25·05 c.c.

Greater accuracy may be attained if the increments of alkali near the end-point are made still smaller. Indeed, the accuracy with which the burette can be read is probably the limiting factor. The end-point may therefore be read direct from the figures; the plotting of a curve is superfluous.

The performance of a titration in this manner is a lengthy operation, but in practice it is not necessary to take more than five accurate readings of the potentiometer, as is shown later. Moreover, in the apparatus described below, the galvanometer is replaced by a pair of head telephones, with an interrupter in the circuit, a modification which causes a great saving in time. Actually, a complete titration occupies only three or four minutes.

III. Description of the Apparatus.

The electrodes and their vessels (Fig. 1) are very simple. The standard half-cell used is not a calomel half-cell, but the standard quinhydrone half-cell of Veibel (**4**). It is a medium-sized tube, containing a buffer solution (pH 2·2) saturated with quinhydrone. The exact value of the buffer solution need not be known, as absolute measurements are not to be made; a solution of pH 2·2 is found to give convenient readings on the potentiometer. The tube is stoppered with a rubber bung pierced by two holes. The electrode is a square centimetre of gold foil attached to a platinum wire which is fused into the bottom of a small glass tube. This tube passes through one of the holes in the bung, and contains mercury, with which contact with the external lead is made.

The twice-bent glass tube which contains the KCl-agar bridge passes through the other hole in the bung. A small bulb is blown in this tube to frustrate the tendency of the jelly to slip bodily out of the tube. The bridge is prepared as follows: 50 c.c. of distilled water is heated on the water-bath to near boiling-point, and 1·5 gm. of agar-agar is then added. Care should be taken to avoid air bubbles. After about five minutes, 20 gm. of pure KCl is added, and after a further five minutes, one end of the glass tube, which is previously heated in hot water, is inserted into the mixture, and enough sucked up to fill the tube, which is then cooled under the tap. It is well to slip a short length of rubber tubing over each end of the glass. Not only does this make filling easier, but when the rubber is removed after the jelly has set, the tube is left quite full; if no rubber is used the jelly, contracting as it cools, withdraws a little up the tube, so that proper cleaning between titrations is difficult. The jelly loses KCl when in use, and has to be replaced at intervals. It may last from three to fifteen days, but this does not seem to depend on the extent to which it has been used.

Titration is carried out in an ordinary beaker. The electrode in this is exactly like that in the other half-cell. Another rubber bung is slipped over the tube which holds the bridge, and the tube into which the platinum wire is fused is held in a second hole in this bung. As Figure 1 shows, the entire assembly is supported by an ordinary retort clamp.

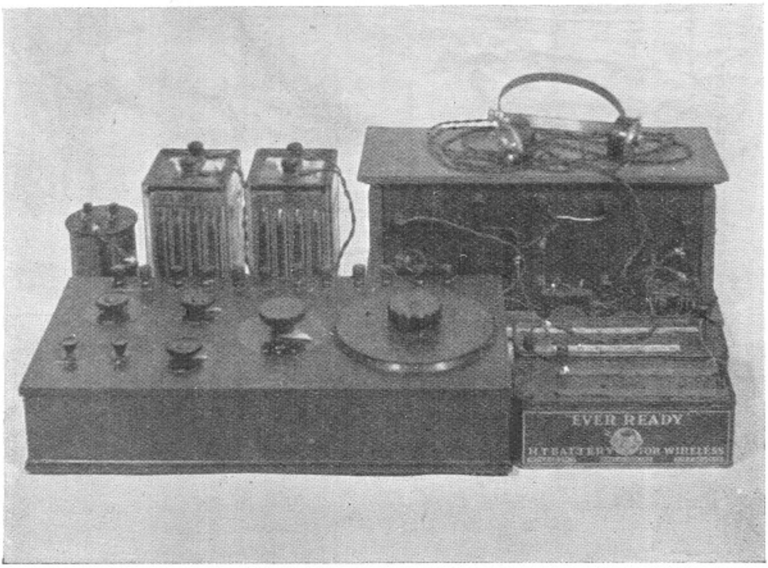

Fig. 2.—The potentiometer and amplifier, and their batteries. The interrupter is kept at the other end of the bench.

A flashlamp bulb in a small metal reflector, and a hand lens, are supported in a wire frame which slides up and down the burette, that it may be more accurately read.

Hand stirring was practised at first, but this proved inadequate, as additions of alkali were not distributed evenly for some time. A mechanical stirrer was therefore arranged, driven by a small electric motor. The power is transmitted by a belt working over a system of pulleys. Meccano components were used for this, as may be seen in Figure 1.

Figure 3 shows that the electrodes are directly connected to a reversing switch, the use of which is illustrated in Table I. Then they pass to the potentiometer and the interrupter respectively. The potentiometer (Fig. 2) used is the " Slide Wire Potentiometer (Modified Form) " of the

Cambridge Instrument Co., Ltd., which is a precision instrument, and was obtained with a view to making hydrogen-ion concentration measurements. But for titrations only, a much cheaper instrument would suffice, since absolute measurements of E.M.F. are not required. Good results could probably be obtained from an improvised potentiometer.

A two-valve amplifier is placed before the head telephones, as was done by Poole (**5**). This was constructed from the standard components sold for radio sets, and contains two transformers, one of which comes before the first valve. As an output transformer is placed between the second valve and the telephones (although not actually incorporated in the amplifier), the batteries of the amplifier are completely insulated from the remainder of the apparatus. The amplifier is built into a wooden case which is lined with copper sheet, to minimise "interference" from the motor which drives the interrupter. This copper sheet, and the negative terminals of the amplifier batteries, are connected to "earth." "Interference" is further reduced by a two-microfarad condenser between "earth" and the primary of the first transformer.

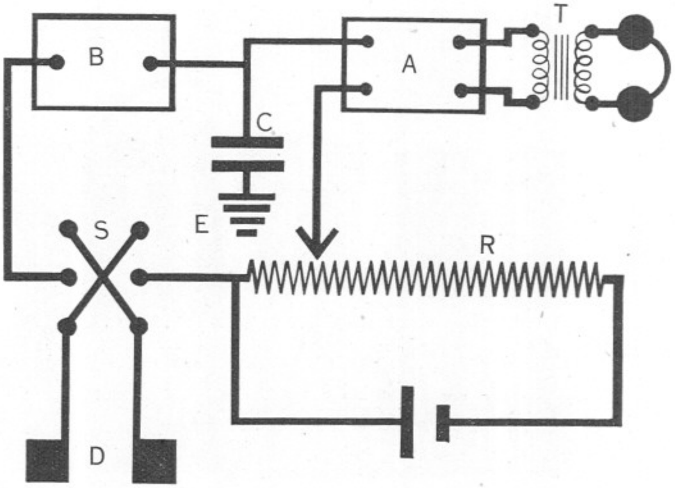

FIG. 3.—The circuit used. The internal circuits of the interrupter and of the amplifier are omitted, and the potentiometer circuit is reduced to its simplest form.

A, amplifier; B, interrupter; C, 2-microfarad condenser; D, electrodes; E, "earth"; P, telephones; R, potentiometer; S, reversing switch; T, output transformer.

Several interrupters have been tried. A Meccano assembly, which seemed to be superior to the buzzer device of Poole (**5**) and to the Meccano assembly of Poole and Atkins (**6**) (both of which were tried), was used for some months. Two teeth out of every three were removed from a heavy-toothed wheel, and the gaps were filled with sealing-wax. This composite wheel was rotated by an electric motor between two pieces of clock spring, pressed firmly against it by rubber buffers. Contact between the springs was made and broken ten times in each revolution. This was very satisfactory, except for the rapidity with which the sealing-wax wore away. When the apparatus had established itself as permanent, a new interrupter was designed, and was manufactured specially by the General Electric Company, Ltd. A motor, driven at 1800 r.p.m. by a 12-volt accumulator, bears on an extension of the armature shaft an extra commutator, carefully insulated from the armature. Figure 4 shows how contact is made and broken between the two carbon brushes. A 0·05 microfarad condenser is connected across the brushes, and almost abolishes "interference." There is very little mechanical noise.

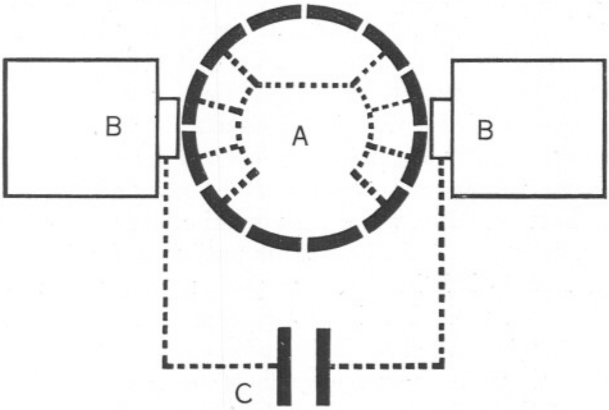

FIG. 4.—Diagrammatic view of the interrupter, showing the electrical connections as broken lines.

A, end view of extra commutator on the armature shaft of the motor; B, sprung carbon brushes, between which contact is made and broken; C, 0·5 microfarad condenser.

IV. PROCEDURE IN TITRATION.

The acid solution is placed in the beaker. When the solution to be titrated is alkaline, it must first be made acid by addition of a known amount of acid. If this is not practicable, e.g. when a precipitate would form in acid solution, the titration cannot be performed.

Quinhydrone is added to the solution in the beaker. Its small solubility causes a small quantity to saturate the solution, and this is usually done. But the result does not seem to be affected if the quinhydrone does not saturate.

The acid solution is usually diluted to a "standard volume," suited to the type of titration. Thus, at Millport, it was necessary to make numerous titrations in which the acid solution was 25 c.c. of 0·1N HCl, partially neutralised by alkali distilled into it, and already diluted to about 190 c.c. The " standard volume " was therefore fixed as 200 c.c., and all the acid solutions in this series of titrations were diluted to this volume. If the titration does not belong to such a series, this dilution is not made. The " standard volume " for any series is made as small as possible, for if a relatively large volume of water be added, the CO_2 dissolved in it may appreciably alter the pH value of the whole.

When, in every titration in such a series, the acid solution has the same volume, the same E.M.F. marks the end-points, provided, of course, that the pH of the buffer solution in the standard half-cell remains constant. Actually this does not remain quite constant, because this solution takes up KCl from the KCl-agar bridge, and is, on this account, periodically renewed. Also, the amount of alkali added, during titrations, naturally varies slightly, so that the volumes at the end-points are not quite the same throughout a series. It is not, therefore, possible to use the Pinkhof method, in which the potentiometer would be set to the known end-point value, and alkali run in until no noise is audible in the telephones. But the E.M.F. at the end-point may be predicted within a few millivolts, so that the E.M.F. at any stage is an excellent indication of the extent to which the titration has proceeded.

In practice, therefore, accurate readings are not taken until within about 1 c.c. of the end point. The interrupter-telephone combination, being completely " damped," allows a rough reading to be taken in a few seconds, and the four or five accurate readings which are necessary, may be taken in two or three minutes. Between each addition of alkali from the burette the liquid in the beaker is very thoroughly stirred, and then the E.M.F. is read. The results are tabulated as in Table I, and the end-point is read direct from this.

The electrodes are subject to polarisation, so that the potentiometer switch should not be held down continuously while a reading is being taken.

If the end-point is overshot, the titration may usually be " brought back " by addition of acid, without serious error.

As there is no galvanometer, and as all the apparatus has sufficient mechanical strength, the whole assembly may be taken to sea, and there worked. It was for this reason that the interrupter was designed to run from an accumulator.

The apparatus is quite independent of colour and turbidity in the liquid. It has been in regular use at Millport for several months, and has been found quite reliable. The accuracy obtainable varies with the strength of the solutions titrated. Successive titrations of 0·01 HCl against 0·01 NaOH tally within 0·02 c.c. This, of course, does not necessarily imply that the absolute accuracy is as high as this, but relative results have been adequate for the purposes for which the apparatus has been intensively employed.

V. pH MEASUREMENTS.

The apparatus is perfectly suited to the measurement of hydrogen-ion concentrations. Smaller electrode vessels are then used, and the standard half-cell is either a calomel half-cell or a quinhydrone half-cell containing a buffer solution of accurately known pH. A single E.M.F. is determined, and then a simple calculation should then give the pH of the liquid under test, as is described by Biilmann (**1**) and Clark (**7**). Unfortunately this has been a complete failure, the results being extremely erratic, owing, doubtless, to some fault in detail, at present undiscovered.

I have to thank Mr. H. B. Moore for considerable help in the designing and in the construction of the stirring apparatus and the various interrupters which have been tried.

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A Contribution Towards the Life-History of the Spur-Dog.

By

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With 16 Figures in the Text.

THE object in publishing these notes on the Spur-Dog, *Acanthias vulgaris* Risso, is to show the close resemblance, in the distribution of the sizes and sexes, between this fish and the Hake. The Hake will be dealt with in a future paper.

The work has been done during voyages in which the Hake has been the principal object of research. The data on Dogfish have therefore been collected at odd times during a very busy programme on the Hake, and this must be my apology for inadequacy or discontinuity in the figures presented. I would especially thank my colleague, Mr. W. Johnston, and my friend, Mr. C. E. D. Enoch, for their willing help in this entirely unofficial work; and Mr. J. Armitage Robertson for his help in the arrangement of the text.

I. SIZE, SEX, AND DEPTH.

A good series of measurements were made during the cruises of the Ministry of Agriculture and Fisheries' research vessel, *George Bligh*, to the western hake grounds in August, 1928. The position of the stations may be seen in the chart in Figure 1.

The material was collected by using a full-size Vigneron-Dahl trawl, with the cod-end covered by fine-meshed shrimp-netting. One can therefore be certain that no small specimens can have slipped through the meshes and have thus been lost.

The stations worked fall into three main groups, as follows :—

Banks-Westward Group.	Stations " between the Banks," Cockburn Bank, and on the Westward Ground.
Fastnet Group.	Stations Bantry Bay, Galley Head, and Inner and Outer Fastnet.
Galway-Bull Group.	Stations " below the Bull," Galway Bay, i.e. off the Aran Islands, and, finally, inside the Aran Islands.

Station 18, about midway between the Banks-Westward and the Fastnet groups of stations, is considered separately.

Where a depth is referred to, the mean depth of the hauls which supplied the data is meant. The data will be found in the Appendix, Table XIII, where the actual frequency at each 5-cm. group is denoted by an upright, the percentage frequency by an italic numeral.

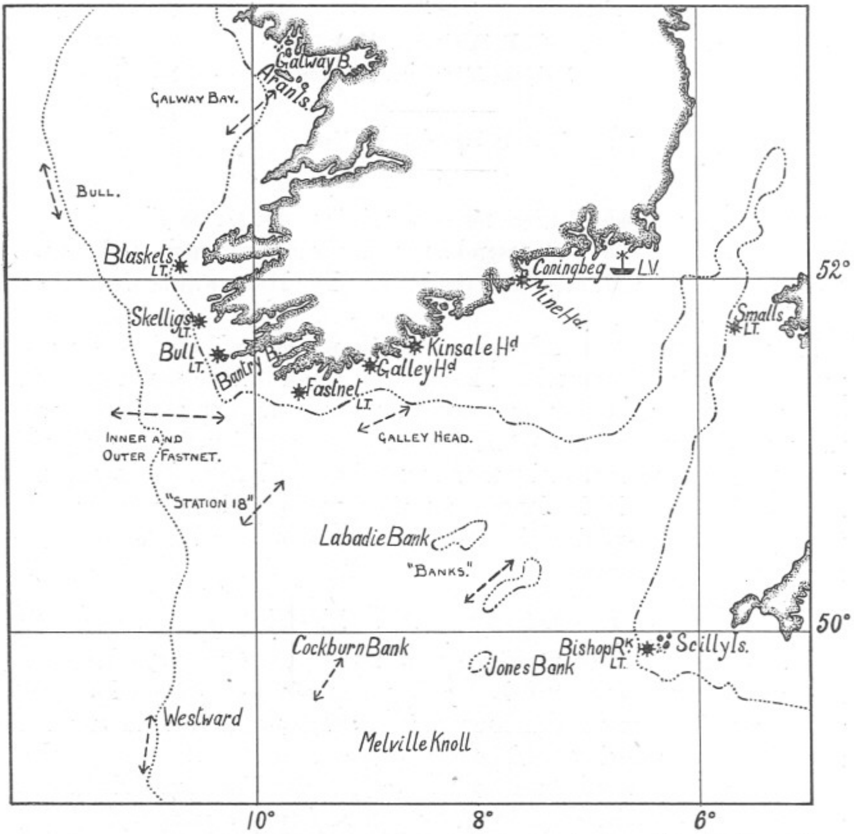

Fig. 1.—Map of South-Western Area, showing the approximate position of the stations sampled, except Bantry Bay, and Inside Aran Islands (Galway Bay).

The Fastnet Stations.

In Figure 2 four pairs of curves are drawn. The pecked line refers to males, the continuous line to females. The curves show the percentage of the fish measured, which were present in each 5-cm. group, each sex being separately considered. The grouping was as follows: more than 25 but less than 30 cm., more than 30 but less than 35 cm., etc. In the figures, the plotted point is at the mid-point of the group.

The uppermost pair of curves refer to the fish measured in Bantry Bay, at a mean depth of 30 fathoms. Both males and females show a well-marked mode at a length, calculated by Wollaston's "three point" method (Wollaston and Hodgson, 1929), of 34·21 and 34·20 cm. respectively. Both curves show a second mode at about 42 cm. (the exact modal length cannot be calculated by Wollaston's method), and a third mode, at 67·5 cm. in the female, and 68·5 cm. in the male. The curves show that the males in the sample tend to be larger than the females, for, in the first mode, 47·8% of the females, but only 39·8% of the males, in the second mode, at about 42 cm., 12·0% of the females, but 15·2% of the males, and in the third mode, at 67 cm., only 2·2% of the females, but 6·3% of the males, are present. In confirmation of this, the median for the females is found to be 35·4 cm., for the males, 37·3 cm.

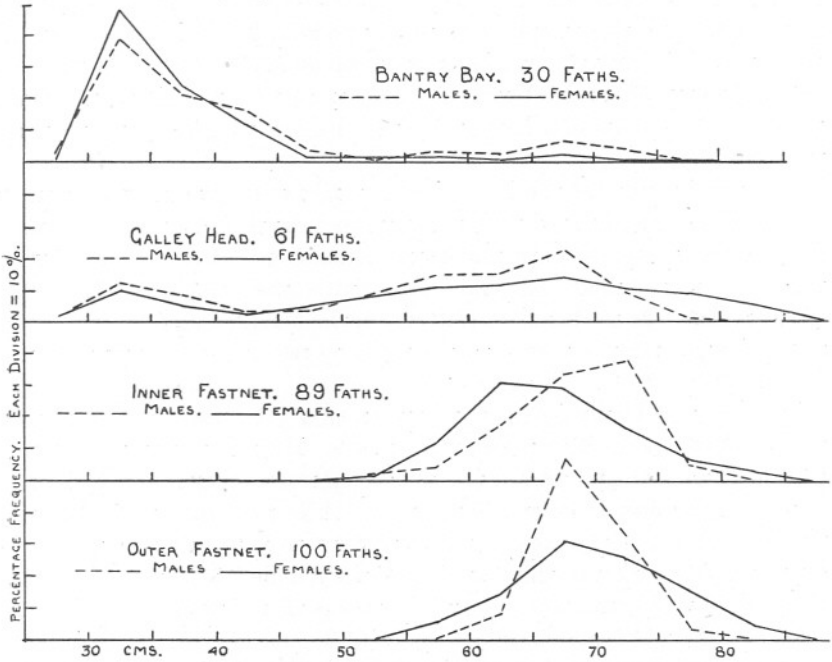

FIG. 2.—The Fastnet Region. Percentage frequencies in the 5-cm. groups of measured fish. *George Bligh*, August, 1928. Data from Table XIII.

The two curves for the Galley Head measurements, at a mean depth of 61 fathoms, show clearly how, with the deeper water, the size of the dogfish has increased. The first mode, at a calculated length of 33·58 cm. in the female, and 34·60 cm. in the male, has a slightly lower modal length than in Bantry Bay, but, on the other hand, only 10·8% of the females and 11·3% of the males are present at this mode. The Bantry mode at 42 cm. is not indicated, but there are two distinct modes, one at about 58 cm., the other at 66·52 cm. in the female (calculated modal length) and 66·67 cm. in the male. Both these modes are foreshadowed in the Bantry sample, but very few fish are present in them. In the Galley Head sample they predominate, with 14·7% of the females and 23·0% of the males. In this sample also, therefore, there is a tendency for the males to be larger than the females; this may be seen in the higher percentage of males than of females in the modes at 58 and 66 cm.; but in the medians, which are 62·7 cm. for females, and 60·0 cm. for males, the reverse is apparent. This is due, however, to the number of very large females in the sample. As the Appendix, Table XIII, shows, no fewer than 5·8% of the females are between 80 and 84 cm. in length, and 3·5% between 85 and 89 cm. As a later section will show, these are pregnant females which have migrated inshore to give birth to their young.

The two curves for the Inner Fastnet measurements show a further increase in size associated with the increased depth (89 fathoms). Small fish are not present; both males and females give an unimodal curve, with a calculated modal length of 64·81 cm. in the female, and 70·33 cm. in the male. The medians are 65·9 cm. in the female, and 69·2 cm. in the male. In this sample, therefore, the males were distinctly larger than the females.

Finally, the Outer Fastnet measurements (100 fathoms) also give unimodal curves for both males and females. Here, however, the females are larger than the males, for the calculated modal lengths are 69·17 cm. in the female, and 68·93 cm. in the male. The medians are 69·9 in the female, and 68·9 in the male. It is important to notice that, in the deepest water, 100 fathoms, there are 5% of the females at 80 to 84 cm., and 1·4% at 85 to 89 cm., whereas at 89 fathoms there are only 2·9% of the females at 80 to 84 cm., and 0·7% at 85 to 89 cm.

In these four samples from the Fastnet group of stations, therefore, we may see the progressive increase in length of the dogfish with increase in depth, manifesting itself in (*a*) a movement of the modal lengths to the right, (*b*) an increasingly higher proportion of the fish at the higher modes, and (*c*) an increasingly higher median.

THE BANKS-WESTWARD STATIONS.

In Figure 3 are drawn three pairs of curves. These refer to the samples collected on the three stations comprising the Banks-Westward group (Figure 1). As the Appendix, Table XIII, shows, the data from these stations are less abundant than those from the Fastnet group of stations, but their interpretation is no less clear and unequivocal. In Figure 3, as in Figure 2, the pecked line refers to the males, the continuous line to the females.

In the Banks sample (69 fathoms) two modes are seen, with calculated modal lengths of 33·55 cm., and 55·30 cm. in the female, and 33·80 cm. and 52·18 cm. in the male. The second modal length is therefore slightly higher in the female than in the male; on the other hand, in the first mode 33·8% of the females, but only 18·4% of the males are present, and in the second mode, 11·5% of the females, but 21·9% of the males. Thus, at this station, as at the Bantry Bay, Galley Head, and Inner Fastnet stations, the males present have a greater size than the females. This is further shown by the medians, namely, 39·5 cm. in the female, and 47·8 cm. in the male.

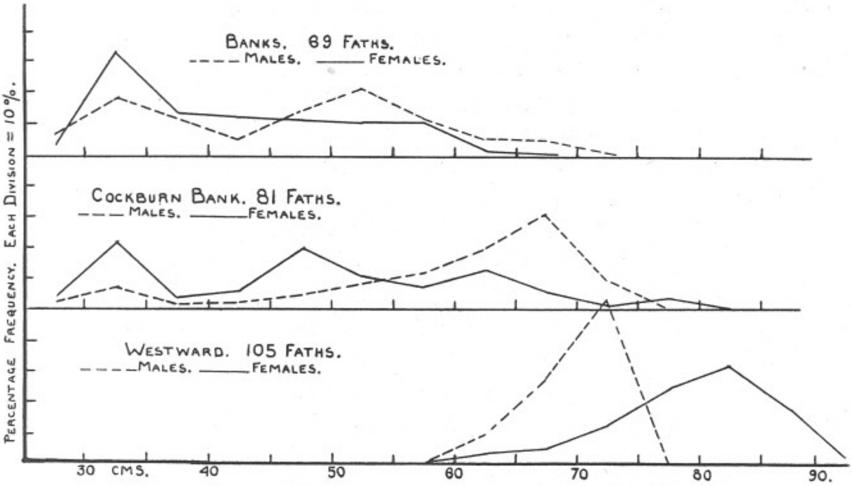

FIG. 3.—The Banks-Westward Region. Percentage frequencies in the 5-cm. groups of measured fish. *George Bligh*, August, 1928. Data from Table XIII.

The measurements made on the Cockburn Bank (81 fathoms) show that, in this deeper water, the length of the fish of both sexes has increased. Three distinct modes are shown by the curve for females, at calculated modal lengths of 32·37 cm., 48·32 cm., and 63·07 cm. The first of these modes is plainly identical with that shown at 33·55 cm. in the Banks sample, but, at 81 fathoms, only 21·5% of the females are present at this mode, as compared with 33·8% at 69 fathoms, while at the second and third modes, at 81 fathoms, 19·5% and 12·7% of the females are present. The males show two distinct modes, which give calculated modal lengths of 32·31 cm. and 66·37 cm. The first of these is identical with the first of the modes in the curve for the females, but only 7·3% of the males are present at this mode, as compared with 21·5% of the females. The second mode in the curve for males, at 66·37 cm., contains no fewer than 30·6% of the males. Here again, therefore, the males in the sample are distinctly longer than the females in the sample, and the medians show this well, that for the males being 63·1 cm., for the females, 48·9 cm.

Finally, the Westward sample shows curves of the same type as the Outer Fastnet sample in Figure 2. The females are distinctly larger than the males, the curves for both sexes are unimodal, with calculated modal lengths of 81·79 cm. in the females, and 71·40 cm. in the males. The medians are 81·0 cm. in the females, and 70·5 cm. in the males.

In the Banks-Westward series of stations there is shown the progressive increase in size of the dogfish of both sexes, with increase of depth, and, except in the Westward sample, the larger size of the males, as compared with the females, in any given sample. When the Banks-Westward stations are compared with the Fastnet stations, however, three points arise which must be noted, as they will be referred to later.

Firstly, there is a different relation to depth in the two groups of stations. The Banks curves, when compared with the Galley Head curves, show, in spite of the closely similar depth, a smaller size of dogfish ; this can be best expressed by comparing the medians, which are 39·5 cm. in the female, and 47·8 cm. in the male, in the Banks sample, at 69 fathoms ; but 62·7 cm. and 60·0 cm. in the males and females respectively, in the Galley Head sample, at 61 fathoms. A comparison of the Inner Fastnet (89 fathoms) with the Cockburn Bank (81 fathoms) shows the same phenomenon.

Secondly, no such shallow water was worked in the Banks-Westward group of stations as was worked in Bantry Bay (30 fathoms), but, on the whole, small newly-born dogfish were much scarcer in the Banks-Westward than in the Fastnet group of stations, and had a smaller size. The modal lengths were 33·5 cm. and 33·8 cm. in females and males in the Banks sample, but 34·2 cm. in male and female in the Bantry sample. The difference, though slight, may be significant.

Thirdly, whereas, in the Fastnet group of stations, the largest females tended to be well represented in the shallow water stations, such as Bantry Bay, and especially Galley Head, in the Banks-Westward stations they are almost absent from the Banks and Cockburn Bank stations. On the other hand, they were concentrated in the deep water on the Westward ground to a much greater degree than on the Fastnet grounds at approximately the same depth. The impression is given that, in the Fastnet region, there had been a migration of the large females into shallow water, which had not yet taken place, or had only just begun, on the Banks-Westward stations at the time of the voyages.

The Galway-Bull Stations.

As the Appendix shows,* dogfish were very scarce on the Bull grounds, probably on account of the comparatively great depths fished there. The few specimens taken were found in the shallowest hauls (98 and 105 fathoms). The distribution of Acanthias with depth has been discussed elsewhere (Hickling, 1928), and it was shown that, in the Faroe-Shetland Channel, and off the West coast of Scotland, this fish was taken at every depth from 90–100 to 500–520 fathoms. The scarcity of dogfish in the deeper water on the Bull and Westward grounds may well be due to a regional, or, much more probably, a seasonal, variation in distribution.

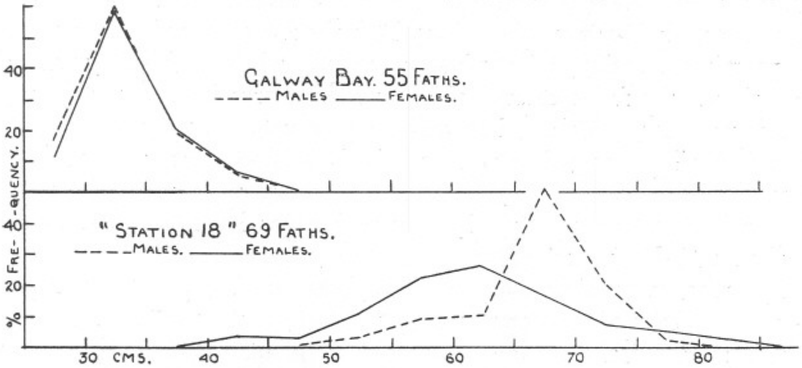

Fig. 4.—Galway Bay and Station 18. Percentage frequencies in the 5-cm. groups of measured fish. *George Bligh*, August, 1928. Data from Table XIII.

The 22 dogfish taken on the Bull grounds were, with five exceptions, between 60 and 90 cm. in length, but the sample is too small to be worth further discussion.

The Galway Bay sample consisted almost wholly of young newly-born fish, as Figure 4 shows. There is a single mode, at a calculated modal length of 32·99 cm. in the females, and 32·75 cm. in the males. The curves for male and females, however, fit more closely than in any other sample. Besides these young fish, there were six large females of 70 to 93 cm.

The third station, at 21 fathoms inside the landlocked waters of Galway Bay, was only sampled with a single haul of one hour's duration. This haul yielded 38 dogfish, which showed a length-distribution as follows :—

Length	25 to 29	30 to 34	35 to 39	40 to 44	———	70 to 74	75 to 79	80 to 84	85 to 89	90 to 94	95 cm. to 99 cm.
Frequency	1	8	6	7	———	2	2	4	5	2	1

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* Table XVIII.

The dogfish found in this very shallow water, therefore, fell into two sharply defined groups, the one, of small fish between 25 and 44 cm., the other, of large fish between 70 and 99 cm. Of the large fish, all but one were females.

A comparison has already been made between the Banks-Westward and the Fastnet groups of stations, and the conclusion was drawn that, among the large females, there was a migration inshore, which had not yet commenced in the Banks-Westward region, but was well advanced in the Fastnet region. It may be suggested that, in the Galway-Bull region, this inward migration of large and, as we shall see in a later section, pregnant females, was even more advanced than in the Fastnet region. For in very shallow water in Galway Bay, the fish consisted almost wholly of pregnant females and newly-born young, while in deeper water, in 55 fathoms, the fish consisted almost wholly of newly-born young, with a few pregnant females. The inshore migration of pregnant females, therefore, which, according to Travis Jenkins (1925), bear their young in very shallow water of 3 to 6 fathoms, is complete in the Galway-Bull region, is far advanced in the Fastnet region, but has hardly commenced in the Banks-Westward region.

The very great abundance of newly-born dogfish in Galway Bay is further evidence of this completion of the birth of the young. They were abundant at 55 fathoms in the Galway-Bull region, whereas, in the Fastnet region, they were most abundant at 30 fathoms, and comparatively scarce at 61 fathoms. This difference is probably the consequence of the earlier birth of the young in the former region, for, according to Travis Jenkins (*loc. cit.*), the young dogfish move away from shallow water shortly after birth.

The sample of dogfish taken at Station 18, midway between the Banks-Westward and the Fastnet regions, furnishes percentage frequency-curves which are shown in the lower part of Figure 4. Both males and females show one predominant mode, at calculated modal lengths of 61·12 cm. in the female, and 68·12 cm. in the male. The medians are 61·4 cm. in the female, and 67·7 cm. in the male. This sample, therefore, furnishes further evidence of the larger size of the males at any given depth, such as has already been shown to be the case in both the Banks-Westward and Fastnet regions.

Both males and females show a mode at a lower length also, indicated by a flattening of the curves at about 45 cm. in the female, and 58 cm. in the male.

When the frequency-curves are compared with the series in Figures 2 and 3, it is clear that the sample from Station 18 more closely resembles the Fastnet samples than the Banks-Westward samples, having regard to the depth at which the sample from Station 18 was fished.

THE SEX-RATIO.

Figures 2, 3, and 4 have represented the percentage frequency-curves of each sex considered separately. They therefore give no information as to the relative numbers of the sexes. Table XIII in the Appendix will show that the sex-ratio shows considerable variation in the samples, but is related to depth in such a way, that, down to a certain depth, the percentage of males increases, but, beyond that depth, decreases, until, in the deepest water, females form the great majority of the fish. The sex-ratios must be interpreted in the light of the length-distributions.

In the Banks-Westward region, the percentage of females was as follows :—

Banks Station	69 fathoms	54·9% females.
Cockburn Bank Station	81 fathoms	37·8% females.
Westward Station	105 fathoms	84·8% females.

In the Fastnet region, the percentage of females was as follows :—

Bantry Bay Station	30 fathoms	59·2% females.
Galley Head Station	61 fathoms	61·3% females.
Inner Fastnet Station	89 fathoms	69·9% females.
Outer Fastnet Station	100 fathoms	88·0% females.

At Station 18 there were 52·2% females, and in Galway Bay 56·9% females.

It will be clear, from what has been said in the foregoing pages, that, in both males and females, there is a segregation according to size, such that the larger fish tend to be found in deeper water. Since in any given sample from shallower water the males tend to be larger than the females, the males are distributed in shallower water than the females.

Ford (1921), whose work will be constantly referred to in this paper, found that male and female dogfish are born in approximately equal numbers, and at the same length. The segregation of males in shallower water than the females will therefore tend to result in a sex-ratio, except in very shallow water, of more than 50% females. For example, in the Galway Bay sample, from a depth of 55 fathoms, the dogfish, which were, by their length, plainly newly-born, already showed 56·9% of females, and in Bantry Bay, where conditions were much the same, 59·2% females. This difference in the distribution of the sexes is the first factor affecting the sex-ratio.

But the females grow to a much greater length than the males. Ford's data show that the largest male examined during his work was 83 cm., but his largest female was 110 cm. in length. My own figures, as in Table XIII, show the same fact equally clearly. Therefore, since females grow to a greater length than the males, and since the dogfish, other things being equal, are segregated according to size, with increase of depth, in the deepest water we should expect to find only big fish, and therefore chiefly female fish. This may be seen in the Westward and Outer Fastnet samples, where the percentage of females is respectively 84·1 and 88·0. This is the second factor affecting the sex-ratio, but it also acts in a somewhat unexpected way, as the next section will show.

The smaller size of the males is very well known as a general phenomenon among fishes. In the case of the Plaice (Wallace, 1907), the Cod (Saemundsson, 1923), and the Hake (Birtwistle and Lewis, 1924 ; Belloc, 1922) at least, it is due to a failure on the part of the males to maintain the rapid rate of growth shown by the females. The older year-groups among the males of these fish are therefore compressed into a much narrower range of length than the females, and, although Wallace rightly suggests that male Plaice are more viable than the females, there will clearly tend to be a region in the scale of length where few year-groups of females, but many year-groups of males are present. At these lengths the males will tend to be more abundant than the females. In the case of the Dogfish, we have seen that the fish are distributed by size according to depth. Therefore there will be a certain depth at which males will predominate over the females. This predominance may be seen in the Cockburn Bank sample, in which there are only 37·8% of females.

This should be regarded as the normal distribution of the sexes, with depth, in the Spurdog. In the shallowest water there should be a slight predominance of males, then a region where there is a slight predominance of females, then a somewhat restricted region where males greatly predominate, and finally, at still greater depths, a gradually increasing predominance of females. It is, therefore, hardly possible to speak of the sex-ratio among dogfish as though this were a constant ; it will clearly vary with depth, and also, almost certainly, with season.

But it has also been shown that there is a shoreward migration of pregnant females. The presence of these females, in any numbers, must tend to reverse the sex-ratio in those regions where males would, on hypothetical grounds, predominate. In the Galley Head sample, and, to a lesser extent, in the Inner Fastnet sample, these pregnant females were present in some abundance, hence none of the stations in the Fastnet series shows such a predominance of males as the Cockburn Bank Station, where the inward migration of the pregnant females had not commenced.

This alteration of the hypothetical sex-ratio in dogfish by the inward migration of the pregnant females reaches its extreme, of course, in the very shallow station inside Galway Bay, at 21 fathoms, in which, of the larger group of fish, 93·8% were females.

For comparison with these results, data collected during the exploratory voyages of the *Florence Brierley* of Fleetwood, in March and April, 1927, are of value, and afford good confirmation. Three cautionary remarks must be made. Firstly, the material is usually much scantier than that available from the stations of the *George Bligh* ; secondly, an ordinary commercial cod-end was used, without a covering of shrimp-mesh ; and thirdly, the shallowest water worked was 96 fathoms.

In Figure 5 are plotted the points representing the variation in sex-ratio, with increase of depth, as shown by the *Florence Brierley* samples. The abscissa represents the depth in fathoms, the ordinate, the percentage of females. The data will be found in the Appendix, Table XIV. A line is drawn through the plotted points, to show the general trend.

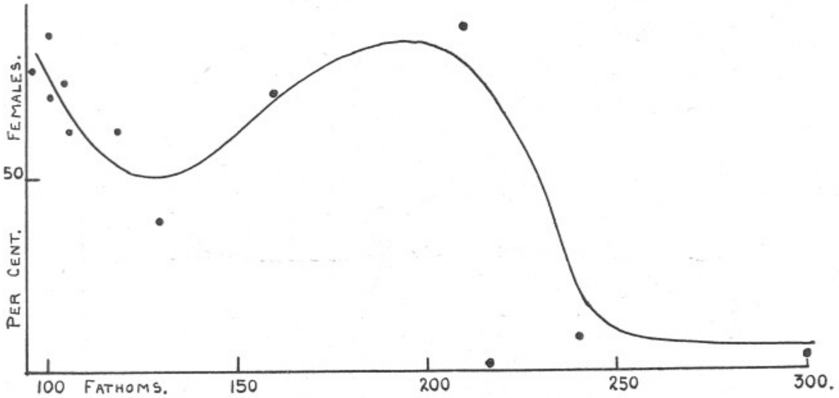

FIG. 5.—Variation in sex-ratio with depth. *Florence Brierley*, April, 1927. Data in Table XIV.

It is evident that, from the shallowest water worked down to about 130 fathoms, the percentage of females decreases. It then increases from 130 to about 200 fathoms. This fluctuation is perfectly understandable from what has been said earlier in this section. There is a region where, for the reasons there stated, the males must tend to predominate, and, in these samples, 130 fathoms is, roughly, the centre of this region. Beyond this depth, females become dominant, until 90% of females is found at 210 fathoms. Moreover, the pregnant females were most abundant in the deep water ; at this time, therefore, there was no inshore migration of pregnant females to mask the concentration of the males at the intermediate depth.

Something quite new shown by Figure 5 is the presence, in very deep water, of shoals of dogfish consisting exclusively of mature males. It may be taken as certain that these males were living pelagically, and were caught during the hauling or shooting of the trawl.

SEXUAL MATURITY, PREGNANCY, AND THE EMBRYO.

Ford (*loc. cit.*) finds that, in the male dogfish, sexual maturity sets in at about 59–60 cm., but, in the female, not until between 70 and 80 cm. The smallest pregnant female in his samples was 72·8 cm. in length, but he concludes that a female "before becoming mature, undergoes an extended adolescent period in which her first set of eggs are developing in the ovaries. The specimens under 70 cm. in length were quite immature, and no conspicuous eggs were present in the ovaries."

In Figure 6 are drawn two curves, showing the percentage, respectively, of mature and immature males at lengths between 52 and 66 cm. The earliest mature fish was 55 cm. in length, the latest immature fish 63 cm.

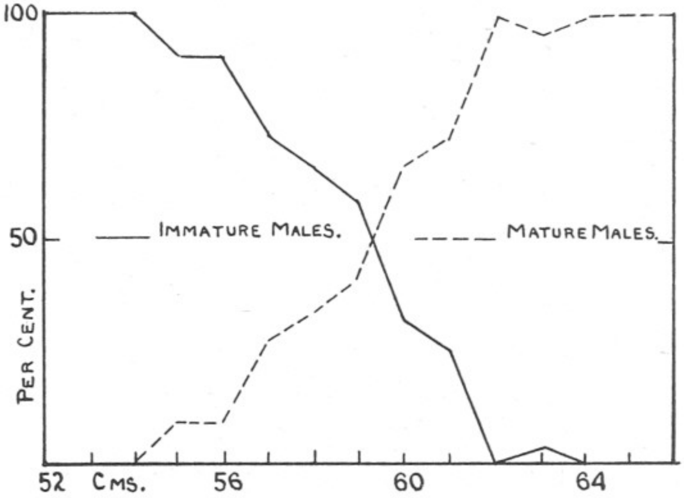

FIG. 6.—Onset of maturity in male dogfish. All stations combined, *George Bligh*, August, 1929. Data in Table XV.

The curves cross at some point between 59 and 60 cm., so that I can entirely confirm Ford. The data are given in the Appendix, Table XV.

The smallest pregnant female found in my samples was 64 cm. in length, but I can confirm Ford's conclusion that pregnancy generally sets in between 75 and 80 cm. In Figure 7 the percentage of pregnant females in the total females, at each 5-cm. group, is shown graphically. The data are to be found in the Appendix, Table XVI. The curve shows its most rapid rise from 75–79 to 80–84 cm., but it never reaches 100% owing to the presence of newly-spent females.

In Table I the pregnant females found at each station are represented by a black dot. It should be said in passing, that these data on pregnancy are based on the females dissected for the weighing experiments to be described in the latter half of this paper.

TABLE I.

Length Group.	Banks 69	Cockburn Bank 81	Westward 105	Bantry Bay 30	Galley Head 61	Inner Fastnet 89	Outer Fastnet 100	Bull 130	Galway Bay 55	Inside Islands 21	Station 18 69
55–59											
60–64		·									
65–69			·								·
70–74		·	··	·		·	·				
75–79		·	·		·				···		·
80–84			····	·······	·······			··	:····	···	
85–89	··		····	···	··		··		::::::	··	·
90–94			·	··					···	··	
95–99										·	

The table shows the occurrence of pregnancy in the various samples quite sufficiently clearly, without the necessity of weighting for the size of the samples.

Pregnant females were few in the Banks and Cockburn Bank samples, but plentiful in the Westward sample. In the Fastnet group of stations, pregnant females were plentiful in the Bantry Bay and Galley Head samples, but scarce in the Inner and Outer Fastnet stations, and from the sample from Station 18. In the Galway-Bull region, pregnant females were scarce in the Bull sample, but plentiful in the Galway Bay sample, and in the shallow water inside the Aran Islands.

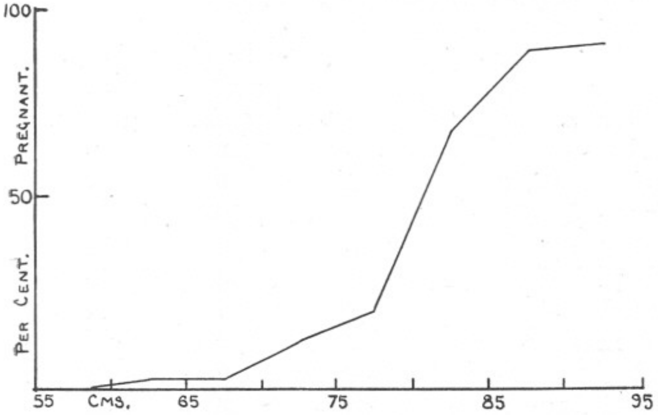

FIG. 7.—Onset of pregnancy in female dogfish. All stations, *George Bligh*, August, 1928. Data in Table XVI.

Recalling what has already been said about the distribution of large females among the stations, it is clear that the distribution of pregnant females is identical with this, and that the inward migration of large females, deduced by an inspection of the frequency-curves, is, in reality, a shoreward migration of pregnant females to bear their young in shallow water. This shoreward migration was far advanced in the Galway-Bull region, was taking place in the Fastnet region, but had not yet commenced in the Banks-Westward region.

This may be illustrated further by showing the percentage of pregnant females among the potentially pregnant females in the different samples. For this purpose, all females greater than 75 cm. are regarded as potentially pregnant. The data are given in Table II in the text below. In many of the samples, the data are thin, in others, fairly adequate, but in all regions one may see that the pregnant females predominate in the shallow water, and that, in the deeper water, in those regions where the inward migration is farthest advanced (the Inner and Outer Fastnet grounds for example), those mature females remaining are non-pregnant. These are probably newly-spent fish, which have returned to deep water after bearing their young.

TABLE II.

PERCENTAGE OF PREGNANT FEMALES IN THE "GEORGE BLIGH" SAMPLES.

