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PHOTOGRAPHY OF THE SEA FLOOR

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(Plate I and Text-figs. 1–2)

Introduction

During the last sixty years many attempts have been made to take photographs underwater at depths varying from just below low-water to many thousands of feet. The pioneer work of Boutan (1893) showed clearly that the essential requirements were a relatively light apparatus fitted with a good source of illumination. Ewing, Vine & Worzel (1946) gave a list of workers who have obtained underwater photographs at wading or diving depths. In their own work Ewing, Vine & Worzel have designed a number of underwater cameras with which they have taken some thousands of pictures of the sea-bottom. In their free-floating cameras the apparatus is allowed to sink to the bottom with a ballast weight. On touching the bottom a trigger sets off the camera which takes two pictures with a time interval of 30 sec. After this the ballast is released and a float brings the apparatus to the surface. In their suspended cameras the component parts are mounted, as in the free-floating cameras, on a vertical pole, with the camera near the top and a trigger at the base. Activation of the camera occurs when the trigger touches the bottom. Their most satisfactory light source proved to be the photoflash bulb. With one or other of these cameras they have obtained large numbers of clear photographs in depths ranging from 10 to 2400 ft., and have used these in studies of bottom deposits, sand ripples, and the distribution of animal life. (See also Ewing, Woolard, *et al.*, 1946.)

In the present work an attempt has been made to design and construct an underwater camera which will serve as a tool for estimating the density of the larger bottom-living invertebrates on the trawling grounds (in depths of 50–80 m.) near Plymouth. The essential requirement was a large number of workable pictures taken at known positions in a limited area. It was decided that photo-flash bulbs would not be suitable, for although they would give a small number of high-quality pictures at each lowering of the camera, they could not be used to produce a large number of consecutive pictures at a single lowering. Up to the present it has not been possible to work with an electronic flash as light source, but Ewing, Vine & Worzel (1946) found that, except in shallow water, the cable losses are so high and the cable itself so heavy that they considered it impractical to use lengths of more than 150 ft. (*c.* 50 m.). It would, of course, be possible to put the supply and conversion unit into a pressure-proof container and lower them with the camera, but this would make the whole apparatus very inconvenient to handle at sea. It was, therefore, decided to use a battery of photoflood lamps as a source of light for the present apparatus, and this has proved relatively successful.

Acknowledgments

I am much indebted to Mr F. J. Warren who designed and installed the electrical circuits and the control box, to Mr F. G. C. Ryder who was responsible for the construction and assembly of the underwater mechanical components, to Captain C. A. Hoodless, D.S.C., and the crew of R.V. *Sabella*, whose skill and patience have enabled the apparatus to be operated efficiently at sea, and to Dr D. P. Wilson and Mr G. M. Spooner for their guidance and assistance in photographic and statistical methods respectively.

Description of the Apparatus

The arrangement of the underwater components is shown diagrammatically in Text-figs. 1 and 2. The camera is mounted near the top of a vertical metal tube. The lamps are arranged asymmetrically round a metal ring attached to the pole at a height of 0·65 m. from the bottom of the pole. The foot switch is mounted in the base of the pole. Between the foot switch and the attachment of the lamp ring to the pole there is a gun-metal junction box for the electrical leads.

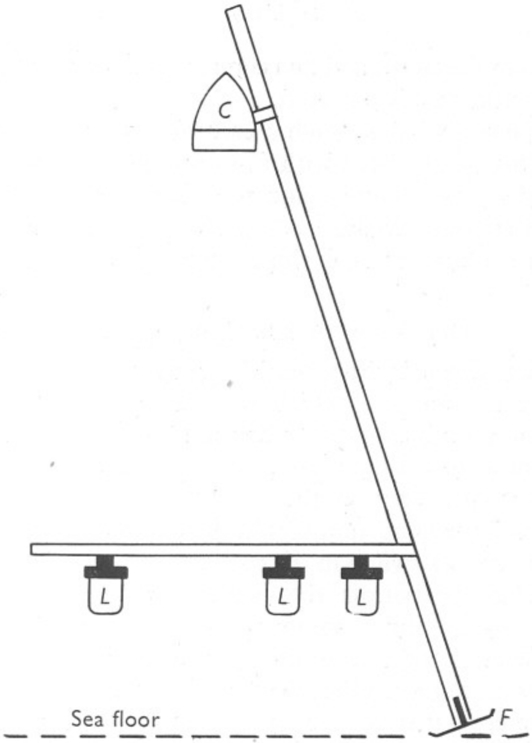
The camera used is a Robot II fitted with a Zeiss Tessar 3·75 cm. lens. The camera switch is depressed by a solenoid mounted behind the camera and activated by the foot switch.

