METHODS OF SURVEYING *LAMINARIA* BEDS

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(This survey was carried out whilst the author was temporarily attached to the Marine Biological Association)

(Plates I–IV and Text-figs. 1–15)

CONTENTS

Introduction

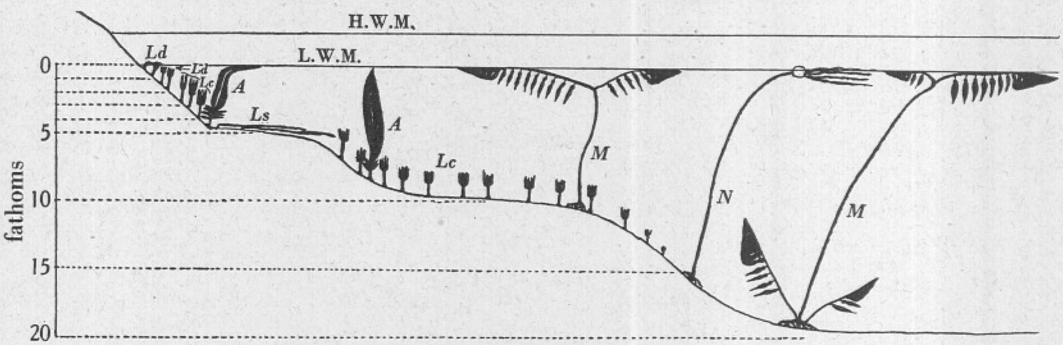
Prior to 1914 commercial interest had been aroused in America by the large beds of *Macrocystis*, *Nereocystis* and *Alaria* (collectively known as kelp)[1] which extend along the Pacific coast from Alaska to Lower California. Between 1910 and 1912 these beds were surveyed with a view to ascertaining the total area covered and the tonnage available. The survey was carried out by a number of workers and was described by Cameron (1913) and Cameron, Crandall, Rigg & Frye (1915). The methods used by these workers involved the use of a boat, a launch or steamboat, which proceeded along or around the beds, the positions being fixed at intervals. The percentage cover of any bed was usually estimated by eye. Some of these beds were cut between 1914 and 1918, but after the war the industry using this particular raw material gradually ceased to operate. I have been informed that some time after 1930 the firm which possessed the option on the majority of the beds arranged for an aerial photographic survey which was duly carried out. A description of the technique employed on this occasion, together with the results, was apparently not published as a *sequitur* to the earlier work.

The purpose of the present paper is to provide a description of the methods employed in surveying *Laminaria* beds around the coast of Great Britain. No estimate will be made in this paper of the actual tonnage available: this information, together with a discussion of other problems, has been reserved for a later date.

It must be appreciated that there is a considerable difference in habit between the weeds surveyed on the Pacific coast of America and those growing

[1] The use of this term for the living weed is not correct, as it properly refers to the burnt weed.

around Great Britain. The American *Macrocystis* and *Nereocystis* are both giant denizens of the deeper waters off-shore, often occurring down to 20 or 30 fathoms. Even when rooted at this depth the fronds may reach to the surface and thus provide an easy means of delineating the extent of the beds. The third species, *Alaria fistulosa*, is somewhat smaller and grows nearer the shore. In Great Britain only one species has its fronds commonly exposed and then only at low water of spring tides. This species is *Laminaria digitata*, which forms a belt that ranges in width depending upon the slope of the shore, just below mean low-water mark and extending out to a depth of 1 or 2 fathoms. Below that depth, if conditions are favourable, it is replaced by another species, *L. cloustoni*, which in places may extend down to depths of 13 or 14 fathoms but which generally disappears at about 10 fathoms below mean low-water mark. Neither species usually grows to much more than about 10 ft.



Text-fig. 1. The vertical distribution of the British and American brown seaweeds that form large beds and which have been surveyed. They are shown in this composite diagram in relation to each other and to high and low water. *A, Alaria*; *Lc, Laminaria cloustoni*; *Ld, L. digitata*; *Ls, L. saccharina*; *M, Macrocystis*; *N, Nereocystis*.

in length (average length about 7 ft.), and consequently while *L. digitata* may be exposed on occasion it is extremely rare for the fronds of *L. cloustoni* to be visible at the surface. The surveyor is therefore faced with the problem of surveying areas of vegetation which are not visible on the surface of the water as they are in America. He has to search for and map something which he may not even be able to see beneath the surface of the water. There is a third species around Great Britain which also has to be considered. This is the leafy *L. saccharina* which generally occupies areas where the substrate is composed of shingle or small stones because neither substrate is sufficiently stable to bear a population of the two stout erect species. It may also occur in sandy bays where the plants are probably attached to stones partially buried in the sand. The fronds of this species may extend up to about 14 ft. in length, whilst the stipe is short and relatively weak. As a result a large expanse of weakly supported frond is exposed to the subsurface currents and in such places it lies on the sea floor and never floats at or near the surface. *Macro-*

cystis and *Nereocystis* would also behave somewhat similarly were it not for the fact that both genera possess large gas-filled vesicles which aid flotation. Some of these giant Pacific seaweeds exist in other parts of the world, but so far as is known no attempt has been made to survey them accurately. Text-fig. 1 illustrates the habit of the Pacific and British species mentioned in relation to each other and to the surface of the water.