Station.	Depth.	No. of Females greater than 75 cm.	No. pregnant.	% pregnant.
Banks	69	2	2	100
Cockburn Bank	81	3	3	100
Westward	105	15	13	87
Bantry Bay	30	20	13	65
Galley Head	61	19	10	53
Inner Fastnet	89	7	1	14
Outer Fastnet	100	19	3	16
Bull	130	8	2	25
Galway Bay	55	33	32	97
Inside Aran Islands	21	9	8	88
Station 18	69	7	3	43

The results of the voyages of the *George Bligh*, therefore, show us the distribution of pregnant females at the time of the birth of the young, which, as Ford finds, takes place from September onwards. The voyages of the *Florence Brierley*, on the other hand, show that, in the early spring, the pregnant females are found in the deeper water. As the Appendix, Table XIV, shows, the four well-sampled hauls of March 29th and 30th, and March 31st and April 2nd, give clear indication of the shoaling of the pregnant females in deeper water. This, however, is simply the consequence of the segregation of the larger sizes of dogfish in the deeper water, already demonstrated earlier in this paper. The segregation is upset only by the inward migration of the pregnant females in the summer and early autumn.

Ford has measured large numbers of embryo dogfish throughout the seasons, with very instructive results. In my judgment, he proves beyond doubt that the breeding season has definable limits, and that embryonic development is lengthy, taking about 25 months. Ford concludes that " from September onwards, specimens from 23 to 31 cm., inclusive, satisfy the conditions for birth." These results are based on samples of dogfish landed at Plymouth. Owing to this protracted gestation period, " on any one day, the embryos are separable into two or three distinct size groups, according to the time of the year."

I have measured a certain number of the embryos found in the pregnant females fished by the *George Bligh*, and my results entirely confirm Ford's. The embryos fell into two distinct groups. One consisted of embryos between 4 and 7 cm. in length, of which very few were measured, while the larger group consisted of embryos between 18 and 27 cm., of which 233 were measured. In Table III are shown the length-frequencies of the embryos measured in the three regions.

TABLE III

MEASUREMENTS OF EMBRYO DOGFISH, GROUPED BY REGIONS.

Length in cm.	Banks-Westward.	Fastnet.	Galway-Bull.
18	–	1	–
19	–	5	1
20	–	9	4
21	2	9	15
22	8	19	17
23	9	27	10
24	13	10	24
25	5	4	12
26	–	–	5
27	–	–	2
Totals	37	84	90
Mean length	23·3	22·2	23·1

Few measurements are available from the Banks-Westward region, but the Galway-Bull embryos were plainly slightly more advanced than the Fastnet embryos, a fact which is wholly consistent with the suggestion that there is an earlier inward migration of the pregnant females in the Galway-Bull region. But the differences are slight, and it is evident that there would be no great lag in the time of birth of the young as between these three regions.

The length distribution of the embryos in my samples agrees with Ford's August measurements.

In Figure 8 are drawn two curves. The pecked line shows the frequency at each centimetre length of the embryos of the larger group (all stations combined), the continuous line, the length-frequencies of the fish in the first mode of free-living young. The data are given in the Appendix, Table XVII. There is an overlap between the curves. Four fish, between 23 and 25 cm. in length, which have been measured with the free-living young, can probably be neglected, for they were almost certainly squeezed from the parent by the violence of capture. Apart from these, the curve for unborn young ends, and that for free-living young commences, at 27 cm.

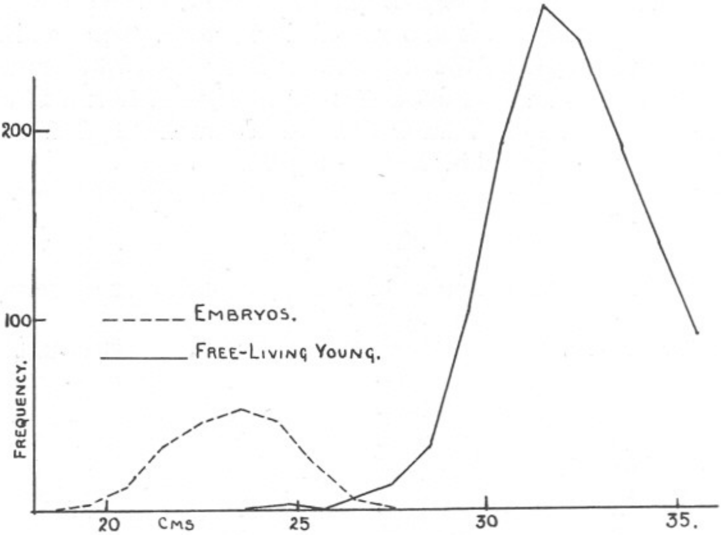

FIG. 8.—Frequency curves of embryos and free-living young of first mode. All stations, *George Bligh*, August, 1928. Data in Table XVII.

It is curious that the modes of the curves for unborn and free-living young should be so widely separated. The modal lengths are roughly 23 and 32 cm.—9 cm. apart. There are four possibilities.

(1) Growth may be very rapid immediately after birth.

(2) There may be a periodicity in the growth and birth of the embryos, such that the smallest free-living young belong to an earlier " wave."

(3) There may be a high mortality among the smaller newly-born fish. The resulting survival of the larger fish would effectively shift the modal-length of the free-living young to the right.

(4) The birth of the young may not have yet begun, contrary to what

has been suggested earlier in this paper. The free-living young may therefore belong to last year's brood, which has grown 9 cm. in the interval.

Taking the last suggestion first, it is very unlikely that this is the correct explanation, because Ford finds that unborn embryos may reach a length of 31 cm. ; secondly, because there is a continuity between the curves for unborn and free-living young, in Figure 8, and 9 cm. seems, on the face of it, to be too small an increment in a year ; and, finally, because, in many of the free-living young, the umbilical scar was still plainly visible, pointing to very recent birth.

While the third possibility given above is quite strong enough to be borne in mind, Ford's extensive measurements do not confirm the fourth suggestion, that there is a periodicity in the birth of the young.

When "condition" is dealt with later in this paper, it will be shown that there is a heavy loss in the condition of the liver as between unborn and free-living dogfish ; in my view, growth immediately after birth is very rapid, and is carried out at the expense of the reserve materials stored in the liver of the embryo.

Summing up the results of the first section of this paper, the distribution of the dogfish at the time of the voyages is as follows : the males are present in shallower water than the females, and, owing to the strict segregation of the fish of both sexes according to size, and the smaller size attained by the males, in the deeper water females predominate. These big females are mostly pregnant, and make a migration from the deep to the shallow water to bear their young. The young are born at about 26 cm., and, growing rapidly, move off to deeper water, the males already separating in shallower water than the females. Apart from the inward migration of the pregnant females, the dogfish seem strictly segregated according to size, in such a way that the larger fish are found in deeper water. The same segregation, according to size, was observed during the voyages of the *Florence Brierley*, in the early spring ; it probably holds good at all times of the year.

The inward migration of the pregnant females, and the bearing of the young, seem to proceed from west to east, the process being most advanced to the West of Ireland, and least advanced in the latitude of Cornwall. This roughly-sketched picture will be compared, in the discussion, with Ford's notes on the dogfish landed at Plymouth market.

II. CONDITION.

A considerable number of weighing experiments were made on the Dogfish during the cruises of the *George Bligh*. The degree of accuracy, to be expected in weighings made at sea, is discussed in Section A of my

Hake report (1930). Only larger dogfish, of more than 50 cm., were dealt with in these weighing experiments.

The procedure was as follows : the fish was first measured, then the gut and gonads were removed, and the gutted fish weighed. The liver was then weighed, the stomach-contents, if any, noted, and, if the fish were a female, whether it were pregnant or not. Any embryos were removed and measured.

The data obtained were, length, sex, sexual condition, weight of liver, and weight of flesh. By " flesh " is here meant the gutted fish.

The data are set out in the Appendix, Table XVIII. The dogfish have been grouped into three classes, namely, males (without distinction into mature and immature), immature and non-pregnant females, and pregnant females. Each class is further sub-divided into 10-cm. groups, and for each 10-cm. group the mean length, mean weight of liver, and mean weight of flesh has been calculated. Further, the value of the " coefficient of condition " k has been calculated for each 10-cm. category. This " coefficient k " is given by the weight of the liver, or flesh, as the case may be, divided by the cube of the length of the fish. The value so obtained has been multiplied by 100 in order to eliminate two decimal places.

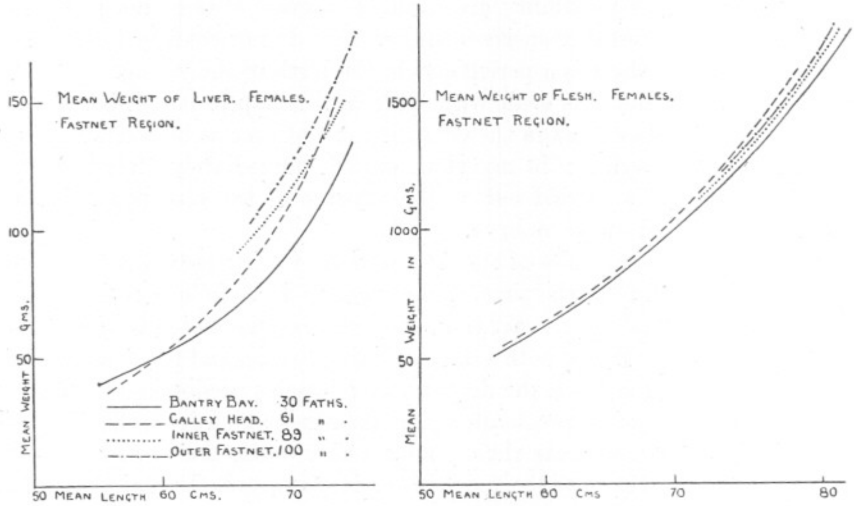

Fig. 9.

Fig. 10.

Figs. 9 and 10.—Fastnet Region. Curves showing increase in mean weight of liver (Fig. 9), and flesh (Fig. 10), with increase of length, in immature and non-pregnant females. August, 1928. Data from Table XVIII.

Selig Hecht (1913) published a note on the relation of weight to length in the dogfish *Mustelus canis*. He found that there was no sexual difference in the relation of weight to length in this fish. When weight was plotted against length, a curve drawn through the plotted points was found to have the form,

$$y = ax^3,$$

where y is the weight, x the length, and a a constant "whose value depends on the units used." He found that the variations in the value of a with length are very slight, and therefore that "the relation of form to mass is clearly indicated by the young fish, and is continued with apparent mathematical accuracy as the fish increases in length and weight." Using his weight determinations, one can show that the value of the coefficient k is highest in the 40–50-cm. group, and decreases until the 70–80-cm. group, after which there is a recovery in the 80–90-cm. group. But it is hardly feasible to compare Hecht's figures with mine, since he has not distinguished, in his means, between females and males, nor between pregnant and non-pregnant females.

An inspection of the data in the Appendix, Table XVIII, will show clearly that the coefficient k is not a constant in the case of either the liver or the flesh, in my observation. In the liver it increases slowly with increase of length, a fact which will be given special emphasis in the discussion, and, in the flesh, as in Hecht's material, it decreases slowly with increase of length. But, for the present purpose, it may be considered constant over a short range of length, and therefore in comparing fish whose mean length varies only slightly from sample to sample. At the same time, this variation renders it risky to compare the mean value of k in samples with a wide range of length. In this section, therefore, the data are divided into length-groups, and the means for the groups compared in the different samples.

First, however, the mean values for all the fish of each biological sub-group, at each station, may be examined. In Table IV below are set out the mean value of k (liver) and k (flesh) in the males, with the mean depth of the stations, and the number and mean length of the fish examined.

TABLE IV.

ALL STATIONS. MALES. MEAN VALUE OF k (LIVER) AND k (FLESH).

Station.	Mean Depth.	Number of fish.	Mean length.	Mean value k (liver).	Mean value k (flesh).
Bantry Bay	30	40	67·0	·0229	·280
Galley Head	61	36	65·3	·0267	·290
"Station 18"	69	25	67·8	·0310	·293
Between Banks	69	25	61·1	·0238	·259
Cockburn Bank	81	20	64·5	·0288	·295
Inner Fastnet	89	25	69·9	·0327	·294
Outer Fastnet	100	30	69·7	·0339	·289
Westward	105	6	71·2	·0349	·292

This table shows clearly that the mean value of k (liver) increases with increase of depth. The only discrepancies are the Banks and Cockburn Bank samples, which give lower values than the other stations of comparable depth. But the table shows that these fish also had a lower mean length than those of these other stations. The mean values for the flesh do not show such a definite relation with depth.

In Table V, a similar comparison is made for immature and non-pregnant females.

TABLE V.

ALL STATIONS. IMMATURE AND NON-PREGNANT FEMALES. MEAN VALUE OF k (LIVER) AND k (FLESH).

Station.	Mean Depth.	Number of fish.	Mean length.	Mean value k (liver).	Mean value k (flesh).
Bantry Bay	30	44	64·2	·0263	·289
Galley Head	61	51	66·8	·0298	·306
" Station 18 "	69	28	67·4	·0325	·305
Between Banks	69	20	57·9	·0245	·274
Cockburn Bank	81	19	63·3	·0252	·295
Innet Fastnet	89	32	70·3	·0352	·303
Outer Fastnet	100	26	73·5	·0407	·298
Westward	105	8	74·4	·0372	·308
Bull	130	15	75·6	·0409	·314

In immature and non-pregnant females also, there is a very well marked increase in the value of the coefficient k (liver) with increase of depth. As in the males, the stations in the Banks-Westward group give lower values than the other stations of a comparable depth. The mean values for k (flesh) do not show the same relation to depth.

In every case, the mean value for k (flesh) is greater in the female than in the male, and in every case except the Cockburn Bank station the value of k (liver) is greater in the female than in the male.

Finally, in Table VI are compared the mean values for k (liver) and k (flesh) in pregnant females.

TABLE VI.

ALL STATIONS. PREGNANT FEMALES. MEAN VALUE OF k (LIVER) AND k (FLESH).

Station.	Mean Depth.	Number of fish.	Mean length.	Mean value k (liver).	Mean value k (flesh).
Inside Aran Islands	21	8	87·9	·0222	·306
Bantry Bay	30	12	85·3	·0227	·302
Galway Bay	55	33	85·5	·0263	·305
Galley Head	61	9	83·3	·0334	·337
Westward	105	13	82·0	·0351	·322

It is clear, from Table VI, that in pregnant females, as in the other two biological sub-groups of the dogfish, there is a very well marked increase in the value of *k* (liver), with increase of depth, and that this increase is not shown, at least so distinctly, in the values of *k* (flesh).

In the Bantry Bay and Westward samples, the mean value for *k* (liver) is distinctly less in pregnant than in non-pregnant females, that for *k* (flesh) greater. The latter is at first sight understandable, since the mean length of the pregnant females is much greater than that of the non-pregnant females. Later in this section, it will be shown that, even when the effect of a different mean length is minimised, the liver of the pregnant female is generally lighter, the flesh generally heavier, than in non-pregnant females.

Tables IV, V, and VI show that, in many of the stations, the sampling is fairly adequate, at others, where very few dogfish were found, it is, of course, less satisfactory. But since the values for the coefficient *k* are not constant with increase of length, it will be necessary to confirm the conclusions drawn from Tables IV, V, and VI, by an examination of the fish divided into 10-cm. categories.

The 10-cm. categories into which the data have been grouped are 50–59 cm., 60–69 cm., etc., the number of weighings from which the mean has been calculated varies considerably from sample to sample, and the reliability of the mean varies accordingly. But, in the Fastnet group of stations, the sampling is satisfactory, and one can regard the results with some confidence. The stations in the Fastnet region will therefore be discussed first, and a comparison will then be made between the Fastnet group of stations and the remaining two groups of stations.

In Figure 9 four curves are drawn. Each curve represents the increase in mean weight of the liver, with increase of length, in immature and non-pregnant female dogfish. The four curves refer to the four stations of the Fastnet group. They are distinguished by conventional signs explained in the figure. An inspection of the curves will show that they arrange themselves in such a way that the lowest curve is that for the Bantry Bay sample, the highest, the Outer Fastnet sample, in other words, the mean weight of the liver increases with increase of depth. This may also be demonstrated by using the coefficient *k*, as in the Table below, which has been extracted from Table XVIII.

TABLE VII.

FASTNET GROUP. IMMATURE AND NON-PREGNANT FEMALES. LIVER.

		50–59 cm.		60–69 cm.		70–79 cm.	
Station.	Depth. Fathom.	Mean length.	Mean value of *k* (liver).	Mean length.	Mean value of *k* (liver).	Mean length.	Mean value of *k* (liver).
Bantry Bay	30	55·0	·0234	64·7	·0250	74·3	·0310
Galley Head	61	55·5	·0216	64·6	·0267	72·3	·0351
Inner Fastnet	89	58·5*	·0238*	65·8	·0321	73·1	·0355
Outer Fastnet	100	—	—	67·3	·0345	75·2	·0413

* Omitted in Figure 9.

In all three length-categories dealt with in the table, the value of k (liver) increases with increase of depth; the only discrepancy is the value of the mean for 50–59 cm. in the Galley Head sample.

In Figure 10 are drawn the four corresponding curves for the mean weight of flesh in the stations of the Fastnet group. The flesh, like the liver, is seen to show a tendency towards an increase in mean weight with increase of depth, though this is not so well-marked as in the liver. The curve for Galley Head, in particular, is high, and the large fish at this station were heavier than the fish of corresponding size at either the Inner or the Outer Fastnet. In the table below are set forth the values of the coefficient k (flesh).

TABLE VIII.

FASTNET GROUP. IMMATURE AND NON-PREGNANT FEMALES. FLESH.

		50–59 cm.		60–69 cm.		70–79 cm.	
Station.	Depth. Fathom.	Mean length.	Mean value of k (flesh)	Mean length.	Mean value of k (flesh)	Mean length.	Mean value of k (flesh).
Bantry Bay	30	55·0	·289	64·7	·289	74·3	·290
Galley Head	61	55·5	·295	64·6	·297	72·3	·325
Inner Fastnet	89	58·5	·313*	65·8	·302	73·1	·299
Outer Fastnet	100	—	—	67·3	·287	75·2	·301

* Omitted in Figure 10.

The relation between depth and "condition" in the flesh can still be traced, but there is a discrepancy in the 60–69-cm. category, where the Outer Fastnet value is lower than the Inner Fastnet value, and in the 70–79-cm. category, where the Galley Head value is very high.

In Figure 11 are set forth the curves for increase in weight of the liver, with increase of length, in male dogfish in the four Fastnet stations. These curves show, even more clearly than those for the females, the increase in mean weight of the liver with increase of depth. There is one curious difference between males and females, however; as Figure 11 shows, the curve for increase of weight with increase of length does not continue to rise, but falls away from the 60–69-cm. category to the 70–79-cm. category. This falling-off in the condition of the larger (and older) males may also be observed in the variations in the value of the coefficient k (liver).

TABLE IX.

FASTNET GROUP. MALES. LIVER.

		50–59 cm.		60–69 cm.		70–79 cm.	
Station.	Depth. Fathom.	Mean length.	Mean value of k (liver).	Mean length.	Mean value of k (liver).	Mean length.	Mean value of k (flesh).
Bantry Bay	30	57·2	·0179	66·5	·0240	72·8	·0235
Galley Head	61	56·8	·0221	66·0	·0278	72·7	·0275
Inner Fastnet	89	—	—	66·4	·0327	72·3	·0326
Outer Fastnet	100	—	—	67·5	·0317	72·2	·0365

There is only one exception to the otherwise perfectly demonstrated increase in mean weight with increase in depth ; this is in the 60–69-cm. category, where it is seen that the Outer Fastnet sample gives a low value of k (liver).

When the curves for increase of weight in the flesh, with increase of length, are drawn, an increase of mean weight with increase of depth is shown more definitely than in the female, though not nearly so well as the liver in either sex. These curves are not shown in the text, since it is plain that the flesh does not share, to an extent comparable with the liver, in the curious agreement between depth and condition to which this section draws attention. The values of the coefficient k will be sufficient to indicate the variations in the condition of the flesh, with regard to depth.

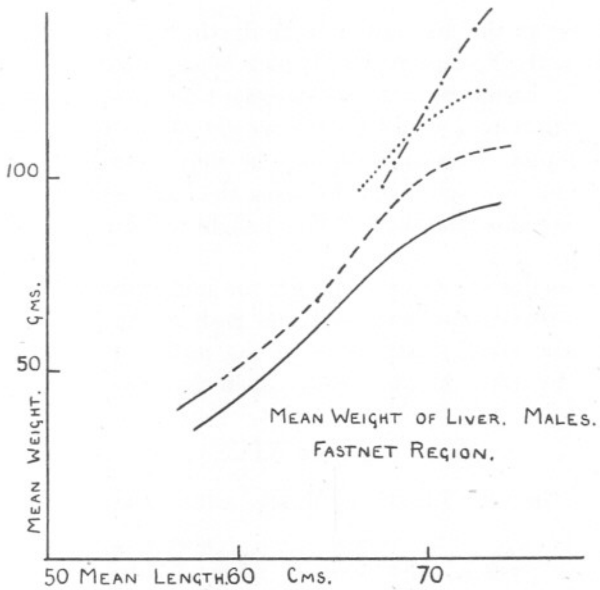

FIG. 11.—Fastnet Region. Curves showing increase in mean weight of liver, with increase of length, in male dogfish. *George Bligh*, August, 1928. Data from Table XVIII.

When these variations, in the case of the males, are examined, as in the table below, it is seen that the Inner and Outer Fastnet samples, in the 60–69-cm. category, have lower values than the Galley Head sample, while, in the 70–79-cm. category, the Outer Fastnet value is lower than the Inner Fastnet value.

TABLE X.

FASTNET GROUP. MALES. FLESH.

Station.	Depth. Fathom.	50–59 cm. Mean length.	50–59 cm. Mean value of *k* (flesh).	60–69 cm. Mean length.	60–69 cm. Mean value of *k* (flesh).	70–79 cm. Mean length.	70–79 cm. Mean value of *k* (flesh).
Bantry Bay	30	57·2	·283	66·5	·281	72·8	·276
Galley Head	61	56·8	·287	66·0	·292	72·7	·285
Inner Fastnet	89	—	—	66·4	·287	72·3	·298
Outer Fastnet	100	—	—	67·5	·290	72·2	·287

In summing up the deductions to be drawn from this examination of the data from the Fastnet region, it may be said that the liver, in both males, and in immature and non-pregnant females, shows a striking agreement with depth, such that the weight of the liver increases with increase of depth. This increase may be shown both by an inspection of the actual mean weights, and by using the length-weight coefficient *k*. The flesh shows this relation to a much slighter degree, especially in the deeper water.

When the males are compared with the immature and non-pregnant females, it is found that both liver and flesh in the female are slightly heavier, at any given depth, than in the male. This may be shown conveniently by using the coefficient *k*, as in the table below.

TABLE XIA.

FASTNET GROUP. LIVER IN MALES AND FEMALES COMPARED.

Station.		Depth. Fathom.	50–59 cm. Mean length.	50–59 cm. Mean value of *k* (liver).	60–69 cm. Mean length.	60–69 cm. Mean value of *k* (liver).	70–79 cm. Mean length.	70–79 cm. Mean value of *k* (liver).
Bantry Bay	♂	30	57·2	·0179	66·5	·0240	72·8	·0235
	♀		55·0	·0234	64·7	·0250	74·3	·0310
Galley Head	♂	61	56·8	·0221	66·0	·0278	72·7	·0275
	♀		55·5	·0216	64·6	·0267	72·3	·0351
Inner Fastnet	♂	89	—	—	66·4	0327	72·3	·0326
	♀		—	—	65·8	·0321	73·1	·0355
Outer Fastnet	♂	100	—	—	67·5	·0317	72·2	·0365
	♀		—	—	67·3	·0345	75·2	·0413

FASTNET GROUP. FLESH IN MALES AND FEMALES COMPARED.

Bantry Bay	♂	30	57·2	·283	66·5	·281	72·8	·276
	♀		55·0	·289	64·7	·289	74·3	·290
Galley Head	♂	61	56·8	·287	66·0	·292	72·7	·285
	♀		55·5	·295	64·6	·297	72·3	·325
Inner Fastnet	♂	89	—	—	66·4	·287	72·3	·298
	♀		—	—	65·8	·302	73·1	·299
Outer Fastnet	♂	100	—	—	67·5	·290	72·2	·287
	♀		—	—	67·3	·287	75·2	·301

The exceptions to the above, in the case of the liver, are in the 50–59-cm. and 60–69-cm. category in the Galley Head sample, and the 60–69-cm. in the Inner Fastnet sample. In the case of the flesh, the only exceptions are the Outer Fastnet values at 60–69 cm., in which the male is slightly heavier than the female. The table justifies one, in my opinion, in stating that the liver and flesh of the female dogfish tend to be heavier, at any given depth, than the liver and flesh of the male.

Hitherto, we have only considered immature and non-pregnant females. In the Fastnet group of stations sufficient numbers of pregnant females to be worth discussing were only found at the Bantry Bay and Galley Head stations. As Table VI shows, pregnant females in the Bantry Bay sample (30 fathoms) had both liver and flesh considerably lighter than in the Galley Head sample (61 fathoms). In this series of stations, therefore, pregnant females show the same increase in mean weight, with increase of depth, shown by immature and non-pregnant females, and by males.

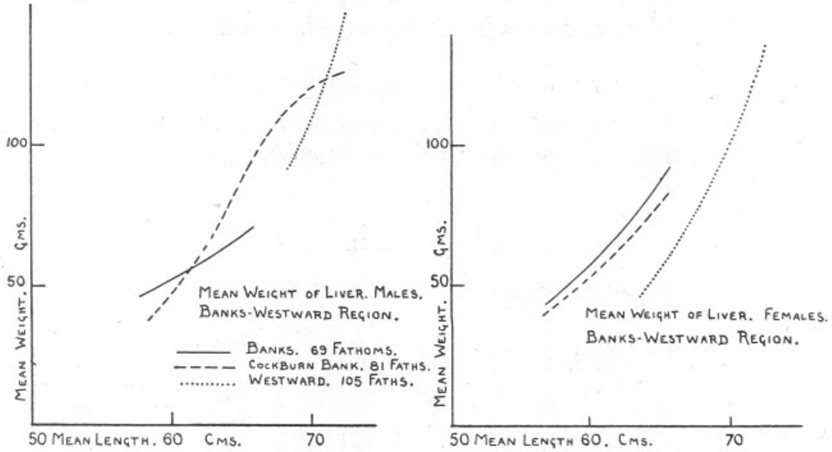

Fig. 12.

Fig. 13.

Figs. 12 and 13.—Banks-Westward Region. Curves showing increase in mean weight of liver, with increase of length, in male (Fig. 12) and female (Fig. 13) dogfish. *George Bligh,* August, 1928. Data from Table XVIII.

These results, based on the well-sampled Fastnet group of stations, confirm, by an inspection of the 10-cm. categories, the conclusions, based on the mean values of all specimens, drawn from Tables IV and V; they may now be compared with the Banks-Westward, and Galway-Bull groups of stations.

A comparison of the mean weights of liver and flesh at the three stations in the Banks-Westward group of stations is difficult, because, as we have seen in Section I, larger fish, especially females, are rare or absent in the Banks and Cockburn Bank samples, while smaller fish are lacking in the Westward sample.

In Figure 12 are drawn three curves, distinguished by conventional signs, representing the increase of mean weight of the liver of male dogfish, with increase of length, in the three stations of the Banks-Westward series. The curves do not lie parallel to one another, and do not show the same increase in mean weight, with increase of depth, shown by the fish in the Fastnet region. The curves for the shallowest (Banks), and the deepest station (Westward), are continuous with each other, while the curve for the Cockburn Bank sample cuts both, showing the same falling-off at the higher-length category shown by the males in the Fastnet stations.

In Figure 13 the corresponding three curves for the females are drawn. Here there is a definite relation between mean weight and depth, but it is the reverse from what was found in the Fastnet region. Here, the mean weight of the liver decreases with increase of depth.

In the table below are set out the values for the coefficient k in both liver and flesh, for both sexes, in the three stations of the Banks-Westward region.

An inspection of this table shows that the relation between depth and condition in the liver tends to be an inverse one, especially in the female, whereas the flesh tends to show a direct correlation between depth and condition.

TABLE XIB.

BANKS-WESTWARD GROUP. BOTH SEXES. LIVER.

			50–59 cm.		60–69 cm.		70–79 cm.	
Station.		Depth. Fathom.	Mean length.	Mean value of k (liver).	Mean length.	Mean value of k (liver).	Mean length.	Mean value of k (liver).
Between Banks	♂	69	58·0	·0238	64·6	·0237	—	—
	♀		57·1	·0237	65·0	·0317	—	—
Cockburn Bank	♂	81	58·3	·0187	64·8	·0307	71·2	·0343
	♀		56·5	·0218	63·9	·0279	76·0	·0171
Westward	♂	105	—	—	68·5	·0288	72·5	·0381
	♀		—	—	63·5	·0177	76·5	·0454

BANKS-WESTWARD GROUP. BOTH SEXES. FLESH.

Between Banks	♂	69	58·0	·261	64·6	·257	—	—
	♀		57·1	·277	65·0	·246	—	—
Cockburn Bank	♂	81	58·3	·268	64·8	·300	71·2	·305
	♀		56·5	·297	63·9	·294	76·0	·296
Westward	♂	105	—	—	68·5	·319	72·5	·279
	♀		—	—	63·5	·258	76·5	·319

When the values of k (liver) and k (flesh) in males and females are compared, as in the table above, it is apparent that, in some cases, the liver and flesh are heavier in the male than in the female, while, in other cases, the reverse is true. Thus, the male liver is lighter than the female liver in the Cockburn Bank sample at 50–59 cm., in the Banks sample at 60–69 cm., and in the Westward sample at 70–79 cm. The male flesh is lighter than the female flesh in the Banks, and Cockburn Bank samples at 50–59 cm., in none of the samples at 60–69 cm., and in the Westward sample at 70–79 cm.

Thus, neither the increase in mean weight of the liver, with increase of depth, nor the greater mean weights of liver and flesh in the female, are definitely confirmed by the Banks-Westward samples, and, though the data available from these are inadequate for a comparison with the Fastnet samples, they must be borne in mind, especially the reversal of the depth-weight relation in the females in the Banks-Westward region.

In the Galway-Bull group, a profitable comparison is only possible as between the pregnant females, since males of a size greater than 50 cm. were practically absent from all three stations, and immature and non-pregnant females were absent from the Galway Bay sample, and from the sample from very shallow water inside the Aran Islands. It may be pointed out, however, that, as Table V shows, immature females have a very high value of k (liver) (·0409) in the Bull sample (130 fathoms). This is also true of the flesh.

Comparing the pregnant females in Table VI from the station inside the Aran Islands (21 fathoms) with those from the Galway Bay station (55 fathoms), it can be seen that the flesh of the pregnant females at these two stations is approximately equal, the liver distinctly lighter in the shallower station.

It should be interesting to compare the mean weight and the mean value of the coefficient k, in pregnant females from the Galway-Bull groups of stations, with the Fastnet and Banks-Westward groups of stations, because it was suggested, in the first section of this paper, from an examination of the length-distributions, that the three groups of stations showed, in the order named, a progressively later stage in the birth of the young. The comparison may be made by an inspection of Table VI.

The lowest value of k, in the flesh, is found in the Bantry Bay sample. The very shallow water station inside the Aran Islands, and the Galway Bay station, have values which, though equal to, or higher than those for Bantry Bay, are considerably less than those for Galley Head, and the Westward ground. The last-named stations have liver and flesh showing contrary tendencies. The liver in the Westward sample is considerably heavier than the liver in the Galley Head sample, but the flesh in the Westward sample is slightly lighter than the flesh in the Galley Head sample. But before the data in this table can be examined for confirmation, or the reverse, as to whether the process of parturition of the year's brood of young progresses from west to east, as suggested earlier in this paper, the liver and flesh in pregnant and non-pregnant females must be compared.

A direct comparison is possible at only two stations, namely, Galley Head, and the Westward, since the fish compared must be of approximately equal length.

In Table XIIA, below, are set out the mean weights, and the mean values of the coefficient *k*, in both liver and flesh, at these two stations, in the 80–89-cm. category.

TABLE XIIA.

COMPARISON OF LIVER AND FLESH IN PREGNANT AND NON-PREGNANT FEMALES. 80–89 CM.

Station.	Depth.	Mean length.	Mean weight (liver).	Mean value *k* (liver).	Mean weight (flesh).	Mean value *k* (flesh).
Galley Head, pregnant	61	83·3	192	·0334	1950	·337
non-pregnant		81·7	233	·0428	1730	·318
	Difference		−41	−·0094	+220	+·019
Westward, pregnant	105	84·5	215	·0353	1960	·325
non-pregnant		81·0	215	·0403	1800	·339
	Difference		0	−·0050	+160	−·014

Both stations agree in the following points : The liver of the pregnant female is lighter, having regard to the mean lengths, than that of the non-pregnant female, and the flesh of the pregnant female is heavier than that of the non-pregnant female. In the 70–79-cm. group, in the Westward sample, the liver is considerably lighter in the pregnant than in the non-pregnant fish, but the flesh is also lighter. As Table XVIII in the Appendix shows, the value of *k* (liver) is always low in pregnant females.

A voyage made on the Fleetwood steam-trawler *Kumu* in October, 1928, to the Inishtrahull grounds, off the north-west of Ireland, gave me a good opportunity to compare the mean weight of liver and flesh as between non-pregnant females, females early in pregnancy, and females late in pregnancy. As in Ford's November samples at Plymouth, there were three groups of embryos at this time. There were large embryos, from 22 to 27 cm., smaller embryos from 7 to 10 cm., and, finally, very young embryos still enclosed in their horny capsules. The female dogfish were divided into three classes, namely, non-pregnant females, females containing horny capsules, and females containing embryos of the two larger sizes. The length-category 80–89 cm. was chosen for the comparison, which is made in the table below.

TABLE XIIB.

INISHTRAHULL. OCTOBER, 1928. COMPARISON OF CONDITION IN FEMALES 80–89 CM.

Female category.	Mean length.	Mean wt. of liver.	Mean value of *k* (liver).	Mean wt. of flesh.	Mean value of *k* (flesh).
1. Non-pregnant	81·9	238	·0433	1625	·296
2. Pregnant (Capsules)	83·8	232	·0391	1810	·308
3. Pregnant (Embryos)	86·0	167	·0261	1945	·305

In comparing the non-pregnant females (row 1) with the pregnant females containing embryos (row 3), exactly the same relation between the two classes is shown, as has been described in the Galley Head and Westward samples. The liver is considerably lighter in pregnant than in non-pregnant females, the flesh decidedly heavier.

In the pregnant females containing capsules, that is, in an early state of pregnancy, the liver is only slightly lighter than the liver of non-pregnant females, but the flesh is already decidedly heavier. Thus one may suggest that the liver is gradually drained of its resources during pregnancy; but the increase of weight of the flesh may be due to a development of the musculature to cope with the extra work involved during the long period of pregnancy.

Returning to Table VI, it is seen that, although the Bantry Bay sample has the lowest k value of liver and flesh, the two stations in the Galway-Bull group have lower combined k values of liver and flesh than the two stations in the Fastnet group, and may therefore probably show a more advanced state of pregnancy in the females, subject to the qualification set out in the following paragraph.

On the other hand, Table XIIA also shows that the difference between the mean weights of the liver and flesh in pregnant and non-pregnant females is much less in the Westward than in the Galley Head sample. In the dogfish samples obtained on the voyages of the *Florence Brierley*, there was no difference between the mean values for k (liver) in pregnant and non-pregnant females. The mean value of k (liver) in the pregnant females was ·042, identical with that for the non-pregnant females. These fish were all taken in very deep water, and it may therefore be possible that the greater part of the weight of the liver lost by the pregnant females may be lost during the actual inward migration from deep to shallow water.

During the 1928 cruise of the *George Bligh* I made a note that the liver of the embryo dogfish appeared remarkably creamy and full, almost filling the body-cavity. During the 1929 cruise, I was able to make some experiments to test this.

The modal length of the embryos found in Galway Bay was 21 cm., and the first mode of free-living young was at 29 cm. The value of k (liver) in the embryos at the modal length (mean of 9 specimens) was ·033, in the free-living young (mean of 15 specimens) ·025. Thus, from an investigation of an admittedly small number of fish, the conclusion seems to be confirmed that the liver in the embryo is very much heavier, relatively, than the liver in the newly-born fish, and that the very rapid growth which seems to take place immediately after birth may be at the expense of the material stored in the liver. Reach (1912) finds that, in Torpedo, the embryo collects reserve fat in the liver, at the expense of the yolk.

During the exploratory voyages for Hake organised by the Fleetwood

Fishing-Vessel Owners' Association, in March, April, and May, 1927, I was able to make some weighing experiments on Dogfish at times when this fish was being caught, but when Hake were few or absent. The liver only was weighed. The results were read at the meeting of the British Association (Section D) at Leeds, in August, 1927. Owing to the fact that the data were too scanty to be grouped in 10-cm. categories, the mean value for the coefficient *k* in all the fish in the sample is used. Full data are given in the Appendix, Table XIX. The results are shown in Figure 14.

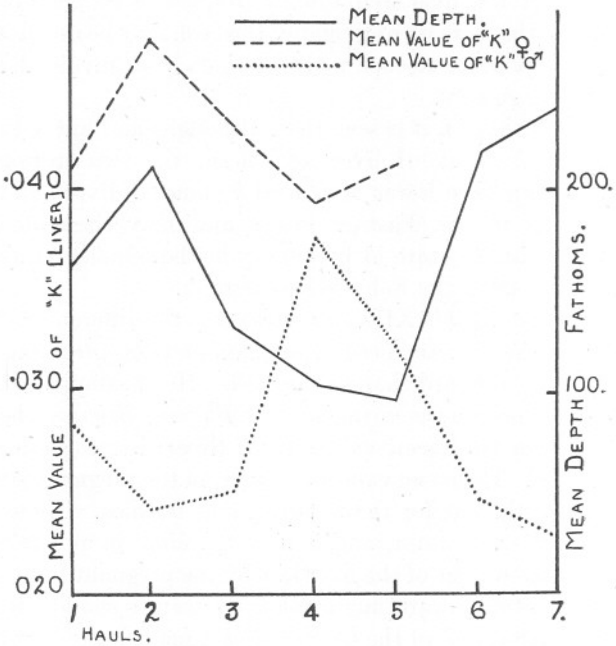

FIG. 14.—Curves showing the correlation between mean depth, and mean value of *k* (liver), in males and females. *Florence Brierley*, April, 1927. Data in Table XIX.

The numbers along the abscissa are the serial numbers of the hauls, in the order in which they were made in the Faroe-Shetland Channel. These numbers may be compared with the numbers in the Appendix,* from which the details of the hauls may be gleaned. The ordinates represent the mean value of the coefficient *k* (liver) (scale on the left), and the mean depth of haul (scale to right).

Three curves are drawn. The continuous line represents the mean depth, the pecked line the mean value of *k* (liver) in the females, and the dotted line the mean value of *k* (liver) in the males.

There is a direct coincidence between the mean value of *k* (liver) and the

* Table XIX.

depth of haul in the female, and in this respect the work on the *Florence Brierley* confirms well the results of the *George Bligh.* A second point in which the two sets of experiments confirm one another is in the much smaller mean weight of the liver in the male as compared with the female. Where they differ entirely is in the relation between the mean value of k (liver) and the mean depth of haul, in the males. Whereas in the experiments on the *George Bligh* we found that the mean weight of the liver increased with increase of depth, in the experiments on the *Florence Brierley* the reverse was true, and there was a strikingly good inverse relation between the mean depth of haul and the mean value of the coefficient k (liver).

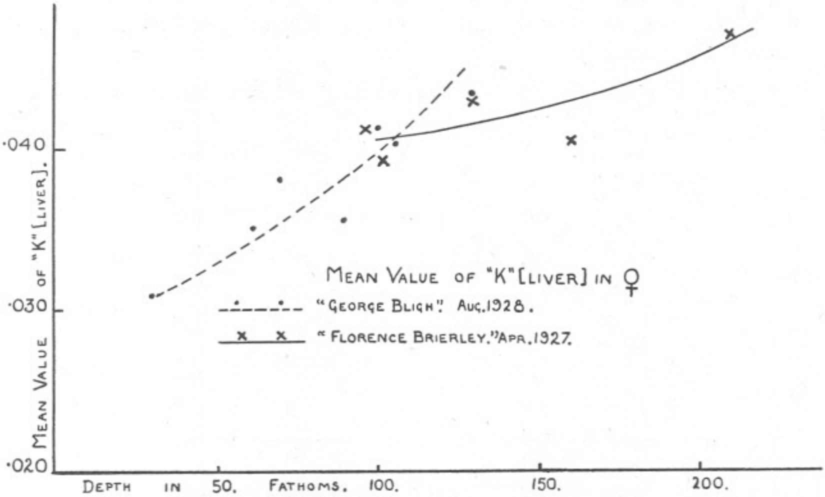

FIG. 15.—Curves drawn roughly through the plotted points for increase in mean value of k (liver), with increase of depth. Females. *George Bligh* and *Florence Brierley*. Data in Tables XVIII and XIX.

In Figure 15 free-hand curves are drawn through the plotted points for mean value of k (liver) in the immature and non-pregnant females from the *George Bligh* series of observations (black dots), and from the *Florence Brierley* series (crosses). As the table in the Appendix shows, the mean length of the females in the *Florence Brierley* samples varied between 74·7 and 83·9 cm., hence they have been compared with the length-category 70–79 cm. in the *George Bligh* series. A further point to notice is, that, in the *Florence Brierley* samples, pregnant and non-pregnant females have not been distinguished ; but, as has been stated, there was no difference in the mean value of k (liver) in pregnant and non-pregnant females.

Figure 15 shows that the two series of samples give free-hand curves which are very similar and reasonably continuous. The curve derived from the *Florence Brierley* samples is decidedly flatter than that derived from the *George Bligh* samples, but one may say that, on the whole, the *Florence Brierley* samples, which continue into deeper water than the *George Bligh* samples, also continue the upward slope of the curve for mean value of the coefficient k (liver).

In Figure 16 are drawn the corresponding curves for males in the two series of samples. As in the females, the males in the *Florence Brierley* samples are compared with the males of 70–79 cm. in the *George Bligh* samples, since the males in the former have a range in mean length of 70·3 to 74·6 cm., or very similar to that of the males of 70–79 cm. in the *George Bligh* samples.

Owing chiefly, no doubt, to the difficulty of assigning a correct mean depth of haul to the hauls made on the slope, which is very steep beyond 150 fathoms in the Faroe-Shetland Channel, the plotted points for the *Florence Brierley* males are scattered somewhat irregularly as compared with the *George Bligh* males. None the less, where the depths worked by the two expeditions meet, at 90–110 fathoms, their plotted points are in good agreement, and the two curves are wholly comparable.

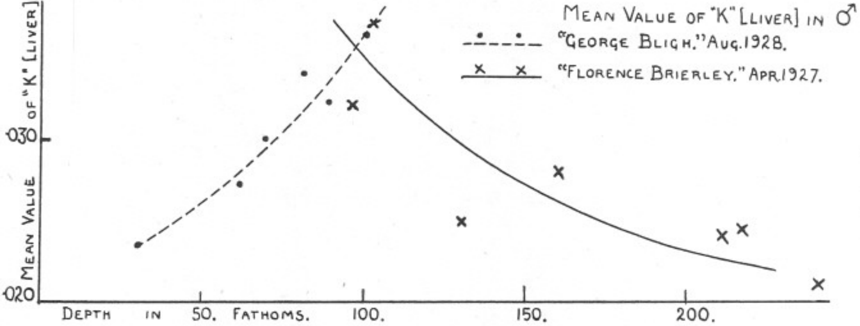

FIG. 16.—Curves drawn roughly through the plotted points for increase in mean value of k (liver), with increase of depth. Males. *George Bligh and Florence Brierley.* Data in Tables XVIII and XIX.

Figure 16 therefore shows that, in male dogfish, the mean value of k (liver) increases, with increase of depth, to a depth between 90 and 110 fathoms. At depths greater than this, the mean value of k (liver) decreases with increase of depth.

In the first section it has been stated that, at or over very great depths, were found shoals of exclusively male dogfish ; these may certainly be regarded as having been taken in midwater during the hauling or shooting of the trawl. In my report on the fishes taken by the *Florence Brierley* (Hickling, 1928), I have shown that Acanthias was taken at every depth fished, from 90–100 to 500–520 fathoms. At depths greater than about 250 fathoms, males alone were taken. Hjort (1912) records the finding of *Acanthias vulgaris* living pelagically over very great depths north of the Faroes. Hence it would appear that, possibly at all depths, and certainly over the very deep water in the region of the continental slope, the spur-dog can, and does, live pelagically.

Figures 15 and 16 should therefore be interpreted thus, in my view. The females are bottom-living to a greater extent than the males, and, while it is possible that, as indicated, perhaps, by the flattening of the curve, in Figure 14, beyond 100 fathoms, they become to some extent pelagic in deeper water, the males certainly do so beyond this depth, and, from this depth toward deeper water, tend to live more and more pelagically, that is, for an increasingly large proportion of the fish to have been taken at depths intermediate between surface and bottom. This would explain the progressive decrease in mean weight of the liver in the males, with apparent increase of depth, beyond about 100 fathoms ; it is entirely consistent with the curious segregation of males alone in, or over, very deep water. But this will be touched on again in the discussion.