The camera case is of gun-metal and is fitted with ½ in. plate-glass window. The case is closed by the compression of a round rubber ring in the joint between the base of the case and the dome. The compression is by a 'samson' with a single ½ in. bolt bearing down on the summit of the dome.

In its present form the apparatus has six 500 W. photoflood lamps, each mounted in a cast aluminium alloy base and enclosed in a standard glass dome. The junction between the glass and the metal is made by grinding a surface on to the edge of the glass with carborundum powder, and then seating this ground glass surface on to the metal base with a little vaseline. The glasses are held in position by a wire 'samson', but the actual sealing is effected by the pressure of the water on the glass dome.

The foot switch consists of a 21 cm. diameter brass plate connected by a socket joint to a small sealed metal bottle containing a mercury switch. When the foot touches the bottom it is driven upwards and inverts the mercury switch which activates the solenoid in the camera case.

Power from the ship's mains (200–210 V.) is supplied to the junction box near the base of the pole by a 7-core rubber-covered cable. From the junction



Text-fig. 1. Side view of underwater photographic apparatus at the moment when a picture is taken. (Lights shown on one side of the ring only.) *C*, camera case; *L*, lamps; *F*, foot and foot switch.

Text-fig. 2. Photograph of the underwater camera, showing camera, ring of lamps and junction box. The foot and foot switch are out of the picture at the bottom.

box four leads go to the lamps and two connect the foot switch and the camera solenoid; the seventh core is not used.

On deck the power is led through a control box before entering the main electric cable. This box is fitted with fuses for the camera and lamp circuits and for the ship's power supply, and with switches and ammeters for the camera and light circuits. It also has a counter which records the number of pictures taken and a buzzer which rings when a picture has been taken.

Operation of the Camera at Sea

The Robot camera is loaded with a metre length of 35 mm. high-speed film and is fitted into the camera case, which is then securely closed. The ship is stopped and a lead sounding gives the depth in metres. The apparatus is then lowered on a wire warp led over the aft boom to the main winch. When the camera is 3–5 m. from the bottom the speed of lowering is reduced, the lamps are switched on and the lamp ammeter in the control box gives a reading. At the same time the camera switch in the control box is switched on, and as soon as the foot touches the bottom the camera circuit is completed, the first picture is taken and the film is automatically wound on. When this happens the camera ammeter in the control box gives a reading and at the same time the counter clicks on to record the number of the photograph, and the buzzer rings to warn the crew that bottom has been reached. The winch is stopped immediately and the apparatus is then lifted from 1 to 2 m. off the bottom by hand hauling on the warp.

The ship is allowed to drift for a known interval of time, and the camera is again lowered steadily to take the second picture. This procedure is repeated until the whole film has been used up (40–45 exposures). The time interval between each exposure can be varied according to the speed of drift of the ship, but it is usually of the order of 30 sec., so that a film of 40 exposures can be taken in 20 min.

One of the main advantages of this method of operation is that it is possible to plot with reasonable accuracy the location of each photograph on a large-scale chart of the area. To do this it is only necessary to know the positions and times of the first and last pictures, and the time interval between each exposure.