It was known from published floras and ecological papers that *Laminaria* beds existed in certain parts of Great Britain, but it was obviously desirable that this information should be checked and extended. The first operation, therefore, was to conduct a preliminary survey in order to ascertain the location of the principal beds, some of which were subsequently surveyed in more detail. The methods used in the preliminary survey differed somewhat from those utilized in the detailed survey because in the former it was only necessary to establish the existence of the beds. The present writer was assisted in both the detailed and preliminary surveys by Messrs R. H. Richens, G. E. Fogg and R. A. Lewin.

Preliminary Survey

For this survey the party was divided into two groups of two members each, one group working from a boat and the other from the shore. Localities where boats might profitably be employed were predetermined from a study of the Admiralty Charts and from a perusal of the available literature. The following methods were utilized to obtain information about the beds.

Boat and Grapnel

This is the most satisfactory method because if properly executed tangible evidence of the weed's existence is produced. In view of the great length of coastline to be covered hauls with the grapnel were usually made at intervals of 1 mile. This distance was also partly determined by the fact that both parties were scheduled to cover from 40 to 80 miles per day, and it was desirable that they should not become separated. The activities of the shore parties were limited daily more or less to 3 hr. before and after the time of low water when beds might be exposed. The best type of boat and grapnel will be discussed in detail later (p. 43), but it may be mentioned that in several places we were unable to carry out the boat programme because of unsuitable weather and sea conditions. It is impossible to use a grapnel to detect *Laminaria* in a rough sea without some risk to life and boat because so much of the work has to be carried out near the shore.

Information about Cast or Drift Weed

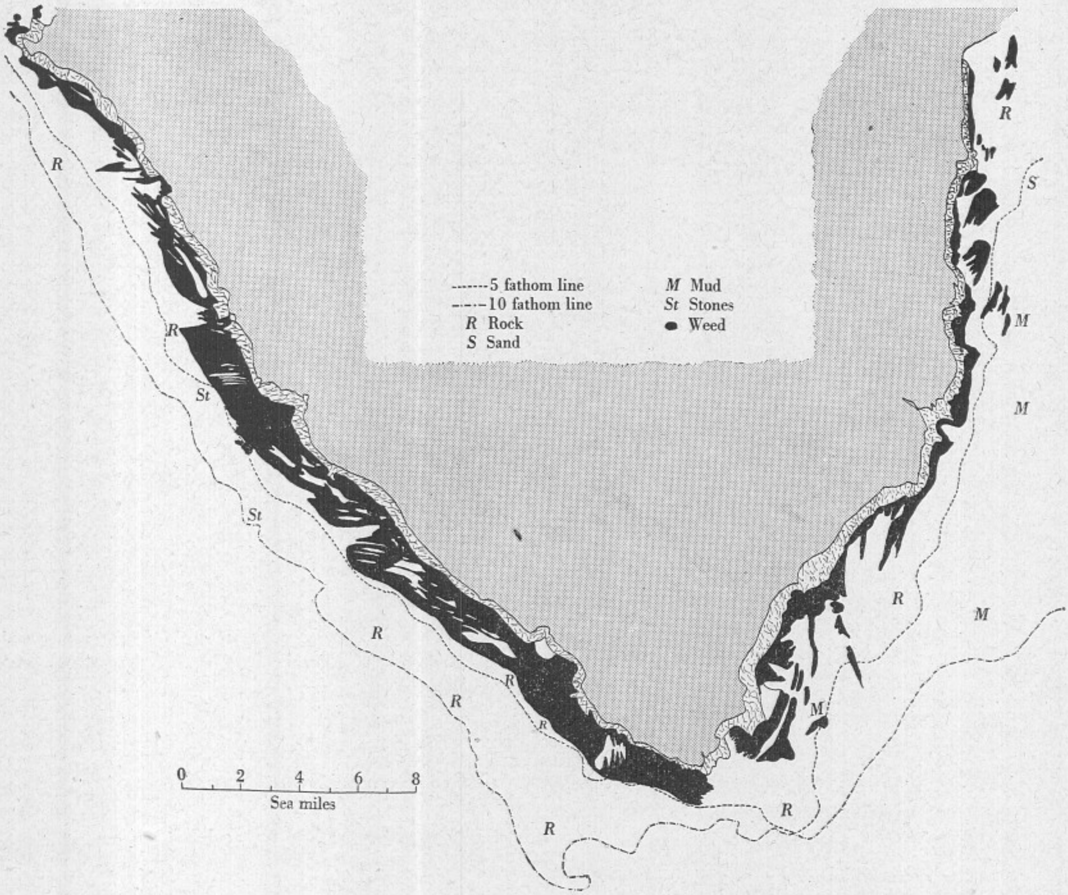
In many areas big casts are reported, and their regular annual occurrence can generally be regarded as indicative of the presence of beds in the immediate or near vicinity. The bed may, however, be as much as 10–15 miles away, and local currents are responsible for depositing the weed on the distant beaches. The shore party was responsible for collecting the information about cast weed: this was obtained by actual inspection of the beaches, when the remnants of any cast could frequently be seen, or else by interrogation of the local residents. In making such inquiries it has to be remembered that *Laminaria* cast can be of two categories which occur at different times of the year. From November to March casts of old stipes with the fronds attached may be thrown up after any gale blowing in the requisite direction. The effective direction is determined by the position of the bed in relation to the run of the coast. From April to June these stem casts are replaced by casts of frond only, or 'may leaf' as it is called. Either type of cast is an indication of *Laminaria* beds.