DISCUSSION.

As a result of the study of the length-distributions of the dogfish at the various stations, it was concluded that (1), the fish are segregated according to size in such a way that the smaller fish are found in shallower, the larger in deeper water ; (2) the males are found in shallower water than the females of the same size ; and (3) the pregnant females make a migration into shallow water, passing through the shoals of dogfish of smaller sizes, to bear their young.

This graduation according to size is well known among fishes. Thus, Meek (1916) writes, of fish in general, "after a period in relatively shallow water, and this period is generally the summer, the shoal migrates to deeper water. At first, the migration is not to a great distance, but with growth the annual pulsation becomes greater and greater." Of the Spurdog he writes, " the young of the species measure 22 to 25 cm., and they remain inshore during the summer. . . . They do not appear to migrate far from the coast in the first winter. The migrations are local during the phase of immaturity, and when the dogfish reach maturity, they tend to migrate into shallow water in summer, and to deep water for winter, keeping together in large companies."

Ford (*loc. cit.*) made notes on the composition of the dogfish shoals occurring off Plymouth. His samples were taken by fishing vessels, hence, as might be expected, he makes no mention of very small newly-born fish. From November 26th to July 29th his samples consisted of "medium-sized fish, of which the majority were immature females," and "immature fish in which males and females were equal in number." The range in length seemed to be from 36 to 60 cm., and usually 40 to 60 cm. This is what one would expect in samples from shallow water. The inward migration of the pregnant females in the autumn is clearly indicated by his samples 11, 12, and 1, in August and early November. The withdrawal of the females after the birth of their young is indicated by the statement that "towards the end of November, it became noticeable that . . . the proportion of the conspicuously large fish was diminishing." Ford's conclusion that "Size and sexual condition are important factors in the constitution of the shoals in this species, the former probably being the more influential one," is also in entire agreement with my results, and I consider that the two sets of observations confirm one another in a very satisfactory way. His sample 2, from the catches of a steam-trawler, in which only 19·8% of females were present, can be explained by the assumption that she was fishing in a region where, as on the Cockburn Bank in our samples, males greatly predominated as a result of the segregation of the dogfish by size, and the concentration of the older year-classes of males at a certain depth, as explained earlier in this paper. The observation of Borcea (1905) that only females are found off Roscoff in the summer, is probably a further observation on the inward migration of the pregnant females. Quigley (1928), however, finds that the shoals of the Pacific dogfish "consisted of both sexes, and all sizes of fish, or else the 'baited set-line' had been visited within a few hours by several different shoals." Especially significant is his observation that "the largest fish were usually taken at a greater depth than the smallest, and it may be that the composition of the shoals is in part determined by size."

The study of the variations in "condition" of the dogfish led to the conclusion that, although indefinite and even contrary results were found in the Banks-Westward region, there is, in the liver, and perhaps to a less striking degree in the flesh, a relation between depth and "condition" in males, immature females, and pregnant females. The "condition" improves from shallower to deeper water.

It should be emphasized that this is no mere "statistical figment"; the work was commenced as a result of the obvious difference in size and oiliness between the livers of dogfish taken in deep, and shallow water, a difference most noticeable on dissection.

Polimanti (1915) investigated the fat-content of a number of fishes from a variety of habitats, and found that the fat-content decreased with increase of depth, in such a way that pelagic fish had the highest fat-content, and that bottom-living fishes had a fat-content decreasing as the depth of the habitat increased. Deep-sea fishes, of which, however. he was able to analyse only one species, the bathypelagic *Cyclothone microdon*, had the lowest fat-content. He was of the opinion that a high fat-content supplements the swim-bladder as an agency of flotation, in fact, that the functional relations between the swim-bladder and the fat and water content are very intimate. He quotes the well-known relation between fat-content and vertical movement in fish eggs and larvæ, and also quotes those authors who have shown that, in Clupeidæ, there is a relation between fat-content and depth : in the summer they live at the surface, and are rich in fat, while in the winter they live in the depths, and are poor in fat.

In a paper to Section D of the British Association in 1927, I pointed out that, since the liver in the dogfish is known to consist largely of oil, a fish with a large liver must be relatively lighter, in relation to the water in which it swims, than a fish with a small liver. The liver, in fact, must act more or less as an organ of flotation, just as Polimanti suggested for fat in general among fishes.

During the 1928 cruise of the *George Bligh* I made direct determinations of the specific gravity of dogfish. The loss in weight on weighing the fish first in air, and then in sea-water, was used for calculating the specific gravity. The results are given in Table XX. The weighted mean value of k (liver) is also given for comparison. The specific gravities are the means of a good number of determinations in each case, made during the most favourable weather conditions. In Table XX the stations at which these determinations were made are arranged in order of depth.

Table XX.

Variations in Weighted Mean Value of k (liver), and in Specific Gravity. *George Bligh*, 1928.

		Male.		Female.	
Station.	Depth.	Weighted mean value of k (liver).	Mean specific gravity.	Weighted mean value of k (liver).	Mean specific gravity.
Inside Aran Islands	21	—	—	·0234	1·044
Bantry Bay	30	·0229	1·046	·0256	1·037
Galway Bay	55	—	—	·0265	1·036
Galley Head	61	·0266	1·040	·0303	1·038
" Station 18 "	69	·0310	1·044	·0325	1·034
Outer Fastnet	100	·0340	1·043	·0407	1·037
Westward	105	·0350	1·040	·0359	1·040
Mean			1·043		1·038

Table XX shows in quite a striking degree the increase in the index of condition, with increase of depth, in both sexes. In the males, the specific gravity tends to decrease with increase of depth, but the females show no relation between the specific gravity and depth. It is possible, however, that the development of the very large eggs, and pregnancy, serve to discount the effect of local differences in the buoyancy of the liver. None the less, the females have a consistently lower specific gravity than the males, which is in good agreement with their consistently heavier and larger liver. This seems to support the hypothesis that the condition of the liver affects the specific gravity.

Masterman (1911) reports on the specific gravity of the Plaice, and found that this decreases with increase of depth, especially in the females where it decreases from 1·077 at depths of less than 20 fathoms, to 1·068 at 30 to 40 fathoms. According to these experiments, in the Plaice, as in male dogfish, the fish are lighter, relatively to the water in which they swim, in deeper than in shallower water.

My observations are confined to weighings only, and no chemical analyses have been possible. But there is no reason to doubt but that the increase in the bulk of the liver, which takes place in the deep, as compared with the shallow water, is due to an accumulation of fat. Therefore my results contradict Polimanti's, except, perhaps, in the females of the Banks-Westward series, and in the males in the deep water of the Faroe-Shetland Channel, where the liver decreased in weight with increase of depth. But it is difficult to see how Polimanti's general conclusion can be upheld in the case of the deep-sea bathypelagic selachians. In *Scymnorhinus lichia*, for example, the liver is enormous: it fills the body-cavity, and may even protrude through the abdominal pores. The liver of this shark is very rich in oil. I have some data on the weight of the liver in the deep-sea selachian *Spinax niger*.

During a voyage on the Cardiff steam-trawler *Nogi* in January, 1928, I weighed the livers of 30 mature specimens of Spinax, ranging from 34 to 45 cm. in length. The mean value for the coefficient k (liver) was ·0736, and the weight of the liver amounted to 24% of the weight of the fish. The range in depth of Spinax, according to my observations on the *Florence Brierley*, is from 120 to 400 fathoms, and of Scymnorhinus from 220 fathoms to at least 520 fathoms (Hickling, 1928). Hence it is plainly incorrect to assume that deep-sea fish are poor in fat—indeed, among selachians, at least, the reverse seems true, for the highest mean value for the coefficient k (liver) in Acanthias was ·0409 (Bull, 130 fathoms), which is far less than the figure of ·0736 quoted above for Spinax.

Channon (1928) has analysed the liver oils from a considerable number of species of fish, and gives, in tabular form, the percentage of unsaponifiable matter in the oils. Of especial interest is his Table III, in which those members of the Selachii which he examined are arranged in order of decreasing content of unsaponifiable matter. It is plain that these fish are also arranged in decreasing order of depth. The deep-sea sharks Scymnorhinus, Lepidorhinus, and Spinax, have very high values, the shallow water sharks Lamna, Scyllium, and Galeus, have very low values for percentage of unsaponifiable matter; while Acanthias and Notidanus have intermediate values. It seems reasonable to suggest that a modification in metabolism, with reference to depth, which takes place in the Selachii as a group, may also take place in a single species ; and that the increase in mean weight of the liver, with increase of depth, observed in Acanthias, may be due to an increasing quantity of unsaponifiable matter. The point will be tested, if opportunity offers.

We may now put side by side the main facts relating to the distribution of the dogfish on the one hand, and the condition, with especial reference to the liver, on the other.

(1) The fish are segregated according to depth, so that the smaller fish are found in shallower water, the larger in deeper water.	(1) The coefficient of condition in the liver is higher in larger than in smaller fish.
(2) The males are found in shallower water than the females of the same size.	(2) The males have a lower coefficient of condition in the liver than the females.
(3) The pregnant females migrate from deep to shallow water to bear their young.	(3) Pregnant females have a lower coefficient of condition in the liver than non-pregnant females, the difference increasing with decrease of depth.

When it is remembered that the coefficient of condition increases with increase of depth quite independently of the increase due to the greater mean length, these three pairs of facts fall surprisingly into line. The large fish have a higher coefficient of condition than the small fish, and are found in deeper water ; the females have a higher coefficient of condition than the males, and are found in deeper water than the males of the same size ; and, finally, the pregnant females are found to lose condition as they migrate from deep to shallow water.

On the other hand, we have seen that, in the Banks-Westward region, the dogfish were present in deeper water than those of the same size in the Fastnet region (Section I), yet, as Tables IV and V show, the mean values for the coefficient k (liver) are lower, not higher, in the Banks-Westward than in the Fastnet series.

It is not suggested that the " condition " is responsible for the distribution : it is hard to see how this could be the case. The only conceivable manner in which condition might affect the vertical distribution of the fish would be, as Polimanti suggested, by its effect on specific gravity. But dogfish with a lower specific gravity are found in deeper water, not in shallower water, as Polimanti's hypothesis demands. It might also be suggested that the inward migration of the pregnant females is due to the drain on the resources of the liver, causing a loss in condition, and therefore a movement into shallower water, but, in deeper water, the condition of pregnant and of non-pregnant females differs only slightly, the difference, however, becomes progressively greater as the water becomes shallower. The " condition " would seem to be rather a consequence of the distribution, than a cause of it.

Borley (1912) found that there was a correlation between distribution and condition in Plaice, such that the smaller Plaice were in better condition in shallower water than in deeper water; the medium-sized Plaice were in better condition at intermediate depths than in either deep or shallow water; while large Plaice were in their best condition in deep water. He suggests that " grounds of different depth . . . are suitable to the nourishment of Plaice of different sizes, the size increasing with depth."

This hypothesis might be applied to the dogfish. If shallower water is better suited to the nourishment of small dogfish than deeper water, then they will tend to collect and remain in shallow water, and to be in their best condition there. In Figures 9 and 12, for instance, the curves tend to intersect so as to indicate that, although the larger fish in the samples have heavier livers in the deep than in the shallow water, among the smaller fish the reverse may be the case. Unfortunately, fish smaller than 50 cm. were not weighed. But the hypothesis would also have to explain the tendency for the males to be found in shallower water than the females of the same size, and to explain the loss of weight during the inward migration of the pregnant females.

Such notes as have been made on the stomach-contents of the dogfish do not support the idea that the deeper water provides more suitable food for the larger fish than the shallower water.

In the very shallow water stations inside the Aran Islands (21 fathoms) and in Bantry Bay (30 fathoms), the food consisted of herrings, small horse-mackerel, garfish (Belone), and whiting; in Galway Bay (55 fathoms) and off Galley Head (61 fathoms), herrings, mackerel, horse-mackerel, whiting, bib (*Gadus minutus*), " smelt " (*Argentina sphyræna*), and Eupagurus, were found in the stomachs; while on the Westward ground (105 fathoms), the food consisted of large horse-mackerel, blue whiting (*Gadus Poutassou*), and squids. The presence of herrings, mackerel, and garfish in the shallower water would seem to provide a richer fare than the large horse-mackerel, blue whiting, and squids in the deeper water.

Of course, a loss of condition can be the result of rapid growth in length, as well as of an environment less favourable to the nutrition of the fish. But if the poorer condition of the dogfish in the shallower water were due to their more rapid growth, one would expect that the fish in the shallower water would be larger than those in the deeper water, whereas the reverse is found.

The shoaling of the dogfish by size is easily understandable on Ford's suggestion that it is more advantageous for fishes of the same size to congregate together, since, in shoals of fish of very varying sizes, it is probable that the small fish would suffer disadvantage, for instance, in their chances of obtaining food. The presence of the very small fish in shallow water is the consequence of their having been born there. But the persistence of the small fish in shallower water, and the very perfect graduation with depth according to size, calls for a special explanation.

A tentative modification of Borley's hypothesis is here suggested. It seems possible that depth itself involves some factor, or factors, tending to modify metabolism in the direction of greater storage of reserve material, and in an increase both in the proportion, and in the actual quantity, of unsaponifiable matter in the liver. The value of one unsaturated hydrocarbon, squalene, as a reserve material, is attested by its presence in the egg-oils of some Selachians. Heilbronn, Kamm, and Owens (1926) found that the young eggs of Spinax contained squalene, and that it was absorbed during the development of the embryo. Temperature may play its part, though the difference in temperature as between deep and shallow water is usually slight. However, in the deeper water there is a greater uniformity of temperature than in the shallower water. Pressure itself may be a factor of importance. This suggestion certainly derives some support from the hake, which retires to deep water during its exhaustion after spawning, and, in the conditions found there, makes a rapid recovery. (Hickling, 1930.)

As sexual maturity in the dogfish approaches, the fish tend to find the depth best suited to the accumulation of reserve material, rather than for growth alone, and thus, according to my hypothesis, seek deeper water. The more katabolic males, in which, in any case, the strain of reproduction is much less severe than in the females, will not need to seek such deep water as the more anabolic females, if the greater depths have an increasingly beneficial effect. Finally, the inward migration of the pregnant females carries them into depths less favourable to the replenishment of the reserve material, which is being withdrawn both to supply the energy for migration, and to nourish the young. There is thus a heavy loss in condition.

In this way, the " condition " might be the result of the distribution, and the distribution the result of the tendency of the fish to place itself in the most favourable conditions to satisfy its present metabolic needs.

While this hypothesis may go some way to meet the facts, it is always possible that the correlation of condition and depth may be dependant on some factors in the life-history of the fish, of which we are at present ignorant.

It may be added, finally, that the Spur-dog is a hardy fish, which would seem well suited to physiological experiments, and especially experiments on metabolism.

SUMMARY.

In August, 1928, dogfish were measured at a series of stations to the south, south-west, and west of Ireland. A relation was found between size and depth, such that the smaller fish were most abundant in the shallower water, the larger fish in deeper water. This relation was broken only by the pregnant females, fish generally over 80 cm. in length, which were in process of migration into shallow water to bear their young.

The male dogfish were present in shallower water than the females of the same size.

The sex-ratio varied with depth. In shallow water there was a slight predominance of females, at intermediate depths a predominance of males, and in deep water a gradually increasing predominance of females. This predominance of males at intermediate depths is liable to be masked by the inward migration of the pregnant females. [Over very deep water in the Faroe-Shetland Channel, in March, 1927, shoals of dogfish, consisting exclusively of mature males, were found.]

Weighing experiments were made both in the Faroe-Shetland Channel and off Ireland. The mean weight of the liver, and to a lesser degree, of the flesh, was greater in deep than in shallow water. That is, the fish were in better condition in the deep than in the shallow water. Exceptions were found both in the series of Irish stations and in the Faroe-Shetland Channel. [In the very deep water worked in the last-named region, the index of condition of the liver in the males decreased with increase of depth. It is suggested that this apparent progressive decrease in condition with increase of depth is actually due to an increasingly large proportion of the fish having been taken in midwater during the hauling and shooting of the trawl.]

The condition of the liver improves with increase of length, in both sexes: the livers of female dogfish are in better condition than those of male dogfish taken under the same conditions. Pregnant females lose condition during the migration from deep to shallow water. In the deep water they have an index of condition almost as high as non-pregnant females. Generally speaking, pregnant females have a lighter liver, but heavier flesh, than non-pregnant females.

These variations in condition are related to the distribution of the dogfish, but, in the discussion, it is concluded that the condition is the result of the distribution, rather than the cause of it, as Polimanti suggests. The better condition of the fish in deeper water is regarded as

due to an effect of depth, possibly pressure, on the metabolism of the fish, favouring anabolism rather than katabolism. Under the increased metabolic strain of maturity, the larger fish may therefore seek deeper water, the more anabolic females to a greater extent than the more katabolic males.

Female dogfish have a lower specific gravity than the males, in agreement with their larger liver.

The index of condition of the liver is much higher in Embryos than in newly-born dogfish, and it is suggested that a sudden spurt of growth takes place immediately after birth, at the expense of the material stored in the liver of the embryo.

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APPENDIX

Table XIII.

Measurements of Dogfish at the Stations. *George Bligh*, August, 1928.

Upright figures denote frequency, italic figures denote percentage frequency.

	Banks—Westward Region.						Fastnet Region.											
Length in cm.	Banks 69 fathoms.		Cockburn Bank 81 fathoms.		Westward 105 fathoms.		Bantry Bay 30 fathoms.		Galley Head 61 fathoms.		Inner Fastnet 89 fathoms.		Outer Fastnet 100 fathoms.		Galway Bay 55 fathoms.		Station 18 69 fathoms.	
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
25–	5	6	6	6			6	6	7	1					56	55		1
29	*3·6*	*5·2*	*4·0*	*2·5*			*1·2*	*1·7*	*1·6*	*0·4*					*12·3*	*16·0*		1·1
30–	47	21	32	18			239	139	47	31	1				268	205		
34	*33·8*	*18·4*	*21·5*	*7·3*			*47·1*	*39·8*	*10·8*	*11·3*	*0·2*				*58·9*	*59·6*		
35–	19	14	5	5			120	77	22	23					93	70	1	
39	*13·7*	*12·3*	*3·4*	*2·0*			*23·6*	*22·1*	*5·1*	*8·4*					*20·5*	*20·3*	*1·0*	
40–	17	6	9	6			61	53	9	6					28	13	3	
44	*12·2*	*5·3*	*6·0*	*2·5*			*12·0*	*15·2*	*2·1*	*2·2*					*6·2*	*3·8*	*3·1*	
45–	16	16	29	12		1	9	12	21	12	2				4	1	3	1
49	*11·5*	*14·0*	*19·5*	*4·9*		*9·1*	*1·8*	*3·4*	*4·8*	*4·4*	*0·5*				*0·9*	*0·3*	*3·1*	*1·1*
50–	14	25	16	22			15	6	36	23	8	2					11	3
54	*10·1*	*21·9*	*10·7*	*9·0*			*2·9*	*1·7*	*8·3*	*8·4*	*1·8*	*1·0*					*11·5*	*3·4*
55–	16	14	11	29			10	9	50	41	52	8	19				22	8
59	*11·5*	*12·3*	*7·4*	*11·8*			*2·0*	*2·5*	*11·5*	*15·0*	*11·6*	*4·2*	*5·3*				*22·9*	*9·1*
60–	2	6	19	48	2	1	9	9	52	42	135	34	51	4			25	9
64	*1·5*	*5·3*	*12·7*	*19·6*	*3·4*	*9·1*	*1·8*	*2·6*	*12·0*	*15·3*	*30·2*	*17·6*	*14·3*	*8·2*			*26·1*	*10·2*
65–	1	5	8	75	3	3	11	22	64	63	130	64	111	27			16	45
69	*0·7*	*4·4*	*5·4*	*30·6*	*5·2*	*27·3*	*2·2*	*6·3*	*14·7*	*23·0*	*29·1*	*33·2*	*31·0*	*55·1*			*16·7*	*51·2*
70–		1	4	23	7	6	9	15	47	28	75	73	95	16	1		7	18
74		*0·9*	*2·7*	*9·4*	*12·1*	*54·5*	*1·8*	*4·3*	*10·8*	*10·2*	*16·8*	*37·8*	*26·5*	*32·6*	*0·2*		*7·3*	*20·5*
75–			6	1	14		7	1	36	4	27	11	58	2			5	2
79			*4·0*	*0·4*	*24·1*		*1·4*	*0·3*	*8·3*	*1·4*	*6·0*	*5·7*	*16·2*	*4·1*			*5·2*	*2·3*
80–					19		7		25		13	1	18		2		2	1
84					*32·8*		*1·4*		*5·8*		*2·9*	*0·5*	*5·0*		*0·4*		*2·1*	*1·1*
85–	2		3		11		2		15		3		5		1		1	
89	*1·4*		*2·0*		*19·0*		*0·4*		*3·5*		*0·7*		*1·4*		*0·2*		*1·0*	
90–			1		2		2		3		1		1		2			
94			*0·7*		*3·4*		*0·4*		*0·7*		*0·2*		*0·3*		*0·4*			
Total	139	114	149	245	58	11	507	349	434	274	447	193	358	49	455	344	96	88
% ♀	54·9		37·8		84·1		59·2		61·3		69·8		88·0		56·9		52·2	
Medians	39·5	47·8	48·9	63·1	81·0	70·5	35·4	37·3	62·7	60·0	65·9	69·2	69·9	68·9	32·2	32·0	61·4	67·7

TABLE XIV.

FLORENCE BRIERLEY DOGFISH. FAROE-SHETLAND CHANNEL.

Date 1927.	G.M.T. of haul.	Mean depth. Fathoms.	Number of males.	Number of females.	Per cent of females.	Number of pregnant females.	Per cent of pregnant females.
March 25	1500	300	100	4	4	—	—
,, 27	0800	119	3	5	63	—	—
,, 28	1700	101	9	22	71	—	—
,, 28	2005	106	23	38	62	—	—
,, 29	0815	105	12	37	75	—	—
,, 29	1510	160	11	28	72	—	—
,, 29	1745	210	5	45	90	18	57
,, 30	1800	130	27	17	39	10	59
,, 31	1245	102	5	33	87	6	18
April 2	1930	96	10	35	78	4	12
,, 3	2115	216	41	0	0	—	—
,, 5	0800	240	24	2	8	2	100

TABLE XV.

AUGUST, 1929. MATURITY OF MALE DOGFISH. ALL STATIONS COMBINED. BASED ON DEVELOPMENT OF CLASPERS.

	Numbers of			
Length.	Immature.	%	Mature.	%
52	21	100		0·0
53	10	100		0·0
54	9	100		0·0
55	10	90·9	1	9·1
56	10	90·9	1	9·1
57	8	72·7	3	27·3
58	4	66·6	2	33·4
59	7	58·3	5	41·6
60	4	33·3	8	66·7
61	4	26·6	11	73·4
62		0·0	12	100·0
63	1	4·5	21	95·5
64		0·0	23	100
65		0·0	11	100
66		0·0	17	100

TABLE XVI.

ONSET OF PREGNANCY IN FEMALE DOGFISH. ALL STATIONS, *GEORGE BLIGH*, AUGUST, 1928.

Length Group.	No. of Females.	No. of Pregnant Females.	Per cent Pregnant.
55–59	—	0	0
60–64	44	1	2·3
65–69	41	1	2·4
70–74	49	6	12·2
75–79	29	6	20·7
80–84	49	33	67·4
85–89	35	31	88·6
90–94	11	10	90·9

TABLE XVII.

ALL STATIONS, *GEORGE BLIGH*, AUGUST, 1928.

FREQUENCIES OF EMBRYOS AND FREE-LIVING YOUNG.

Length.	Embryos.	Free-living Young.
18	1	
19	4	
20	13	
21	34	
22	48	
23	54	1
24	48	2
25	24	1
26	6	
27	2	14
28		34
29		106
30		191
31		264
32		244
33		195
34		142
35		94
36		94

TABLE XVIII.

GEORGE BLIGH, AUGUST, 1928. GROUPED RESULTS OF WEIGHING EXPERIMENTS. LIVER.

		50–59 cm.				60–69 cm.				70–79 cm.				80–89 cm.				90–99 cm.			
Station.	Depth. Fm.	No. of specimens.	Mean length.	Mean weight of liver.	Mean value of k (liver).	No. of specimens.	Mean length.	Mean weight of liver.	Mean value of k (liver).	No. of specimens.	Mean length.	Mean weight of liver.	Mean value of k (liver).	No. of specimens.	Mean length.	Mean weight of liver.	Mean value of k (liver).	No. of specimens.	Mean length.	Mean weight of liver.	Mean value of k (liver).
Banks	69																				
Males		13	58·0	47	·0238	12	64·6	66	·0237												
*Immature ♀		18	57·1	44	·0237	2	65·0	88	·0317												
Pregnant ♀																					
Cockburn Bank	81																				
Males		4	58·3	37	·0187	13	64·8	83	·0307	3	71·2	123	·0343								
*Immature ♀		5	56·5	39	·0218	12	63·9	73	·0279												
Pregnant ♀										2	76·0	75	·0171								
Westward	105																				
Males						2	68·5	93	·0288	4	72·5	145	·0381								
*Immature ♀						2	63·5	45	·0177	4	76·5	208	·0454	2	81·0	215	·0403				
Pregnant ♀						1	69·5	110	·0328	3	75·8	127	·0289	8	84·5	215	·0353				
Bantry Bay	30																				
Males		6	57·2	33	·0179	22	66·5	71	·0240	12	72·8	91	·0235								
*Immature ♀		16	55·0	40	·0234	14	64·7	67	·0250	14	74·3	129	·0310								
Pregnant ♀														10	83·9	128	·0222	2	92·5	203	·0257
Galley Head	61																				
Males		7	56·8	40	·0221	23	66·0	81	·0278	6	72·7	106	·0275								
*Immature ♀		10	55·5	38	·0216	22	64·6	73	·0267	13	72·3	135	·0351	6	81·7	233	·0428				
Pregnant ♀														9	83·3	192	·0334				
Inner Fastnet	89																				
Males						10	66·4	98	·0327	15	72·3	123	·0326								
*Immature ♀		2	58·5	48	·0238	15	65·8	93	·0321	10	73·1	140	·0355	5	82·9	280	·0486				
Pregnant ♀																					
Outer Fastnet	100																				
Males						16	67·5	98	·0317	14	72·2	139	·0365								
*Immature ♀						8	67·3	106	·0345	15	75·2	177	·0413	3	81·5	293	·0542				
Pregnant ♀																					
Inside Aran Islands	21																				
*Immature ♀																					
Pregnant ♀														5	84·9	156	·0261	3	92·8	125	·0156
Galway Bay	55																				
Males																					
*Immature ♀										3	74·2	109	·0264								
Pregnant ♀										3	76·5	101	·0227	25	85·3	165	·0266	5	92·1	211	·0270
Bull	130																				
Males																					
*Immature ♀						4	65·5	81	·0282	9	74·4	178	·0433	2	86·0	355	·0555				
Pregnant ♀														2	82·5	225	·0401				

* Including non-pregnant females.

George Bligh, August, 1928. Grouped Results of Weighing Experiments. Flesh.

Station.	Depth. Fm.	50–59 cm.				60–69 cm.				70–79 cm.				80–89 cm.				90–99 cm.			
		No of specimens.	Mean length.	Mean weight of flesh.	Mean value of *k* (flesh).	No. of specimens.	Mean length.	Mean weight of flesh.	Mean value of *k* (flesh).	No. of specimens.	Mean length.	Mean weight of flesh.	Mean value of *k* (flesh).	No. of specimens.	Mean length.	Mean weight of flesh.	Mean value of *k* (flesh.)	No. of specimens.	Mean length.	Mean weight of flesh.	Mean value of *k* (flesh).
Banks	69																				
Males		13	58·0	510	·261	12	64·6	700	·257												
*Immature ♀		18	57·1	520	·277	2	65·0	680	·246												
Pregnant ♀																					
Cockburn Bank	81																				
Males		4	58·3	530	·268	13	64·8	820	·300	3	71·2	1100	·305								
*Immature ♀		5	56·5	540	·297	12	63·9	770	·294												
Pregnant ♀										2	76·0	1300	·296								
Westward	105																				
Males						2	68·5	1030	·319	4	72·5	1060	·279								
*Immature ♀						2	63·5	660	·258	4	76·5	1490	·319	2	81·0	1800	·339				
Pregnant ♀										3	75·8	1317	·300	8	84·5	1960	·325				
Bantry Bay	30																				
Males		6	57·2	530	·283	22	66·5	830	·281	12	72·8	1060	·276								
*Immature ♀		16	55·0	480	·289	14	64·7	790	·289	14	74·3	1200	·290	10	83·9	1780	·301	2	92·5	2400	·304
Pregnant ♀																					
Galley Head	61																				
Males		7	56·8	530	·287	23	66·0	840	·292	6	72·7	1090	·285								
*Immature ♀		10	55·5	510	·295	22	64·6	810	·297	13	72·3	1240	·325	6	81·7	1730	·318				
Pregnant ♀														9	83·3	1950	·337				
Inner Fastnet	89																				
Males						10	66·4	840	·287	15	72·3	1130	·298								
*Immature ♀		2	58·5	630	·313	15	65·8	860	·302	10	73·1	1170	·299	5	82·9	1780	·312				
Pregnant ♀																					
Outer Fastnet	100																				
Males						16	67·5	900	·290	14	72·2	1080	·287								
*Immature ♀						8	67·3	870	·287	15	75·2	1290	·301	3	81·5	1700	·315				
Pregnant ♀																					
Inside Aran Islands	21																				
*Immature ♀																					
Pregnant ♀																					
Galway Bay	55													5	84·9	1920	·315	3	92·8	2330	·291
Males																					
*Immature ♀										3	74·2	1220	·297								
Pregnant ♀										3	76·5	1300	·291	25	85·3	1910	·307	5	92·1	2340	·299
Bull	130																				
Males																					
*Immature ♀						4	65·5	830	·295	9	74·4	1330	·320	2	86·0	2080	·356				
Pregnant ♀														2	82·5	1900	·339				

* Including non-pregnant females.

TABLE XIX.

FLORENCE BRIERLEY. APRIL, 1927. WEIGHING EXPERIMENTS.

	Haul.			Mean Depth.	Sex.	Mean Length.	No. of Specimens.	Mean value of *k* (liver.)
1.	March	29	1510	160	♀	74·7	27	·0407
					♂	70·3	12	·0284
2.	,,	29	1745	210	♀	83·9	31	·0470
					♂	74·6	5	·0242
3.	,,	30	1800	130	♀	83·9	17	·0430
					♂	72·4	16	·0252
4.	,,	31	1245	102	♀	75·1	32	·0393
					♂	72·4	5	·0376
5.	April	2	1930	96	♀	74·1	35	·0412
					♂	73·3	9	·0322
6.	,,	3	2115	216	♀	—	—	—
					♂	72·8	27	·0248
7.	,,	5	0800	240	♀	—	—	—
					♂	71·6	24	·0234

A Note on the Formation of the Egg Case of the Skate.

By

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With 2 Figures in the Text.

THERE seems to be some uncertainty about the exact stage at which the horny case is secreted around the fertilised Elasmobranch egg. Those textbooks which have been consulted either pass over the matter in silence or give the impression that the shell is secreted while the egg is passing through the nidamental organ. Sedgwick (1905), for example, says (p. 143): "The shell is formed round the ovum and its albumen in the lower dilated part of the oviduct, but the material of which it is composed is secreted by the oviducal gland." Of late years the question seems to have received little attention, but there are several papers on the subject published twenty or more years ago.

Gerbe (1872) considered that in rays the albumen and shell are secreted simultaneously round the egg. He observed: "Un œuf à moitié engagé dans la glande, et qui possède une partie de son albumen, possède en meme temps une partie de sa coque."

Perravex (1884) investigated the structure of the nidamental organ of *Scyllium canicula* and discovered "dans une glande nidamenteuse de *Scyllium canicula* un œuf à demi engagé; les cornes antérieures et la partie inférieure seules étaient formées. . . ." His conclusion was that, although secretion of the matter of which the shell is composed begins before the egg reaches the gland, yet the shell is actually formed around the egg.

Borcea (1904) concluded that formation of the shell begins before the egg reaches the nidamental organ on the ground that the pressure of the egg within the gland would prevent the secretion from passing between the lamellæ at the base of which the individual tubular glands open. He considered that "Le phenomène se passe d'une manière reflexe: l'œuf n'est qu'un stimulus qui le détermine." He did not, apparently, come across any specimens directly confirming his view, although he cited the occurrence of fully-formed egg cases containing only albumen as showing that the egg is not the only stimulus which can cause the secretion of a shell.

The most extensive paper on this subject is that of Widakowich (1906), who described the structure of the nidamental organ of *Scyllium canicula* in great detail and endeavoured to deduce the process of shell formation from his observations. He recognised that the caudal processes of the egg case are laid down during the passage of the egg down the part of the oviduct cranial to the nidamental organ. He thought, however, that the body of the case is formed during the subsequent movement of the egg through the gland. He found one specimen in which the anterior part of the egg case had not been completely formed, but here, apparently, the egg had already passed through the nidamental organ and was lying in the already fully-formed part of the case in the caudal region of the oviduct.

Beard (1890) stated that in skates, "It appears very likely, nay, almost certain, that the lower half of the purse is formed before the egg arrives at the oviducal gland, and that after the arrival of the egg the closure of the purse is at once effected." This conclusion, which is in complete agreement with the observations to be described in the present note, was based on the following circumstances. Firstly, "One often finds part of a purse in the oviduct and no yolk or egg within it." Secondly, about 10 per cent of some shark egg cases laid in captivity were found to contain no egg. It is unfortunate, with regard to the first observation, that it is not stated whether an egg was present in the oviduct.

It may be seen from the above references that, although intermediate stages in shell formation in Elasmobranchs have on several occasions been observed, there is a lack of precision in the descriptions which renders it difficult to draw definite conclusions as to the sequence of events in this process. Consequently, it is thought that the following observations may be of interest although they are based only on a single specimen of *Raia radiata* Donovan. Beard (1890) states that breeding specimens of this species are rare in the Firth of Forth. *Raia radiata* is now, however, the commonest species among those dissected in the Department of Zoology in the University of Edinburgh (*cf.* Lamont, 1926), and individuals containing egg cases are fairly plentiful.

Pregnant individuals almost invariably are found with one or two fully-formed and closed egg cases in the part of the oviducts posterior to the nidamental organ or in the vagina. Occasionally a specimen may be noticed in which the anterior horns of the cases are still within the nidamental organ. The exception to be described in which the egg cases are only half formed is the only one which has been noticed in such a condition among, at a rough estimate, 150 pregnant female skate of several species. This indicates that, once ovulation has taken place, the passage of the egg down the cranial part of the oviduct and the formation of the shell is accomplished quickly.

A general view of the specimen of *Raia radiata*, on which the following observations are based, is seen in Fig. 1. The liver and alimentary canal have been removed in order to display the reproductive organs. The left ovary has been turned over towards the middle. Anterior to the nidamental organ (N.O.) each oviduct is swollen by a mature ovum (Od.) which is yet devoid of either white or shell. Behind the nidamental organ on either side the oviduct is greatly distended by the posterior half of the egg case (E.C.), whose vague outlines can be distinguished through the oviducal wall. Behind the egg case each oviduct is at liberty to retain its normal diameter and turns sharply towards the middle line to join that of the other side to form the cloaca (C.). Fig. 2 shows the condition of the egg case. The ventral half of the left nidamental organ and of the oviduct immediately posterior to it has been removed. The egg case (E.C.) can be seen lying in the distended part of the caudal oviduct. At O.U. is the opening into the yet undistended part of the oviduct. About half of the egg case has already been formed. Its only difference from the final product is that it is lighter in colour and somewhat softer. Widakowich

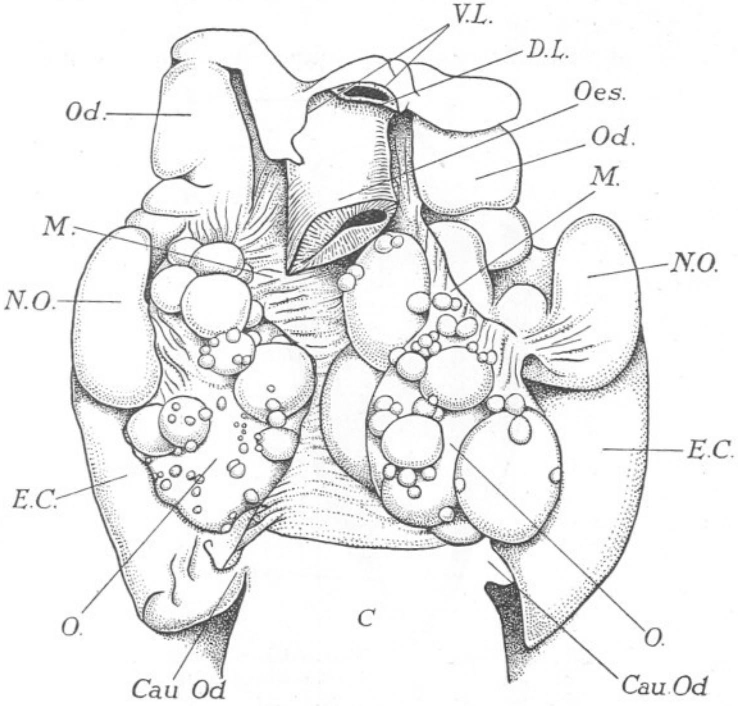

Fig. 1.—O., ovary; M., mesovarium; D.L., V.L., dorsal and ventral lips of oviducal funnels; Od., ovum in cranial part of oviduct; N.O., nidamental organ; E.C., egg case in caudal part of oviduct; Cau. Od., undistended part of caudal oviduct; C., cloaca; Oes., œsophagus. (Nat. size.)

(1906) has pointed out that the case of *Scyllium canicula* is formed by a large number of separate elements (" Platten ") which adhere to each other comparatively loosely at first but later, and especially after contact with sea-water, much more closely so that the whole shell hardens.

The half-formed egg case is quite empty. Its dorsal and ventral walls are well separated from one another so that at the anterior end there is an opening which will admit the egg when it is ready to pass into the case. It is probable, however, that the egg has to undergo a certain amount of distortion during this process.

It is evident that this specimen confirms the opinions expressed by Beard (1890) and by Borcea (1904), although neither of these workers presented critical evidence in favour of their views. At least half, and possibly considerably more, of the egg case is already formed before the egg comes into contact with the nidamental organ at all. Various authors (e.g. Perravex, Widakowich) have described the presence of shell material already secreted in the tubules of the shell gland before the egg has even been shed from the ovary. It is probable, therefore, that the shell gland commences activity some time before ovulation occurs. The scarcity of observations between this period of preparation and the fully-formed

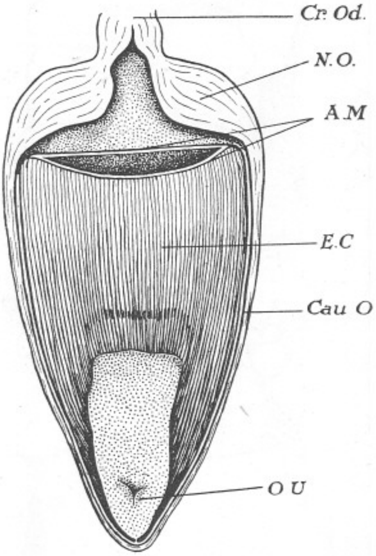

Fig. 2.—Ventral half of left nidamental organ and part of caudal oviduct removed to show half-formed egg case *in situ*. (×2.)

Cr. Od., cranial part of oviduct; N.O., nidamental organ; Cau. O., caudal part of oviduct; O.U. opening into undistended part of caudal oviduct; E.C., egg case; A.M., anterior margin of egg case.

egg case with the egg enclosed, suggest that once the egg has reached the oviduct, events move rapidly.

It is a familiar fact that two ova are shed from the ovaries simultaneously, so that in each oviduct there is an egg in the same stage of development. In the specimen here described it may be noted that both eggs appear to have been shed from the right ovary. In Fig. 1 it can be seen that in the left ovary are several eggs in an advanced stage of development, whereas in the right ovary the largest eggs present are only about half-grown. This may indicate an alternation in the activity of the ovaries. Many further observations would be needed to establish this, but if it should prove to be generally true, it may readily be seen how, from such a condition, that found in *Scyllium canicula*, for example, could be derived, in which only one ovary develops and becomes functional.

One further point is illustrated in Fig. 1. In textbooks the oviducal funnels of both the skate and the dogfish are described and figured as being united to form a single median ostium. In *Raia radiata*, at any rate, this seems not to be the case. The upper and lower lips of the funnels are, indeed, united, but the openings remain so widely separated as to be, probably, functionally distinct. Redeke (1898) stated that in *Trygon pastinaca* there are two separate ostia (quoted by Ihle, 1927, p. 745). *Raia radiata*, therefore, seems to exhibit a condition intermediate between this and the completely fused ostia of *Raia batis*.

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

By

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THIS paper is a continuation of Part I in a strict sense, and deals with the methods and samples considered previously. More prolonged immersion tests have enabled a more accurate estimate to be reached as to the relative values of the methods of preservation. One new preservative has been tried, an oily substance sold as "Neo-Russigen," a sample of which was supplied by the Ministry of Fisheries; in the absence of any chemical analysis of this there is no guarantee that subsequent supplies will approximate to the sample received, to which alone must the data presented be considered to apply.

The tables are completed or continued from Part I, and bear the numbers by which they were designated in Part I, to which reference as to the methods of treatment should be made. Table 14 is the only new one. In the tables more weight should be attached to the life of the net than to the percentage life, taking the untreated net as 100; this is because an untreated net placed to rot in October experiences cold weather and may last as long as five months, whereas if the immersion dates from early summer the warm weather results in more rapid decay and it may only last two months. The preserved nets will however go through both summer and winter. It might be better to take three months as a standard time for the rotting of untreated nets, but this varies also with the thickness of the twine, so the observed values have been given in each case.

A correction must be mentioned as regards the results shown in Table 7, Part I. Sample 51A, treated with the copper soaps and tar mixture, was rejected in error after eleven months. In reality it lasted for twenty months, but this is decidedly lower than usual with the mixture, cp. No. 14A, 39 months, No. 39A, over three years.

TABLE 3.

Hemp net rotting in Aquarium tank water; initial strength, average of sets of six, $13\frac{1}{2}$ and $14\frac{3}{4}$ lbs. dry; after soaking for three hours, $12\frac{1}{2}$ lbs. Immersed 26/9/'25.

No.	Treatment.	Till unserviceable, months.	Percentage life of net.
10	Untreated	5	100
11	Copper soaps, 12%, viz. 1 lb. per gal.	9	180
12‡	Do. with resin 1 lb. per gallon (12%)	11	220
13	Do. with anti-fouling paint, 12%	29*	580
14	Do. with tar, 12%	36†	720

‡ The soap and resin, paint or tar respectively were mixed, so that only one dip was required, 1 lb. of each being added to the gallon of copper soap solution in petrol.

* Half-strength after 26 months, still serviceable, looked as new.

† Slightly under half-strength after 26 months, still serviceable, looked as new.

TABLE 5.

Cotton net rotting in Aquarium tank water; initial strength, dry, $19\frac{1}{2}$ lbs. Immersed 26/9/'25.

No.	Treatment.	Till unserviceable, months.	Percentage life of net.
10A	Untreated	$5\frac{1}{2}$	100
11A	Copper soaps, 12%	$10\frac{1}{4}$	190
12A	Do. with resin 1 lb. per gallon (12%)	26*	470
13A	Do. with anti-fouling paint, 12%	37†	670
14A	Do. with tar, 12%	39‡	710

* Strength 10 lbs. after 25 months.

† Strength $17\frac{1}{2}$ lbs. after 36 months.

‡ Strength 18 lbs. after 36 months.

TABLE 9.

Hemp net rotting in Aquarium tank water; initial strength, dry, averages of sets of six tests each, $15\frac{1}{4}$, $15\frac{3}{4}$, $18\frac{1}{2}$; maximum single strand 21, minimum $12\frac{1}{2}$ lbs. Immersed 17/3/'26.

		Life of net.	
No.	Treatment.	Months.	Percentage.
28	Untreated	$2\frac{1}{2}$	100
29	Cutch, 2% infusion, two boilings	6	240
30	Do. followed by Olie's ammonia copper sulphate	30*	1200
31	As 29, followed when dry by 12% copper soaps	30*	1200
32	Copper soaps, 12%, but soaked for 3 hrs.	19	760
33	Copper soaps, 12% with 1 lb. resin per gallon	$13\frac{1}{2}$	540
34	Copper soaps, 12%, followed when dry by No. 33 treatment	29*	1160

* After 20 months strengths were 8 lbs., about half-strength.

TABLE 10.

Cotton net rotting in Aquarium tank water ; initial strength, dry, 12 lbs. Immersed 17/3/'26.