Preliminary Results

It was found that the most satisfactory method of interpreting the photographs and counting the larger invertebrates was by examining the negatives under a binocular dissecting microscope. When there were large concentrations of animals on a single frame counting was facilitated by the use of some form of grid. Using this method of interpretation in conjunction with a micrometer slide it was possible to obtain size measurements of the animals counted. The following preliminary results on the density and distribution of bottom-living animals in four areas near Looe and Plymouth were obtained from the examination of 479 photographs, each covering 1 m.[2] of the bottom. The figures obtained for the size of each animal will be given in a later paper.

Area of Station L 4 (Pl. I).

This station is mid-way between Plymouth breakwater light and the Eddystone. Photographs were taken along the following three transects:

Date	Start of transect	End of transect
7. vii. 49	½ mile W. of L 4	¾ mile W. of L 4
24. viii. 49	Rame Head, 005° T., 3·7′	Rame Head, 050° T., 4·8′
8. viii. 50	Eddystone, 200° T., 3·0′	Eddystone, 200° T., 4·0′

The bottom in this area was muddy sand with small patches of gravel and shell debris, often lying in pockets. Trawl catches in recent years have repeatedly suggested that the epifauna of this area is poor, and this is confirmed from an examination of photographs representing 83 m.[2] of bottom. An analysis of the numbers of each species found in this area is given in Table I, which also records comparable figures for the other three areas surveyed. The only large invertebrates recorded more than once on any transect in the L 4 area are *Asterias rubens*, *Ophiura texturata* and *Chlamys opercularis*. The figures for *Asterias rubens*, although small, suggest that this species is rather unevenly distributed at a rate of not more than one individual to every 10 m.[2], while *Chlamys opercularis* is perhaps a little more abundant. The only other invertebrate found in any number is *Cellaria*, the figures given for this bryozoan denoting clumps of about 20 cm. in length. In two of the three transects there are numbers of holes, *c.* 1·3 cm. diameter, probably formed by tubicolous worms or burrowing molluscs or crustaceans.

Area south and south-west of Eddystone.

Photographs were taken along the following two transects:

Date	Start of transect	End of transect
16. viii. 49	Eddystone 360° T., 2·0′	Eddystone 360° T., 3·0′
23. x. 50	Eddystone 019° T., 3·2′	Eddystone 030° T., 4·3′

The bottom in this area is clean sand, and in 1947–48 trawling records showed a rich and abundant population of *Asterias rubens* feeding on *Chlamys opercularis* (Vevers, 1949). Trawl catches in this area during 1949 and 1950 have shown a marked decrease in the numbers of these species, although the individuals of *Asterias rubens* are still large in size. A total of 122 clear photographs (= 122 m.[2]) shows the paucity of both *A. rubens* and *Marthasterias glacialis* in 1949 and 1950 (Table I). *Chlamys opercularis* appears to be still relatively abundant, at a rate of about one individual to 2 m.[2]. There was no sign of *Cellaria* on these grounds, although another, unidentified, bryozoan (or ? sponge) occurred occasionally. A few specimens were recorded of unidentified burrowing sea anemones.

TABLE I. NUMBERS OF ANIMALS IDENTIFIED ON UNDERWATER PHOTOGRAPHS, 1949–50.