Information from Lobster Fishermen

It is a common practice for the lobster fishermen to lay their pots just along the margin of a *Laminaria* bed or in bare patches within the bed because such sites are the most profitable. It was a primary duty of the shore party to make contact with lobster fishermen in the principal towns and villages visited, and these men were usually very willing to impart their information. Indeed, it may be stated that their knowledge of the *Laminaria* beds was often extremely accurate, and they could on occasion even tell us the size of the plants in the different parts of the beds and also the location of any big bare patches. It sometimes proved difficult to translate their information on to a map because they were not familiar with maps, and they preferred to give us the information in the form of bearings on different landmarks. We had subsequently to identify the landmarks on the map or else follow their directions from a boat and then plot the positions of the beds.

Information from other Sources

Apart from the lobster fishermen there were other sources that provided fruitful information. Borough surveyors were often in a position to provide us with figures about the quantity of cast weed, especially in places where it was a nuisance and had to be removed. Farmers, if approached tactfully, could also on occasion give some data about the quantity of cast. This source could be used in those places where the cast was deposited in sufficient volume to make it worth while removing for agricultural manure. Fishermen, other than lobster fishermen, were not usually in a position to assist much, but very occasionally some useful facts could be gleaned. Fishery officers, on the other hand, proved extremely valuable, because even though they themselves could not provide any information they put us in touch with the most likely informants in their area. Other officials who could on occasion be helpful were harbour masters and coastguards. The coastguards are a fine body of men, often recruited locally, and as a consequence their knowledge was usually reliable. Their practice of patrolling the beaches meant that they could often give us satisfactory information about the casts, whilst some members of the service were able to provide data about the location and extent of the beds.



Text-fig. 2. Map illustrating an area with an extensive rocky shelf, only a portion of which is colonized by *Laminaria*. (Reproduced by permission of the Hydrographer of the Navy.)

Visibility from Cliffs

If one stands on a cliff 100 ft. or more high with the sun behind one's back a *Laminaria* bed in the sea below shows up a deeper blue in contrast with the surrounding bare patches. It is very rarely that the seaward extent of such beds can be observed, but a good picture can be obtained of the percentage cover. This method could not be used very often because some of the coastline does not reach the required height, or the position of the sun was not favourable, or the day was, as frequently happened, completely sunless.