No.	Treatment.	Life of net. Months.	Life of net. Percentage.
24A	Untreated	2	100
26A	Cutch, 2% infusion, two boilings	3	150
25A	Do. followed by Olie's ammonia copper sulphate	5	250
27A	As 26A, followed when dry by 12% copper soap	5	250
28A	Copper soap, 12%, soaked for 3 hrs.	5	250
29A	Do. with 1 lb. resin per gallon	5	250
30A	As 28A, followed when dry by 29A treatment	25*	1250

* Strength 12½ lbs. after 19 months, all colour gone and strength 7½ lbs. after 20 months.

TABLE 11.

Cotton net rotting in Aquarium tank water ; initial strength, dry, 18 lbs. Immersed 20/10/'26.

No.	Treatment.	Re-treatments.	Strength, after years. 1	2	3
34A	Untreated. Life 5½ months	None	0	0	0
35A	Cutch, two boilings	Every two months	16·3	0	0
36A	Do.	Every three months	18	9·8	4·6
37A	Do. followed by Olie's ammonia copper sulphate	Every four months	22·5	20·9	18·8

TABLE 12.

Hemp net Nos. 35–39 rotting in Aquarium tank water ; Nos. 40–44 in fresh water. Immersed 25/11/'26. Initial strength, dry, 16½ lbs.

No.	Treatment.	Strength, after years. 1	2	3
35	Copper soaps, 12%. Life 14 months	5·3	0	0
36	Do. with tar as No. 14	14·3	11·4	7·5
37	Cuprinol with equal volume of petrol	12·3	8·3	4·8
38	As No. 37 with 1 lb. tar per gallon of mixture	16·3	12·3	13·1
39	Copper soaps as No. 35, Cuprinol as No. 37, equal volumes of each	13·0	10·1	5·8
40	As No. 35	7·0	7·4	5·3
41	As No. 36	9·0	9·1	6·6
42	As No. 37. Life 25 months	14·0	7·9	0
43	As No. 38	13·5	11·3	13·6
44	As No. 39	12	9·6	7·7

TABLE 13.

Cotton net Nos. 38A–42A rotting in Aquarium tank water ; Nos. 43A–47A in fresh water. Immersed 25/11/'26. Initial strength, 18½ lbs., done on 40A before treatment, 17½ lbs. done on 45A similarly.

No.	Treatment.	Strength, after years. 1	2	3
38A	Copper soaps, 12%. Life 21 months	22	0	0
39A	Do. with tar as in 14A	18	17	18
40A	Cuprinol with equal volume of petrol	25	26	18
41A	As No. 40A with 1 lb. tar per gallon of mixture	25	22	19
42A	Copper soaps as 38A, Cuprinol as 40A, equal volumes of each. Life 30 months	25	13½	0
43A	As 38A	22	17	16
44A	As 39A	21	20	14
45A	As 40A	16½	20	21
46A	As 41A	21	19	22
47A	As 42A	26	21	25

TABLE 14.

Cotton net rotting in Aquarium tank water. Immersed 28/4/'28.

No.	Treatment.	Life of net. Months.	Percentage.
52A	Dipped in Neo-Russigen. Initial strength 11 lbs.	14	700
54A	Cutch, two boilings. Initial strength 12 lbs.	4½	220
55A	Untreated. Initial strength 11 lbs.	2	100

DISCUSSION OF RESULTS.

Tables 3 and 5 show how great is the advantage of adding 1 lb. tar to the copper soaps mixture, 1 lb. to the gallon of petrol. Nets, hemp and cotton lasted up to or over three years when thus treated. The results shown in Tables 12 and 13, Nos. 36 and 39A confirm this. The degree of preservation achieved is undoubtedly very good, No. 39A having its initial strength after the three years. The results with anti-fouling paint were not quite as good as with tar ; it is more expensive and the proprietary paints vary greatly. It is also far more messy than tar mixed in copper soap.

Tables 12 and 13 compare the British product, mixed copper soaps (stearate, palmitate, and oleate), with the Danish "Cuprinol," the copper soap of a naphthenic acid (or acids) derived from petroleum, probably Galician. Comparisons were made with and without tar, in both fresh and salt water. Both types of copper soap are more effective on cotton than on hemp. In sea-water Cuprinol is far more durable than is the fatty acids soap. The two are about equal on cotton in fresh water, but on hemp the advantage lies with the fatty acids soap. The fresh water was the Plymouth tap supply, a very soft water with scarcely a trace of lime in it. When both are mixed with tar, Cuprinol and the fatty acids copper soap appear to be about equal, and the latter is very much the cheaper. Both give excellent preservation to cotton nets for three years under soakage conditions. With hemp Cuprinol shows up better than the fatty acid soap ; the latter is the product developed by Lever Bros. and later supplied as Pilot Protective Copper Soap by Messrs. Ogston and Tennant, of Renfrew. The results may probably be taken as applicable without serious error to the copper oleate, manufactured according to the American formula by Messrs. Wm. Bailey & Son, of Wolverhampton. It was, however, found (Atkins, 1926) that a 5% solution of the mixed soaps was just as effective as 10% of the pure oleate and it is possible that the former is more effective because of a lesser solubility. With tar such differences should be reduced, and the oleate is rather more readily soluble in petrol.

Table 14 shows that Neo-Russigen is much better than cutch alone, though not as good on cotton as fatty acid copper soaps, cp. No. 38A, but better according to No. 11A. It falls far behind copper soap and tar, however.

Tables 9 and 10 make a comparison of cutch and Olie's ammonia copper sulphate with copper soap. All the results are poor on the cotton of Table 10, except copper soap followed by copper soap with resin. On the hemp of Table 9, however, the preservation was good, Olie's method and copper soap after cutch coming out equal. Undoubtedly a preliminary treatment with cutch greatly enhances the preservative effect of both Olie's method and the copper-soap method.

It seemed advisable to test whether good preservation could be obtained by repeated treatments with cutch at two or three month intervals and of Olie's method at four-month intervals. Table 11 shows that three-monthly re-treatments with cutch are better than two-monthly, also that, under the test conditions, four-monthly re-treatments with Olie's method result in the original strength having been maintained for three years, which is equivalent to one treatment with copper soap and tar or Cuprinol and tar. The nets boiled in cutch and treated with ammonia copper sulphate feel rather harsh to the hand and give a clean break in the tensile test. The nets have not the softness and pliability of those treated with copper soap with or without tar. Fillon (1925) speaks highly of Olie's method and prefers it.

SUMMARY.

1. The most efficient preservation for a single treatment is given by a mixture of copper soaps and tar, either :

(*a*) One pound of a copper soap of mixed fatty acids (Pilot Protective Copper Soap) dissolved in one gallon of petrol or gas-works benzol. This gives a 12% solution approximately, to which 1 lb. of tar to the gallon is afterwards added. (*b*) "Cuprinol" may be used instead of the fatty acid copper soap as in (*a*). Cuprinol may be used alone and is more effective than fatty acid copper soap in sea-water; it is also more expensive. It is, however, improved, especially for hemp nets, by the addition of tar, 1 lb. to the gallon of mixed Cuprinol ; the latter is sold as a solution, to be mixed with an equal volume of petrol before use. Hemp and cotton nets treated according to methods (*a*) and (*b*) have lasted three years when allowed to soak in Aquarium sea-water, in jars, the water being changed three times a week.

2. Efficient preservation, with maintenance of the original strength for three years, has also been given to cotton nets treated according to Dr. Olie's method and re-treated every four months. This treatment consists of boilings in cutch on two occasions, the net being dried in between. It is then soaked for 15 minutes in a 1% solution of copper sulphate* to which ammonia has been added in an amount just sufficient to re-dissolve the precipitate first formed.

I am indebted to my laboratory assistant, Mr. F. J. Warren, for performing the tensile tests during the last year.

REFERENCES.

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FILLON, R. 1925. Les traitements préservateurs des filets de pêche en coton. Office sci. et tech. des pêches maritimes. Notes et mém., No. 45. Paris.

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* One pound dissolved in ten gallons of fresh water, with about six ounces by weight of strong ammonia.

An Instrument for Sampling Marine Muds.

By

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and

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With 5 Figures in the Text.

THIS instrument was designed for taking marine muds for analysis. The requirements were that it should raise a column of mud, from eight to sixteen inches long, and without appreciable disturbance, or contamination with metal. An instrument working on the same principle was used here by Mr. R. Macdonald, and was made in Oslo. The advantages of the present model are that, while small enough to be worked by hand, it is capable of taking larger samples, and from bottoms of very varying consistencies.

Essentially it is a heavy brass body containing a glass tube, the latter being open at both ends when descending, so that the water may stream through it. The sampler falls under its own weight, and drives deeply into the mud, which partially fills the glass tube. A valve at the top closes when the sampler stops, and by this, and by its own friction against the glass, the mud is held in the tube while the sampler is hoisted. The overall length of the machine is 35 inches, the greatest diameter $3\frac{3}{4}$ inches, and the weight 35 pounds.

Glass tubes of three different diameters are used, to cope with the varying nature and holding capacity of the ground.

The instrument is shown assembled in Fig. 1, while Fig. 2 shows the details of the valve region. Fig. 4 is a horizontal section of the instrument. The main body is a heavy brass tube (Fig. 4, B), closed at the top by a brass plate, in which is a circular aperture ; the lower end is open, but has a projecting flange, threaded externally to take a lock-ring. The main tube or body is 9·57 inches long ; the plate at the top is 0·38 inches thick, and the body has an overall length of 9·95 inches. The aperture in the top of the plate is one inch in diameter. The walls of the body are 0·79 inches thick, and its external diameter is 3·75 inches.

The sheath (Fig. 4, D) into which the glass tube is loaded is a tube of ·075 inch brass, 14·8 inches long, and 2·15 inches in external diameter.

Five inches from the top is a heavy flange which fits against the bottom of the body. At its lower end the sheath is turned in to the extent of ·15 inch, to give protection to the bottom of the glass tube. The sheath is clamped to the body by a brass lock-ring (Fig. 3, C) which screws on to the bottom of the body. The ring and sheath are removed when inserting or withdrawing the glass tube.

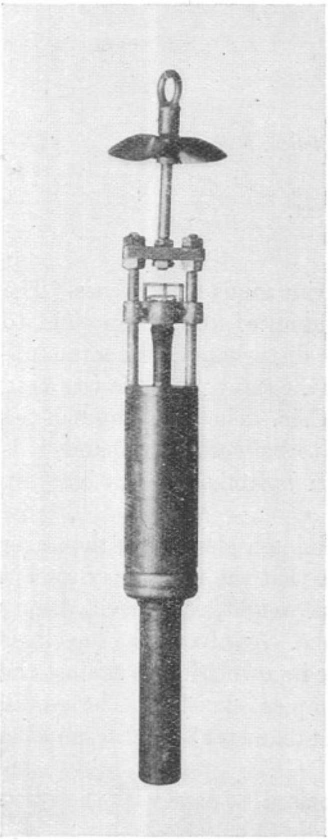
FIG. 1.—Photograph of bottom sampler.

Two brass rods (Fig. 4, A), 7·45 inches long and 0·63 inches in diameter, rise from the top of the body and support the valve mechanism, which is described below; to the link which unites them at the top is attached the central rod that bears the propeller. This shaft is 8·4 inches long, and carries at the top a ring for the attachment of a rope. The propeller itself revolves freely on the shaft, and is fitted to ensure straight descent. It has four blades, with a distance from tip to tip of six inches.

The glass tubes and their rubber connections are not shown in Fig. 4. For the sake of clearness, they have been displaced to the right, and are shown as Fig. 5. The shaded areas represent rubber, the unshaded glass. The glass sampler tube is 1·85 inches in external diameter, 0·1 inches thick, and 18·25 inches long: it lies within the sheath, and extends almost to the top of the body. The dimensions of these tubes vary slightly owing to the difficulty of obtaining uniform supplies. The bottom of the glass tube is open; the top receives a rubber bung, which must be tight-fitting. This is pierced for a small glass tube, 3·5 inches long, and just under an inch in external diameter, which passes through the aperture in the top plate of the body, and is connected by a rubber sleeve with the actual valve. The rubber bung, in addition to making the joint, serves to take up some of the shock, if, as sometimes happens, the sampler strikes a stone on the bottom. For the same reason it has been found desirable to adjust the bung so that the larger glass tube is not actually in contact with the turned-in bottom of the sheath. The glass tube is held as rigidly as is necessary, when the bung is sufficiently tight-fitting to ensure the essential water-tight joint.

The valve is a glass tube, 2·25 inches long and slightly less than one inch in external diameter. Near the bottom it has a swelling to allow the sleeve to grip it. At the top it is turned over to form a rim about a quarter of an inch wide, and the upper surface of this rim is ground. On it lies a circular ground glass plate, confined only by the small cage shown in the figures. As the sampler descends, the water streams through the tube, and escapes through the valve, the ground glass plate being lifted by the pressure of the water. But as soon as the sampler comes to rest in the

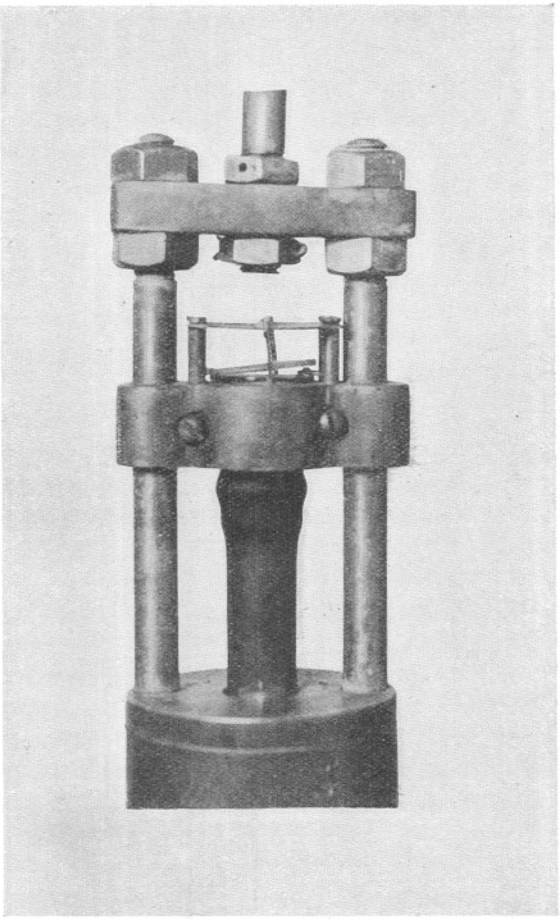

FIG. 2.—Photograph of valve region of bottom sampler.

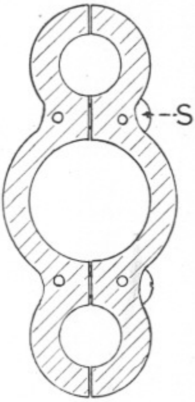

FIG. 3.—Plan of valve bar, $\times\frac{1}{2}$.

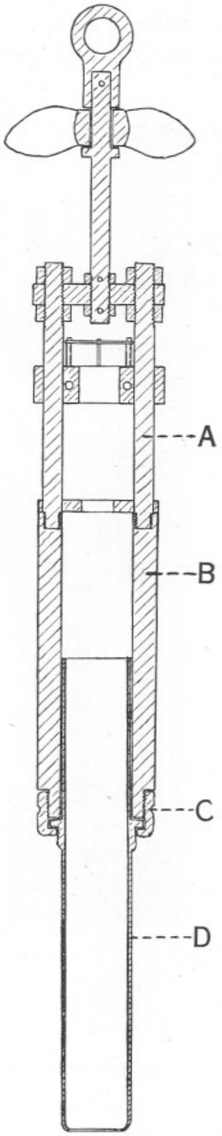

FIG. 4.—Diagram of bottom sampler, $\times\frac{1}{6}$: for lettering see text.

FIG. 5.—Glass parts of bottom sampler.

egg case with the egg enclosed, suggest that once the egg has reached the oviduct, events move rapidly.

It is a familiar fact that two ova are shed from the ovaries simultaneously, so that in each oviduct there is an egg in the same stage of development. In the specimen here described it may be noted that both eggs appear to have been shed from the right ovary. In Fig. 1 it can be seen that in the left ovary are several eggs in an advanced stage of development, whereas in the right ovary the largest eggs present are only about half-grown. This may indicate an alternation in the activity of the ovaries. Many further observations would be needed to establish this, but if it should prove to be generally true, it may readily be seen how, from such a condition, that found in *Scyllium canicula*, for example, could be derived, in which only one ovary develops and becomes functional.

One further point is illustrated in Fig. 1. In textbooks the oviducal funnels of both the skate and the dogfish are described and figured as being united to form a single median ostium. In *Raia radiata*, at any rate, this seems not to be the case. The upper and lower lips of the funnels are, indeed, united, but the openings remain so widely separated as to be, probably, functionally distinct. Redeke (1898) stated that in *Trygon pastinaca* there are two separate ostia (quoted by Ihle, 1927, p. 745). *Raia radiata*, therefore, seems to exhibit a condition intermediate between this and the completely fused ostia of *Raia batis*.

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

By

W. R. G. Atkins, F.I.C., F.R.S.,

Head of the Department of General Physiology at the Plymouth Laboratory.

THIS paper is a continuation of Part I in a strict sense, and deals with the methods and samples considered previously. More prolonged immersion tests have enabled a more accurate estimate to be reached as to the relative values of the methods of preservation. One new preservative has been tried, an oily substance sold as "Neo-Russigen," a sample of which was supplied by the Ministry of Fisheries; in the absence of any chemical analysis of this there is no guarantee that subsequent supplies will approximate to the sample received, to which alone must the data presented be considered to apply.

The tables are completed or continued from Part I, and bear the numbers by which they were designated in Part I, to which reference as to the methods of treatment should be made. Table 14 is the only new one. In the tables more weight should be attached to the life of the net than to the percentage life, taking the untreated net as 100; this is because an untreated net placed to rot in October experiences cold weather and may last as long as five months, whereas if the immersion dates from early summer the warm weather results in more rapid decay and it may only last two months. The preserved nets will however go through both summer and winter. It might be better to take three months as a standard time for the rotting of untreated nets, but this varies also with the thickness of the twine, so the observed values have been given in each case.

A correction must be mentioned as regards the results shown in Table 7, Part I. Sample 51A, treated with the copper soaps and tar mixture, was rejected in error after eleven months. In reality it lasted for twenty months, but this is decidedly lower than usual with the mixture, cp. No. 14A, 39 months, No. 39A, over three years.

TABLE 3.

Hemp net rotting in Aquarium tank water; initial strength, average of sets of six, 13½ and 14¾ lbs. dry; after soaking for three hours, 12½ lbs. Immersed 26/9/'25.

No.	Treatment.	Till unserviceable, months.	Percentage life of net.
10	Untreated	5	100
11	Copper soaps, 12%, viz. 1 lb. per gal.	9	180
12‡	Do. with resin 1 lb. per gallon (12%)	11	220
13	Do. with anti-fouling paint, 12%	29*	580
14	Do. with tar, 12%	36†	720

‡ The soap and resin, paint or tar respectively were mixed, so that only one dip was required, 1 lb. of each being added to the gallon of copper soap solution in petrol.

* Half-strength after 26 months, still serviceable, looked as new.

† Slightly under half-strength after 26 months, still serviceable, looked as new.

TABLE 5.

Cotton net rotting in Aquarium tank water; initial strength, dry, 19½ lbs. Immersed 26/9/'25.

No.	Treatment.	Till unserviceable, months.	Percentage life of net.
10A	Untreated	5½	100
11A	Copper soaps, 12%	10¼	190
12A	Do. with resin 1 lb. per gallon (12%)	26*	470
13A	Do. with anti-fouling paint, 12%	37†	670
14A	Do. with tar, 12%	39‡	710

* Strength 10 lbs. after 25 months.

† Strength 17½ lbs. after 36 months.

‡ Strength 18 lbs. after 36 months.

TABLE 9.

Hemp net rotting in Aquarium tank water; initial strength, dry, averages of sets of six tests each, 15¼, 15¾, 18½; maximum single strand 21, minimum 12½ lbs. Immersed 17/3/'26.

		Life of net.	
No.	Treatment.	Months.	Percentage.
28	Untreated	2½	100
29	Cutch, 2% infusion, two boilings	6	240
30	Do. followed by Olie's ammonia copper sulphate	30*	1200
31	As 29, followed when dry by 12% copper soaps	30*	1200
32	Copper soaps, 12%, but soaked for 3 hrs.	19	760
33	Copper soaps, 12% with 1 lb. resin per gallon	13½	540
34	Copper soaps, 12%, followed when dry by No. 33 treatment	29*	1160

* After 20 months strengths were 8 lbs., about half-strength.

TABLE 10.

Cotton net rotting in Aquarium tank water; initial strength, dry, 12 lbs. Immersed 17/3/'26.

No.	Treatment.	Life of net. Months.	Percentage.
24A	Untreated	2	100
26A	Cutch, 2% infusion, two boilings	3	150
25A	Do. followed by Olie's ammonia copper sulphate	5	250
27A	As 26A, followed when dry by 12% copper soap	5	250
28A	Copper soap, 12%, soaked for 3 hrs.	5	250
29A	Do. with 1 lb. resin per gallon	5	250
30A	As 28A, followed when dry by 29A treatment	25*	1250

* Strength 12½ lbs. after 19 months, all colour gone and strength 7½ lbs. after 20 months.

TABLE 11.

Cotton net rotting in Aquarium tank water; initial strength, dry, 18 lbs. Immersed 20/10/'26.

No.	Treatment.	Re-treatments.	Strength, after years. 1	2	3
34A	Untreated. Life 5½ months	None	0	0	0
35A	Cutch, two boilings	Every two months	16·3	0	0
36A	Do.	Every three months	18	9·8	4·6
37A	Do. followed by Olie's ammonia copper sulphate	Every four months	22·5	20·9	18·8

TABLE 12.

Hemp net Nos. 35–39 rotting in Aquarium tank water; Nos. 40–44 in fresh water. Immersed 25/11/'26. Initial strength, dry, 16½ lbs.

No.	Treatment.	Strength, after years. 1	2	3
35	Copper soaps, 12%. Life 14 months	5·3	0	0
36	Do. with tar as No. 14	14·3	11·4	7·5
37	Cuprinol with equal volume of petrol	12·3	8·3	4·8
38	As No. 37 with 1 lb. tar per gallon of mixture	16·3	12·3	13·1
39	Copper soaps as No. 35, Cuprinol as No. 37, equal volumes of each	13·0	10·1	5·8
40	As No. 35	7·0	7·4	5·3
41	As No. 36	9·0	9·1	6·6
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39A	Do. with tar as in 14A	18	17	18
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41A	As No. 40A with 1 lb. tar per gallon of mixture	25	22	19
42A	Copper soaps as 38A, Cuprinol as 40A, equal volumes of each. Life 30 months	25	13½	0
43A	As 38A	22	17	16
44A	As 39A	21	20	14
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SUMMARY.

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An Instrument for Sampling Marine Muds.

By

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With 5 Figures in the Text.

THIS instrument was designed for taking marine muds for analysis. The requirements were that it should raise a column of mud, from eight to sixteen inches long, and without appreciable disturbance, or contamination with metal. An instrument working on the same principle was used here by Mr. R. Macdonald, and was made in Oslo. The advantages of the present model are that, while small enough to be worked by hand, it is capable of taking larger samples, and from bottoms of very varying consistencies.

Essentially it is a heavy brass body containing a glass tube, the latter being open at both ends when descending, so that the water may stream through it. The sampler falls under its own weight, and drives deeply into the mud, which partially fills the glass tube. A valve at the top closes when the sampler stops, and by this, and by its own friction against the glass, the mud is held in the tube while the sampler is hoisted. The overall length of the machine is 35 inches, the greatest diameter $3\frac{3}{4}$ inches, and the weight 35 pounds.

Glass tubes of three different diameters are used, to cope with the varying nature and holding capacity of the ground.

The instrument is shown assembled in Fig. 1, while Fig. 2 shows the details of the valve region. Fig. 4 is a horizontal section of the instrument. The main body is a heavy brass tube (Fig. 4, B), closed at the top by a brass plate, in which is a circular aperture ; the lower end is open, but has a projecting flange, threaded externally to take a lock-ring. The main tube or body is 9·57 inches long ; the plate at the top is 0·38 inches thick, and the body has an overall length of 9·95 inches. The aperture in the top of the plate is one inch in diameter. The walls of the body are 0·79 inches thick, and its external diameter is 3·75 inches.

The sheath (Fig. 4, D) into which the glass tube is loaded is a tube of ·075 inch brass, 14·8 inches long, and 2·15 inches in external diameter.

Five inches from the top is a heavy flange which fits against the bottom of the body. At its lower end the sheath is turned in to the extent of ·15 inch, to give protection to the bottom of the glass tube. The sheath is clamped to the body by a brass lock-ring (Fig. 3, C) which screws on to the bottom of the body. The ring and sheath are removed when inserting or withdrawing the glass tube.

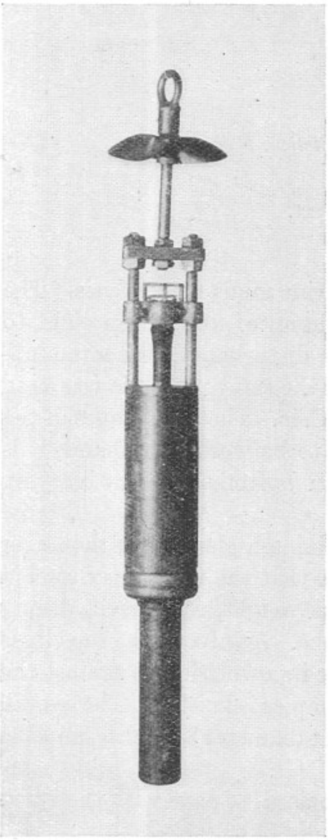

FIG. 1.—Photograph of bottom sampler.

Two brass rods (Fig. 4, A), 7·45 inches long and 0·63 inches in diameter, rise from the top of the body and support the valve mechanism, which is described below; to the link which unites them at the top is attached the central rod that bears the propeller. This shaft is 8·4 inches long, and carries at the top a ring for the attachment of a rope. The propeller itself revolves freely on the shaft, and is fitted to ensure straight descent. It has four blades, with a distance from tip to tip of six inches.

The glass tubes and their rubber connections are not shown in Fig. 4. For the sake of clearness, they have been displaced to the right, and are shown as Fig. 5. The shaded areas represent rubber, the unshaded glass. The glass sampler tube is 1·85 inches in external diameter, 0·1 inches thick, and 18·25 inches long: it lies within the sheath, and extends almost to the top of the body. The dimensions of these tubes vary slightly owing to the difficulty of obtaining uniform supplies. The bottom of the glass tube is open; the top receives a rubber bung, which must be tight-fitting. This is pierced for a small glass tube, 3·5 inches long, and just under an inch in external diameter, which passes through the aperture in the top plate of the body, and is connected by a rubber sleeve with the actual valve. The rubber bung, in addition to making the joint, serves to take up some of the shock, if, as sometimes happens, the sampler strikes a stone on the bottom. For the same reason it has been found desirable to adjust the bung so that the larger glass tube is not actually in contact with the turned-in bottom of the sheath. The glass tube is held as rigidly as is necessary, when the bung is sufficiently tight-fitting to ensure the essential water-tight joint.

The valve is a glass tube, 2·25 inches long and slightly less than one inch in external diameter. Near the bottom it has a swelling to allow the sleeve to grip it. At the top it is turned over to form a rim about a quarter of an inch wide, and the upper surface of this rim is ground. On it lies a circular ground glass plate, confined only by the small cage shown in the figures. As the sampler descends, the water streams through the tube, and escapes through the valve, the ground glass plate being lifted by the pressure of the water. But as soon as the sampler comes to rest in the

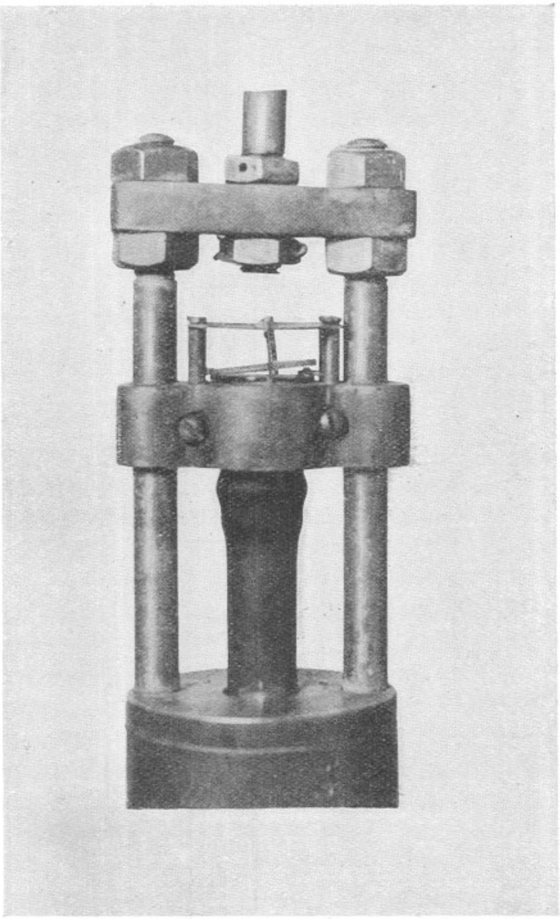

FIG. 2.—Photograph of valve region of bottom sampler.

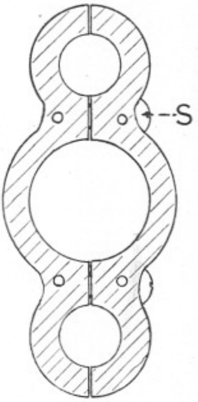

FIG. 3.—Plan of valve bar, ×½.

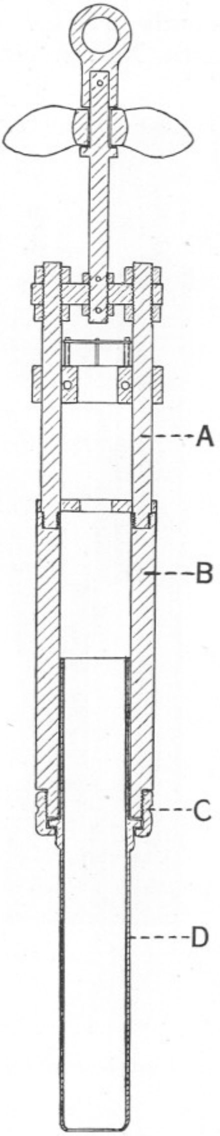

FIG. 4.—Diagram of bottom sampler, ×⅙: for lettering see text.

FIG. 5.—Glass parts of bottom sampler.

mud, the plate drops on to the ground rim beneath it, making a watertight joint.

The valve carrier is shown in plan in Fig. 3. It consists of a split bar, 1·2 inches deep, which slides on the two uprights previously referred to : it is cut away in the centre to accommodate the valve. Two screws (Fig. 3, s) serve to clamp the two halves to each other, and to the supporting rods. Thus the valve is accessible, and its distance from the main body can be varied if necessary.

The length of the column of mud taken varies with the nature of the mud itself, and with the diameter of the glass tube with which the sampler is working. Sandy muds hold only in the medium or small tubes, and some clayey muds also hold badly owing to their slipperiness. The longest samples are usually taken in the 1·5 inch tubes. It is essential that all connections between rubber and glass should be good, or the muds will slip out. The instrument was designed to take three sizes of tubes, with external diameters of 2·0, 1·5, and 0·95 inches respectively. The figures show only the largest tube in position, but there are three interchangeable sheaths, one to fit each size of tube. They are all the same length, and the flange which the lock-ring grips is the same diameter in each. The assembly is the same with the 1·5-inch tubes as with the large ones, but with the smallest tubes there is this difference, that the tube itself is about three inches longer than the others, and projects through the aperture in the top of the body of the instrument, connecting directly to the valve by the rubber sleeving, the 3·5-inch tube, and the bung being dispensed with.

The instrument has now been in use at the Millport Laboratory for some months, in depths ranging from 10 to 70 fathoms, and has proved very satisfactory. With the 2-inch tubes, samples 12 inches long have been taken from depths of 60 fathoms, and the 1·5-inch tubes frequently give 16-inch samples. Whilst it has been designed for use with muds only, shorter samples of sands have been taken successfully with the small tubes.

The fauna of the muds can be seen well through the glass tubes. Whilst crustacean larvæ, etc., have been taken swimming in the water immediately over the mud, many burrowing molluscs and polychæts have been taken, as well as crustaceans and ophiuroids on some grounds. One interesting catch was a specimen of *Calocaris macandreæ*, taken in its burrow eight inches below the surface, at a depth of 35 fathoms.

The mud is raised without contamination, as it is never in contact with anything but glass. That it is raised without appreciable disturbance is shown by the fact that layers of different types of mud are often visible in the same sample, with very clear boundaries. Also there is very little disturbance of the fine upper layers.

After the tubes have been removed from the machine, the mud is pushed out of them with a ramrod. A certain amount of breakage occurs with the glass tubes, and also the valves, so that it is well to have a reserve supply. It is often found most convenient to bring the mud back in the tubes, in which case spare ones are necessary. When ordering these it is advisable to specify that they shall be straight, as our first supply included some that were curved to such an extent that they would not enter the sheaths.

The instrument probably could be most profitably worked from a wire, but in our case it has proved more convenient to work it from a rope ; and we found that the speed of descent was quite sufficient with a 2-inch rope, even when working in depths of over 70 fathoms.

The Muds of the Clyde Sea Area.
1. Phosphate and Nitrogen Contents.

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With 5 Figures in the Text.

THE Clyde Sea Area is in many ways an ideal ground for the investigation of the nutrient salts in the bottom deposits. The different lochs present a range of depth of water of from 0 to 200 metres: some parts have strong tidal currents up to five knots, while others are practically unaffected by the tide: some lochs have also been affected by the dumping of sewage and harbour sludge, and the effect of these can be examined. Conditions may also be compared in muds ranging from the loch heads to the almost open sea conditions at Ailsa Craig.

The fact that the mud is as nearly homogeneous as any bottom deposit can well be, coupled with the taking of eight or ten cores from each station, ensures the representative sampling of any region. Also, since cores of up to forty centimetres in length can be taken, the vertical distribution of the components of the mud may be examined.

A series of investigations is being made on the chemical, physical and geological nature of these muds, and on the relation of these to the fauna. The present paper deals only with their phosphate content, and their organic content as represented by total nitrogen. The organic content has not been estimated directly, as there is no accurate method that is applicable, whereas the nitrogen can be determined with great accuracy; further, the nitrogen content is of importance in giving a link in the chain of the nitrogen cycle in the sea. The results are tabulated, and then discussed.

This is only a preliminary statement, and it is hoped later to trace a connection between more of the factors concerned. In dealing with such a very complex set of conditions, and before drawing conclusions, it is necessary to take a sufficient number of stations to give significant results, and one must not apply them to a single station as a test of their truth. Irregularities are frequent, such as those due to the interpolation of a layer of sand at some level, and similar causes, but neglecting these cases, it is possible to see a certain amount of correlation between some of the factors in the area.

The muds in general are soft for the top ten centimetres or more, but rarely so soft, even at the very surface, as to form a so-called "Pea Soup" layer; they then become more clayey deeper down. The mud sampler, which is described in another paper (**3**), takes perfectly undisturbed samples, and shows that the surface of the mud is clearly marked off from the overlying water, with no contamination of the latter which would be clearly visible if present. It is not, however, the purpose of the present paper to discuss the physical character of the muds.

Although clear demarcation into layers is often present, no attempt has so far been made to analyse these natural layers separately. All samples taken are cut up on board the boat into five-centimetre lengths, and these are set aside in separate pots, to be taken back and dried as soon as possible. After drying at about 110° C. they are ground in an iron mortar and then passed through a 1 mm. sieve. They can then be stored in this condition in airtight jars until required.

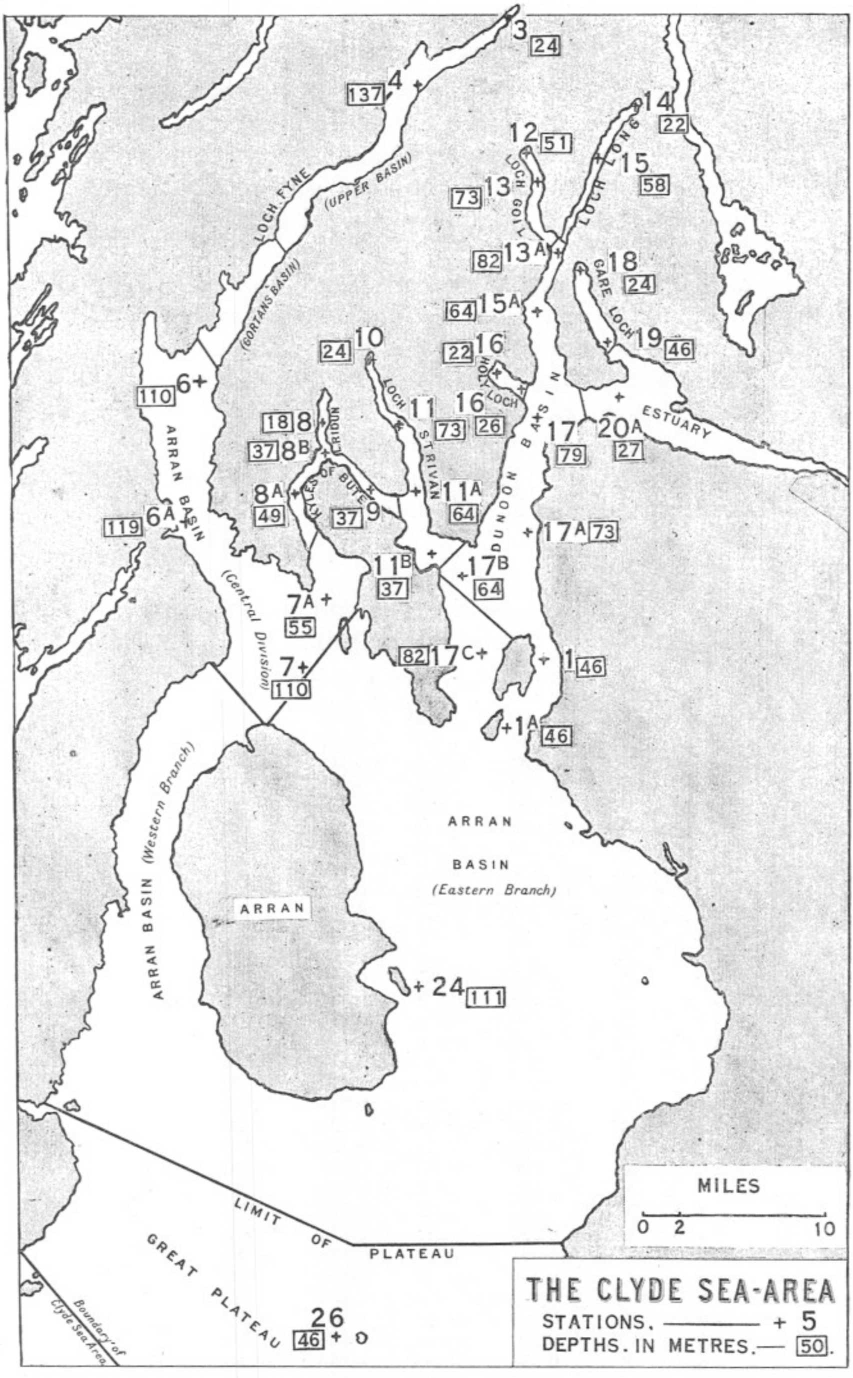
Thirty-three stations have so far been worked, and their positions and depths are shown in the accompanying chart (Fig. 1). Wherever possible the stations have been those used by Marshall and Orr in their work on the plankton of the area (**1**).

Note on the Tides.

The chief points in the tidal streams, which vary greatly throughout the area, are given below. The figures refer to the maximum spring tides, and where two figures are quoted the first refers to the flood, and the second to the ebb tide. Up the Kilbrennan Sound (Arran Basin, west branch) the tide is about $2\frac{1}{2}$ knots, though greater in some shallows. In Loch Fyne the average tide is 2 knots, with an increase to $3\frac{1}{2}$ and $5\frac{1}{2}$ at the Otter Spit just north of St. 6, and $2\frac{1}{2}$ and 4 at the Minard Narrows: at St. 4 it has dropped to $1\frac{1}{4}$ and $1\frac{3}{4}$. The stream up the east coast of Arran is $1\frac{1}{2}$ knots, and the branch of this up the Inchmarnock Sound and West Kyle has a maximum of $2\frac{1}{2}$ knots. St. 7 has practically no tide, and there is very little in Loch Riddon (L. Ridun): at the top of the East Kyle there is a tide of 3 knots, but Rothesay Bay and Loch Striven have very little indeed.

To the east of Cumbrae the tide is 2 knots, and to the west, $1\frac{1}{2}$ knots. In the Dunoon Basin it is about 1 knot, rising off Gourock to 2 knots (St. 20a.) The Holy Loch, and Lochs Long and Goil have very little tide, but in the mouth of the Gare Loch there is a peculiar swirl, and a tide of up to 5 knots.

These figures of course refer to the surface currents, little being known of the bottom currents which directly influence the muds themselves. Further details with regard to the area may be found in Mill's "Clyde Sea Area" (**2**).


3
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13A
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11A
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6A
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11B
37
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7A
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82
17C
1
46
7
110
1A
46
24
111
26
46
LOCH FYNE
(UPPER BASIN)
(GORTAN'S BASIN)
LOCH GOIL
LOCH LONG
GARE LOCH
HOLY LOCH
LOCH STRIVAN
RIDUN
KYLES OF BUTE
ESTUARY
DUNOON BASIN
ARRAN BASIN
(Central Division)
ARRAN BASIN (Western Branch)
ARRAN
ARRAN BASIN
(Eastern Branch)
LIMIT OF PLATEAU
GREAT PLATEAU
Boundary of Clyde Sea Area
MILES
0 2 10
THE CLYDE SEA-AREA
STATIONS. ——— + 5
DEPTHS. IN METRES.— 50.

Fig. 1.

PHOSPHATE CONTENT.

Since any extract of the mud is very highly coloured, no colorimetric method of estimation of phosphate can be used; the most suitable method has been found to be that used in soil analysis, viz., of precipitation as ammonium phospho-molybdate, and solution of this in standard sodium hydrate solution, the excess of the latter being then titrated (**3** and **4**).

20 gm. of the dried mud are extracted for 48 hours with hydrochloric acid, in a water-bath, and the extract after filtering is made up to 250 c.c. Four portions of 25 c.c. are then taken from this for analysis. It has not been found necessary to compare with a known standard at each estimation, but each extract was estimated, as stated, four times for the sake of accuracy. The results for each station, at depth intervals of 5 cm., are given in Table I, together with a note of the general type of the mud, and the depth of the water at each station.

TABLE I.

PHOSPHATE VALUES EXPRESSED AS PERCENTAGE BY WEIGHT OF P_2O_5 IN THE DRIED MUD.

M. = MUD. S.M. = SANDY MUD. S. = SAND.

			Depth in Mud in cm.					
Station.	Depth in Metres.	Type.	0–5.	5–10.	10–15.	15–20.	20–25.	25–30.
1	46	M.	0·244	0·195	0·187	0·175	—	—
1a	46	S.	0·152	0·145	0·142	0·142	—	—
3	24	S.M.	0·250	0·213	0·201	0·185	—	—
4	137	M.	0·270	0·220	0·240	0·216	—	—
6	110	M.	0·201	0·199	0·188	0·185	—	—
6a	119	M.	0·179	0·164	0·166	0·156	—	—
7	110	M.	0·214	0·177	0·180	0·169	—	—
7a	55	M.	0·169	0·156	0·142	0·149	—	—
8	18	S.M.	0·219	0·215	0·173	0·155	—	—
8a	49	M.	0·199	0·188	0·206	0·201	—	—
8b	37	M.	0·248	0·206	0·167	0·157	—	—
9	37	M.	0·237	0·203	0·229	0·201	—	—
10	24	M.	0·228	0·198	0·201	0·172	—	—
11	73	M.	0·226	0·206	0·220	0·204	—	—
11a	64	M.	0·266	0·188	0·219	0·216	—	—
11b	37	M.	0·219	0·178	0·177	0·185	0·170	0·175
12	51	M.	0·305	0·219	0·214	0·186	0·169	0·186
13	73	M.	0·406	0·219	0·239	0·211	0·207	0·203
13a	82	M.	0·284	0·266	0·230	0·226	0·236	0·200
14	22	M.	0·243	0·224	0·191	0·201	0·201	0·240
15	58	M.	0·328	0·321	0·289	0·266	0·299	0·253
15a	64	M.	0·241	0·209	0·261	0·228	—	—
16	22	M.	0·291	0·219	0·179	0·174	—	—
16a	26	M.	0·255	0·216	0·219	0·178	—	—
17	79	M.	0·267	0·228	0·198	0·087	—	—
17a	73	S.	0·149	0·142	0·109	0·099	—	—
17b	64	S.M.	0·215	0·187	0·209	0·183	0·182	0·197
17c	82	M.	0·200	0·181	0·181	0·172	0·156	0·152
18	24	S.M.	0·260	0·203	0·197	0·207	—	—
19	46	M.	0·364	0·298	0·263	0·284	—	—
20a	27	S.M.	0·168	0·189	0·185	0·141	—	—
24	111	M.	0·158	0·150	0·161	0·152	0·148	—
26	46	M.	0·117	0·101	0·129	0·119	—	—

Total Nitrogen Content.