Locality	Area of L 4 (muddy sand with small patches of gravel)			S. and S.W. of Eddystone (clean sand)		S.E. of Looe Island (muddy sand and gravel with pebbles)			S.W. of Looe (muddy sand and gravel with pebbles)	
Date	7. vii. 49	24. viii. 49	8. viii. 50	16. viii. 49	23. x. 50	30. vi. 50	7. vii. 50	26. vii. 50	5. x. 49	2. viii. 50
Mean depth (m.)	55	52	55	69	70	50	50	48	46	54
Number of pictures (each 1 m.²)	23	44	16	34	88	91	21	53	72	37
Species:										
Callionymus sp.	—	—	—	1	—	—	—	—	—	—
Asterias rubens	4	3	1	—	1	5	3	1	3	—
Marthasterias glacialis	—	—	—	1	2	2	—	—	2	—
Porania pulvillus	—	1	—	—	—	—	—	—	—	—
Astropecten irregularis	—	—	—	2	1	3	1	—	—	—
Palmipes membranaceus	—	—	—	—	—	1	—	—	—	—
Echinus esculentus	—	—	—	—	—	—	—	—	2	—
Ophiura texturata	1	3	—	10	7	—	—	—	—	1
Ophiocomina nigra	—	—	—	—	—	—	—	—	2	—
Ophiothrix fragilis	—	—	—	—	26	—	—	—	18	1280*
Pecten maximus	—	—	—	—	—	16	—	1	12	1
Chlamys opercularis	5	5	1	35	30	14	—	—	3	17
Turritella communis	1	—	—	—	—	—	—	—	—	—
Eupagurus prideauxi	—	1	—	—	3	1	—	—	2	—
Portunus depurator	—	—	—	—	—	1	—	—	—	—
Crab sp.	—	1	—	—	—	2	—	—	—	—
Hyalinoecia tubicola	1	—	—	—	—	1	—	—	—	—
Cellaria sp.	5	23	—	—	—	2	—	—	—	—
Lepralia foliacea	—	—	—	—	—	—	5	—	—	—
Bryozoan (or sponge)	—	—	—	6	1	6	—	—	—	—
Sea anemone spp.	—	—	—	2	1	5	—	—	—	—
Hydroid spp.	2	—	—	—	—	4	—	—	—	—
Depressions *c.* 4·4 cm. diam.	—	—	—	—	—	5	9	27	—	—
Holes *c.* 1·3 cm. diam.	—	29	71	—	4	463	134	294	526	77

* The 1280 specimens of *O. fragilis* were actually present in 12 only of the 37 m.² interpreted.

Area south-east of Looe Island.

Photographs were taken along the following three transects in 1950:

Date	Start of transect	End of transect
30. vi. 50	Looe Island 328° T., 3·7′	Looe Island 328° T., 4·7′
7. vii. 50	Looe Island 326° T., 3·4′	Looe Island 318° T., 4·0′
26. vii. 50	Looe Island 337° T., 3·4′	Looe Island 316° T., 2·3′

The bottom was mainly of muddy sand and gravel with pebbles in some parts. The distribution of invertebrates on the bottom was variable, only the films taken on 30 June 1950 showing any large number of individuals. On this transect starfishes (*Asterias rubens*, *Marthasterias glacialis* and *Astropecten irregularis*) were present in small numbers. The large scallop, *Pecten maximus*, was relatively abundant, when compared with its frequency on other grounds, while the queen scallop, *Chlamys opercularis*, was far less abundant than on the clean sand area south of Eddystone. Sea anemones and hydroids also appeared to be more numerous than on the other grounds, and in one film there is a short length showing clumps of the polyzoan *Lepralia foliacea*. However, the most striking feature of all three transects in this area is the high number of holes made by the infauna (*c.* 1·3 cm. diameter) similar to those found in the L 4 area. In addition, there were patches of ground showing smaller numbers of irregular wide-mouthed depressions about 4·4 cm. diameter. These depressions were similar to those produced at the anterior end of some polychaete burrows. Further work, including larger scale pictures, dredge or grab hauls in the area, and experiments in the laboratory will be required before the occupants of these and the smaller holes can be identified.

Area south-west of Looe Island (Pl. I).

Photographs were taken along two transects:

Date	Start of transect	End of transect
5. x. 49	Looe Island 025° T., 4·6′	Looe Island 035° T., 4·8′
2. viii. 50	Looe Island 013° T., 4·9′	Looe Island 360° T., 5·5′

The bottom deposits were, in general, similar to those in the area south-east of Looe Island, consisting of muddy sand and gravel with pebbles. The two photographic transects available for this area show quite different features. The first transect (5 October 1949), consisting of 72 m.^{2}, is similar to the transect taken south-east of Looe Island on 30 June 1950. It has a number of the larger starfishes, as well as *Pecten maximus* and the unidentified holes (*c.* 1·3 cm. diameter); it only differs in the scarcity of queen scallops and in the presence of small numbers of *Ophiothrix fragilis*.