Admiralty Charts

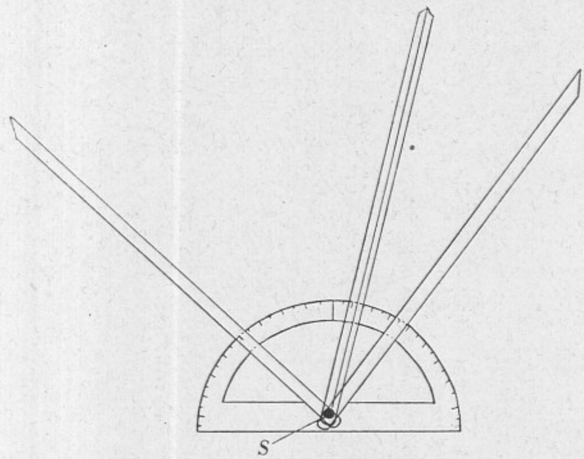
These can be utilized on the justifiable assumption that *Laminaria* beds can be expected to occur in those areas where the charts indicate a rocky or stony bottom to the sea bed and where the depths are not greater than 10 fathoms. A fringe of weed will occur around most of the rocky shores of Great Britain, but there are only a few localities where the beach extends seaward as a shallow rocky shelf. These places can be detected readily on an Admiralty Chart, but it must not be regarded as a foregone conclusion that extensive weed beds will be found in such positions. In one area that we encountered, where from a study of the chart one would have expected to find an extensive bed, much of the area proved on survey to be bare (Text-fig. 2).

Detailed Survey

As a result of the preliminary work detailed surveys were carried out in certain places. These areas varied in size but usually they did not involve more than about 50 miles of coastline. The time taken over such a survey depended very largely upon the weather conditions and ranged from 14 to 28 days. During these detailed surveys the whole of the shore was covered on foot, and on these excursions every opportunity was taken to secure additional information by the means already outlined. Apart from these excursions, however, new methods were employed in order to render the survey as accurate as possible. At the termination of each detailed survey the outlines of the beds were plotted on 6 in. maps or on large-scale Admiralty Charts. It is not suggested that these outlines have the accuracy of a 6 in. Ordnance Survey map, but it is believed that they are as accurate as the methods employed permit. It would probably be possible to improve upon the accuracy of the mapping if the services of a deep-sea diver were available. For the immediate purpose, however, our methods proved adequate. Maps on a smaller scale are not satisfactory as they do not provide enough landmarks for plotting the readings of the box sextant.

Boat, Grapnel and Box Sextant

At selected spots the engine of the boat is put into neutral and the grapnel thrown overboard. When it reaches bottom a series of sharp tugs on the rope soon shows whether weed is present or not, although *L. saccharina* may not make itself felt immediately. Large stems of *L. cloustoni* are sometimes strong enough to anchor the boat unless it has a powerful engine. During the operations if no weed appeared to be present slow speed ahead was ordered: careful watch has to be exercised when going ahead, because should the grapnel catch on a rock it is essential to put the engine into reverse at once otherwise the rope or an arm of the grapnel may break. The bending of an arm may occur in such cases, and if this happens too frequently the arm eventually breaks, because after each mishap it requires to be hammered back into position, if the grapnel is to remain 100% efficient. The life of the grapnel can be extended if the arms are not hammered back whilst cold, though unless spare grapnels are carried on the boat this treatment may become necessary. At the same time as the grapnel is lowered the position of the boat is established by using a box sextant to obtain the angle values between at least three points on the shore, preferably four or five. These readings have to be obtained as quickly as possible so as to discount the forward motion of the boat. It is also important that the selected points should be easily identifiable on the maps. The position of the boat is subsequently plotted on the map using the home-made station pointer[1] shown in Text-fig. 3. By means oft he screw the arms are fixed at the angles recorded for the shore points *A*, *B* and *C*; the instrument



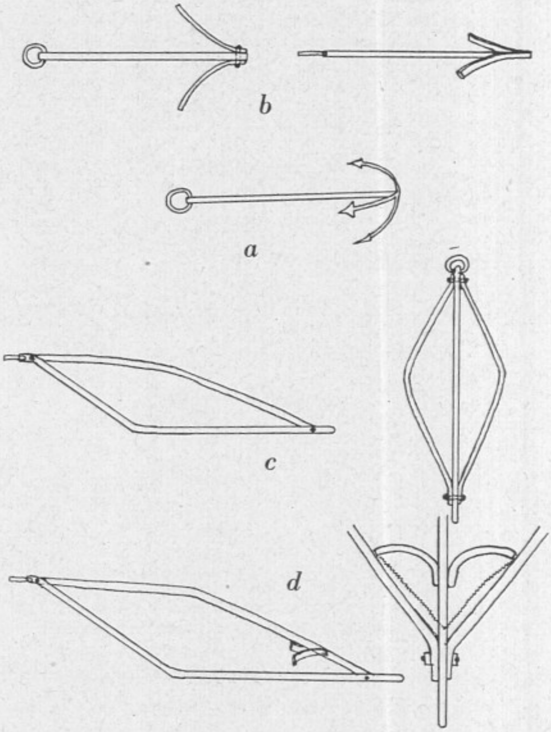
Text-fig. 3. Station-pointer used for plotting box-sextant readings. *S* is the screw retaining the three arms. The whole was made of celluloid.

is laid on the map and then gently moved about until the three arms each lie over the points to which they relate. The position of the boat is then given by the common axis of all the arms (i.e. the screw). With a little practice this method is extremely quick and accurate.