As the various methods of organic content estimation are not of sufficient accuracy, whereas the total nitrogen can be estimated easily and very accurately, the latter estimation was chosen, and the ordinary Kjeldahl method used (**4**). Ten grammes of mud are taken for each estimation, and these are only duplicated when the results are suspected. The values found are given in Table II in the same form as those for the phosphates, the depths of water and types of mud being repeated for convenience.

TABLE II.

Nitrogen Values expressed as Percentage by Weight of N_2 in the Dried Mud.

M. = Mud. S.M. = Sandy Mud. S. = Sand.

Station.	Depth in Metres.	Type.	Depth in Mud in cm.					
			0–5	5–10	10–15	15–20	20–25	25–30
1	46	M.	0·189	0·170	0·165	0·181	—	—
1a	46	S.	0·099	0·101	0·097	0·083	—	—
3	24	S.M.	0·211	0·211	0·237	0·279	—	—
4	137	M.	0·304	0·279	0·232	0·209	—	—
6	110	M.	0·201	0·178	0·168	0·145	—	—
6a	119	M.	0·135	0·132	0·134	0·097	—	—
7	110	M.	0·183	0·167	0·162	0·161	—	—
7a	55	M.	0·089	0·083	0·074	0·074	—	—
8	18	S.M.	0·256	0·202	0·139	0·132	—	—
8a	49	M.	0·233	0·188	0·170	0·166	—	—
8b	37	M.	0·335	0·284	0·290	0·251	—	—
9	37	M.	0·219	0·201	0·195	0·194	—	—
10	24	M.	0·177	0·148	0·135	0·124	—	—
11	73	M.	0·238	0·237	0·211	0·204	—	—
11a	64	M.	0·262	0·245	0·223	0·211	—	—
11b	37	M.	0·137	0·153	0·132	0·146	0·114	0·114
12	51	M.	0·275	0·265	0·286	0·273	0·295	0·285
13	73	M.	0·379	0·291	0·267	0·237	0·260	0·250
13a	82	M.	0·257	0·198	0·167	0·211	0·242	0·210
14	22	M.	0·337	0·330	0·295	0·302	0·312	0·307
15	58	M.	0·268	0·271	0·231	0·172	0·216	0·188
15a	64	M.	0·242	0·208	0·206	0·202	—	—
16	22	M.	0·184	0·187	0·160	0·156	—	—
16a	26	M.	0·232	0·203	0·187	0·168	—	—
17	79	M.	0·208	0·255	0·221	0·212	—	—
17a	73	S.	0·069	0·051	0·043	0·041	—	—
17b	64	S.M.	0·229	0·204	0·205	0·178	0·180	0·177
17c	82	M.	0·195	0·201	0·176	0·174	0·167	0·160
18	24	S.M.	0·191	0·205	0·166	0·159	—	—
19	46	M.	0·221	0·285	0·158	0·163	—	—
20a	27	S.M.	0·208	0·123	0·150	0·099	—	—
24	111	M.	0·230	0·177	0·133	0·135	0·144	—
26	46	M.	0·119	0·116	0·111	0·102	—	—

Discussion of Results.

The results show that there is no general correlation of the depth of water with either the phosphate or nitrogen content of the mud in any layer, with the following exception. In the case of those shallow-water stations less than forty metres, all the phosphate values lie close together, while covering a much wider range in the deeper stations. As in the case of most such linkages, the surface layers do not agree quite so well as the deeper layers where conditions seem to have become more stabilised. The distribution of P_2O_5 with depth of water for the 5–10 cm. layer, is shown in Figure 2, where the phosphate values for shallow stations range only from 0·178% to 0·224%. In the case of the nitrogen content there does not seem to be such a correlation.

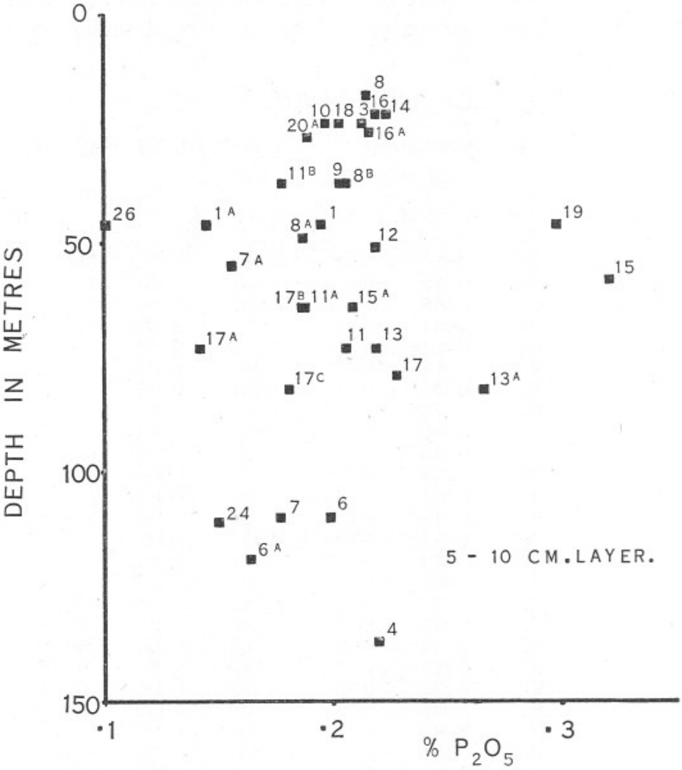


FIG. 2.—Graph showing the distribution of P_2O_5 with depth of water, in the 5–10 cm. layer throughout the area.

The distribution of phosphate with depth in the mud, throughout the area, is shown in Figure 3. The value falls with increasing depth in the mud in all but three stations in the whole area. These are St. 11b, 18 and 19, in all of which the value first drops and then rises again. The latter two stations are in the Gare Loch, which is a backwater into which much fine silt from the river is carried, forming a thick layer all over the bottom. (Mill, p. 646, **2.**)

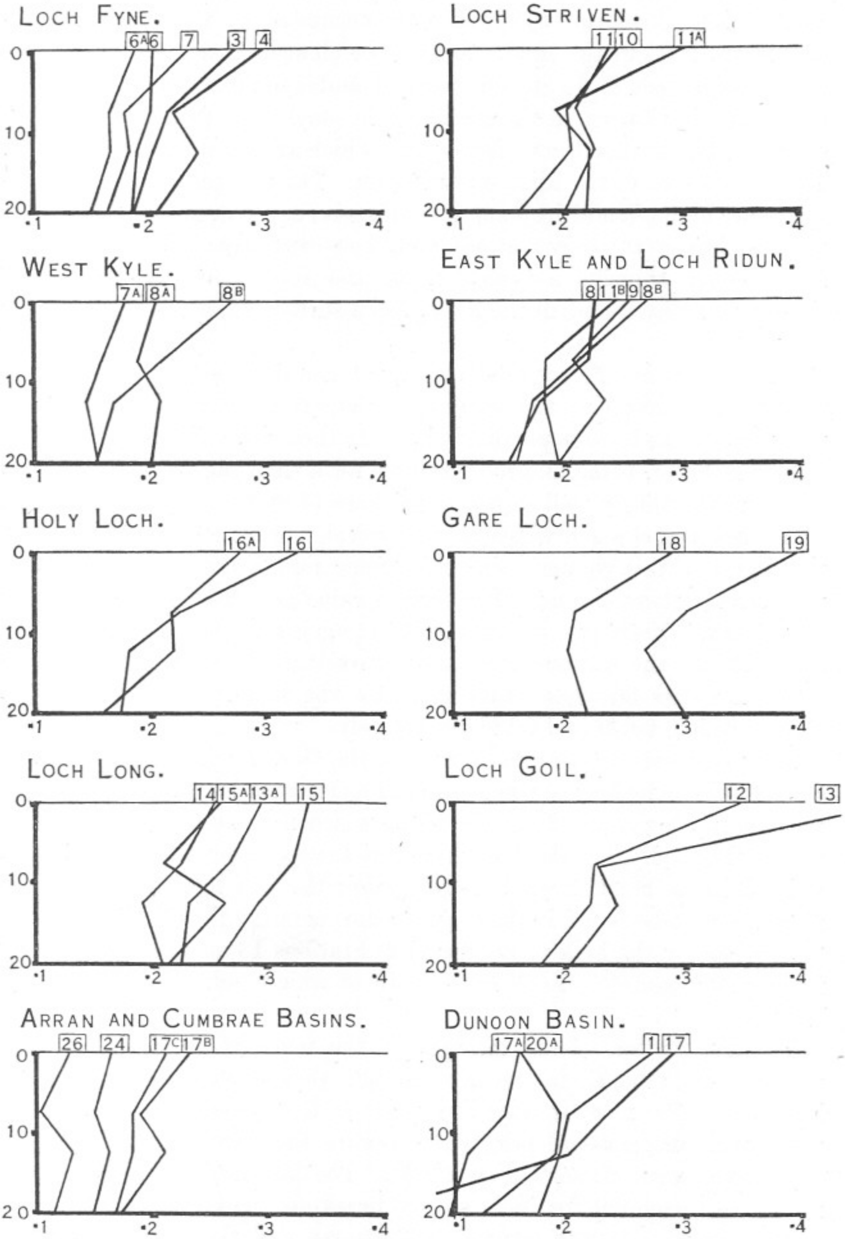


FIG. 3.—Distribution of phosphate with depth in the mud, in the main channels. Depth in cm. (ordinate) against % P_2O_5.

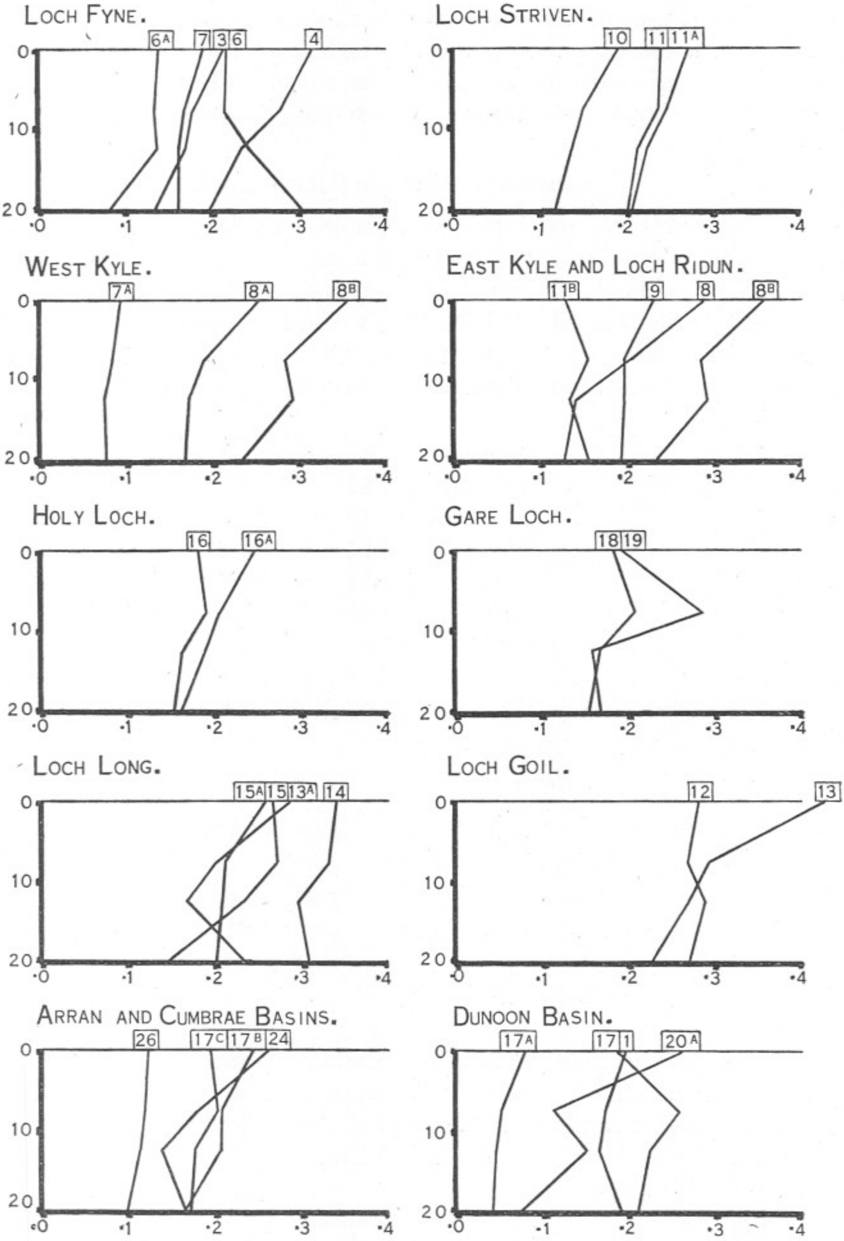
The most noticeable point, however, about the phosphate distribution, is the "Kink," or rise which so often occurs about the ten to fifteen-centimetre level in the mud. A kink, or change of slope of the curve, occurs in nineteen of the stations worked, and is so pronounced as to be an actual rise in thirteen of the stations: in some cases (St. 15a, 24, 26) it even rises higher than the surface values, which are usually far the highest. The significance of the kink is not known. The phosphate values themselves are high. While dropping low off shore, as at St. 26 by Ailsa Craig, they are lowest at sandy stations and those with a strong tide. Station 26, although showing a typical mud, and similar in appearance and texture to many found in the lochs, has a surface value for P_2O_5 of only 0·117%.

Where there is a heavy tidal action, the fine particles of the mud tend to be washed out; also, the sediment in the water does not settle, and the phosphate value is correspondingly low. In these cases, the nitrogen value falls even lower, being in a more soluble form than the phosphate. This action of the tide is well shown in the case of Station 17a, which lies in 73 metres in a channel which shows typical mud at either end; but in the centre of this channel, where for some reason the tide seems to be very strong, there is sand. The surface value here for phosphate is ·149 falling at the 15–20 cm. layer to 0·099, as against surface values of 0·267 and 0·244 for the stations above and below it in the same channel. The nitrogen values for these stations follow the same trend being, at the surface, 0·208, 0·069 and 0·188 respectively.

The phosphate values are highest in the Gare Loch and Lochs Long and Goil, the highest stations being 19, 15, and 13. The Gare Loch receives much rich silt from the river, which may account for the high values there. During the war there was sewage dumping at the mouth of Loch Long, but this would hardly affect the loch head. The cause is more likely to be found in the large streams entering these lochs, and this is born out by the high values found at Stations 16 and 16a in the Holy Loch, and 3 and 4 in Loch Fyne, both of which lochs are fed by large streams.

The distribution of the nitrogen in the muds is more erratic. Its variation with depth in the mud at the various stations is shown in Figure 4. The most outstanding point is the general fall of nitrogen value with increasing depth, which occurs in twenty-five stations, as against two with a rise, and six erratic. The fall in nitrogen with depth might be accounted for by a steady break-down of the organic nitrogenous compounds into nitrites and nitrates, and the removal of these by solution in the water.

Stations 18 and 19 are peculiar as regards nitrogen distribution, as they were for phosphates, and a type similar to them is found at St. 17,


LOCH FYNE.

LOCH STRIVEN.

WEST KYLE.

EAST KYLE AND LOCH RIDUN.

HOLY LOCH.

GARE LOCH.

LOCH LONG.

LOCH GOIL.

ARRAN AND CUMBRAE BASINS.

DUNOON BASIN.

FIG. 4.—Distribution of nitrogen with depth in the mud, in the main channels. Depth in cm. (ordinate) against % N_2.

off Dunoon, where there is a fairly strong tide, though a typical mud. As is to be expected, the values are low in the sand at St. 17a, and in the sandy mud at St. 7a. They are very high at all depths at St. 14, and curiously they are also high at St. 8b where, though at the surface, at any rate, there is a strong tidal current, there is quite a typical mud.

PHOSPHATE NITROGEN RATIO.

The ratio P_2O_5/N_2 also yields some interesting figures. There does not seem to be any constant relation of this ratio either to depth of water or depth in the mud, but in a chain of stations down any loch the ratio frequently varies similarly with depth in the mud, in successive stations. This variation, however, differs from one loch to another. Thus in Loch Long, the ratio tends to rise at first, and then fall again :—

	Depth in Mud.	Stations.		
		15	13a	15a
P_2O_5/N_2	0–5 cm.	1·22	1·10	1·00
	5–10 ,,	1·19	1·34	1·01
	10–15 ,,	1·21	1·38	1·26
	15–20 ,,	1·54	1·07	1·12
	20–25 ,,	1·38	0·97	—
	25–30 ,,	1·34	0·95	—

In Loch Striven, except the station at the loch head, the ratio tends to fall at first, and then to rise again

	Depth in Mud.	Stations.			
		10	11	11a	11b
P_2O_5/N_2	0–5 cm.	1·28	0·95	1·02	1·60
	5–10 ,,	1·34	0·87	0·77	1·16
	10–15 ,,	1·48	1·04	0·98	1·34
	15–20 ,,	1·38	0·99	1·02	1·27
	20–25 ,,	—	—	—	1·48
	25–30 ,,	—	—	—	1·54

The ratio is very high in the sandy Stations 7a and 17a, and also at St. 19 in the mouth of the Gare Loch, all of which stations have strong tides. It is lowest at St. 8b at the head of the Kyles, and then at St. 3 at Loch Fyne head, St. 12 at Loch Goil head, and St. 14 at Loch Long head.

Depth in Mud.	Stations.						
	7a	17a	19	8b	3	12	14
0–5 cm.	1·90	2·15	1·65	0·74	1·18	1·10	1·72
5–10 ,,	1·88	2·82	1·04	0·72	1·01	0·83	1·68
10–15 ,,	1·92	2·51	1·67	0·58	0·85	0·75	0·65
15–20 ,,	2·03	2·40	1·74	0·63	0·66	0·68	0·66

Figure 5 shows the nitrogen values in the 15–20 cm. layer, plotted against the corresponding P_2O_5 values. While, as is usual, the points are rather more scattered in the upper layers, with increase in depth they come more into line, and at this depth all but seven lie close to a straight line, as indicated by the two parallel lines in the figure. Certain stations lie outside these lines, and are discussed below. In the higher layers other stations also outlie, but come into line lower down. The extreme stations, too, are well in line, from the very low values in St. 17a, to the high values in the upper layers of Stations 13a, 15a and 19. The only stations which lie below the line in this figure are St. 15 in Loch Long, and St. 19 in the Gare Loch. In the layer five cm. higher, however, Stations 13a and 15a, both in Loch Long, also fall below the line, as well as St. 19. Stations 3, 12 and 14, which lie above the line, are all loch-head stations, near the entry of a large stream, and St. 8b and 17, which also

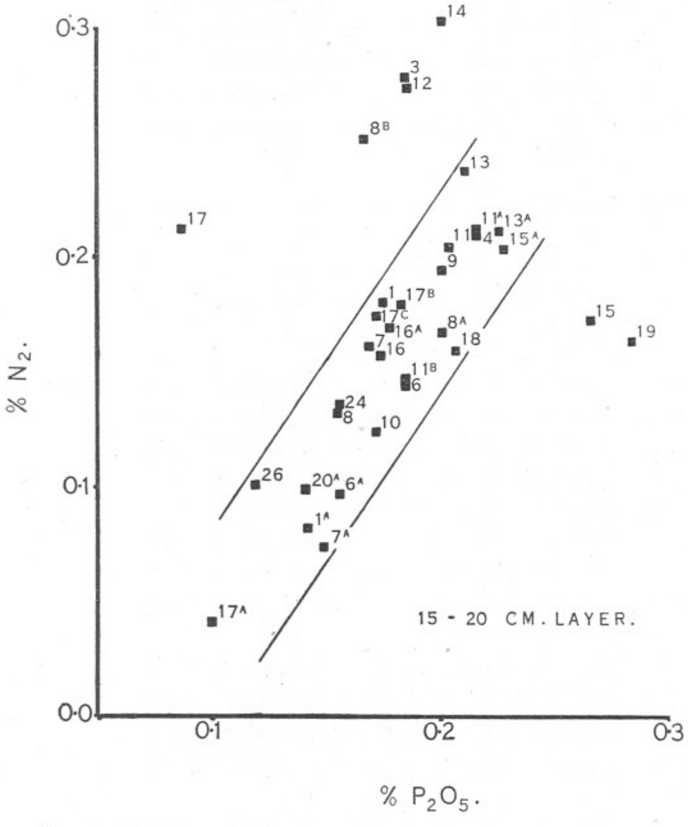


Fig. 5.—Percentage P_2O_5 against percentage N_2 in the 15–20 cm. layer throughout the area.

lie above, both have strong tides, though still remaining fairly normal muds.

Although subject to local irregularities, the successive stations down the various deep channels frequently conform to a typical pattern throughout the chain ; and this type is distinctive for each chain. We have already shown that some of the lochs have typical ratio distribution curves. Similarly the curves for the distribution of phosphates, and nitrogen, are often closely linked in the successive stations of a chain, and frequently grade in character from the head to the mouth of the loch. This agreement within the chains, and the difference between the chains, is well seen as far as phosphates are concerned, in the following groups of stations (Fig. 3).

St. 10, 11, 11a, 11b. In Loch Striven.
St. 18, 19. In the Gare Loch.
St. 12, 13. In Loch Goil.
St. 17b, 17c, 24, 26. In the Cumbrae and Arran Basins.
St. 14, 15, 13a, 15a. In Loch Long.

In the case of the last chain, it is interesting to note that the curves for the upper three stations of the loch have an unusual form, similar in them all, whilst the lowest station in the loch (15a) has attained the more normal type, with a pronounced kink. In this it comes more into series with Stations 12 and 13 in the adjoining Loch Goil, which, though abnormal, shows a distinct kink. Whilst the Loch Goil chain and the upper part of the Loch Long chain show an increase of phosphate towards the mouth, the chain which runs out to Ailsa Craig shows a marked fall seawards.

The nitrogren distribution shows a similar behaviour in some of the lochs (Fig. 4) though often masked by local irregularities. Thus the Gare Loch, Loch Goil and the Holy Loch all show typical curves throughout. Here again the seawards stations, 24 and 26, show a decided drop in nitrogen values.

Finally I wish to express my thanks to the members of the staff of the Millport Laboratory, who have assisted throughout the work.

SUMMARY.

1. The P_2O_5 and N_2 contents of the muds at 33 stations in the Clyde Sea Area, have been determined, at 5-cm. stages, down to 20, and sometimes 30 cm. below the mud surface.

2. In estimating, the phospho-molybdic method for phosphates, and the Kjeldahl method for total nitrogen, were used.

3. There is no general relation between P_2O_5 or N_2 values and the depth of water, with the following exception :—

4. The P_2O_5 values in depths of less than 40 metres all lie close together.

5. The P_2O_5 values fall off with increasing depth in the mud, but usually show a rise at the ten- to fifteen-centimetre level.

6. The nitrogen values usually fall with increasing depth in the mud.

7. Stations with strong tides, usually have low P_2O_5 and N_2 values.

8. A chain of stations down a deep channel holds more or less to the same type of distribution curve throughout ; but the type of curve varies in the different chains and is distinctive of each.

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Salinity Interchange between Sea-Water in Sand and Overflowing Fresh-Water at Low Tide.

By

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With 1 Figure in the Text.

THE following investigations were carried out in order to test the validity of the oft-recurring statement to the effect that "burrowing organisms live under fresh-water conditions during low tide in estuaries." This type of statement is usually made in respect to organisms which live in the sand or mud of estuaries in which, at low tide, a stream of fresh water passes over the ground in which the organisms are buried.

I have not been able to find any references to show that work has ever been done on this subject with the idea of determining the actual salinity of the water held by such sand. Therefore I carried out the following experiments to try to find if data could be procured which would be sufficiently consistent to lead to any conclusions.

LOCALITY.

For preliminary purposes the experiments were carried out in a bay known as Traigh Allt Chailgeag on the North Coast of Scotland about three miles east of the village of Durness. Traigh Allt Chailgeag seemed very suitable for these experiments because,

1. The distance from H.W.M. to L.W.M. is short (250 yards),
2. At low tide a stream of fresh water flows across the sand,
3. The sand-grains are of fairly even size and the texture of the whole ground is uniform,
4. The animal population of the sand is small, since the bay is open to the north and is exposed to continuous heavy surf,
5. The slope is gentle and uniform,
6. There is a good depth of sand.

APPARATUS.

The apparatus consisted of a number of glass tubes, each of 15 c.c. capacity, fitted with rubber stoppers; and a long glass pipette marked off in inches and fitted with a rubber bulb of about 100 c.c. capacity. For use in sand of even texture the glass of this pipette need only be 5 mm. in internal diameter and 1 mm. in wall thickness. Further, it should be of uniform bore without constrictions or swellings.

PROCEDURE.

Observations were made at a number of stations at measured distances along the course of the stream from H.W.M. to L.W.M. following the retreating tide. At each station samples were taken of 1, the flowing water of the stream, and 2, 3 and 4, the water in the sand at a depth of 2, 4 and 6 inches respectively.

The taking of the first sample from each station presented no difficulties. Samples 2, 3 and 4, which were from the sand beneath the flowing water, were procured by compressing the bulb and pushing the graduated end of the pipette into the sand to the required distance. The bulb was then allowed to expand slowly so that a quantity of sand and water was drawn up the tube. If the pipette be withdrawn and held vertically the sand will collect towards the open end, whence it can be ejected and the superincumbent water poured into a collecting tube and labelled.

At each station, before taking the samples, the depth and surface speed of the flowing water were measured. The speed was estimated by floating a thin slab of cork, 6 in. × 5 in. in area, on the surface of the water and measuring with a stop-watch the time taken to cover a known distance.

The depth of the water over the sand was measured with a thin glass ruler placed so that one of its edges was against the flow of the water.

The temperature of the atmosphere and of the flowing water was then taken.

The results at first sight appear to be somewhat erratic, but allowance must be made for the difficulties in sampling, as it is impossible to avoid slight admixture of water from higher layers when taking samples of those below.

As was to be expected, the flowing water was found to increase steadily in salinity from H.W.M. to L.W.M., although the final salinity was much less than might have been anticipated.

From the curves (Fig. 1) showing the salinity of the water in the sand at different depths there appears to be a possibility of dividing the area between H.W.M. and L.W.M. into three well-defined sections as regards the water in the sand, viz. :—

1. A section from H.W.M. down shore for a distance of 90 yards in which the salinity increases with great rapidity.

TABLE OF READINGS.

DATE—8.iv.29. WEATHER—Mild, Wet. WIND—O.

Height of High Tide, 8.iv.29 13·3 ft.

*Tidal Data.**

Max. Height of Spring Tides 14·4 ft.

Height of Low Tide, 8.iv.29 0·8 ft.

Fall in level from H.W.S.T. to L.W., 8.iv.29 13·6 ft.

Average Tide Heights from 8.iii.29 to 8.iv.29 { High Tide, 13·2 ft. Low Tide 2·7 ft.

Average Tidal Range 10·5 ft.

	Locality.	Time of Sampling. Hours before L.W.	Flowing Water. Depth.	Speed.	Temp.	$S^{\circ}/_{\circ\circ}$	pH	2 ins. in sand $S^{\circ}/_{\circ\circ}$	pH	4 ins. in sand $S^{\circ}/_{\circ\circ}$	pH	6 ins. in sand $S^{\circ}/_{\circ\circ}$
1.	H.W.M. in stream, Traigh Allt Chailgeag	11.30 a.m. G.M.T. 1 hr. 41 m. before L.W.	300 mm.	1 ft. per sec.	10° C.	0·35	7·0	2·25		1·55	7·0	12·42
2.	50 yds. below H.W.M. (all measurements made along the stream)	11.45 a.m. 1 hr. 26 m. before L.W.	150 mm.	1 ft. per sec.	10·5°	0·28	7·0	5·91		1·23		13·78
3.	90 yds. below H.W.M.	Noon 1 hr. 11 m. before L.W.	375 mm.	2 ft. per sec.	11°	0·35	7·3	18·12		16·62		24·15
4.	150 yds. below H.W.M.	12.15 p.m. 56 minutes before L.W.	75 mm.	1·4 ft. per sec.	11·5°	1·8	7·4	16·4		17·45	7·75	24·9
5.	200 yds. below H.W.M.	12.30 p.m. 41 minutes before L.W.	450 mm.	0·25 ft. per sec.	12°	5·43	7·4	29·47	7·75	29·47		29·02
6.	250 yds. below H.W.M. and just above L.W.M.	12.45 p.m. 26 minutes before L.W.	150 mm.	2 ft. per sec.	11°	8·08	7·5	32·57		34·34	7·85	

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* Admiralty Tide Tables, Parts I and II.

2. A middle section of about 60 yards in which there is very little increase in salinity.
3. A final section of about 100 yards extending to L.W.M. in which the rate of increase of the salinity is comparable to that of the first section.

This would seem to indicate that towards H.W.M. and L.W.M. the salinity of the water, at least in the shallower layers of the sand, is subject to a certain amount of fluctuation with the tides, whereas in the middle portion there exists a condition of greater stability which may be explained in the following way. In each of the three sections a different set of conditions prevail. Section 1 is under fresh water for the greater portion of 12 hours; Section 3 is under sea-water for the greater portion of 12 hours, while Section 2 is under fresh and sea-water alternately for approximately equal periods. Also, during neap tides Section 1 is never under sea-water, Section 3 is always under sea-water, but Section 2 is subject to both sea- and fresh water.

At most, however, the exchange in salinity between the overflowing water and the water in the sand must be extremely slow. For instance, although these readings were taken within a short period of a spring tide the salinity of the water in the sand at H.W.M. and L.W.M. at 6-inch depth was considerably different from that of the overlying water. The two areas over which the graphs are drawn is an attempt to express this in another way. Assuming that the slope of the beach is a straight line between high- and low-water mark, the time that any point between H.W.M. and L.W.M. is under fresh water or sea-water can be found approximately by comparing the relative lengths into which a vertical from that point is cut by the harmonic curve.* For example, if it be desired to determine the time during which a point 180 yards below H.W.M. is under fresh water, it is only necessary to take the vertical AXB. Then the proportions of sea and fresh water will be (since total time is AXB) $\frac{AX}{AXB}$ and $\frac{XB}{AXB}$ or $\frac{210}{300}$ and $\frac{90}{300}$ (hours) respectively of the time between H.W. and L.W. of that tide.

DEPTH AND SPEED OF FLOWING WATER.

The relation between these and the salinity of the water in the sand does not appear to be very clear. Certain factors, not met with in the case

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* This simple harmonic curve was drawn in accordance with the formula $h = \pm \frac{1}{2} r \operatorname{Cos} \theta$ where h = height of tide above mean tide level.
r = range of tide.
θ is an angle = $\frac{\text{Interval from H. or L.W.}}{\text{Duration of rise or fall}} \times 180°$.

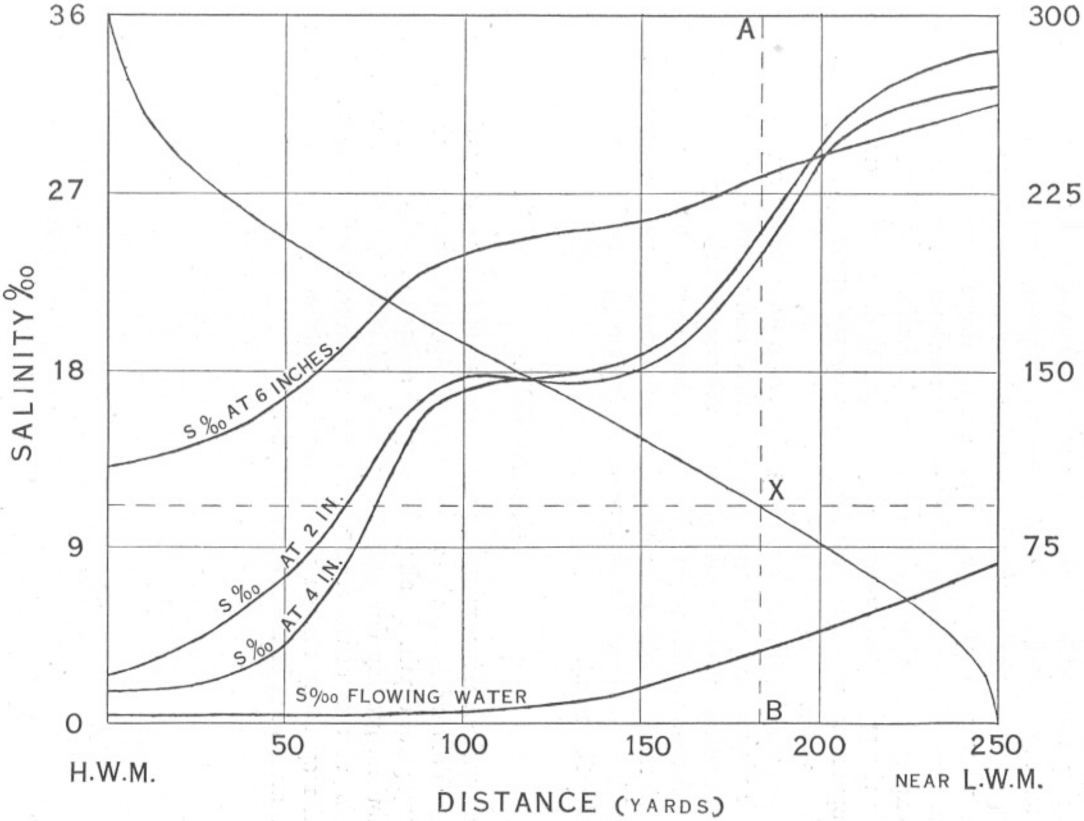

FIG. 1.—Curves representing the salinity of the water at various depths. These curves refer only to the times stated, they are not given as representing static nor minimum values.

of streams which flow over a more coherent bed, also appear to disturb the relationship between depth and speed. When a stream of fresh water flows over loose sand of even texture ripple-marks are rapidly formed. These impede the progress of the water so that, in the first instance, although the surface layers may be travelling at a fair pace, eddy formation may cause other degrees of speed or direction of flow in the other layers. The second stage occurs when the ripple-marks form a bar great enough to force the stream to change its course. This change of course take place with great frequency. In the deeper pools, also, certain peculiarities are noticeable. The walls are much more vertical than might be expected, so that the through flow is limited to the surface layer while the rest of the water eddies slowly round. In these experiments no apparatus was available for estimating the speed of any but the surface water.

From this it will be seen that there are a great many small factors which play a part in determining the speed and volume of the flowing water and its effect on the salinity of the water in the sand. Some of these factors would appear to balance others, so that, for the present at least, it might be advisable to disregard variations in speed and depth, and, by taking an average, consider them as constant (speed$=1{\cdot}2$ feet per sec., depth$=250$ mm.).

CONCLUSION.

In conclusion, it would seem that a stream of fresh water passing over inter-tidal sand has little effect on the salinity of the water in that sand to any great depth. In all probability, at a depth of 10 inches (although, doubtless, grading down slightly towards H.W.M.) the salinity will be similar to that of the sea. Organisms, therefore, which burrow in the sand may easily remain under tolerably constant (salinity) conditions no matter what be the state of the tide.

Studies on Conditioned Responses in Fishes. Part II.

By

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Biologist at the Dove Marine Laboratory, Cullercoats, Northumberland.

With 11 Figures in the Text.

CONTENTS.

I. Introduction.

The present paper continues the account of my experiments on the capacity of fishes to form conditioned responses towards definite stimuli under strict experimental control. No change has been made in the method of recording the results except in the section on auditory discrimination in the wrasse. This slight variation is explained in the appropriate place.

All the experiments described in this part belong to Section A of the previous paper (**1**), in which food is the unconditioned stimulus. The work which has been carried out in Section B will receive fuller treatment at a later date.

II. THE CAPACITY OF THE WRASSE, *CRENILABRUS MELOPS* (L.), TO DIFFERENTIATE BETWEEN TWO DIFFERENT SOUNDS.

Being a continuation of the experiment described in Part I, p. 508.

Mention was made in the earlier paper (**1**) of the likely continuance of discrimination experiments with a wrasse which had already formed a stable conditioned response towards the stimulus of a tuning-fork vibrating at the rate of 128 d.v.'s per second. The discrimination attempted was a simple one, in which the fish had to establish an association between two new factors, in the form of an electric buzzer and a food-bottle at one end of the tank, as distinct from the original response involving entry to a food-bottle at the opposite end of the tank. In Figure 8, Part I, of these studies (**1**), page 508, B1 represents the position of the new food-bottle and its associated buzzer. All other parts are unchanged. The buzzer was of a common type used as a door-bell, enclosed in a stout brass box with a thin brass diaphragm, giving a somewhat harsh note of high pitch approximating to the note F in the 2nd octave of the pianoforte scale, contrasting very strongly with the rich low note from the tuning-fork.

The results are given in Figure 1, a diagram requiring more detailed explanation for the sake of clearness. In any one section of this there is firstly a continuous base line along which dates are marked off as before. Above this are three horizontal sets of positions, the median one shown as a continuous dotted line. Where the original tuning-fork was used as the conditioning stimulus that test is denoted by the symbol O, the symbol X signifying the uses of the buzzer as the signal. Each such symbol O or X entered at regular intervals along the record represents a single test, and the position of it in relation to the dotted line gives the behaviour of the fish.

Thus, referring to the first day's work recorded in the diagram, November 29th, it is to be seen that 7 presentations of the auditory stimulus were given that day. The first two of these being the buzzer, X, the next two, the primary stimulus of the tuning-fork, O. If the fish entered food-bottle B (the original response), no matter which stimulus preceded it, the diagram records a line starting from the median dotted line, then directed upwards to the symbol, and back again to the dotted line. Such, for example, was the response to the buzzer at the first of the tests recorded. If entry was to the opposite bottle B1 (the new response), there is shown a similar line directed downwards, and back again. At the fifth test of the first day this is the result recorded, the correct one for that stimulus—the buzzer. Should a vacillating response be the result, the fish going first to one bottle and then to the other, the order and course of this is shown as in the sixth test of the first day, by a dotted line in the corresponding directions, the symbol occurring at the top or the bottom depending on whether it was bottle B, or B1, in which the fish finally came to rest. In the sixth test just mentioned, this was B1, the correct one. Not infrequently, there was no decisive entry to either bottle, and this is shown in the record by the appropriate symbol remaining on the dotted middle line, as, for example, in the last test of the day.

With this explanation the diagram becomes a concise picture of the results obtained, but the more salient points may be outlined in a running commentary.

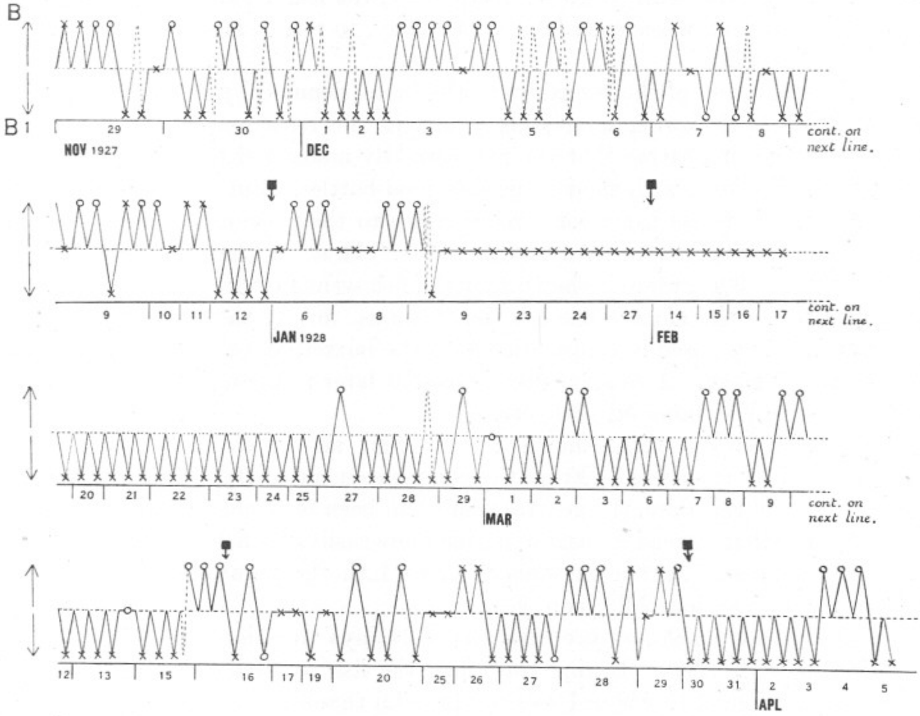

FIG. 1. Record of the discrimination between the sound of a tuning-fork and the sound of an electric buzzer shown by the wrasse, *Crenilabrus melops*, in the formation of conditioned responses.

Explanation in text: O = tuning-fork; X = buzzer.

The introduction of the second bottle and the buzzer at once interfered with the very clear-cut result of the earlier experiments. Although on the first two occasions when the buzzer was used as the signalling stimulus the actual swimming response was a wrong one from the conditioned response point of view, yet the fish, in order to obtain the food used at those tests, finally entered the new bottle. Watched for some time between these and the next tests, the fish was seen to go first to the old bottle and then into the new one, showing an obvious and rapid learning of the relationship of the new bottle to food. It was a striking feature of the earlier conditioned response to the tuning-fork stimulus, that after entry into the food-bottle the fish continued to remain there making signs fairly to be described as anticipatory, until such time as food was given, if the giving of food was intentionally delayed, or not given at all; with the greater complexity this behaviour was somewhat modified. After entry into the food-bottle, the fish usually stayed but a short time, a few seconds, then swam away, to return after a greater or lesser interval.

Examination of the record up to the break denoted by the first arrow reveals the following interesting points in the response. Statistically, there is an indication that the fish correctly associated the buzzer, and the tuning-fork, with their respective food-bottles. But it is to be seen that the response bears some relationship to the previous, immediately preceding response in many of the tests. Thus, at the fourth test of November 30th, there is shown that the fish went first to bottle B1, and then to B, the correct one for the stimulus, for, at the previous test, bottle B1 was used in conjunction with the buzzer, and the response was correctly given. A similar effect is seen at later tests on the same date, as also on December 5th, 6th, etc.

On December 12th, shown by the first arrow, experiments were temporarily suspended. From the commencement of the differentiation tests, until this date, the general result had been inconclusive, with some evidence that instead of discriminating more easily, the fish was becoming more confused. From December 7th to 12th the number of incorrect responses had decidedly increased.

The break which now occurred was of 24 days' duration, and lasted till January 5th, 1928. During this time, the fish was fed for me by Dr. Amirthalingam, to whom I owe my grateful thanks.

One very obvious fact emerges from a study of the responses given immediately after this date. It is to be seen that where the buzzer was used as stimulus, no definite response was noted, the fish not entering either bottle during two minutes' observation at these tests; whilst, on the other hand, when the tuning-fork was sounded, it at once elicited the original response of entry into bottle B. The explanation of this is probably to be found in the fact that this last is a much older, and therefore more stable response, for all my previous work shows that these responses, when once thoroughly established, are stable over long periods. The response involving entry to B1, associated with the buzzer, could not as yet be regarded as well established, and further, many incorrect responses had previously resulted when the buzzer was used. It was therefore decided, on January 27th (2nd arrow, Fig. 1), to continue with the buzzer alone, in the hope of establishing the response when not complicated by intermittent presentations of the sound of the tuning-fork. But for a while the fish ignored all food, and it was not until February 14th that a serious start could again be made. At the next 9 trials, up to February 17th, there were still no signs that the process of forming this association was in any way advancing, so that it was somewhat surprising to get a clear-cut response to B1 at the third test of that date. This, however, initiated a fairly lengthy period from February 20th to March 15th, during which, at 45 separate trials, the fish never failed to enter bottle B1 when the buzzer was used as conditioning stimulus ; 15 presentations of the tuning-fork were given at irregular intervals from February 27th, the original and correct response resulting at twelve of these, and an incorrect one at only one test. On the remaining two occasions no response occurred, nor was food eaten when given. It appeared then that, by this date, the fish had truly learnt to discriminate between the sound of the buzzer, and that of the tuning-fork. There still remained the possibility, however, that it was the relative positions of the two sounds which was being discriminated, and not the sounds themselves. This was put to the test by placing the buzzer over by the bottle B at the opposite end of the tank, but otherwise continuing the tests unchanged (3rd arrow, March 16th, Fig. 1). During the next two weeks thirty tests were made. Of these, twelve tests gave a correct response to the buzzer, but ten were incorrect ; two out of seven presentations of the tuning-fork were also followed by the wrong response. Here was a clear indication that it was the *position* of the two sounds which had been the factor discriminated. So on March 30th (4th arrow, Fig. 1) the buzzer was replaced in its original position. When tests were resumed there was no hesitation such as had persisted before this change back. The responses towards both the buzzer, and the tuning-fork, were given rapidly and correctly until April 5th, when the experiment was concluded owing to my taking up duties elsewhere.