The second transect (2 August 1950) shows no starfishes, crustaceans or polyzoan colonies, but a very large population of *O. fragilis*, with a few queen scallops and occasional patches of ground with the unidentified holes (*c.* 1·3 cm. diameter). Twelve interpreted photographs in this transect yielded a count of 1280 *O. fragilis*. But the brittle star also occurred in large numbers in frames other than those counted, that is, they were present in the unclouded portions of the partly clouded frames. Examination of 33 successive photographs for the presence or absence of the brittle star gave the following result, the interval between each frame in this transect being approximately 10 m.:

TABLE II. OCCURRENCE OF *OPHIOTHRIX FRAGILIS* IN SUCCESSIVE PHOTOGRAPHS, 2 AUGUST 1950

Serial numbers of photographs	Occurrence of *O. fragilis* (+ = present, − = absent, ? = doubtful)
1891–93	+
1894–97	−
1898–99	+
2000	? +
2001–15	+
2016–17	?
2018–20	+
2021–22	?
2023–24	+

Taking that part of the transect covered by pictures 1898–2015 (inclusive), a sample of 18, there were 17 squares with *O. fragilis*, and one square doubtfully occupied by the same species. If, on a simple presence and absence basis, each one of a sample of 17 squares is found occupied, then it may be shown that there is a 95% chance that at least 83% of the squares of the sampled area (i.e. 170 m.^{2}) are occupied, or a 99% chance that at least 79% of the squares of the sampled area are occupied (since $0{\cdot}84^{17}$ gives a P of 0·95, $0{\cdot}83^{17}$ gives a P of 0·04, $0{\cdot}80^{17}$ gives a P of 0·023, and $0{\cdot}79^{17}$ gives a P of 0·018.)

However, since the number of individuals in the counted squares was large, varying from 38 to 206, the chances are even greater than this that all the squares in the sampled area were occupied, or, at any rate, that very few of the squares were unoccupied.

The total number of *O. fragilis* in the 12 fully interpreted and counted squares was 1280, giving a mean of $107 \pm 14{\cdot}7$ individuals to the square metre. So that a transect of, say, 150 m. would have a total of 11,550–20,550 individuals.

In all the counts of *O. fragilis* on this transect the numbers recorded are minimum figures, for it is possible that in some patches individuals may have been obscured by those lying above them.

DISCUSSION

Collections of animals from the sea-bed by means of dredge, otter trawl and Agassiz trawl give satisfactory qualitative samples of the epifauna. However, quantitative estimations by these methods involve errors owing to the impossibility of knowing the exact length of time during which the fishing gear has been on the bottom, and, in the case of the otter trawl, the lack of knowledge on the shape and size of the trawl mouth when in operation. Sampling of the bottom by means of grabs, such as that of Petersen (1918), or the scoop bottom sampler of Holme (1949) probably gives reasonably accurate results when used for the estimation of the infauna, but it is doubtful whether they give comparable results when used for the estimation of the larger epifaunal invertebrates, which are often sparsely distributed on the floor of the sea.

The use of an underwater camera to give photographs of a number of quadrats along a transect is similar in principle to the sampling methods used in extensive surveys of land vegetation (Tansley, 1923). The apparatus described in this paper is designed to obtain a succession of sample quadrats of known area at known intervals along a transect. The preliminary results from photographs of four different areas suggest that the method can be used as a competent and reasonably accurate tool, not only for the estimation of epifaunal invertebrates, which is its primary purpose, but also for counts of those infauna species which produce a tube or burrow with an opening on the surface of the sea-bed. Many photographs have been taken which show high densities of such burrowing animals. Counts of these burrows would help to confirm estimations made from the catches of bottom-sampling gear. Before this can be done, however, more information must be obtained on the shape, size and general appearance of these surface holes, so that the species producing them can be easily distinguished.