There is ample evidence in these results for the conclusion that *this specimen of a common wrasse,* Crenilabrus melops, *could rapidly form a stable conditioned motor response involving entry into a special bottle for food, using as the conditioning stimulus either a tuning-fork sounding the note lower C, or an electric buzzer giving a mixed note corresponding approximately to the note F in the* 2nd *octave, when these were used singly.*

It could not, however, differentiate between these two sounds as sounds, if they were used to build up a differential response. The factor discriminated in such tests was found to be the place of origin of the sound, not the quality or nature of the sound. In this respect, the auditory sense of this fish appears to resemble the visual sense, when investigated in the same manner, for in reviewing the evidence on pp. 516 and 519 of the earlier paper (**1**) the conclusion was reached that in visual differentiation the *source of light* played a greater part in the discrimination than a wide range in the *intensity* of the two lights. Finally, it is interesting to note how strongly these conclusions upon two senses of major importance to man and most higher vertebrates contrast with the conclusions already reached upon the fineness of perception shown by the blennies in forming these responses towards thermal and salinity changes, and towards gustatory stimuli, such as are described in a later portion of the present paper.

III. (*a*). THE CAPACITY OF THE PLAICE, *PLEURONECTES PLATESSA* (L.), TO FORM A CONDITIONED RESPONSE TOWARDS *VISUAL* STIMULI.

The experiments described in this section, including the present one and the two following, were carried out in order to ascertain whether the results previously obtained with the wrasses (**1**, p. 510) were to be obtained generally amongst fishes of different habits.

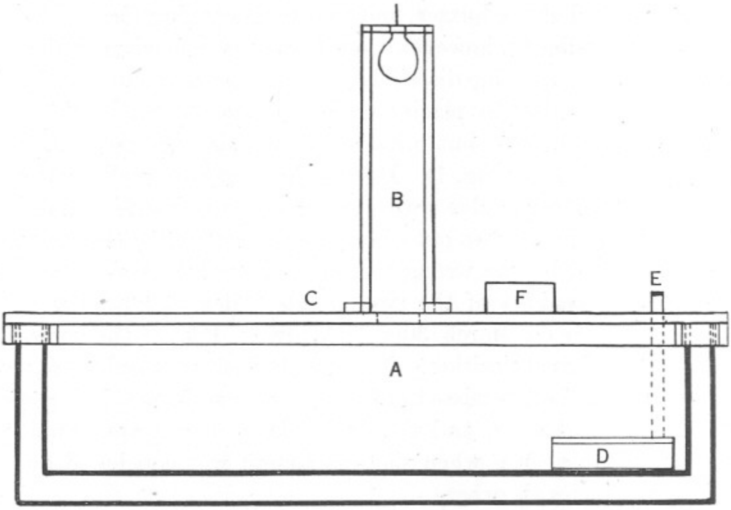

FIG. 2.—Diagram of apparatus used in the formation of a conditioned response in the plaice towards *visual* stimuli. Description in text.

Essentially, both the apparatus and the mode of experimentation were the same as there described, but minor changes were made to suit the conditions at the Cullercoats laboratory, where they were carried out. Figure 2 is a diagram of the tank and general arrangement. The tank was of concrete, 2 ft. by 3 ft. 6 in. by 10 in. deep. It was completely covered in, to exclude all light. A small hole, A (Fig. 2), 2 in. square, was cut out of the top, over which was placed the light chamber B, with a lantern slide-holder C at the lower end for use with Wratten light filters. The food-box D was rectangular, measuring 9 in. by 6 in. by 2 in. deep, with an opaque tube E leading down into it at the hindmost end, for the introduction of food. A periscope F fitted over the entrance to the food-box served to note the response.

The visual stimulus was the unscreened light of a 100w. opal gas-filled electric lamp, 12 in. from the water surface, suspended in the light chamber.

The mode of experimentation was at first the normal one for the type of experiment, i.e. light switched on, food in the form of a small piece of Mytilus introduced 30 seconds later; light then switched off after a further 30 seconds. But on December 8th, 1928, I was led to change this procedure in a marked manner. The reasons for this can be revealed in a few words. It is to be seen from the diagrammatic record of the results in Figure 3 that the period of learning, or the period during which no positive conditioned response was noted, was a somewhat lengthy one (October 30th to December 8th). It appears from the record that the response came suddenly into operation on December 8th, and remained constant for a long period after. This early negative stage is therefore, I think, probably incorrectly recorded. I was puzzled at the unusual length of time which this fish was taking to build up the response, as compared with other fishes investigated. I had noticed also that, although a full 30 seconds was allowed after food was introduced, and before the light was switched off, the fish never became visible beneath the periscope during that time, yet on performing the next test, one hour or so later, the food had been taken. On December 8th, then, I removed the periscope, which only allowed of a limited field of vision, and settled down to watch the behaviour of the fish from the time the light appeared, taking especial care to remain quiet and still. As these tests were all

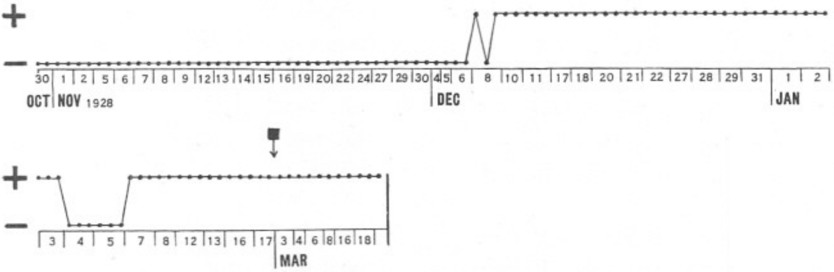

FIG. 3.—Record of the process of formation of a conditioned response in the plaice towards a *visual* stimulus. Explanation in text.

carried out in late evening, the room was always in darkness, and it was not difficult to remain unobserved. By this means I was able to discover that the behaviour of the plaice was strikingly different from that of any of the other fishes with which I had worked.

For one minute the fish made no movement whatever. It then commenced to move slowly and hesitantly towards the illuminated area at the opening of the food-box, but with a curious side-to-side movement—a short swim at an angle to the right of the direct path, then pause—then another short swim at an angle to the left—and in this erratic, slow, zigzag way the fish approached the opening of the food-box. Still with the same hesitant zigzag motion it entered completely into the food-box. After remaining motionless in the food-box for a further space of time, the fish suddenly took the food in the box, and then backed away quickly to a remote corner of the tank. The conditioned response was thus at this time already well formed, for the whole movement, though lasting twelve minutes, was directed in an obviously purposive manner. It should be added that, in the very early stages of conditioning, food was not introduced directly into the food-box only, but was divided into two portions, one of which was dropped into the tank at the opening of the food-box where it could be seen from any part of the tank, and the other placed in the food-box. It is clearly impossible to build up this response without doing this.

As a result of the observation just described, the light was left on in all subsequent tests for 15 minutes, or until such time as was required for the fish to complete the response, watching the whole time through the periscope. It soon became apparent that the suggestion that the response was already well-formed by December 8th was correct ; for the behaviour of the fish at that test was typical of the conditioned response shown by this fish throughout the remainder of the tests. There was some variation in the time taken by the fish to enter the food-box completely, but it was rarely less than 2 minutes and more usually was 6 to 8 minutes. If no entry occurred within 15 minutes, as on January 4th and 5th, the response was regarded as negative. The fish ignored all food on these two days. With this exception the response was obtained at the whole of the tests made up to the date upon which the experiment was concluded, March 18th, 1929. This statement, however, ignores the fact that from January 18th to March 2nd the fish constantly refused all food, which was a feature shown by most of the aquarium fishes for the whole or portion of this time, owing to the intense cold then prevailing. An arrow indicates this date in the record. It was most interesting to find, when feeding was once more resumed on March 3rd, that the conditioned response had been in no way diminished in strength, or altered in nature by this long abstention. Such a high degree of retention, supported as it is by many similar instances from my other experiments, lends additional support to a suggestion made by me recently (**3**) that associations of this nature, when set up in natural conditions, may acquire sufficient stability to bring about a permanent change in the habits of a large body of fish, through the purposive association (by one or more of these fish) of some slight change in an environmental factor with more advantageous conditions of living.

III. (*b*). The Capacity of the Coal-fish or Saithe, *Gadus virens* (L.), to form a Conditioned Response towards *Visual* Stimuli.

The apparatus and mode of experimentation was the same as that used in III (*a*).

The results are given as a diagrammatic record in Figure 4.

The fish used was a small male, 14·5 cm. long. The experiment was carried out alongside that on the plaice, using a similar 100w. opal gas-filled electric lamp as the conditioning stimulus. Eighteen associations spread over the period October 31st to November 9th, 1928, were required before the first conditioned response was obtained. This was followed by a short period when the response was uncertain, lasting over a further period of nine trials of which four gave a positive response, and after November 16th the response was firmly established. On January 3rd the fish ceased feeding, and at tests carried out from the 3rd to the 6th January a completely negative result occurred. The fish was in a torpid condition. It may be recalled that the plaice also went off food on January 4th and 5th as well as from January 17th onwards. No further tests were made on the coal-fish after January 6th as it continued to refuse all food, and it eventually succumbed to the severe cold at the end of the month.

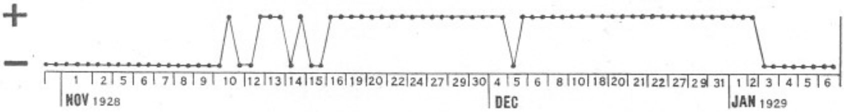

Fig. 4.—Record of the process of formation of a conditioned response in the coal-fish towards a *visual* stimulus. Explanation in text.

The diagrammatic record of the results needs no further comment.

The individual behaviour of this fish closely resembled that shown by the wrasses under these conditions. At an interval of from 10 to 25 seconds, no matter what was its position in the tank, the fish swam rapidly to the food-bottle, taking the food quickly when given, and swimming away again with equal rapidity.

III. (*c*). THE CAPACITY OF THE COD, *GADUS CALLARIUS* (L.), TO FORM A CONDITIONED RESPONSE TOWARDS *VISUAL* STIMULI.

Essentially a repetition of the last experiment, the conditions of the test remaining unchanged.

The results are expressed in diagrammatic form in Figure 5 and require little comment, so closely do they follow those obtained in the last experiment. The commencement is shown as March 9th, 1929. Actually the experiment began on February 23rd, upon which date the fish was placed in the tank. Work was not at once possible, as the fish remained in a torpid state, eating no food, in common with the other specimens at this time. When more lively habits were shown, learning was fairly rapid, only nine days, covering 21 associations, being required before the first conditioned response was obtained. For a further period of 4 days, including twelve trials, the result was uncertain, but thereafter the conditioned response was given invariably, except on April 6th and 7th, for which no reason was apparent. The experiment was concluded on April 17th. After my return from a cruise the fish was removed, and used for work on thermal stimuli to be described later.

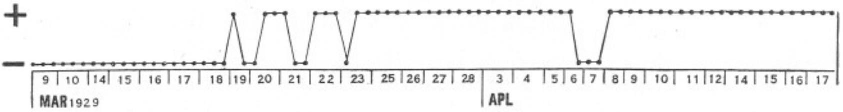

FIG. 5.—Record of the process of formation of a conditioned response in the cod towards a *visual* stimulus. Explanation in the text.

IV. THE CAPACITY OF THE BLENNIES, *BLENNIUS PHOLIS* (L.) AND *BLENNIUS GATTORUGINE* BLOCH, TO FORM CONDITIONED RESPONSES TOWARDS GUSTATORY AND OLFACTORY STIMULI.

Blennies were again chosen to make the preliminary investigations into these two stimuli on account of the ease with which their responses can be noted and also for their general adaptability. They are additionally well suited to the object in view, since they are fishes which normally capture food by sight and not by taste or smell, so far as can be judged from ordinary observation. At the Plymouth Laboratory I used *Blennius gattorugine* throughout, but this species being rare at Cullercoats, it was necessary, on continuing the work there, to carry on with *Blennius pholis*. It is not, I think, likely that these two species should differ greatly in their response to this stimulus, but it is by no means improbable that there may be some slight variation, so the fact should be remembered in considering the results.

The Apparatus.

After many slight modifications the apparatus shown in Figure 6 was the one finally used. It differs but little from the apparatus used in the earlier experiments on blennies. The whole of the right-hand side of the figure is exactly the same as that of Figure 5, p. 503, of the earlier paper (**1**), whilst the remaining parts in the left-hand side of the figure are simple changes to meet the requirements of the present stimulus. A is a straight 10-in. Liebig's condenser from which the inner tube was removed, graduated, and then replaced, afterwards connecting it with the tube E which supplies the water to the aquarium *via* the home jar of the blenny. Water from the main aquarium supply enters the condenser at the lower end F, passes upwards in the condenser and down again through the tube C, to enter into the inner tube E, immediately below the pinch-cock D. The solution to which the fish is to be conditioned is placed in the inner tube at the funnel B. By this system absolute equality of temperature is assured. The pinch-cock D is of a type familiar to many chemists but possibly not to biologists. It is especially easy to use, and accurate and noiseless in delivery, so that it is far preferable to the ordinary patterns for this purpose. A description is given by Sutton (**2**). The rate of flow of the main current of water into the tank was maintained constant at 20 c.c. per second.

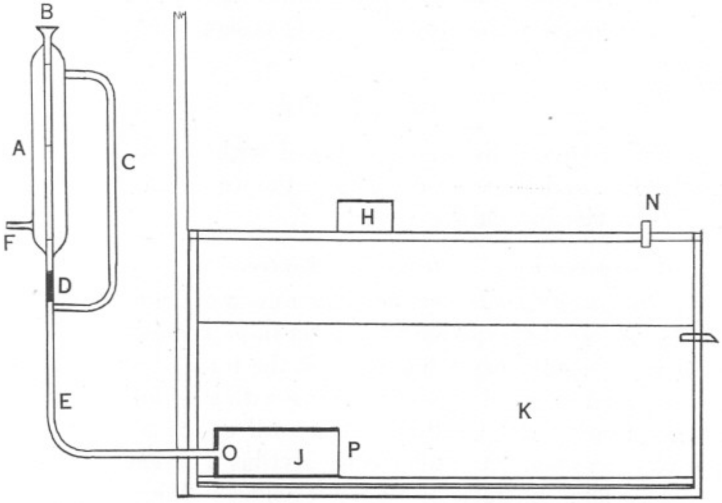

FIG. 6.—Diagram of apparatus used in the formation of conditioned responses in blennies towards *gustatory* and *olfactory* stimuli. Explanation in text.

Method of Experimentation.

The routine of the tests was again that of the salinity and temperature experiments. The taste solution is placed in the inner condenser tube and left for ten minutes for temperature equalisation. When ready, pinchcock D is opened and the experimental solution flows into the main stream ; 10 c.c. was used and the time taken to enter the ingoing stream was 5 seconds. Food is dropped into the tank 15 seconds later through the opening in the screen N. The fish, if healthy, and desirous of food, at once swims to the spot, takes the food, and returns to its jar. The object in view, as in previous experiments of a similar nature, is to ascertain whether the fish can build up the response involved in the capture of food, to the stimulus of the solution serving as signal for that food.

THE RESULTS.

These are of two kinds—those obtained with the use of " natural " sapid solutions, and those resulting from the use of an " unnatural " or artificial substance in solution.

A. *Results obtained with " natural " substances.*

At the Plymouth Laboratory, nereid worms was the food most readily available. In all the experiments on *Blennius gattorugine* which were made there, the gustatory stimulus took the form of extracts of these worms, obtained by grinding up the worms with sand and sea-water, and afterwards filtering the resulting extract till clear, using the vacuum pump and glass-wool. At Cullercoats, Mytilus and Patella formed the main food supply. Extracts of these were made in the same way.

Specimen No. 1. *Blennius gattorugine*, ♂, 12 cm.

After being installed in the apparatus on August 14th, 1927, it was thought first of all, that it would be interesting to attempt to build up the conditioned response towards a solution which had merely stood in contact with the living worms in an intact and healthy condition. From August 15th to 31st such a solution was given three times daily unaccompanied by food but without any resultant response. The solution was made by taking several worms, and after washing them thoroughly in sea-water placing them in 100 c.c. of sea-water for 24 hours. It was soon felt, however, that there was little chance of stabilising the strength or nature of this solution, and the experiment was then dropped. On September 1st a fresh start was made with the definitive worm extract made in the manner described above, and in the first place, of a strength of 0·5%, i.e. 0·5 grm. of *Nereis diversicolor* (live, wet weight) to 100 c.c. sea-water.

A diagrammatic record of the results is given in Figure 7.

After no more than nine associations of this solution, the conditioned response became apparent at the first test made on September 3rd. Two further tests on the same day gave no observable response, but the fourth again produced it, and from then onwards it became firmly fixed. The generalisation of stimuli observed with others was again found to occur here, for two days later, on September 5th, when a 0·1% solution, indicated in the diagram of the results by a well-defined square dot, was tried, three successive tests elicited the conditioned response. Three succeeding tests with the original 0·5% extract diluted ten times, i.e. a 0·05% solution (shown in Fig. 7 by black triangle) were followed at the first by no observable response, but at the two following ones by well-marked positive responses.

It should here be added, that in order to eliminate any possibility that some movement or change in conditions other than that of the worm extract might be responsible for bringing about the response, frequent controls were carried out. On September 8th, 12th, 20th, 22nd, and 29th, all possible movements of taps and tubes were made several times over, but using the aquarium sea-water only in place of the worm solution. Not one of these was followed by an observable response, and it can be safely asserted that this solution was indeed acting as sole stimulus. After the control tests had been made on September 8th, the fish was presented with a solution only one-fiftieth the strength of the original or primary stimulus, i.e. a 0·01% solution (shown in Fig. 7 by an open triangle), and the conditioned motor response again occurred at two such tests. A little later in the same day a 0·02% solution (shown in Fig. 7 by a plain circle o) brought about the response, but several hours later this failed to do so. The following morning, September 9th, tests one to three, this negative result continued with the 0·01% solution, but later in the afternoon, when presented with an extract of the original strength, 0·5%, the fish gave the characteristic response.

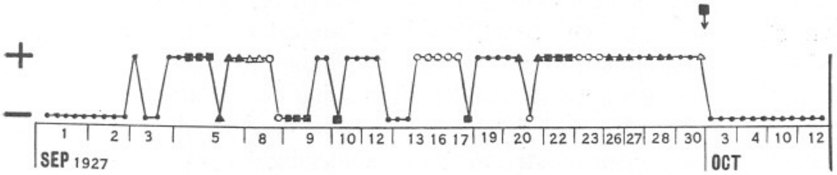

FIG. 7.—Record of the process of formation of a conditioned response in *Blennius gattorugine* towards gustatory stimuli. *Specimen* 1. Explanation in text.

● = 0·5% extract of *Nereis diversicolor* (primary stimulus).
■ = 0·1% ,, ,, ,,
▲ = 0·05% ,, ,, ,,
○ = 0·02% ,, ,, ,,
△ = 0·01% ,, ,, ,,

A study of the diagrammatic record up to the date indicated by the arrow shows plainly that the response was being given with greater certainty, as the number of associations was increasing, negative responses being given only on isolated occasions. It is noteworthy also that the conditioned responses could be brought about with any of the solutions tried, i.e. solutions containing from 0·01 to 0·5% of worm. This experiment thus provided the first indications obtained by me, that this type of stimulus may be as generalised in its perception by the fish, as the thermal or salinity changes previously recorded. I had hoped to begin a complete investigation into the extent of this, but on September 30th (arrow) I found that the fish had inexplicably got out of the tank and was picked up from the floor almost dead. It did, in fact, recover sufficiently to give the appearance of normal health and tests were carried out with the primary stimulus, 0·5% solution, up till October 12th, though quite without any signs of obtaining the conditioned response ; neither would the fish take food. On the 12th it was found dead. The figure shows plainly the inhibitory effect of such a disturbing influence.

In considering the results, and their bearing on the actual perception of the stimulus, there is a further factor to be considered. Whilst being introduced into the main stream of water entering the tank, the gustatory solution is subjected to dilution. Measurements of time of flow, and the quantity of water passing in that time, show that this dilution is approximately ten times. On account of diffusion this would be still greater when it reached the receptors of the fish.

With this fish then, it was shown that, not only was it able to perceive, but it could also form a conditioned response towards, a solution containing 0·5 grm. of worm in 100 c.c. of sea-water, and that it could react similarly towards one containing 0·01 grm., and to various intermediate concentrations.

Specimen No. 2. *Blennius gattorugine*, ♀, length 13 cm.

After being used for experiments described in the next section, this specimen was taken to repeat the observations made on Specimen 1. Work was begun at once, as the fish had already been in the apparatus the whole of the previous month. The stimulus was the same as the primary one in the last example.

The results are presented in Figure 8. The general impression received is that the results are not of the clear-cut and decisive nature which it is so desirable to obtain, in order to arrive at any positive conclusions upon the sense of discrimination. So erratic was the behaviour of this fish that this stage was never reached, yet the results are none the less interesting from other points of view when examined. In the early stages, after the second day, the actual behaviour of the fish showed clearly that the stimulus was being perceived. When the sapid solution was entering, the fish frequently made irregular body movements, accompanied by the peculiar gulping and chewing movements of the mouth, such as were noticed in the advanced stages of the experiments on blennies with thermal and other stimuli. In the description of these, I referred to these movements as additional features of the conditioned response, occurring only when this was firmly established, and to be regarded as anticipatory in nature. These movements are such as might be actually expected if the stimulus was affecting the taste buds of the mouth region. But there is also some individuality about it, for it was not seen at any time in specimen 1, and in all the experiments where it has appeared, it has only done so after one or more associations of stimulus with food. Beyond this, there is nothing in the diagrammatic record which needs further comment.

It is a fitting place, however, to make a few general remarks upon the use of this method in investigating any total behaviour response. If such a record as that showing the results of the present experiment were the result of an ordinary subjective type of experiment with a similar object, it could not be regarded as satisfactory positive evidence of gustatory perception. Such a result in those circumstances would need to be analysed statistically, and in considering the whole period of the experiment, it would be found that there are 40 occasions where the conditioned response was evoked, 33 where it was not. It would be concluded that the evidence is indeed slightly in favour of a positive perception, but nothing more could be said. On the other hand, under the conditions of the present tests, and by very reason of the nature of the response studied, it is not permissible to use a mathematical analysis of the record to determine whether *chance* has, or has not, played any part in the result after the response has once been built up. The *real* reason for the irregularity of the conditioned response in this fish must be sought in some internal factors of the fish, which are unknown to us. It was, for instance, from the moment when it was brought to the Laboratory, of a sluggish nature. On December 9th the experiment was stopped whilst I was absent from the Laboratory until January 5th, 1928. During this time the fish was plentifully supplied with food, but none

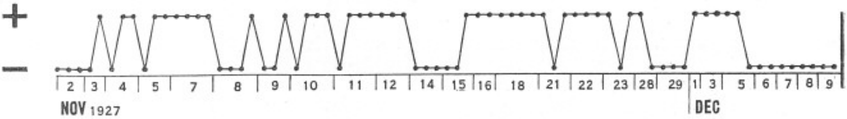

Fig. 8.—Record of the process of formation of a conditioned response in *Blennius gattorugine* towards *gustatory* stimuli. *Specimen* 2. Explanation in text.

was eaten; more significant still, the abdomen was found distended with eggs when I returned. It was therefore impossible to continue the experiment further as previous experience had shown what has since been abundantly confirmed, that the onset of gonad development in female fishes entirely inhibits the building up of conditioned responses. I have no evidence that it does so in male fishes.

Specimen No. 3. *Blennius gattorugine*, ♂, 11 cm.

The taste experiments in this example were again preceded by other experiments described in the next section which lasted from January 26th to February 27th, 1928.

The results are presented in Figure 9, showing a typical picture of conditioned response formations in fishes. From February 28th to March 27th (arrow) the fish was given 38 associations of a solution containing 1 grm. of worm in 1000 c.c. of sea-water, i.e. a 0·1% solution, but no signs of the conditioned response appeared. It was therefore decided on March 27th to increase the strength of the extract to 0·4%. With this new solution four further associations only were required to bring about the conditioned response, accompanied also by vigorous mouth movements which had not appeared with the lower concentration. After a short period of no responses, from April 2nd to 6th, the responses became definite and never failed to appear at the remaining associations made until the experiment was concluded by my leaving Plymouth for Cawsand.

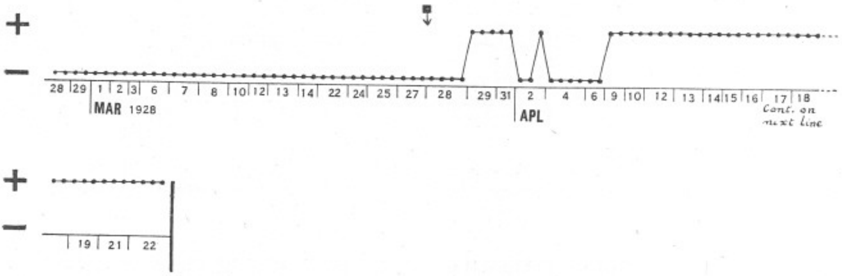

FIG. 9.—Record of the process of formation of a conditioned response in *Blennius gattorugine* towards *gustatory* stimuli. *Specimen* 3. Explanation in text.

Specimen No. 4. *Blennius pholis*, ♀, 11 cm.

Results in Figure 10.

After being used for experiments in the next section, it was found impossible to continue at once with the experiments with sapid substances, owing to the development of the ovaries, and the refusal of food. These eggs were shed in March, 1929. The fish was again feeding freely by

April 2nd and a start was made on April 3rd (shown by arrow). The portion of the record preceding this represents the results with artificial musk as stimulus, which are here included in the same figure, in order to contrast a consistently negative result with the typical result obtained when perception is positive.

The conditioning stimulus was here changed from the worm solution such as was used in specimens 1–3 to a solution containing 5 grm. of *Mytilus edulis* in 1000 c.c. of sea-water, extracted by grinding with sand and filtering through glass-wool using the vacuum pump. Continuing the routine as before, with the 15-second interval between stimulus and food, seventeen associations of this stimulus were required before the first conditioned response was obtained. It was a response however, differing in several important particulars from that shown by any of the specimens of *Blennius gattorugine* investigated at Plymouth. Instead of the direct swimming response to the food place, which was always shown without other motor complications in that species, the response here obtained was made up of a vigorous body movement directed *away* from the opening P (see Fig. 6, P) and towards the incoming taste solution at O. It should be added for those who are not familiar with the habits of these fishes, that

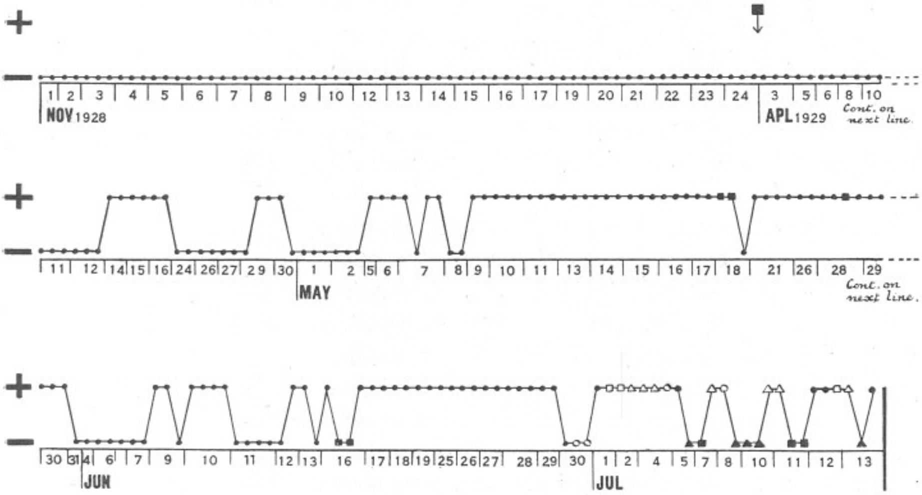

FIG. 10.—Record of the process of formation of a conditioned response in *Blennius pholis* towards *gustatory* stimuli, including also a record of experiments on the same fish with artificial musk. *Specimen* 4. Explanation in text.

Symbols.
Before April 3rd ● = artificial musk.
After April 3rd ● = 0·5% extract of Mytilus.
○ = 0·02% ,, ,,
□ = 0·01% ,, ,,
△ = 0·0075% ,, ,,
▲ = 0·00375% ,, ,,
■ = 0·0015% ,, ,,

the fish when at rest is usually in a slightly curved position with the tail at O and the head just inside the opening of the home jar ; the curve of the body adapted to fit as close as possible to the hindmost corner (see Fig. 6). When returning to the jar after taking food, the fish enters head-first, but at once turns round and fits itself to this position. So that this complete turn round at the beginning of the conditioned response is a striking movement, especially when accompanied, as it frequently was, by deliberate biting at the incoming solution ! It was also obtained in a parallel experiment on the same species shortly to be described (Specimen 5). There are, I believe, two possible explanations for this new development. (1) That it represents an actual specific difference in the behaviour of the two species ; (2) that the solution of the Mytilus has a different physiological significance to the fish.

It seems hardly likely that the second of these two can be the reason, for it would have been expected that such a movement would result from the stimulus straightway, and without the association with food. It is more probable that it is a true specific physiological difference between the two species, and indicating that *Blennius pholis* has not lost the capacity for unconditioned gustatory response so completely as has *Blennius gattorugine.* I have considered the neurological significance of this reformed gustatory response elsewhere (**3**). It remained a definite feature of the fully formed conditioned response towards the primary stimulus, and is therefore to be regarded as an essential part of it. For this reason, even when not followed by actual movement to the food place, I have recorded in the diagrammatic record as a positive response, all those occasions where this biting and turning response occurred. Practically the whole of the positive results up to May 17th were of this nature. There was a rather lengthy period, from April 12th to May 8th, during which the response gradually became more firmly established. From May 21st onwards the fully formed conditioned response was given invariably in response to the primary stimulus, whilst the biting and turning-back movements continued to precede it.

The effect of external conditions is noticeable at June 4th, 6th, 7th, 9th, and 11th, upon which days there were many disturbances in the room prior to the carrying out of the tests, including loud hammering. On June 29th the tank was cleaned, resulting in inhibition on the following day, June 30th. For all the negative results shown in the record subsequent to May 8th there was a well-defined cause. On June 30th tests were begun to ascertain the extent of generalisation of this stimulus, and the limits of perception. Different symbols are employed in the diagram to denote tests with extracts of different strengths, the details of which are given in the legend.

It is to be seen that by making use of the principle of generalisation of stimuli, the positive conditioned motor response continued to be given to extracts containing 0·5% (the original and primary stimulus), 0·02% (a plain circle in the record), 0·01% (a plain square), and 0·0075% (a plain triangle), of Mytilus, whilst a consistently negative result was obtained when either of the two following and much lower concentrations was tried,—·00375% (a black triangle), and ·0015% (a black square).

Specimen No. 5. *Blennius pholis*, ♂, 10 cm.

Results in Figure 11.

This experiment was started on June 12th, 1929, the fish having been brought in from the shore that very morning and placed directly in the experimental tank. On the 12th, 13th, and 14th I introduced three times each day 10 c.c. of a solution containing 0·5 grm. of *Patella vulgata* in 100 c.c. of sea-water extracted in the the same way as the Mytilus extract

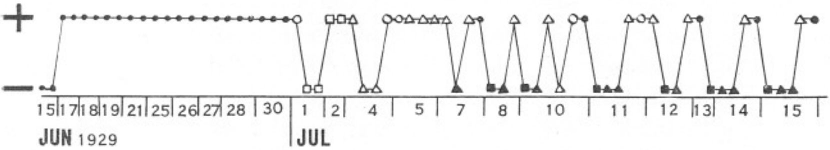

FIG. 11.—Record of the process of formation of a conditioned response in *Blennius pholis* towards gustatory stimuli. *Specimen* 5. Explanation in text.

Symbols.

● = 0·5% extract of Patella.
○ = 0·02% ,, ,,
□ = 0·01% ,, ,,
△ = 0·0075% ,, ,,
▲ = 0·00375% ,, ,,
■ = 0·0015% ,, ,,

used for Specimen 4. This solution formed the primary conditioned stimulus for this experiment. There was no response whatever shown when the above tests were applied.

On the morning of June 15th, 1929, a start was made with the process of conditioning, and the first association made of the Patella solution with food (a small piece of Patella) given 30 seconds later. This interval is a longer one than any yet tried. A second association was made later in the day. On neither of these two occasions was there any sign of the conditioned motor response; the food when given was fetched, and eaten at once in a typical healthy manner. At the third association of the series, given on the morning of June 17th, I was very surprised to get a perfect response to the Patella solution. Immediately after the solution had begun to enter the jar containing the fish, its head appeared at the opening and exhibited violent gulping movements—an exact replica of those described in Specimen 4 when the response had been perfected. At 10 seconds the fish turned round facing the incoming solution and biting at it. At 25 seconds it resumed the normal position, and then went straight across the tank to the food-hole where it stayed until food was given at 60 seconds (intentionally delayed). The fish took this at once with great avidity, and returned quickly to the jar. This constituted a record for my experiments in the number of associations required to bring about this type of response, and it was still further remarkable in that it continued to be given throughout the remainder of the experiments without the least hesitation or failure.

It was soon apparent that this specimen was an ideal one for ascertaining the range of perception for such a stimulus by means of the process of generalisation. This was begun on July 1st and the diagrammatic record clearly indicates the strengths of the solutions employed and the resultant responses. The symbols used in the figure represent the same strengths of solution as in the last specimen. It was most interesting to find that the conditioned response failed to occur with the same strengths of Patella extract as the Mytilus extract which was inadequate in Specimen 4, whilst the lowest strength which was able to bring about the response was also the same (0·0075%).

Certain features which were common to the behaviour of both Specimens 4 and 5 appear to have some significance in deciding the *nature* of the perception of this type of stimulus. These concern the appearance of the biting and gulping movements and the sharp turn backwards to bite the incoming extract. I have elsewhere (**3**) concluded that this phase of the total response represents a reformation of the typical *gustatory response* as defined by Herrick (**4**), and which characterises all fishes which at the present time normally seek their food by the aid of gustatory organs. It appears then that this may be built up under experimental conditions, although under their ordinary conditions of living, both of the species of blennies we have investigated have lost this originally dominant sense. In both species also this reformed gustatory response was not obtained at any time when the strength of the extract of Mytilus or Patella used as stimulus was lower than 0·02%, although the characteristic motor response remained unchanged. This would seem to indicate that *olfaction* has been associated with gustatory perception in building up the response, and that in the response to the lower concentrations it (olfactory perception) has taken over the whole or major part of the perception. At the present stage this suggestion is only hypothetical.

Summarising these experiments, it may be said that these fishes, the blennies, are able to form conditioned motor responses towards gustatory stimuli, that the stimulus is capable of wide generalisation, and that the limits for perception of extracts of Mytilus or Patella lie between the strengths represented by the 0·0075 and 0·00375% solutions, *equivalent to an actual stimulation by concentrations slightly less than one-tenth of this.*

B. *Results obtained with artificial substances.*

Although I have spent much time at work on this section only one definite result is available, and that of a negative kind. Ultimately a comparison between this section and the last should prove of great interest in defining the exact meaning of gustation and olfaction in fishes.

The object has been to ascertain whether under the same conditions as those of the last section blennies are able to build up the conditioned response to artificial substances, whose concentration in sea-water is such that it can be firmly regarded as a stimulus of a true olfactory nature. A stimulus of this nature is hard to find, for it is very difficult getting such a solution without changing some major factors in the chemical equilibrium of the water. Artificial musk, Trinitro-butyl-toluene, a perfume of cheap soaps, was regarded as fulfilling all requirements. It is not actually soluble to any measurable extent in sea-water, but by adding 1 mgrm. to 1000 c.c. of sea-water, shaking vigorously, and allowing to stand for 24 hours, a solution possessing a highly characteristic and penetrating perfume could be obtained.

By carrying out the experiments in the typical manner, associating the giving of 10 c.c. of this solution with the giving of food 15 seconds later, the result was a totally negative one in all the fishes investigated. Of the fishes used in the last section, and previously used here,

Specimen 2 received 51 such associations over a period of three weeks;
Specimen 3 received 70 spread over a period of four weeks; and
Specimen 4, as shown in the first part of Figure 10, was given 64 between November 1st and 24th, 1928.

These experiments taken together provide good evidence that *Blennius gattorugine* and *Blennius pholis* are both unable to perceive this substance in solution when it is presented to them in this manner.

V. GENERAL REMARKS.

A fairly large body of evidence has now been collected by the experiments on visual stimuli. This is sufficient, I think, to enable one to regard the capacity to build up these associations between food and some visual stimulus as general amongst fishes. The experiments on the cod and the coal-fish indicate that the association proceeds just as readily in fishes which under natural conditions do not normally rely so much upon vision as upon other modes of perception, as it does in fishes which do, such as the wrasse and blenny.

It was considered more important to investigate this before proceeding to a finer analysis of vision in one or two species. These experiments are well in hand, and I hope shortly to be able to make a comprehensive statement of visual acuity and colour sense of at least one species of Blennius, and later to contrast it with such a form as Motella, where the role of vision is a very insignificant one in normal life.

In the description of the experiments throughout, many seemingly small details have been mentioned, as I believe them to have value in a final analysis of fish behaviour, and especially when we shall come to a closer comparison of these results with those obtained by a large number of investigators in the dog. This comparison was one of the principal objects of the investigation. In carrying out the work, however, it has become evident that information of more immediate economic application is made possible by the use of this method, so that this aspect is now being given first consideration.

Owing to the length of time taken by these experiments, however, and the great interest of the results for comparative psychology as well as fishery research, it is much to be desired that other workers should take up special aspects of the problem, or work out the finer details in regard to one particular receptor system, such as H. Stetter (**5**) has recently done with the auditory system.

There are many environmental stimuli which are potential governors of fish movement and behaviour, but of whose influence we know absolutely nothing. This is especially so with those factors which have not a direct influence upon the fish, and which cannot in themselves have either a beneficial or a noxious influence. It is for this very reason that it is impossible to ascertain their effect by ordinary methods. Whether the present type of experiment will help, still remains to be seen. The experiments in Section 4 of the present paper lead me to hope that it will. Occasionally difficulties of a perplexing nature arise. In the course of an investigation on the capacity of a cod to form a conditioned response towards an induced temperature gradient in a 10-ft. tank, I had to abandon the test after more than two months' work owing to the fish having taken up a more or less permanent position in the food-box!

VI. SUMMARY.

1. The wrasse, *Crenilabrus melops*, is able to form stable conditioned motor responses to the note of a tuning-fork, sounding the note lower C, or to an electric buzzer giving a mixed note corresponding to the note F in the second octave, when either of these is used singly. In a discrimination test employing both these sounds the wrasse was not able

to distinguish between them as sounds, but differentiated them by their position.

2. Conditioned responses involving visual stimuli have been built up in the following additional species : plaice, cod, and coal-fish. Individual variations in the response are described.

3. *Blennius gattorugine* and *Blennius pholis* are able to form stable conditioned responses towards gustatory stimuli such as sea-water extracts of natural food substances. These stimuli are widely generalised in their action. The limits for perception lie between concentrations slightly less than 0·000375% and 0·00075% of the weight of living food substance in sea-water. Many significant details in the responses are described and discussed.

These fishes do not appear to be able to respond to an artificial olfactory stimulus such as artificial musk.

4. The essential similarity between these responses and conditioned reflexes in dogs is becoming more emphasised as the data accumulate.

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The Vertical Distribution of Marine Macroplankton. IX. The Distribution of the Pelagic Young of Teleostean Fishes in the Daytime in the Plymouth Area.

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With 7 Figures in the Text.

CONTENTS.

INTRODUCTION.

In continuation of the study of the vertical distribution of the pelagic young of Teleostean fishes, already reported on for 1924 and 1925 (**1**), a further fifteen stations were made with the two-metre stramin net in the daytime between April and September in 1926. The collections were made in a manner exactly similar to that for those of the previous years, hauls of ten minutes' duration being made almost always at six different depths with the net towed horizontally as near as possible at the same speed on each occasion. The Admiralty depth-recording instrument was used at every station, and the results for each haul are given in Figures 6 and 7 on pages 666 and 667, which show the graphic records of the path of the net through the water for each haul. (That for June 25th is not included, an unsatisfactory record being obtained on that day owing to the drum of the recorder not having been fully screwed down, see **4**, p. 431.)

Nearly all the collections were made in the same locality, namely, about two miles east of the Eddystone Lighthouse, in water of a depth of about 54 metres. (This position is known in this and previous papers as " A ".)

The full details as to the time of day, weather conditions, depths of hauls, etc., are given in the log on page 668 at the end of the report.

Previous research had indicated that possibly some species may have lived in the daytime in water layers nearer the bottom than had been sampled by the ring-trawl. Accordingly the work has been supplemented in 1927 and 1928 by collections made with the bottom plankton net described in a previous publication (**5**), and, for comparison, oblique hauls made with the two-metres ring-trawl fishing in the water layers from a depth of about 35 metres up to the surface itself. In making the oblique hauls the net has been fished at six different depths using exactly the same lengths of wire as have been used for the serial hauls in the previous years. The net was fished for five minutes at each depth, the necessary amount of wire being wound in after that period until the six depths including the surface had been fished. On two occasions the depth recorder was in use, and Figure 1 shows the path of the net through the water on these occasions. In the first case, June 29th, 1927, the maximum depth reached was 30 metres, and on July 8th, 1927, it was 46 metres. These depths probably represent the limits within which the maximum depth reached on each occasion lies : in all the previous collections to study the vertical distribution of the plankton, the maximum depth of the deepest haul has usually been between these depths. When possible the collections with the bottom plankton net and those of the oblique hauls were made on the same day, one haul being made with the ring-trawl at Station A, and three with the bottom net, viz. at A, at the International Hydrographic Station L4, and at a position about 2 miles W.S.W. of the

Rame Head on a muddy bottom. Altogether 36 oblique hauls with the ring-trawl and 114 hauls with the bottom plankton net were made. The data for these catches are necessarily bulky and are not being published; they have been carefully examined, and it is considered sufficient for the present purpose that they should be given as in Tables 5 and 6, pages 675–6, namely, as average monthly catches only. The total number of fish caught in any one month has been divided by the total number of hauls for that month. On page 642 are given the dates on which the various collections were made. All the collections were made in daylight.

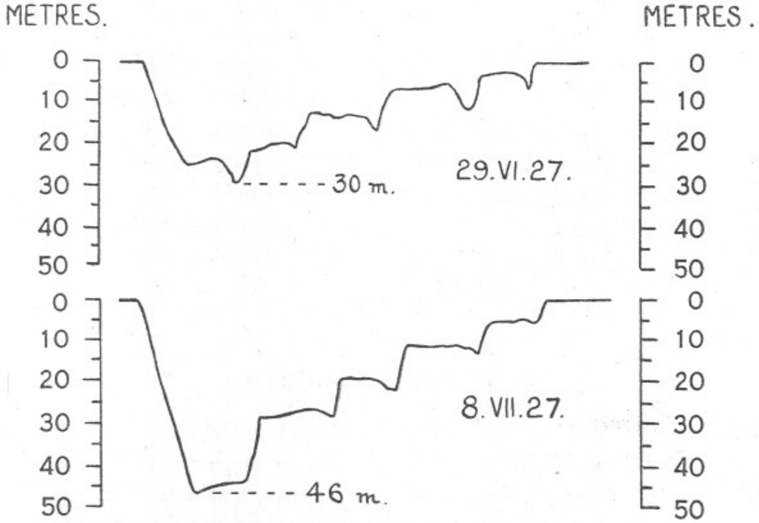

FIG. 1.—Tracings given by the depth-recorder indicating the path of the ring-trawl through the water for the half-hour oblique hauls on June 29th, 1927, and July 8th, 1927. The net enters the water on the right-hand side of each curve.

In compiling Table 5, giving the average monthly catches for the bottom plankton net, the actual figures have been multiplied by 8·5 to bring them as nearly comparable to the oblique ring-trawl figures as possible. The bottom plankton net was so constructed that the area of its mouth was 1/8·5 that of the two-metre ring-trawl (**5***, p. 107).

It is with pleasure that I acknowledge my indebtedness to Capt. V. Lord and the crew of the s.s. *Salpa* for their co-operation and assistance in making the collections.

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* I am greatly indebted to Mr. J. S. Colman for pointing out an error in this publication (**5**, p. 107). In line 23, "fishing area" should read "circumference," and in line 25, "a quarter" should read $\frac{1}{8\cdot5}$: on the following pages, therefore, 8·5 should be read in place of 4 on each occasion and the necessary corrections made.

Dates of Collections with Ring-trawl and Bottom Plankton Net.

	Bottom-stramin net, 30-minute hauls at three different stations.	Ring-trawl, 30-minute oblique hauls 2 miles East of the Eddystone.
1928.	January 3, 11, 17, 26	January 9, 16, 26, 30
	February 3, 10, 14, 24, 29	February 2, 20, 27
	March 8, 23, 30.	March 5, 21, 30
	April 12, 18, 23, 24, 30	April 4, 11, 12, 23
	May 11, 17	—
1927.	June 2, 29	June 2, 9, 29
	July 8, 15	July 8, 12, 21, 26
	August 5, 12, 19, 25, 31	August 4, 8, 19, 26, 31
	September 6, 15, 20, 30	September 6, 15, 19
	October 4, 13, 18, 25	October 4, 13, 18, 24
	November 1	November 1
	December 6, 15, 21	December 15, 21
	114 hauls.	36 hauls.