The number of photographs required to give an accurate estimate of the density of animals on a ground will clearly depend upon the nature of the bottom deposit and the type and habits of the species living there. On a poor ground, such as the L 4 area, or on a ground with heterogeneous bottom deposits, such as the muddy sand and gravel area south-east of Looe Island, a relatively large number of pictures, perhaps 300–500 $m.^2$ for 2–4 square miles in area, would be required in order to obtain a reasonably good estimate of animal density. In the latter ground there is considerable variation in the numbers and types of animals found along each of the three transects photographed.

The muddy sand and gravel area south-west of Looe Island also showed evidence of patchiness, the first transect being relatively poor in numbers of animals, while the second transect had an area which was very rich in one species only. In this latter transect, however, a small number of pictures showing homogeneous features was sufficient to enable definite conclusions to be reached on the extent of this local population of animals.

The presence of aggregations of brittle stars on localized areas of the sea-bed has long been suspected from the very large catches of these animals brought up by the dredge and Agassiz trawl. Nevertheless, the size of the aggregations, as estimated from the present photographs, is considerably greater than would be suspected from random dredge hauls. The existence of such large monospecific concentrations of animals raises a number of problems. Blegvad (1914) found that *O. fragilis* was essentially carnivorous. It is possible, therefore, that the brittle stars photographed were feeding on an extensive bed of animals, perhaps lamellibranch or other spat. Their massing behaviour might also be connected with spawning, and further photographs at different times of the year might provide further evidence on this point. The species is, in fact, known to be gregarious under laboratory conditions, and it is not uncommon for young specimens to be found clinging to adults rather in the fashion of the young of brood-protecting species. Their gregarious behaviour may not, therefore, be entirely related to food and spawning, and the individuals may react in a positive way to tactile, chemical or other stimuli produced by their fellows.

Although the quality of many of the photographs in the present series is by no means satisfactory, a sufficient number of them were clear enough for interpretation, and it is considered that larger scale pictures of an area smaller than 1 m.^{2} would also yield useful results.

There are still a number of technical difficulties, in particular the provision of a continuous source of illumination adequate for a long series of pictures or even for a ciné film. These difficulties must, of course, be overcome without rendering the apparatus unwieldy.

There is little doubt that photography of the sea-bed can yield much information which will be of use in estimating the numbers of bottom-living animals, not only in inshore waters, but also in the offshore trawling grounds. There is also the possibility that use could be made of television to view the sea-bottom, and film records of the television screen would render permanent the results obtained by this method.