GENERAL RESULTS.

The general results of the above collections have confirmed and extended those previously published. There can now be no doubt that the different species of fish differ markedly in the depths at which their post-larvæ are to be found most abundantly in the daytime in the waters off Plymouth.

It would appear to be possible to place our post-larval fishes under the following headings as regards their vertical distribution in the daytime on a sunny day in waters of 50 metres depth off Plymouth during the months in which they are most abundant. When a note of interrogation (?) appears after the name of a fish, it implies that the number of individuals caught of that species are not sufficient to be considered significant, and the indications only are that the fish may come under the category in which it is placed.

Most abundant from surface layers down to 5 to 10 metres.

Gadus pollachius (Pollack); *Blennius gattorugine* (Tompot Blenny); Labridæ (Wrasses); *Rhombus* sp. (Brill and Turbot) (?).

Abundant at all depths, but mostly above 25 to 30 metres and sometimes avoiding the actual surface.

Onos sp. (Rockling); *Arnoglossus* sp. (Scaldbacks); *Scomber scomber* (Mackerel); *Trachinus vipera* (Lesser Weaver); *Caranx trachurus* (Horse Mackerel).

Abundant below 15 metres, and falling off in numbers below 30 to 35 metres.

There is a tendency for the following species which come under this category to show slight differences in their preference of depth, becoming successively deeper in the following order (see Fig. 2):

Scophthalmus norvegicus (Ekstrom's Topknot); *Pleuronectes flesus* (Flounder) (?); *Gadus merlangus* (Whiting); *Solea vulgaris* (Sole) (?); *Pleuronectes limanda* (Dab); *Solea variegata* (Thickback); *Trigla* spp. (Gurnards); *Callionymus* sp. (Dragonets), deeper in June and July than in April and May; *Pleuronectes microcephalus* (Merrysole); *G. luscus* (?) (Pouting); *Molva molva* (Ling) (?); *Merluccius merluccius* (Hake) (?); *Zeugopterus punctatus* (?); *Lebetus scorpioides* (?).

Becoming abundant below 20 to 25 metres, with maximum abundance probably very near bottom.

Gadus minutus (Bib or Poor Cod); *Gobius* spp. (Gobies); *Lepadogaster bimaculatus* (?); *Cottus bubalis* (Bullhead) (?).

Irregular in their type of distribution, though usually avoiding the actual surface.

Clupeid spp. (Sprat and Pilchard), when present in daytime; *Ammodytes* spp. (Sandeels).

A certain elasticity must be allowed in a scheme like this where one is dealing with a population of living animals in their natural environment; but it seems legitimate to say that on a clear sunny day, with the sea surface calm, just before midday, such would be the vertical distribution of the post-larvæ of the above fish in water of 50 metres depth off Plymouth in the months when the respective fish are most abundant.

An average vertical distribution, in the case of those species whose post-larvæ have been numerously represented in the collections on several occasions, has been estimated by superimposing all the diagrams so far obtained giving the actual vertical distribution of the fish in question on sunny days; that is, by tracing through, one over the other, each vertical distribution diagram that has been obtained. From this superimposition of figures an average vertical distribution for the species has been drawn freehand and is shown in Figure 2. The accuracy of these diagrams has been checked by working out the average catch of each fish on sunny days for every five metres depth from the total of all the collections made in 1925 and 1926. On the top half of Figure 2 are given the vertical distribution diagrams which can be expected on sunny days during the months of April and May for the commoner species found here whose chief spawning period lies in the spring. On the lower half of the figure similar diagrams are given for the vertical distribution of the post-larval stages of those whose spawning period lies in the summer months and whose post-larvæ are most abundant in June, July and August. The data for these

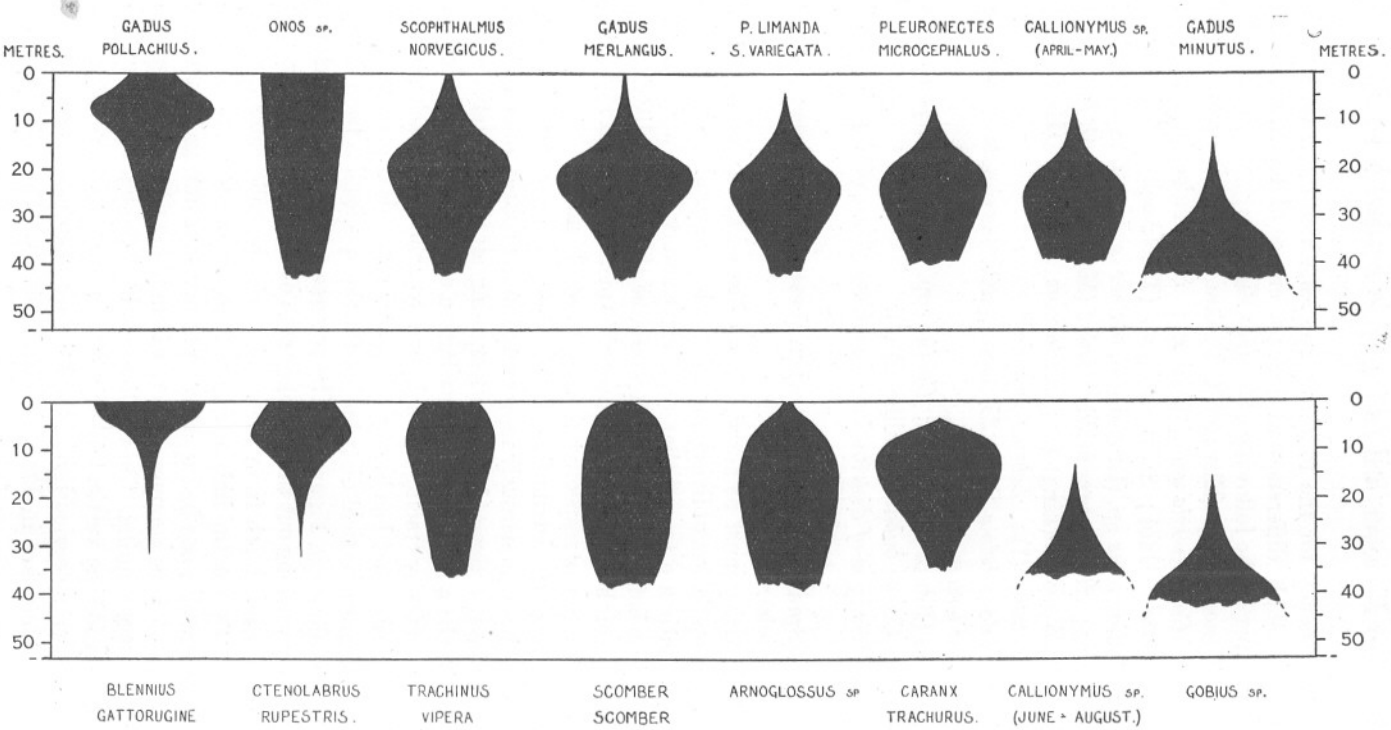

FIG. 2.—Average vertical distribution for the post-larvæ of the above species during the months when they are most abundant on sunny days just before noon in water 54 metres deep off Plymouth. The upper half shows the expected vertical distribution for the post-larvæ of certain spring-spawners; while the lower half shows that for some summer-spawners.

latter are by no means so definite as are those for the post-larval stages of the spring spawners ; the numbers of times on which they have been taken in sufficient numbers to give significant results are few, and in one or two cases (e.g. *Trachinus vipera* and *Caranx trachurus*) the figures are based on one result only. It is a general rule that the summer forms are not nearly so abundant as the spring forms.

While the above scheme can be taken as holding for the conditions stated, namely, a sunny day before noon, with a calm sea, there are certain factors which operate to affect such distributions under the same conditions, and other conditions which give rise to changed distributions during the day and from one day to the next. These factors are :—

1. Dull weather.
2. Time of day.
3. Abundance of other plankton organisms.
4. Nearness to coast.

1. *Dull weather.* There are definite indications that in dull weather certain species of post-larvæ are higher in the water than on sunny days. While the number of observations made on dull days are fewer than those made on sunny days, there is nevertheless a certain consistency to be found in the results.

For example, in Figure 4, page 658, the upward trend in the vertical distribution of Callionymus post-larvæ can be seen between the days April 22nd (Sunny) and April 26th (Dull), as also between May 6th (Sunny) and May 19th (Dull) ; the same also can be seen for other species of fish in this and the previous paper (**1**).

2. *Time of day.* The majority of the observations recorded here represent the results of collections made between the hours of 10 a.m. and 12 noon (G.M.T.) (see List of Stations, p. 668). Figures 3, page 652, and 4, page 658, show, however, in the case of *Gadus merlangus* post-larvæ and of those of Callionymus the vertical distribution at two periods during the day. On April 13th, 13.iv.26 (i) represents the results of the collections made between 11.3 a.m. and 12.38 p.m., while the 13.iv.26 (ii) hauls were between 1.40 p.m. and 2.51 p.m. ; the surface haul was taken in the first case at 11.3 a.m. and in the second at 2.51 p.m., and the bottom hauls at 12.38 p.m. and 1.40 p.m. respectively. It can be seen that there has been a quite definite, though slight, move upwards in the vertical distribution of these species between the morning and afternoon observations.

Any alterations caused by the passage from daylight to darkness have been recorded in previous papers (**2** and **3**).

3. *Abundance of other plankton organisms.* There have on several occasions been indications that certain changes in the normal vertical

distribution of post-larval fishes may be found correlated with extreme abundance of certain other plankton animals in the surface layers.

The following occasions have already been recorded. On May 19th, 1925 (**1**, p. 109), the occurrence of post-larvæ of *Gadus merlangus*, *Scophthalmus norvegicus*, *Solea variegata*, and *Callionymus* sp., at the surface was noticed to coincide with the presence of a dense swarm of the megalopas of *Corystes cassivelaunus* in the surface layers. In another locality on the same day, where the megalopas were scarce in the surface layers, the post-larvæ of the above-mentioned species exhibited a normal vertical distribution.

On June 4th, 1926 (**3**, pp. 833 and 841), post-larvæ of *Scophthalmus norvegicus, Solea variegata*, and *Callionymus* sp., were very much higher in the water than on the previous day ; this was correlated with the presence of very dense swarms of *Calanus finmarchicus* in the surface layers.

On August 4th, 1926, the numbers of post-larvæ taken in the surface layers were unusually large, and on this day the swarms of Calanus on the surface were exceptional (**4**, p. 432).

4. *Nearness to coast.* It has already been shown (**1**, p. 108) that " the post-larvæ of many species of fish become abundant at much smaller depths below the surface close inshore over shallow water than they do a few miles from the coast over depths of 50 metres or more."

THE DIFFERENCE IN BEHAVIOUR BETWEEN POST-LARVÆ OF SPRING AND OF SUMMER SPAWNERS.

Figure 2 shows up a very striking general result that has arisen from the observations of 1926 supplemented with those of previous years. This is that there appears to be a fundamental difference between the behaviour of the post-larvæ of the spring spawners and that of the post-larval stages of the summer spawners. While the majority of the post-larvæ of spring spawners (with the exception of those of *Gadus pollachius* and of *Onos* sp.) tend to be below 15 metres in the daytime with their maximum numbers at 20 metres or deeper, those of the summer spawners seem to prefer the upper layers and are usually most numerous above 25 metres, except such forms as *Gobius* spp. and *Lepadogaster bimaculatus*.

The significance of this is not understood. The summer spawners are mostly representatives of warm-water fish on whose northern limit of distribution this region lies or whose distribution is affected by the movements of the warm waters of the Gulf Stream Drift. Possibly in the latitudes in which they are most prevalent they live deeper, although, owing to the greater sunlight in those latitudes, they may experience normally higher intensities of light than do the cold-water forms in their normal habitat. These intensities are only to be found in the upper layers in this region. On the other hand, it may be that the preference for the upper layers is conditioned by temperature, and in these layers the highest temperatures are to be found.

A COMPARISON BETWEEN THE CATCHES OF THE BOTTOM PLANKTON NET AND THOSE OF THE OBLIQUE HAULS WITH THE TWO-METRE RING-TRAWL.

Between June, 1927, and May, 1928, 114 hauls were made with the bottom plankton net, and 36 oblique hauls with the two-metre ring-trawl. The results of these catches have been expressed in Tables 5 and 6, pages 675 and 676, as average monthly catches (see p. 643); in these tables the 1928 hauls have been placed before those of 1927 so that the results show conveniently the sequence of a regular calendar year. Unfortunately in 1928 there were no oblique-haul collections made during the month of May; in the table, however, are given for that month the average half-hourly catches for the five years 1924, 1925, 1926, 1927, and 1929.

During the course of the researches on the vertical distribution of plankton it had become evident that certain forms, e.g. Clupeid post-larvæ and *Tomopteris helgolandica*, were not being taken in numbers in the daylight catches although night collections showed that they were really present in abundance in the region investigated. The natural conclusion was that such forms lived in the daytime in layers deeper than those normally sampled by the ring-trawl, that is somewhere between 35 metres and the bottom at about 54 metres. In order to obtain definite evidence on this point the net described in a previous publication (**5**) was employed.

The area of the mouth of the ring-trawl was 8·5 times that of the bottom plankton net, and the results shown in Table 5 are therefore the actual results multiplied by 8·5.

In most cases where the normal distribution has been shown by previous ring-trawl collections to be well up in the water it would be expected that the comparable bottom plankton net hauls would provide catches less than, or at any rate never greatly exceeding, those of the obliquely-hauled ring-trawl. Such has proved to be the case when the species in question have occurred in the catches in sufficient numbers to give significant results. Those forms which normally live high in the water up to the surface layers naturally appeared in far fewer numbers in the bottom plankton net than in the oblique hauls, e.g. *Gadus pollachius* post-larvæ were 25·9 times more numerous in the oblique hauls than in those of the bottom net, and in the case of *Scomber scomber* this figure was 7·3.

It has already been pointed out that the post-larval sprats and pilchards became ten to thirty times as numerous in the dark as in the daytime in the ring-trawl catches (**3**, p. 835), and in the 24-hour series of observations made in 1926 there were indications that these Clupeids moved down to levels below those sampled in the daytime. It was hoped, therefore, that the results of the collections with the bottom stramin net might settle this point. Examination of Table 6, page 676, shows, however, that the average catch for any month with the oblique ring-trawl sometimes exceeds, and sometimes is less than, that with the bottom plankton net, the total number for the year being approximately the same in the ring-trawl as in the bottom net. The evidence that the post-larval clupeids seek the actual layers next to the bottom is therefore negative. The possibility remains that they do not actually hug the bottom, but swim two or three metres above it, in which case a net with a much deeper mouth must be employed. There is one other possible explanation for their absence in the daytime catches, that is that in the daytime they are shoaling and only if the net actually passes through a shoal will the post-larvæ appear in any quantity in a catch ; whereas at night the shoals break up and certain numbers are bound to be caught in all layers (**2**, p. 401).

While these researches have not definitely furthered our information on the habits of post-larval Clupeids, they have produced striking evidence on the behaviour of two other kinds of fish, namely, the post-larvæ of *Gadus minutus* (the Bib or Poor Cod) and those of *Gobius* spp.

Previous daylight observations on the vertical distribution of *Gadus minutus* showed that they lived always below about 30 metres. The fact also that at the lowest depths sampled their numbers were still increasing indicated that possibly the region of maximum abundance lay still deeper and had not been sampled. The results with the bottom plankton net show that, while the smaller post-larvæ are about as numerous near the bottom as they are in the oblique hauls, those of 12 mm. length and over have congregated in great numbers right close to the bottom itself.

In a previous paper (**1**, p. 108) it had been pointed out that the post-larval Gobies in the collections in 1925 were extremely few compared with those of 1924, and it had been suggested that they were indeed scarce that year. Night observations showed, however, a considerable increase in their numbers, and the results of the bottom plankton net have revealed their presence quite close to the bottom in the daytime in great quantities. Rather similar results were shown also for post-larvæ of *Lepadogaster bimaculatus* although their numbers were very much smaller.

In the foregoing pages are briefly given the observations for each species for the recent collections and the conclusions drawn from these and the previous collections already published (**1**, **2**, and **3**). In Tables 1, 2, 3, and 4 at the end of the paper are to be found the numbers of fish of each species caught during the course of the investigations.

CLUPEIDÆ.

CLUPEA SPRATTUS L. (Sprat) and SARDINA PILCHARDUS (Walb.) (Pilchard).

Figure 4, page 658, shows the results of the vertical distribution observations for these species in 1926; while the earlier catches can be taken to consist mostly of sprat, those of the later months will be mostly pilchard.

These observations confirm the previous conclusions that these post-larvæ, 4–20 mm. long, when caught in the daylight appear to be distributed rather indiscriminately. At the same time, series of observations which have been made at night (**2** and **3**) show that the daytime distribution cannot be a true picture of the habits of the majority of these Clupeid post-larvæ since they increase in number 10 to 30 times in the catches at night.

It was hoped that the results of the bottom plankton net collections would throw light on this question by showing an increased number in the bottom layers. Tables 5 and 6 (pp. 675 and 676) show, however, that while in six months in the year more were taken in the ring-trawl oblique hauls than in the bottom plankton net, in the other six months the reverse was the case. Actually, taking the total of the monthly averages for the year, approximately the same number were taken in the ring-trawl as in the bottom plankton net, and in June and July, the months in which a marked increase in numbers has been shown in the upper layers at night, there were 9 and 10·6 times as many in the ring-trawl as on the bottom. It should here be mentioned that the post-larvæ occurring in the catches from January to the beginning of March will be mostly those of *Clupea harengus*, the Herring, and there is perhaps an indication in the March hauls of their being near the bottom; but in this case, and in other months when the bottom plankton net catches exceed those with the ring-trawl, nothing like the striking differences were found as were shown in the case of *Gadus minutus*, the Gobies, or *Lepadogaster bimaculatus*.

It would therefore seem that the true behaviour of Clupeid post-larvæ remains yet to be shown. It is possible that the bottom plankton net samples too narrow a layer above the bottom and that some net fishing a metre or more above the sea bottom may show the presence of these young fish in abundance in the daytime. Alternatively, as mentioned above on page 648, the post-larvæ may shoal in the daytime, the shoals breaking up at night.

GADIDÆ.

GADUS POLLACHIUS L. (Pollack).

In the 1926 collections few only of this species were taken, and these indiscriminately at all depths. There was no evidence that they avoided the surface layers, and the conclusions based on these and the previous observations would seem to be that they may be taken at all depths, but are on the whole more numerous actually in the surface layers. The post-larvæ in question are from 4 to 10 mm. in length.

The collections in the oblique hauls with the ring-trawl in April, 1928, showed a fairly high average of 21·6 specimens per haul against the low average of 0·9 in the bottom plankton net, confirming that they are not abundant in the layers near the bottom.

GADUS MERLANGUS L. (Whiting).

Figure 3 shows diagramatically the results of the 1926 collections. They confirm the conclusion previously stated that the majority of whiting post-larvæ, 5 to 12 mm. in length, live below 15 metres, although the seasonal change suggested in the previous report was not shown so markedly. The rise of these young fish in the water on May 19th is no doubt due to the fact that the day was very dull.

All results can be summarised as follows :—

Post-larvæ 5–12 mm. mostly below 15 metres ; region of maximum abundance 20 to 30 metres, falling off in numbers considerably below 35 metres.

Post-larvæ 12–50 mm. in association with Cyanea, living at the depths that the Cyanea are in the daytime and following their migrations at night.

Ratio oblique hauls with ring-trawl : bottom plankton net=7·5 : 1.

GADUS MINUTUS (O. F. Müll.) (Bib or Poor Cod).

The 1926 results (Figure 3) confirm the fact that post-larvæ of the poor cod, 4–10 mm. in length, are the deepest living of the common Plymouth gadoids, being most abundant almost always well below 20 metres.

Further light is shown on their behaviour by the collections made with the bottom plankton net. Below are given the numbers caught in half-hour oblique hauls with the ring-trawl and the average catches for three half-hour hauls on each day with the bottom plankton net.

Ring Trawl (Oblique).		Bottom Plankton Net.*	
February 27th	12	February 29th	–
March 5th	29	March 8th	36·6
,, 21st	14	,, 23rd	17
,, 30th	30	,, 30th	385·1
April 4th	166	April 12th	229·5
,, 11th	120	,, 18th	133·5
,, 23rd	65	,, 23rd ,, 24th	138·6
		,, 30th	3689
		May 11th	3034·5
		,, 17th	325·6

It can be seen from the above figures that up to April 23rd the numbers of post-larval poor cod taken in the bottom plankton net are on the whole greater than those taken in the oblique hauls with the ring-trawl, but after that date there is an enormous increase in the numbers caught in the bottom net, though unfortunately there are no catches with the ring-trawl for comparison.

An examination of the following table, which gives the lengths in millimetres of the fish taken on various dates, shows very definitely that this increase in numbers is due to a sudden descent to the bottom of fish from the layers above.

Length in millimetres.

		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
March 30th	B.N.	–	5	14	9	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
April 12th	B.N.	2	5	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
,, 18th	B.N.	–	1	2	5	3	–	1	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–
,, 25th	B.N.	–	1	4	7	3	2	4	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
,, 23rd	R.T.	–	1	4	10	8	13	5	–	2	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–
,, 30th	B.N.	–	–	–	–	–	–	–	1	–	2	2	7	13	24	34	27	20	11	4	3	3	3	5	1
May 11th	B.N.	–	–	–	–	–	–	2	1	3	13	19	32	38	36	18	12	3	1	1	–	–	–	1	–
,, 17th	B.N.	–	–	–	–	–	2	1	3	3	4	2	4	5	4	3	1	2	–	–	–	–	–	–	–

B.N. = Bottom Plankton Net. R.T. = Ring-trawl.

In all previous collections it appears that the post-larval poor cod disappear from the catches at a length of between 10 and 12 mm. In the previous publication (**1**, p. 119) it is said, "The majority of post-larvæ caught were between 5 and 10 mm. in length, and there is no evidence of any differentiation in the distribution of the various sizes within these lengths ; for those above 10 mm., however, there is an indication that they live deeper down."

Here we have definite evidence that there is a sudden descent of the young fish to the layers immediately above the bottom soon after the

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* Average of catches at three stations on each day, multiplied by 8·5 for comparison with ring-trawl.

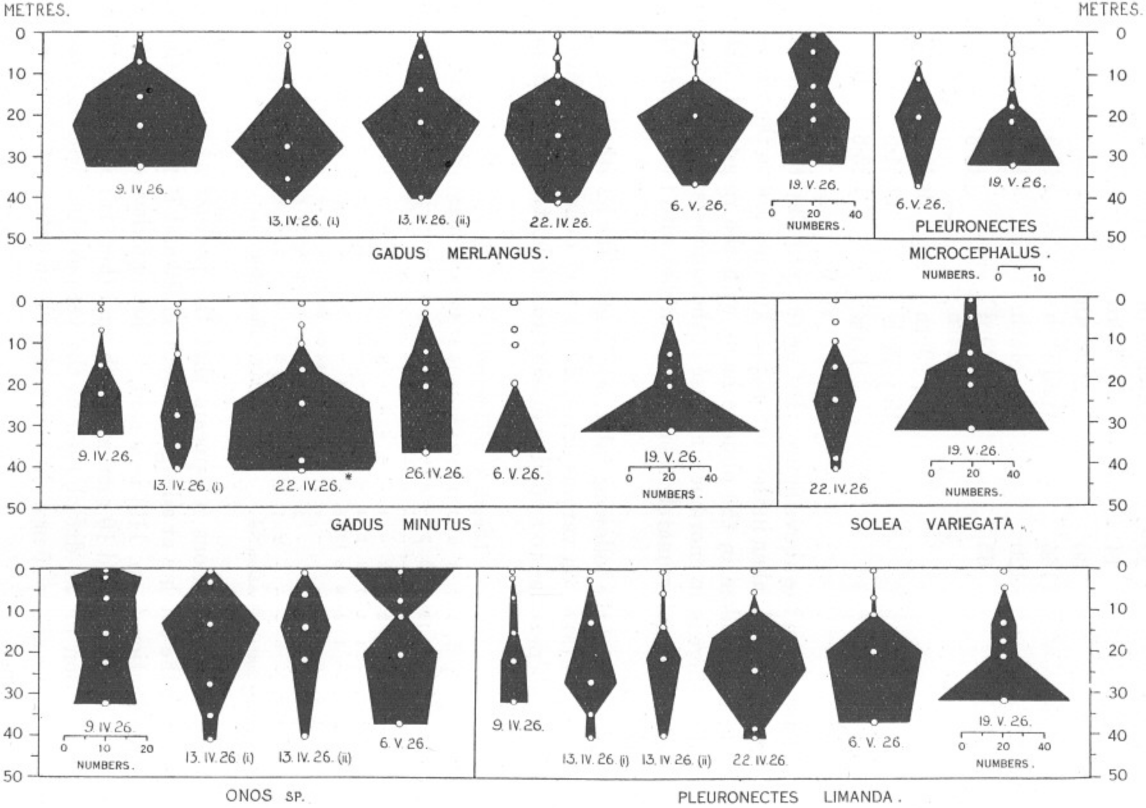

FIG. 3.—The vertical distribution of post-larvæ of the above species on the dates given. The white spots and black circles indicate the "average depths" at which hauls were taken. **Gadus minutus*, on 22. iv. 26, is drawn to half the scale of the others.

fish has reached 10–12 mm. in length ; the majority of fish in the bottom net catches on April 30th were between 12 and 21 mm. long, and the largest was 27 mm. It is possible that above this length they are fully able to avoid capture by the slow-moving net.

Summary of results :

Post-larvæ 4–12 mm., chiefly in water layers between 20–25 metres and the bottom.

Post-larvæ 12–27 mm. in water layers immediately above the bottom.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1 : 13·9.

GADUS LUSCUS L. (Pouting).

Post-larvæ of this species were not abundant in the 1926 catches, the main breeding period lying possibly between December and April. Altogether 74* post-larvæ, mostly between 4 and 8 mm. long, were taken, and of these one was taken from between the surface and 10 metres, 9 between 10 and 20 metres, 34 between 20 and 30 metres, and 30 between 30 and 41 metres, confirming the 1925 results which pointed to the post-larvæ of the pouting being deep-living.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1·8 : 1.

GADUS CALLARIAS L. (Cod).

A few post-larvæ of the cod, 5 to 8 mm. in length, occurred in the catches during April in 1926, but the numbers were too low to be significant. Altogether 4 specimens were taken above 10 metres, 9 between 10 and 20 metres, 3 between 20 and 30 metres, and 5 between 30 and 41 metres, the largest catch being 8 at 15·5 metres on April 9th.

ONOS SP. (Rockling).

Figure 3 shows the results of the collections in 1926. These confirm the previous conclusions that Onos post-larvæ are to be found at all depths with a slight preference for the surface layers. The post-larvæ in question are 4–10 mm. in length, and after this size they are to be found always in large numbers congregated under masses of drifting weed.

Ratio, oblique hauls with ring-trawl : bottom plankton net=4·1 : 1.

MOLVA MOLVA L. (Ling).

Only a few post-larvæ of this species were taken, but these were all but one from below 15 metres ; this confirms the previous observations.

None were taken in the bottom plankton net.

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* On this and all succeeding occasions the numbers taken in the daylight on June 3rd–4th are included (**3**, Table X, p. 850) although they are not repeated in Table 2.

MERLUCCIUS MERLUCCIUS L. (Hake).

Post-larvæ of the hake were only taken on July 26th, 1926, when 4 specimens, 4 to 5 mm. in length, were caught, 2 at 18·5 metres, one at 28·7 metres, and one at 35·1 metres ; and on June 3rd, when one specimen, 5·5 mm. long, was taken at 31·5 metres.

Ratio, oblique haul with ring-trawl : bottom plankton net=1·9 : 1.

RANICEPS RANINUS L. (Lesser Forkbeard).

Only five post-larvæ of this species, 4–6 mm. in length, were caught in 1926, one at 43·1 metres on June 25th, two at 40·7 metres on July 13th, and one each at 21·5 and 34·1 metres respectively at E1 on July 15th.

No post-larvæ of this species appeared in the bottom plankton net.

CAPROIDÆ.

CAPROS APER L. (Boarfish).

Four post-larvæ only of this species were taken ; one of 3½ mm. from 13·7 metres at E1 on July 15th, and three of 4–4½ mm. from 22·2 metres on August 4th.

No post-larvæ of this species appeared in the bottom plankton net.

BOTHIDÆ.

ARNOGLOSSUS SP. (Scaldbacks).

Figure 5, page 662, shows the results for Arnoglossus sp. post-larvæ, probably *A. laterna* (Will), on the three days on which they were at all numerous ; but on this occasion, and in the previous year, the numbers were not great enough to allow conclusions to be drawn with safety. The indications are, however, that post-larvæ, 6 to 20 mm. long, may occur at any depth, but there is generally a tendency to avoid the actual surface layers down to a depth of about 5 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=2·2 : 1.

RHOMBUS SPP. (Turbot and Brill).

Post-larvæ of these species, *Rhombus maximus* Will. and *R. lævis* Rond., were never very numerous, but the indications were definitely that they preferred the upper layers above 10 metres and actually at the surface itself. Altogether 36 specimens were caught between the surface and 10 metres, 9 between 10 and 20 metres, one between 20 and 30 metres, and 5 between 30 and 40 metres. No post-larvæ of these species occurred in the catches of the bottom plankton net.

SCOPHTHALMUS NORVEGICUS (Günther), (Norway Topknot).

The only occasion on which this species was present in anything like its usual abundance was on June 3rd, 1926, when its distribution has already been reported (**3**, p. 841). The small numbers caught on all other occasions, however, confirm the previous conclusions that post-larvæ, 4 to 10 mm. in length, usually occur in greatest abundance below about 10 metres, being most numerous between 15 and 30 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1·2 : 1.

ZEUGOPTERUS PUNCTATUS (Bloch.).

Only very few post-larvæ of this species were taken ; on April 13th, one each at 21·6 and 40·1 m.; on April 22nd, one at 16·9 m. and four at 24·6 m. ; on April 26th, one at 12·6 metres and one at 16·7 metres ; on May 6th, two at 37·1 metres, and on May 19th, two at 17·6 metres and six at 32 metres. On June 3rd and 4th, 29 were caught, all below 10 metres depth. This confirms previous observations that these post-larvæ occur usually only below 10 metres and deeper.

Ratio, oblique hauls with ring-trawl : bottom plankton net=2·5 : 1.

PLEURONECTIDÆ.

PLEURONECTES LIMANDA L. (Dab).

Figure 3 and the results given in Tables 1–4 confirm the previous conclusions that post-larval dabs, 5–13 mm. in length, occur most abundantly below a depth of 15 to 20 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1·9 : 1.

PLEURONECTES MICROCEPHALUS (Don.), (Merrysole).

Figure 3 and the results given in Tables 1–4 confirm the previous conclusions that post-larval merrysoles, 4–13 mm. in length, occur most abundantly below a depth of 15 to 20 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1·7 : 1.

PLEURONECTES FLESUS L. (Flounder).

Post-larvæ of the flounder, 4–9 mm. in length, were not very numerous in the catches, and of the total number caught 7 were from between the surface and 10 metres, 25 between 10 and 20 metres, 17 between 20 and 30 metres, and 13 between 30 and 41 metres. Thus it would seem that these post-larvæ occur slightly higher in the water than those of the dab, being already comparatively abundant at 10 metres.

Ratio, oblique hauls with ring-trawl to bottom plankton net=4·5 : 1.

SOLEIDÆ.

Solea variegata (Don.), (Thickback).

Post-larvæ of the thickback, 4–10 mm. in length, as shown by Figure 3 and previous records have a vertical distribution similar to that of the dab, becoming most abundant below a depth of 15–20 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=4 : 1.

Solea vulgaris (Quens.), (Common Sole).

As in the previous year's collections the post-larvæ of the common sole were never very abundant in the 1926 catches. The largest catches were on April 22nd, when the majority lay below 10–15 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1 : 3·7.

Solea lascaris Risso. (Sand Sole).

Only one post-larva of this species, 6·5 mm. in length, was taken, this being from 20·1 metres on July 13th. None were taken in the bottom plankton net.

SERRANIDÆ.

Serranus cabrilla L. (Sea Perch).

Three post-larvæ of this species occurred in the catches; one of 6 mm. from 13·7 metres at E1 on July 15th, and two of 4½ and 5 mm. from 3·5 metres on August 4th.

CARANGIDÆ.

Caranx trachurus (L.), (Horse Mackerel).

Post-larvæ of the horse mackerel, 4–15 mm. in length, only occurred in any numbers on August 4th (Fig. 5, p. 662). On this occasion while they were numerous at depths below 20 metres the greatest catch was from 9·5 metres. This seems to confirm the previous indications that the majority of the post-larvæ of this species are to be found above 20 metres. None were taken in the bottom plankton net. Below are given the actual sizes of the post-larvæ caught at each depth on August 4th. It can be seen that while the majority were between 4 and 10 mm. in length, at 9·5 metres there were a few larger specimens up to as much as 15 mm., although these were absent from other depths. In the same table are given the sizes of four of the medusa, *Cyanea capillata*, that were caught at the same time in the upper layers, and it seems very probable that the larger post-larvæ at 9·5 metres were in association with the large Cyanea which was 6 inches in diameter.

	Length in millimetres.												Cyanea.
August 4th, 1926	4	5	6	7	8	9	10	11	12	13	14	15	
Surface (ii)	–	5	2	–	–	–	1	–	–	–	–	–	2″
3·5 m.	–	–	–	1	–	–	–	–	–	–	–	–	3″
9·5 m.	1	2	15	20	20	12	13	9	12	3	3	1	6″ : 3″
22·2 m.	–	5	7	5	2	1	–	–	1	1	–	–	–
28·2 m.	–	16	13	8	1	–	–	–	–	–	–	–	–
39·4 m.	1	23	13	5	–	–	–	–	–	–	–	–	–

SCOMBRESOCIDÆ.

BELONE VULGARIS Flem. (Garfish).

One post-larval garfish, 22½ mm. long, was taken at the surface on August 4th.

AMMODYTIDÆ.

AMMODYTES TOBIANUS L. (Lesser Sandeel).

Post-larvæ of this species were taken in too small numbers to give a significant picture of their distribution, though the indication was that they showed no definite preference for any depth.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 1·5 : 1.

AMMODYTES LANCEOLATUS (Lesauv.), (Greater Sandeel).

Post-larvæ of this species, 5–20 mm. in length, were never very abundant, but what evidence there was confirmed the previous conclusions that they are somewhat irregularly distributed from the surface downwards with a tendency to avoid the actual surface layers.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 1 : 1.

CEPOLIDÆ.

CEPOLA RUBESCENS L. (Red Band Fish).

Four post-larvæ of this species were taken on July 26th, two of 4½ mm. from 18·5 metres, and one each of 4½ and 5 mm. from 28·7 and 35·1 metres respectively. One of 3½ mm. was taken at the surface on August 4th.

CALLIONYMIDÆ.

CALLIONYMUS SPP. (Dragonets).

Figure 4 shows the results of the collections of Callionymus post-larvæ in 1926; in the earlier months these will all be *C. lyra* (L.), but a few *C. maculatus* (Rafin.) will occur in the later collections. They confirm the previous conclusions that their region of maximum abundance lies below 20 metres. At the same time there is here definite evidence that in April and perhaps May the post-larvæ tend on the

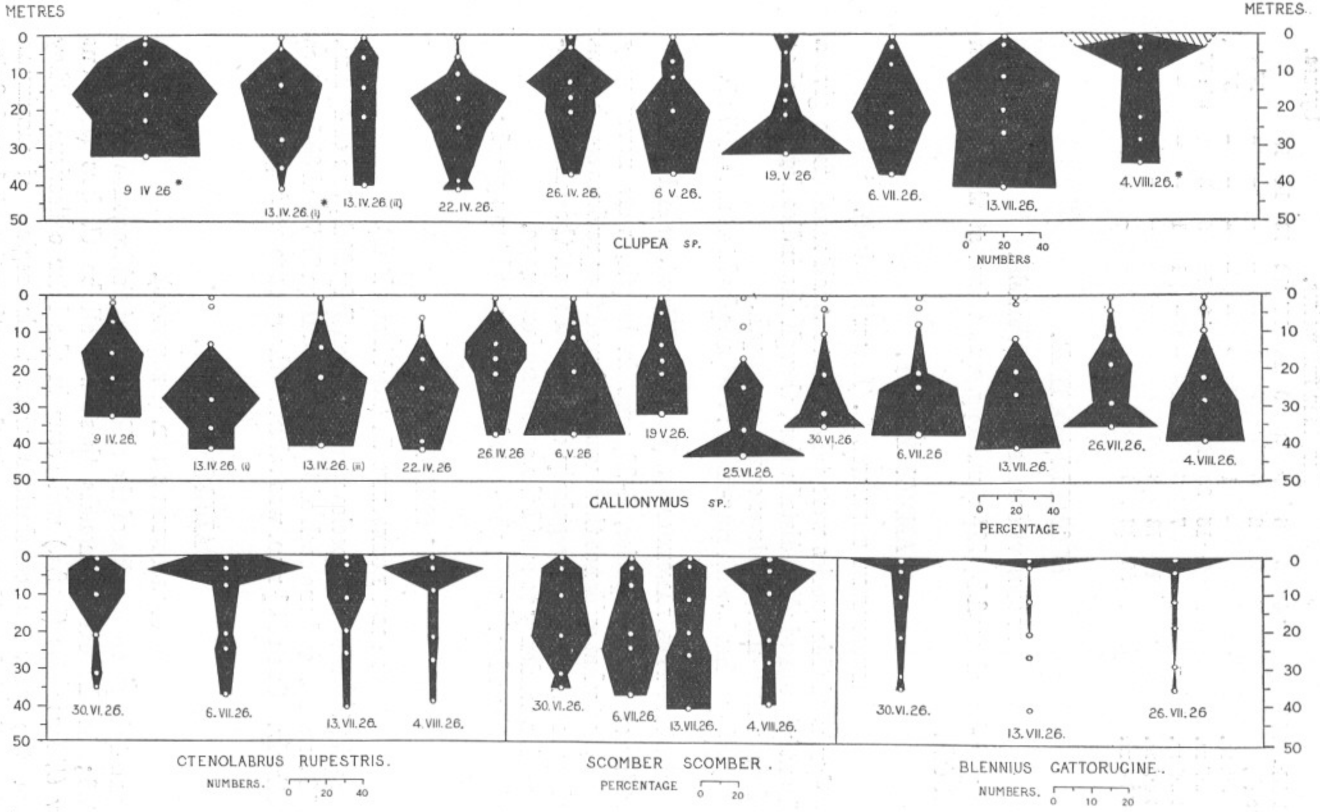

FIG. 4.—The vertical distribution of post-larvæ of the above species on the dates given. The white spots and black circles indicate the "average depths" at which hauls were taken. * Clupeid sp., on 9. iv. 26; 13. iv. 26 (i); and 4. viii. 26, are drawn to half the scale of the others.

whole to be higher in the water than in June, July, and August, because their numbers were still increasing with depth in the catches in these latter months, while in April the collections indicated that the region of maximum abundance had been fished through and their numbers were decreasing in the deepest hauls. See also Figure 2, p. 644, in which is given the average distribution in sunny weather as a result of superimposing all the records for April and May, and also those of June, July, and August.

Ratio, oblique hauls with ring-trawl : bottom plankton net=2·6 : 1.

LABRIDÆ (Wrasses).

The post-larvæ of five species of wrasse appear in these collections : *Labrus bergylta* Asc., *Labrus mixtus* (L.), *Crenilabrus melops* (L.), *Ctenolabrus rupestris* (L.), and *Centrolabrus exoletus* (L.). It was concluded in 1925 (**1**, p. 130) that " all species showed a tendency to be most abundant above 20–25 metres."

Although in 1926 *Ctenolabrus rupestris* was the only species present in any numbers, the following figures for the remaining species bear this out.

	Total numbers of post-larval wrasses caught.			
	Surface–10 m.	10–20 m.	20–30 m.	30–45 m.
Labrus bergylta	36	32	23	23
Labrus mixtus	9	8	20	20
Crenilabrus melops	24	12	4	3
Centrolabrus exoletus	15	5	6	3

Of these *Labrus mixtus* would appear to be the exception, although they are not definitely absent from the upper layers ; the few caught in the previous collections pointed to the majority being above 25 metres.

A figure showing the vertical distribution of *L. bergylta* post-larvæ has already been published (**3**, p. 846), when it was evident that the majority were at 10 metres or above.

As for the post-larvæ of *Ctenolabrus rupestris*, 4–8 mm. in length, the diagrams shown in Figure 4 and the numbers represented in the catches in Tables 3 and 4 show conclusively that this form definitely prefers the upper layers, and is indeed most abundant above 10 metres and at the surface itself.

The ratios, oblique hauls with ring-trawl : bottom plankton net were :—
L. bergylta 1·4 : 1 ; *L. mixtus* 1·2 : 1 ; *C. melops* 0·4 : 1 ; *C. rupestris* 1 : 1 ; and *C. exoletus* 3·7 : 1.

TRACHINIDÆ.

TRACHINUS VIPERA C. and V. (Lesser Weever).

Post-larvæ of this species, 4–7 mm. in length, were only numerous in the catches on August 4th (Fig. 5, p. 662). On this occasion it was very evident that, while they may be found at all depths, the post-larvæ showed a decided preference for the surface layers. This supports the indications given by the previous collections that they were most abundant above 25 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net=3 : 1.

SCOMBRIDÆ.

Scomber scomber (L.), (Mackerel).

In 1925 (**1**, p. 133) the indications were that post-larval mackerel were most numerous above 25 metres. Post-larvæ of this species, mostly 4–10 mm. in length, were unusually abundant in 1926, and Figure 4 and Tables 3 and 4 show that we have quite definite evidence as to their vertical distribution. We see that they tended to be very evenly distributed from the surface downwards, though there was a tendency for the numbers to be slightly less actually at the surface itself.

Actually the greatest catches on each day were on June 30th at 21·4 metres, on July 6th at 24·7 metres, on July 13th at 26·4 metres, on July 15th at E1 at 2·9 metres, on July 26th at 18·5 metres, and on August 4th at 3·5 metres. This indicates that while they may occur in numbers at any depth, there is perhaps a tendency for them to be most abundant round about 20–25 metres.

I give below the sizes of the mackerel post-larvæ caught at each depth on two occasions showing that there is no differentiation of size with depth.

	Length in millimetres.							
July 6th, 1926	4	5	6	7	8	9	10	11
Surface	–	3	1	1	1	–	–	–
3·3 metres	20		18	12	9	7	2	–
7·8 ,,	16	12	29	8	3	2	1	1
20·9 ,,	6	69	54	25	4	3	–	–
24·7 ,,	9	22	90	45	14	2	–	–
37·2 ,,	5	27	52	15	4	1	–	–

	Length in millimetres.										
August 4th, 1926	4	5	6	7	8	9	10	11	12	13	14
Surface (i)	–	2	1	4	7	7	1	–	1	–	–
,, (ii)	–	–	3	3	4	9	1	1	3	–	–
3·5 metres	1	5	21	25	40	32	15	3	2	–	–
9·5 ,,	1	8	13	14	16	7	3	–	–	1	1
22·2 ,,	–	1	7	5	4	4	1	1	–	–	–
28·2 ,,	–	–	8	5	3	1	–	1	–	–	–
39·4 ,,	–	4	8	4	3	2	–	–	–	–	–

Ratio, oblique hauls with ring-trawl : bottom plankton net=7·3 : 1.

ZEIDÆ.

ZEUS FABER L. (John Dory).

Only four post-larvæ of this species were taken; one of 4½ mm. at E1 from 13·7 metres on July 15th, and one of 5 mm. from 9·5 metres and two of 4 and 4½ mm. from 28·2 metres on August 4th.

GOBIIDÆ (Gobies).

On occasions when post-larval gobies were at all numerous they were always taken from below about 25 metres (Fig. 5). This agrees with the results for the year 1925, but in the few collections made in 1924 they appeared to be higher in the water. It was remarked previously (**1**, p. 108) that by comparison with the numbers taken in 1924 there was an amazing absence of young gobies in 1925. During the course of a series of hauls taken during 24 hours on June 3rd–4th in 1926 however, the numbers of post-larval gobies show a great increase at night, there being more than eight times as many caught in the dark as in the daytime. In 1925, also from observations made two nights in succession (**2**, p. 398), it appears that the post-larval gobies were very much more abundant at night than in the daytime. This at once suggests that actually, although not present in the catches from the upper layers as abundantly as in 1924, they were not really scarce, but were living in the daytime in layers deeper than those sampled by the net in 1925 and 1926. Evidence obtained by means of the bottom plankton net gives a striking confirmation to this suggestion. Actually throughout the year on an average the bottom plankton net caught 298 times as many post-larval gobies as the oblique hauls with the ring-trawl. The greatest number of post-larval gobies were taken in July when the average half-hourly catch (×8·5) with the bottom plankton net was 3247 as against 2·1 for the same time with the ring-trawl hauled obliquely through the upper water layers. This would seem to afford definite proof that normally in the daytime, at any rate in 1925, 1926, and 1927, the post-larval gobies, 4–12 mm. in length (species unidentified), live in the water layers immediately adjacent to the bottom. What was the cause for the unusual behaviour in 1924 when the post-larvæ were high in the water is not known, but there is evidence that other plankton animals behaved differently that year from the two succeeding years.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 1 : 297·8.