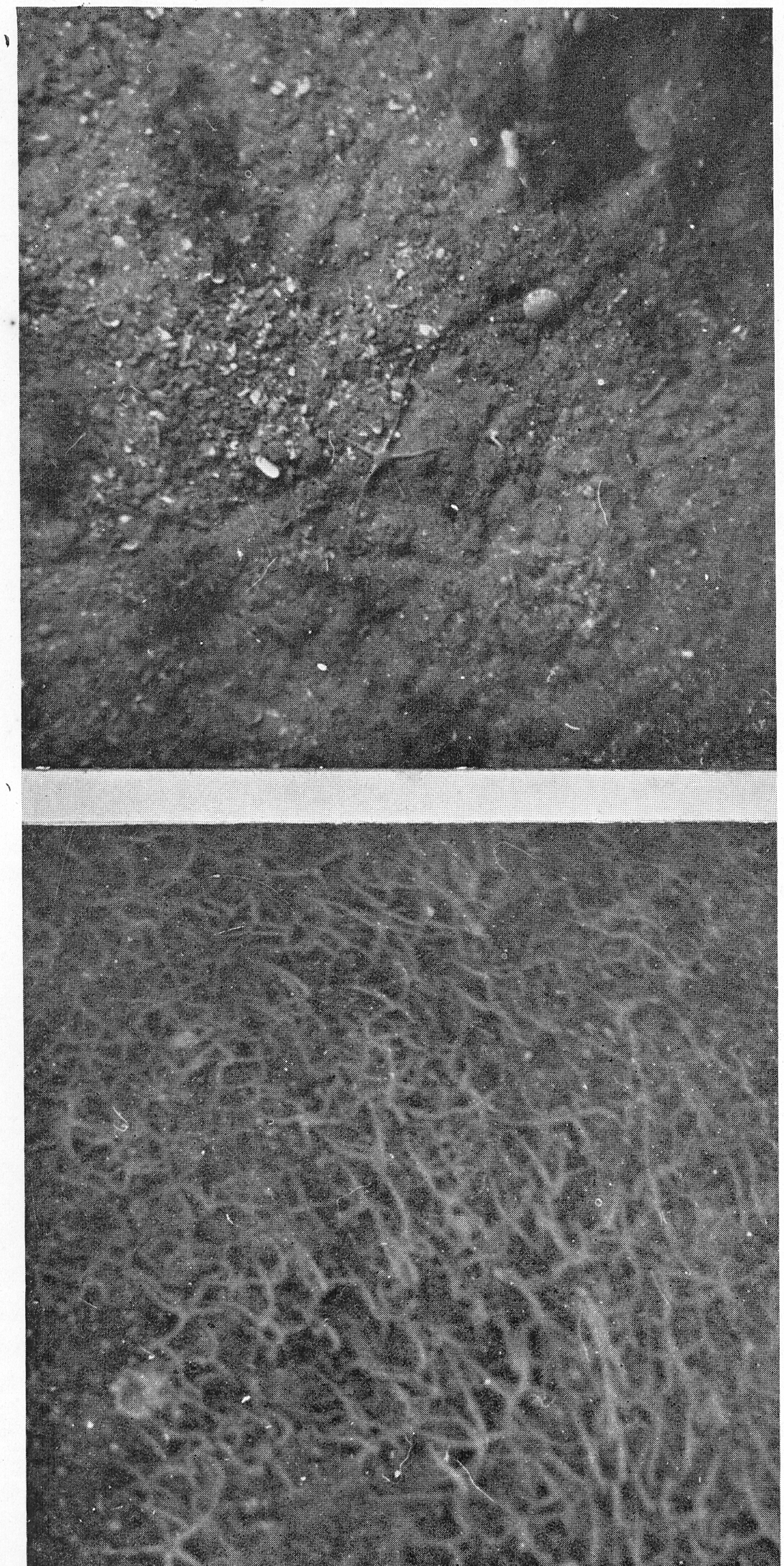
Summary

A description is given of an underwater photographic apparatus designed to take a transect of 40–50 exposures, each 1 m.^{2}, at depths up to at least 80 m. The camera used was a Robot II, and light was provided by six 500 W. photoflood lamps. Power was led from the ship's mains to the camera release and the lamps by a rubber-covered 15 amp. cable.

Photographs have been obtained of the sea-bottom on four different grounds near Plymouth and Looe, and from their interpretation a preliminary estimate has been made of the relative abundance of some of the larger bottom-living invertebrates in these areas. On some transects the sample photographs show a high density of unidentified holes made by members of the infauna.

On one transect a sample of 33 pictures showed a dense aggregation of the brittle star, *Ophiothrix fragilis*. This animal was present at the rate of $107 \pm 14{\cdot}7$ individuals to the square metre, and calculations have shown that the population was relatively homogeneous at this density over a distance of more than 100 m.

As the number of pictures taken at each lowering of the camera is relatively large it is considered that the photographic method described can be used to give a reasonably accurate estimate of the epifaunal invertebrates in known positions and at depth up to at least 70–80 m.



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EXPLANATION OF PLATE I

Above: Photograph of 1 $m.^2$ of bottom near L4, showing one *Chlamys opercularis*, one *Ophiura texturata*, and also a patch of shelly gravel and (top right-hand corner) a large hole. Depth 55 m. *Below*: Photograph of 1 $m.^2$ of bottom, 5 miles south-west of Looe Island, showing dense mass of *Ophiothrix fragilis* lying on a bottom of muddy gravel. Depth 54 m.