LEBETUS SCORPIOIDES (Coll.).

Post-larvæ of this species were never abundant, but as in previous records there was a tendency for them to keep to the deeper layers.

Actually 20 were caught between the surface and 10 metres, 7 between 10 and 20 metres, 49 between 20 and 30 metres, and 52 between 30 and 45 metres. They were most abundant on August 4th, and Table 4 definitely shows that they were most numerous below 20 metres and that their numbers were still increasing with depth.

Ratio, oblique hauls with ring-trawl : bottom plankton net=3·3 : 1.

BLENNIIDÆ (Blennies).

The three species of blennies whose post-larvæ appeared in the 1926 catches were *B. ocellaris* (L.), *B. pholis* (L.), and *B. gattorugine* (L.).

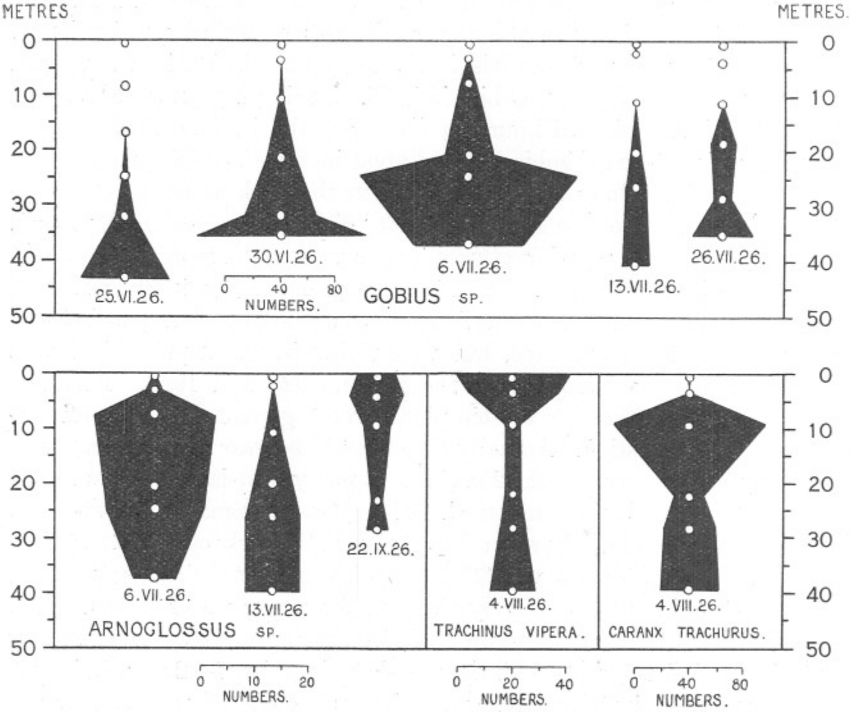

Fig. 5.—The vertical distribution of post-larvæ of the above species on the dates given. The white spots and black circles indicate the "average depths" at which hauls were taken.

Although few were taken in previous years the conclusions were (**1**, p. 135), "it would appear that on the whole the majority of the post-larvæ of the above three species frequented the water layers above a depth of 25 metres right up to the surface itself."

In 1926 the only species whose post-larvæ appeared in significant numbers was *Blennius gattorugine*, and Figure 4, p. 658, shows very clearly that post-larvæ of this form, 5–10 mm. in length, definitely prefer the actual surface layers.

Ratio, oblique hauls with ring-trawl : bottom plankton net = *B. pholis* 0·6 : 1 ; *B. gattorugine* 0·7 : 1.

CHIROLOPHIS GALERITA L. (Yarrell's Blenny).

Four post-larvæ of this species occurred in the catches of 1925 (**1**, p. 154) on April 2nd and April 8th, but their presence was not mentioned in the text. These four specimens, 4–5 mm. in length, came from 5 metres, 12·5 metres (2), and 32·5 metres. In 1926 none were caught during the observations made on vertical distribution.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 2·2 : 1.

CENTRONOTUS GUNNELLUS Bl. Schn. (Gunnell).

Two post-larvæ of this species, 12 and 18 mm. in length, were caught from 22·4 metres on April 9th, 1926.

TRIGLIDÆ (Gurnards).

Post-larval gurnards, probably comprising *Trigla gurnardus* L. *T. cuculus* L., *T. hirundo* Bl., and *T. lineata* L., were not very numerous in the 1926 collections, but the few present tend to confirm the previous conclusions that post-larvæ, mostly 5–11 mm. in length, generally begin to become abundant at about 15 metres.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 2·5 : 1.

COTTIDÆ.

COTTUS BUBALIS (Euphr.), (Bullhead).

Only 17 post-larvæ of this species occurred in the 1926 collections, and of these 12 were caught from below 20 metres, which confirms the results of the few caught in the previous years.

Ratio, oblique hauls with ring-trawl : bottom plankton net = 6·7 : 1.

CYCLOPTERIDÆ.

LIPARIS MONTAGUI (Donov.), (Montagu's Sucker).

Only three post-larvæ of this species were taken, one from 21·6 metres, one from 39 metres, and one from 41 metres (Table 1.). Previous evidence, though slight, pointed to this being a deep-living form.

Only four were taken in the bottom plankton net.

GOBIESOCIDÆ.

Lepadogaster bimaculatus (Penn.), (Doubly spotted Sucker).

Twenty-four post-larvæ of this species were taken and of these 11 were caught between 20 and 30 metres, and 13 between 30 and 45 metres. This confirms the previous indications, and results with the bottom plankton net point to their living very near the bottom, as do also the 24-hour series on June 3rd–4th, 1926, when the post-larvæ showed a definite increase in numbers at night.

Ratio, oblique hauls with ring-trawl : bottom plankton net=1 : 76·8.

LOPHIIDÆ.

Lophius piscatorius (L.), (Angler).

Eighteen post-larval anglers, 5–9½ mm. in length, were taken in 1926, and of these 2 occurred between the surface and 10 metres, 2 between 10 and 20 metres, 7 between 20 and 30 metres, 4 between 30 and 40 metres, and 3 below 40 metres.

SUMMARY.

1. From April to September in 1926 a further series of collections were made with the 2-metre ring-trawl in water 54 metres deep off Plymouth, to supplement the results already published (**1**) on the vertical distribution of post-larvæ of teleostean fishes in the daylight.
2. From June, 1927, to May, 1928, collections were made with a bottom plankton net for comparison with catches made with oblique hauls with the ring-trawl during the same period.
3. The results confirm to a very large extent the conclusions already published as to the vertical distribution of the post-larvæ of many of our commoner fish ; and the bottom plankton net collections together with the series of 24-hour observations already published (**2** and **3**), throw further light on the behaviour of such species as *Gadus minutus* and the Gobies.
4. The true distribution of the post-larvæ of the clupeids, the sprat and the pilchard, in the daytime remains yet to be discovered.
5. On page 642 is given a scheme in which the fish are classified as to their vertical distribution on a sunny day as far as is possible from the data obtained.
6. It is remarked that there is a definite difference in the behaviour of the post-larvæ of certain spring-spawning fish as opposed to those of summer-spawners. Most of the post-larvæ of spring-spawners keep to the layers below about 15 metres, while most of the latter are to be found above 25 metres up to the very surface itself.

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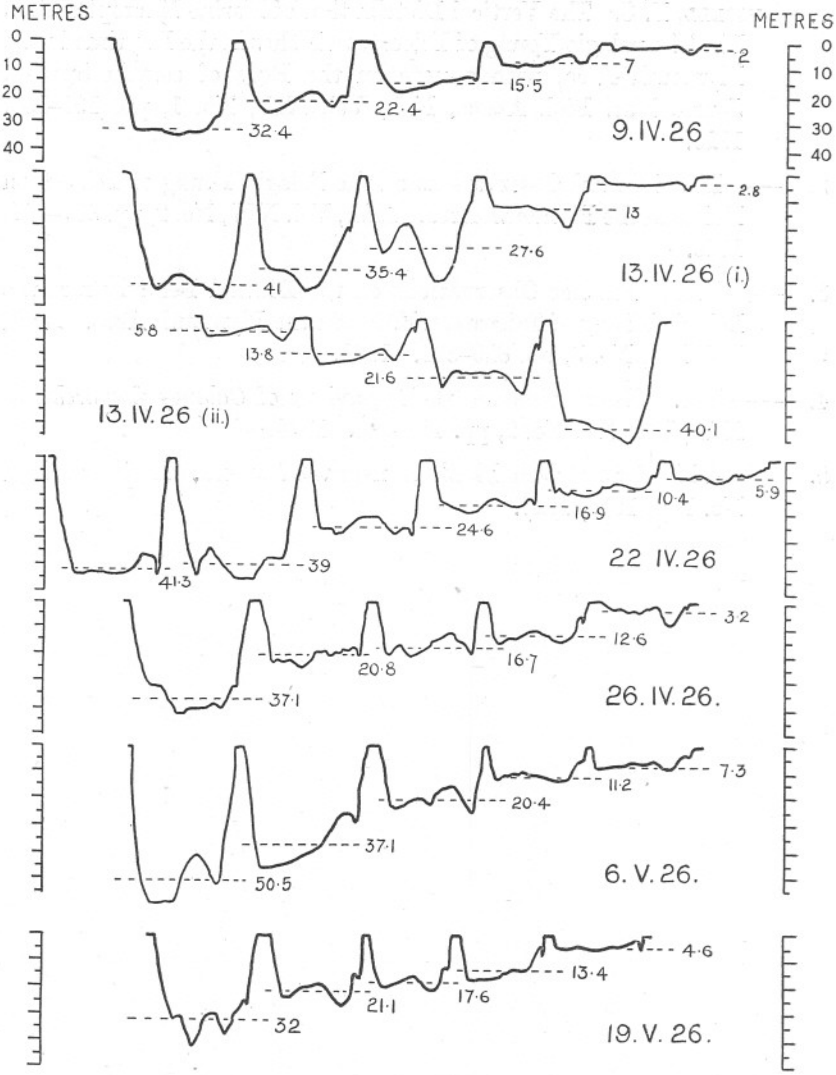

Fig. 6.—The series of curves given by the depth-recorder indicating the path of the net through the water for each haul on the dates given. The net enters the water on the right-hand side of each curve. The dotted lines indicate the calculated "average depth."

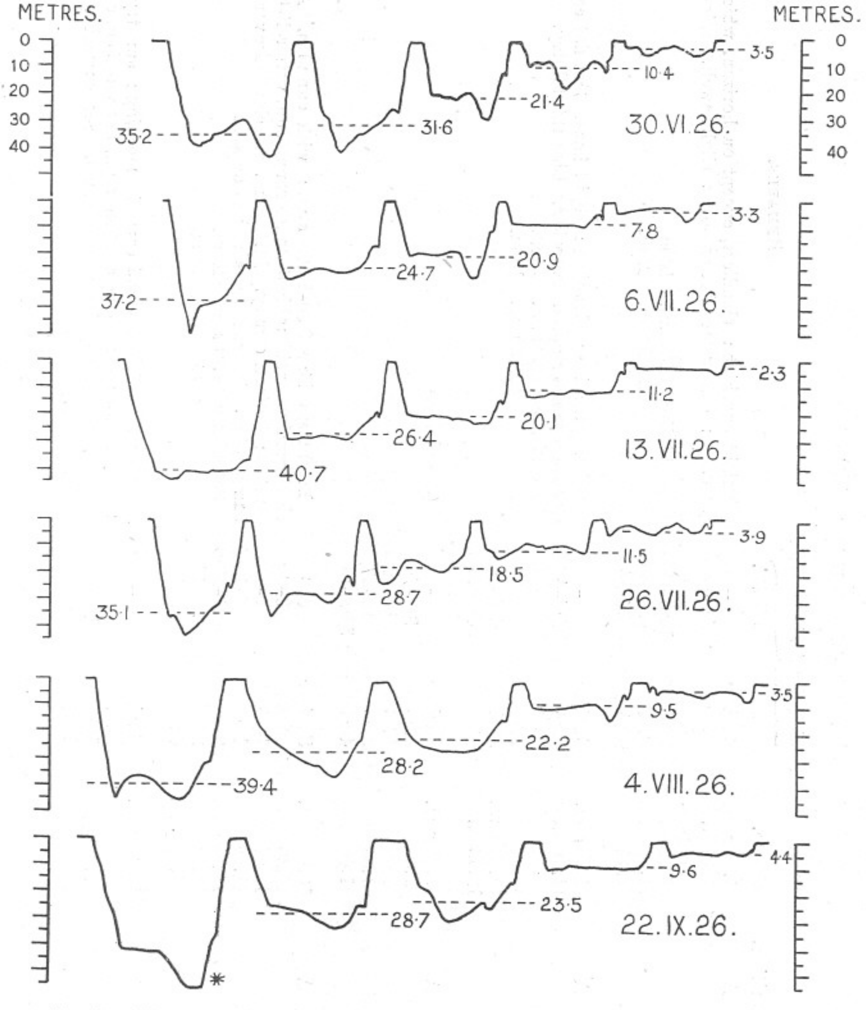

Fig. 7.—The series of curves given by the depth-recorder indicating the path of the net through the water for each haul on the dates given. The net enters the water on the right-hand side of each curve. The dotted lines indicate the calculated "average depth." * 22. ix. 26 : Struck bottom.

List of Stations, 1926.*

			Fishing depths in metres.		
Date.	Position.	Time.	Average.	Limits.	Remarks.
April 9th	A	11.29 a.m.	Surface	–	Bright sunshine ; cloudless, except on horizon, which was hazy. Sea calm ; but surface not smooth ; slight swell. Wind light, from west. Secchi disc 11.27 a.m. 10 m. 1.25 p.m. 12 m.
		11.46 ,,	2	1·5–4	
		12.3 p.m.	7	4–9	
		12.22 ,,	15·5	12·5–18·5	
		12.42 ,,	22·4	18–25·5	
		1.04 ,,	32·4	27–34	
April 13th (i)	A	11.3 a.m.	Surface	–	Bright sunshine ; cloudless ; slight haze. Sea flat calm ; surface smooth without ripples. No wind. Like this all day. Secchi disc 11.00 a.m. 12 m. 12.55 p.m. 10 m.
		11.21 ,,	2·8	2·5–4	
		11·39 ,,	13	11–18	
		11.59 ,,	27·6	18–38	
		12.18 p.m.	35·4	25–42	
		12.38 ,,	41	37·5–46	
April 13th (ii)	A	2.51 p.m.	Surface	–	(See above.)
		2.35 ,,	5·8	3·5–7·5	
		2.17 ,,	13·8	10–16·5	
		1.58 ,,	21·6	19–27	
		1.40 ,,	40·1	36·5–45	
April 22nd	A	10.18 a.m.	Surface	0–3	Bright sunshine 8.30–10.00 a.m. ; with cumulus. At 10.15 sky cloudless for considerable distance round sun, with a little high cirro-stratus : horizon cloudy. 11.10 a.m. sun clouded over : 11.59 a.m. sun shining. Sea surface calm but broken. Secchi disc 11.12 a.m. 10 m. 1.40 ,, 11 m.
		10.35 ,,	5·9	3–8	
		10.56 ,,	10·4	6–13	
		11.15 ,,	16·9	15–19·5	
		11.35 ,,	24·6	21–27·5	
		11.59 ,,	39	35–45	
		12.22 p.m.	41·3	35–44	
April 26th	A	10.3 a.m.	Surface	–	Dull with thickish cloud early in morning ; sun trying to break through later ; sun shone at 10.40 a.m., but was soon covered again, showing only dimly for rest of hauls. Sea surface choppy ; stiff N.W. breeze. Secchi disc 10.00 a.m. 11·5 m. 12.45 p.m. 13 m.
		10.21 ,,	3·2	1–8	
		10.38 ,,	12·6	7·5–16	
		10.52 ,,	16·7	11·5–20	
		11.12 ,,	20·8	18–25	
		11.35 ,,	37·1	31·5–40·5	

May 6th	A	10.8 a.m.	Surface	–	Clear and cloudless until 10.00 a.m., when there was intermittent sunshine with cumulus clouds ; one or two drops of rain. Sea surface choppy ; stiff N.W. breeze. Secchi disc 10.7 a.m. 9·5 m. 12.30 p.m. 9 m.
		10.26 ,,	7·3	4–9	
		10·44 ,,	11·2	6·5–13	
		11.4 ,,	20·4	15–25	
		11.27 ,,	37·1	25–45	
		11.48 ,,	50·5	40–58†	
May 19th	A	9.32 a.m.	Surface	–	Weather from sunrise to start of work close, sky overcast. Sun tried to come through at 10.00 a.m., but only shone brightly at last haul. Wind very slight ; sea surface with slight ripple. Secchi disc 9·25 a.m. 13 m. 12.00 p.m. 11 m.
		9.53 ,,	4·6	3–5	
		10.14 ,,	13·4	7–16·5	
		10.36 ,,	17·6	12·5–20	
		10·56 ,,	21·1	16–25	
		11.22 ,,	32	25–40	
June 25th	A	9.52 a.m.	Surface‖	–	Cloudless ; slight haze ; no wind ; sea surface glass calm. Secchi disc 9.50 a.m. 19½ m. 12.00 p.m. 20½ m.
		10.10 ,,	8·2‡	6–9	
		10·29 ,,	16·9‡	15–20	
		10.49 ,,	24·6‡	19–27	
		11·10 ,,	32‡	31–33	
		11.31 ,,	43·1‡	39–49§	
June 30th	L4	10.57 a.m.	Surface	–	A little very high cirrus, otherwise cloudless. Bright sunshine ; slight haze. Stiff east wind ; sea moderate.
		11·13 ,,	3·6	2–5·5	
		11.30 ,,	10·4	7–16	
		11.46 ,,	21·4	18–28	
		12.4 p.m.	31·6	25–39	
		12.24 ,,	35·2‖	30–42·5	
July 6th	A	9.56 a.m.	Surface	–	Very thick clouds ; dull ; visibility fair. Sea calm, but surface broken by breeze. Secchi disc 11.47 a.m. 14 m.
		10.11 ,,	3·3	2–6	
		10.28 ,,	7·9	5–9	
		10.45 ,,	20·9	18–28	
		11.5 ,,	24·7	17–28·5	
		11.28 ,,	37·2	25–50·5	

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* All hauls were of 10 minutes' duration, the time given being the start of the haul.

‡ Drum of depth-recorder not screwed home ; 4 metres have been added to recorded depth.

† Net struck bottom.

§ Wire broke ; net fished for 13½ minutes.

Date.	Position.	Time.	Fishing depths in metres.		Remarks.
			Average.	Limits.	
July 13th	A	9.41 a.m.	Surface	–	Cloudless; brilliant sunshine; haze in distance. Fresh easterly wind; sea surface choppy. Secchi disc 11.30 a.m. 13 m.
		9.58 ,,	2·3	2–4	
		10.15 ,,	11·2	10–12	
		10.33 ,,	20·1	15–22	
		10.53 ,,	26·4	20–29	
		11.11 ,,	40·7	35·5–44	
July 15th	E1	10.46 a.m.	Surface	–	Sun partially obscured by hazy cloud; visibility poor. Secchi disc 10.35 a.m. 12 m. 1.30 p.m. 13 m.
		11.00 ,,	2·9	1·5–4·5	
		11.15 ,,	6·6	4–8·5	
		11.33 ,,	13·7	11·5–19	
		11.53 ,,	21·5	17–23·5	
		12.10 p.m.	34·1	29–40	
		12.31 ,,	49	44–57	
July 26th	A	10.16 a.m.	Surface	–	Very dull and overcast at start of day, with heavy clouds; 9.45 a.m. clouds broke up and sun came out bright; remained out till 11.15 a.m.; 11.40 a.m. raining. Sea surface calm, but rippled. Secchi disc 12.00 p.m. 12 m.
		10.32 ,,	3·9	2–6	
		10.49 ,,	11·5	10–14	
		11·6 ,,	18·5	14–24	
		11.22 ,,	28·7	23–35·5	
		11.41 ,,	35·1	25–43	
August 4th	A	9.41 a.m.	Surface	–	Bright sunshine; cloudless; no haze. Sea surface choppy; slight swell. Secchi disc 12.55 p.m. 9 m.
		10.00 ,,	3·5	2·5–6	
		10.18 ,,	9·5	7–13	
		10.37 ,,	22·2	14·5–25	
		10.56 ,,	28·2	21–35	
		11.17 ,,	39·4	31·5–43	
		11.36 ,,	Surface	–	
September 22nd	A	1.20 p.m.	Surface	–	Weather dull; at 1.40 p.m. sun was shining through thin cloud for short time. Sea calm.
		1.40 ,,	4·4	2–5	
		1.57 ,,	9·6	9–10	
		2.18 ,,	23·5	15·5–30	
		2.39 ,,	28·7	25–33·5	
		2.58 ,, ‖			

‖ Net struck bottom.

Table 1.

	Depth in metres.	Clupea sp.	Gadus pollachius.	G. merlangus.	G. minutus.	G. luscus.	G. callarias.	Onos sp.	Scophthalmus norvegicus.	Zeugopterus punctatus.	Pleuronectes limanda.	P. microcephalus.	P. flesus.	Solea vulgaris.	S. variegata.	Rhombus sp.	Ammodytes tobianus.	A. lanceolatus.	Callionymus sp.	Labrus bergylta.	Gobius sp.	Centronotus gunnellus	Trigla sp.	Cottus bubalis.	Liparis montagui.	Lophius piscatorius.	*Total Young Fish.*
April 9th, 1926	*S.*	–	1	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**7**
	2	39	5	2	–	–	1	17	–	–	–	–	1	–	–	–	2	–	1	–	1	–	–	–	–	–	**69**
	7	101	1	6	–	1	3	14	–	–	3	–	2	–	–	–	–	1	12	–	–	–	1	3	–	–	**148**
	15·5	151	2	52	6	–	8	15	–	–	4	2	5	2	–	–	2	4	50	–	–	–	5	1	–	–	**309**
	22·4	112	–	64	19	4	–	11	–	–	12	1	–	1	–	1	–	–	41	–	–	2	14	1	–	–	**283**
	32·4	117	–	55	22	3	1	15	–	–	13	1	2	6	–	–	1	1	46	–	1	–	1	4	–	–	**289**
April 13th, 1926 (i)	*S.*	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
	2·8	2	2	–	–	–	–	6	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	1	**13**
	13	87	4	4	1	–	–	24	–	–	10	6	–	–	–	1	2	–	–	–	–	–	1	–	–	–	**140**
	27·6	55	3	54	17	2	1	10	–	–	25	1	1	2	–	–	3	–	33	–	1	–	9	–	–	–	**217**
	35·4	11	–	25	13	1	1	4	–	–	4	–	2	1	–	–	–	–	15	–	–	–	2	–	–	–	**79**
	41	2	1	3	5	–	1	3	–	–	5	–	3	–	–	–	–	–	15	–	–	–	–	1	1	–	**40**
April 13th, 1926 (ii)	*S.*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**–**
	5·8	15	1	9	–	–	–	7	–	–	1	–	3	–	–	–	1	2	2	–	–	–	–	–	–	–	**41**
	13·8	13	–	18	2	–	1	12	–	–	2	–	2	–	–	–	1	2	7	–	2	–	2	–	–	–	**64**
	21·6	13	1	56	11	1	2	7	–	1	17	–	7	2	–	–	–	–	29	–	1	–	5	–	1	–	**154**
	40·1	11	1	9	3	–	2	2	–	1	4	–	3	1	–	–	5	–	20	–	–	–	2	1	–	–	**65**
April 22nd, 1926	*S.*	1	1	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**6**
	5·9	2	–	2	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	**5**
	10·4	12	3	2	2	1	–	1	–	–	5	–	10	1	–	–	–	1	8	–	–	–	2	–	–	–	**48**
	16·9	51	–	45	31	3	–	1	1	1	41	4	8	8	12	–	–	2	77	–	3	–	5	–	–	–	**293**
	24·6	30	1	51	132	13	–	3	1	4	49	6	7	11	20	–	1	–	186	2	3	–	6	1	–	–	**527**
	39	10	–	21	144	5	–	3	2	–	10	2	2	10	5	–	1	–	110	–	2	–	–	–	1	1	**329**
	41·3	17	4	13	131	6	–	–	2	–	11	3	1	18	5	–	1	2	95	–	6	–	1	3	–	–	**319**

Table 2.

	Depth in metres.	Clupea sp.	Gadus pollachius.	G. merlangus.	G. minutus.	G. luscus.	Molva molva.	Onos sp.	Raniceps raninus.	Scophthalmus norvegicus.	Zeugopterus punctatus.	Pleuronectes limanda.	P. microcephalus.	P. flesus.	Solea vulgaris.	S. variegata.	Rhombus sp.	Ammodytes tobianus.	A. lanceolatus.	Callionymus sp.	Labrus bergylta.	Labrus mixtus.	Crenilabrus melops.	Ctenolabrus rupestris.	Centrolabrus exoletus.	Scomber scomber.	Gobius sp.	Lebetus scorpioides.	Blennius pholis.	B. gattorugine.	Trigla sp.	Lepadogaster bimaculatus.	*Total Young Fish.*
April 26th, 1926	*S.*	6	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**7**
	3·2	4	–	–	–	–	–	1	–	–	–	6	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	**17**
	12·6	47	–	12	13	1	–	–	–	1	1	11	6	–	–	7	–	–	–	100	–	–	–	–	–	–	–	–	–	–	–	–	**199**
	16·7	16	–	1	22	–	1	1	–	1	1	6	2	–	–	2	–	–	2	98	–	–	–	–	–	–	–	–	–	–	–	–	**153**
	20·8	27	–	21	25	2	–	–	–	1	–	7	2	–	1	12	–	–	1	68	–	–	–	–	–	–	1	–	–	–	1	–	**169**
	37·1	9	2	2	23	–	–	–	–	–	–	9	2	–	1	1	–	–	–	33	–	–	–	–	–	–	–	–	–	–	2	–	**84**
May 6th, 1926	*S.*	–	2	1	–	–	–	25	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	**29**
	7·3	12	5	1	–	–	–	12	–	1	–	1	–	–	–	–	–	–	2	11	1	–	–	–	–	–	–	–	–	–	–	–	**46**
	11·2	11	2	–	–	–	–	3	–	1	–	2	5	–	–	–	1	1	1	15	1	–	–	–	–	–	–	–	–	–	–	–	**43**
	20·4	39	4	56	–	–	–	18	–	2	–	46	22	2	–	–	–	–	1	54	1	–	–	–	–	–	–	–	–	–	1	–	**246**
	37·1	23	2	13	30	6	1	13	–	1	2	34	3	–	1	12	–	–	4	98	–	–	–	–	–	–	–	–	–	–	1	–	**244**
May 19th, 1926	*S.*	13	1	10	–	–	–	3	–	–	–	–	1	–	1	5	–	–	–	24	1	–	–	–	–	–	–	–	–	–	–	–	**59**
	4·6	4	–	25	–	–	–	3	–	2	–	–	–	–	–	6	–	–	3	132	3	–	–	–	–	–	–	–	–	–	3	–	**181**
	13·4	5	1	14	10	2	1	–	–	12	–	12	2	–	–	11	–	–	7	267	3	–	–	–	–	–	–	–	–	–	1	–	**348**
	17·6	11	1	24	12	–	7	1	–	10	2	12	6	–	–	43	–	–	13	401	–	1	–	–	–	–	–	–	–	–	5	–	**549**
	21·1	26	–	35	16	3	–	1	–	14	–	13	21	–	2	46	–	–	10	498	1	1	–	–	–	–	–	1	–	–	7	1	**696**
	32	70	1	30	87	2	10	1	–	17	6	64	44	–	3	74	–	–	13	493	–	–	–	–	–	–	–	2	–	–	4	–	**921**
June 25th, 1926	*S.*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	2	–	–	**4**
	8·2	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	8	1	8	1	3	1	–	–	2	3	–	–	**28**
	16·9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	2	–	3	–	–	1	1	–	1	2	–	–	**13**
	24·6	2	–	3	–	–	–	–	–	3	–	–	3	–	–	–	–	1	3	41	4	–	3	–	–	2	5	2	–	4	1	–	**77**
	32	–	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	4	26	1	1	2	–	–	–	14	–	1	–	1	–	**54**
	43·1	–	–	–	–	–	–	–	1	9	–	2	1	–	–	2	–	–	2	127	1	2	1	–	–	1	64	3	–	–	1	2	**219**

TABLE 3.

	Depth in metres.	Clupea sp.	Gadus merlangus.	Onos sp.	Merluccius merluccius.	Raniceps raninus.	Capros aper.	Arnoglossus sp.	Scophthalmus norvegicus.	Pleuronectes microcephalus.	Solea variegata.	S. lascaris.	Rhombus sp.	Serranus cabrilla.	Caranx trachurus.	Ammodytes lanceolatus.	Callionymus sp.	Labrus bergylta.	L. mixtus.	Crenilabrus melops.	Ctenolabrus rupestris.	Centrolabrus exoletus.	Trachinus vipera.	Scomber scomber.	Zeus faber.	Gobius sp.	Lebetus scorpioides.	Blennius ocellaris.	B. pholis.	B. gattorugine.	Trigla sp.	Lepadogaster bimaculatus.	Lophius piscatorius.	*Total Young Fish.*
June 30th, 1926	*S.*	1	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	–	7	–	–	–	–	–	26	–	–	–	**46**
	3·5	6	–	1	–	–	–	–	–	–	–	–	1	–	–	1	–	8	–	8	31	2	–	31	–	–	–	–	1	5	–	–	–	**95**
	10·4	6	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	1	–	7	29	4	–	35	–	2	–	–	–	4	–	–	1	**92**
	21·4	8	3	1	–	–	–	1	7	5	5	–	–	–	–	3	26	4	3	1	1	3	1	47	–	22	–	–	3	2	2	–	1	**149**
	31·6	6	1	2	–	–	–	4	5	4	–	–	–	–	–	6	74	7	1	–	5	2	3	10	–	54	5	–	1	1	2	1	–	**194**
	35·2	21	1	–	–	–	–	2	8	3	–	–	–	–	–	6	183	4	3	–	2	–	–	16	–	123	1	–	–	2	1	2	1	**379**
July 6th, 1926	*S.*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	37	2	–	6	–	–	–	–	–	–	–	–	–	**45**
	3·3	8	3	–	–	–	–	3	–	–	–	–	–	–	–	3	–	–	–	–	83	3	–	68	–	–	1	–	2	–	–	–	–	**174**
	7·8	16	–	–	–	–	–	22	–	–	–	–	7	–	–	1	–	–	–	–	14	3	1	72	–	12	5	–	2	–	–	–	–	**155**
	20·9	42	–	–	–	–	–	19	1	1	–	–	1	–	–	–	8	–	2	–	7	1	1	161	–	37	7	2	–	3	–	–	2	**295**
	24·7	33	–	–	–	–	–	18	4	3	2	–	–	–	1	9	40	1	1	–	11	–	–	182	–	159	2	–	1	–	5	1	–	**473**
	37·2	13	–	–	–	–	–	8	5	4	3	–	2	–	–	4	49	–	2	–	5	1	–	104	–	79	3	1	–	2	–	1	2	**288**
July 13th, 1926	*S.*	–	1	–	–	–	–	–	–	–	–	–	3	–	–	–	1	–	–	–	18	–	–	16	–	1	–	–	–	35	–	–	–	**75**
	2·3	16	–	–	–	–	–	–	–	–	–	–	2	–	–	6	–	–	–	–	22	–	4	77	–	–	–	–	1	–	–	–	–	**128**
	11·2	59	–	–	–	–	–	3	–	–	–	–	2	–	–	5	–	–	–	–	20	1	2	73	–	1	3	–	–	1	–	–	1	**171**
	20·1	54	–	–	–	–	–	7	–	–	4	1	–	–	1	6	14	–	–	–	4	1	4	61	–	7	4	1	–	–	1	–	1	**171**
	26·4	50	1	–	–	–	–	10	–	–	6	–	–	–	3	5	21	–	2	–	4	–	5	106	–	15	3	–	–	–	1	–	3	**235**
	40·7	54	–	–	1	2	–	10	–	–	4	–	–	–	–	20	30	–	1	–	3	–	2	99	–	21	6	–	–	–	3	1	1	**258**
July 15th, 1926	*S.*	4	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	2	–	1	14	–	–	–	–	–	–	–	–	–	**23**
	2·9	27	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	15	–	1	44	–	–	–	–	–	–	–	–	–	**90**
E 1	*6·6*	69	–	–	–	–	–	–	–	–	–	–	2	–	2	1	–	–	–	–	5	–	–	34	–	–	–	–	–	5	–	–	–	**118**
	13·7	255	–	–	–	–	1	6	–	–	–	–	4	1	4	1	–	–	–	–	3	–	7	23	1	2	–	1	–	–	–	–	–	**309**
	21·5	30	–	–	–	1	–	1	–	–	–	–	–	–	–	1	1	–	–	–	6	–	2	14	–	1	1	–	1	–	–	–	–	**59**
	34·1	254	–	–	–	1	–	13	–	1	–	–	–	–	–	2	31	–	–	–	1	–	–	31	–	13	1	1	3	–	–	–	–	**352**
	49	203	–	–	1	–	–	6	–	2	–	–	–	–	2	2	59	–	–	–	2	–	1	26	–	26	–	–	2	–	–	–	2	**334**

TABLE 4.

	Depth in metres.	Clupea sp.	Gadus merlangus.	G. luscus.	Merluccius merluccius.	Raniceps raninus.	Capros aper.	Arnoglossus sp.	Scophthalmus norvegicus.	Solea variegata.	Rhombus sp.	Serranus cabrilla.	Caranx trachurus.	Belone vulgaris.	Ammodytes lanceolatus.	A. tobianus.	Cepola rubescens.	Callionymus sp.	Crenilabrus melops.	Ctenolabrus rupestris.	Centrolabrus exoletus.	Trachinus vipera.	Scomber scomber.	Zeus faber.	Gobius sp.	Lebetus scorpioides.	Blennius ocellaris.	B. gattorugine.	Trigla sp.	Lepadogaster bimaculatus.	*Total Young Fish.*
July 26th, 1926	*S.*	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	1	–	–	–	4	–	–	–	–	29	–	–	**36**
	3·9	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	–	–	6	–	1	–	–	2	–	–	**16**
	11·5	4	–	–	–	–	–	1	–	–	1	–	–	–	2	–	–	4	–	1	–	1	11	–	–	–	–	1	1	–	**27**
	18·5	11	–	–	2	–	–	3	–	2	–	–	1	–	7	–	2	17	–	2	–	–	12	–	18	4	–	1	–	–	**82**
	28·7	6	–	–	1	–	–	1	–	1	–	–	–	–	4	–	1	14	–	1	1	3	5	–	13	2	–	–	3	–	**56**
	35·1	10	–	–	1	1	–	4	1	1	1	–	2	–	10	–	1	36	–	3	–	3	8	–	44	11	3	1	–	1	**142**
August 4th, 1926	*S.* (*i*)	7	–	–	–	–	–	1	–	–	3	–	–	–	–	–	–	2	–	–	–	42	23	–	1	1	–	–	2	–	**82**
	S. (*ii*)	163	–	–	–	–	–	2	–	–	4	–	8	1	6	–	1	7	–	54	1	19	24	–	8	–	–	48	–	–	**346**
	3·5	134	1	–	–	–	–	–	–	–	7	2	1	–	29	–	–	3	–	5	–	34	144	–	1	3	–	1	–	–	**365**
	9·5	39	–	–	–	–	–	–	–	–	4	–	111	–	6	–	–	–	–	5	–	5	64	1	–	8	–	9	1	–	**253**
	22·2	43	–	–	–	–	3	4	–	–	–	–	22	–	5	–	–	27	–	3	–	6	23	–	4	7	1	5	1	1	**155**
	28·2	37	–	1	–	–	–	3	–	–	–	–	38	–	3	–	–	50	–	3	–	10	18	2	3	15	–	2	1	2	**188**
	39·4	40	–	4	–	–	–	12	–	–	2	–	42	–	2	–	–	59	–	1	–	17	21	–	2	17	1	–	5	1	**226**
September 22nd, 1926	*S.*	–	–	–	–	–	–	7	–	–	–	–	8	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**16**
	4·4	1	–	–	–	–	–	10	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	2	–	–	–	–	**15**
	9·6	1	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	**7**
	23·5	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
	28·7	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	**5**

TABLE 5.

AVERAGE MONTHLY CATCHES OF BOTTOM PLANKTON NET, 30-MINUTE HAULS MULTIPLIED BY 8·5.

	1928					1927							
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Clupeid sp.	35·7	50·2	51·0	65·5	74·0	0·9	7·7	6·0	6·8	13·6	17·0	6·0	334·4
Gadus pollachius	–	–	–	0·9	–	–	–	–	–	–	–	–	0·9
G. merlangus	–	0·9	0·9	9·4	2·5	–	–	–	–	–	–	–	13·7
G. minutus	–	–	146·2	1047·7	1680·5	7·7	–	–	–	–	–	–	2742·1
G. luscus.	–	0·9	1·7	6·0	12·8	–	0·9	1·7	–	1·7	11·1	8·5	45·3
Onos sp.	–	–	–	2·6	4·3	2·6	0·9	–	–	–	–	–	10·4
Merluccius merluccius	–	–	–	–	–	–	–	–	1·7	–	–	–	1·7
Arnoglossus sp.	–	–	–	–	–	0·9	3·4	5·1	2·6	–	–	–	12·0
Scophthalmus norvegicus	–	–	–	1·7	10·2	2·6	0·9	–	–	–	–	–	15·4
Zeugopterus punctatus	–	–	–	0·9	1·7	–	–	–	–	–	–	–	2·6
Pleuronectes limanda	–	–	0·9	15·3	23·0	7·7	–	–	–	–	–	–	46·9
P. flesus	–	–	–	2·6	–	–	–	–	–	–	–	–	2·6
P. microcephalus	–	–	1·7	7·7	11·1	–	–	–	–	–	–	–	20·5
Solea vulgaris	–	–	8·5	4·3	4·3	–	–	–	–	–	–	–	17·1
S. variegata	–	–	–	–	12·8	–	–	–	–	–	–	–	12·8
S. lutea.	–	–	–	–	–	0·9	–	–	–	–	–	–	0·9
Ammodytes tobianus	0·9	68·0	1·7	0·9	1·7	–	–	–	–	–	–	–	73·2
A. lanceolatus	–	11·1	1·7	11·1	–	0·9	11·9	–	–	–	–	–	36·7
Callionymus sp.	–	–	6·0	44·2	150·5	22·1	17·0	4·3	3·4	3·4	–	–	250·9
Labrus bergylta	–	–	–	–	–	6·0	–	–	–	–	–	–	6·0
L. mixtus	–	–	–	–	–	0·9	–	–	–	–	–	–	0·9
Ctenolabrus rupestris	–	–	–	–	–	5·1	6·0	–	–	–	–	–	11·1
Crenilabrus melops	–	–	–	–	–	5·1	0·9	–	–	–	–	–	6·0
Centrolabrus exoletus	–	–	–	–	–	–	0·9	–	–	–	–	–	0·9
Scomber scomber	–	–	–	–	–	2·6	0·9	–	–	–	–	–	3·5
Gobius sp.	3·4	1·7	5·1	4·3	114·8	1354·1	3247·0	109·7	59·7	11·1	6·0	26·4	4943·3
Crystallogobius nillsoni	–	–	–	41·7	95·2	34·0	30·6	1·7	0·9	–	–	–	204 ·1
Lebetus scorpioides	–	–	–	–	–	–	0·9	–	0·9	–	–	–	1·8
Trachinus vipera	–	–	–	–	–	–	0·9	1·7	–	–	–	–	2·6
Blennius pholis	–	–	–	–	–	2·6	–	–	–	–	–	–	2·6
B. gattorugine	–	–	–	–	–	–	9·4	–	–	–	–	–	9·4
Chirolophis galerita	–	0·9	–	–	–	–	–	–	–	–	–	–	0·9
Trigla sp.	–	–	–	–	8·5	–	0·9	0·9	–	–	–	–	10·3
Cottus bubalis	–	–	1·7	–	–	–	–	–	–	–	–	–	1·7
Lepadogaster bimaculatus	–	–	–	–	14·5	5·1	9·4	1·7	–	–	–	–	30·7

TABLE 6.

AVERAGE MONTHLY CATCHES IN RING-TRAWL, 30-MINUTE OBLIQUE HAULS.

	1928					1927							
	Jan.	Feb.	March.	April.	May.*	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Clupeid sp.	23·7	30·3	11·1	82·5	*25·0*	8·1	81·3	14·1	1·2	2·4	30·0	22·5	332·2
Gadus pollachius	–	–	1·2	21·6	*1·6*	–	–	–	–	–	–	–	24·4
G. merlangus	–	–	7·8	29·7	*55·9*	8·4	0·6	0·2	–	–	–	–	102·6
G. minutus	–	3·9	24·6	135·6	*33·6*	–	–	–	–	–	–	–	197·7
G. luscus.	0·9	6·9	5·4	8·4	*1·8*	0·3	0·3	0·6	0·3	2·1	3·9	49·5	80·4
Onos sp.	–	–	–	31·8	*10·4*	0·9	–	–	–	–	–	–	43·1
Merluccius merluccius	–	–	–	–	–	–	0·2	0·6	–	1·5	0·9	–	3·2
Arnoglossus sp.	–	–	–	–	–	–	15·0	7·2	3·0	0·9	–	–	26·1
Scophthalmus norvegicus	–	–	–	4·8	*29·8*	3·6	0·9	–	–	–	–	–	39·1
Zeugopterus punctatus	–	–	0·7	2·1	*6·2*	–	–	–	–	–	–	–	9·0
Pleuronectes limanda	–	–	6·6	37·2	*45·3*	2·1	–	–	–	–	–	–	91·2
P. flesus	–	–	0·3	10·8	*0·7*	–	–	–	–	–	–	–	11·8
P. microcephalus	–	–	0·3	17·7	*16·1*	0·6	–	–	–	–	–	–	34·7
Solea vulgaris	–	–	0·3	3·3	*1·0*	–	–	–	–	–	–	–	4·6
S. variegata	–	–	–	10·3	*40·5*	0·3	–	–	–	–	–	–	51·1
S. lutea.	–	–	–	–	–	0·3	3·6	–	–	–	–	–	3·9
Ammodytes tobianus	0·6	90·9	20·7	0·9	*0·1*	0·3	–	–	–	–	–	–	113·5
A. lanceolatus	–	–	–	21·0	*13·9*	5·4	3·6	0·9	–	–	–	–	44·8
Callionymus sp.	–	–	8·7	212·1	*377·6*	24·1	11·4	7·8	1·8	18·9	0·9	–	663·5
Labrus bergylta	–	–	–	–	*1·3*	6·9	–	–	–	–	–	–	8·2
L. mixtus	–	–	–	–	*0·2*	0·9	–	–	–	–	–	–	1·1
Ctenolabrus rupestris	–	–	–	–	–	0·6	6·0	4·5	–	–	–	–	11·1
Crenilabrus melops	–	–	–	–	–	2·4	–	–	–	–	–	–	2·4
Centrolabrus exoletus	–	–	–	–	–	3·0	0·3	–	–	–	–	–	3·3
Scomber scomber	–	–	–	–	*0·1*	1·2	23·4	0·9	–	–	–	–	25·6
Gobius sp.	–	–	–	2·1	*1·8*	2·1	2·1	6·1	0·9	0·6	0·9	–	16·6
Crystallogobius nillsoni	–	–											–
Lebetus scorpioides	–	–	–	–	*0·2*	0·3	1·2	1·5	0·3	0·3	–	2·1	5·9
Trachinus vipera	–	–	–	–	–	1·2	2·4	3·9	0·3	–	–	–	7·8
Blennius pholis	–	–	–	–	*0·1*	0·3	0·9	0·3	–	–	–	–	1·6
B. gattorugine	–	–	–	–	–	0·9	2·1	3·6	–	–	–	–	6·6
Chirolophis galerita	–	–	2·0	–	–	–	–	–	–	–	–	–	2·0
Trigla sp.	–	–	1·5	0·3	*13·4*	3·9	6·0	1·5	–	–	–	–	26·4
Cottus bubalis	–	–	4·7	6·0	*0·7*	–	–	–	–	–	–	–	11·4
Lepadogaster bimaculatus	–	–	–	–	*0·1*	–	–	0·3	–	–	–	–	0·4

* The figures given here are the average catches per half-hour haul obtained from the years 1924, 1925, 1926, 1927, and 1929, the total number of hauls at each station being regarded as one oblique haul in the first three years.

OBJECTS

OF THE

Marine Biological Association

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, an 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 1926 a sum of over £6,500 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. The reader is referred to page 4 of the Cover for information as to membership of the Association.

CONTENTS OF NEW SERIES, Vol. XVI., No. 2.

NOTICE.

The Council of the Marine Biological Association wish it to be understood that they do not accept responsibility for statements published in this Journal excepting when those statements are contained in an official report of the Council.

TERMS OF MEMBERSHIP.

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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.