During the course of the survey we experimented with various types of grapnel which are all illustrated in Text-fig. 4. Type *a* is not satisfactory because the slippery nature of the blades and stipes of *Laminaria* makes them tend to slide over the prongs. Occasionally a small piece of frond can be brought up, but this grapnel is not sufficiently reliable for accurate surveying. Type *b* is quite good in operation so long as it is made of strong material. Most of our grapnels of this type were constructed by blacksmiths who used bars of shoeing iron, but this material is not really strong enough. The best specimen, which undoubtedly became increasingly heavy to haul in as the

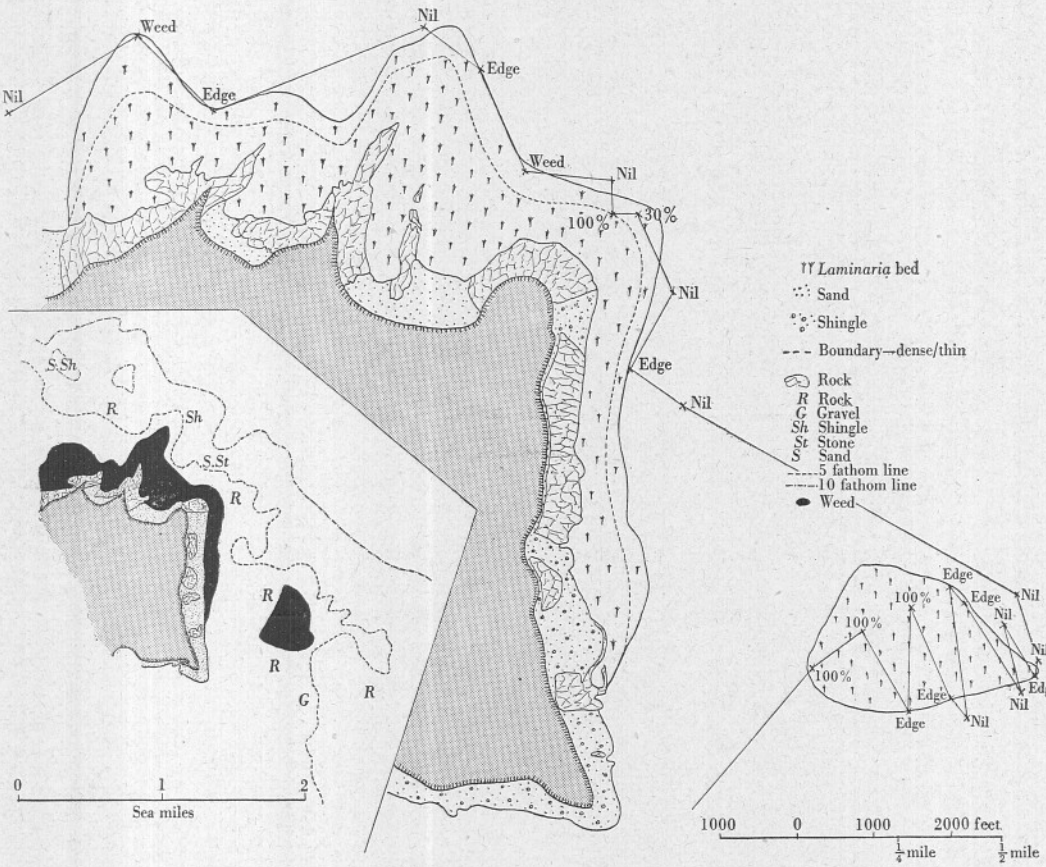
[1] Professional surveyors employ more elaborate instruments.

day progressed but which nevertheless possessed the longest life, had a main stem of iron $\frac{3}{4}$ in. square, whilst the two arms were of bar iron $\frac{3}{4}$ in. wide by $\frac{1}{4}$ in. thick. It is important that the arms forming the arrows should be both bolted on and welded. Bolting or welding alone did not seem to be so efficient. The two arms should be attached at an acute angle to the stem because then the stipes and fronds quickly become wedged in the crook and the grapnel need only be lowered for a short period. This type of grapnel does not always lie



Text-fig. 4. Different types of grapnel used for surveying seaweed beds.

properly on the bottom and it also tends to catch if the rock surface is irregular. Type *c* was therefore evolved in order to overcome this difficulty and it proved highly successful. Type *d* incorporated some minor modifications, and, whilst opinions were divided as to whether it was really more efficient than its predecessor, I believe that it probably represents the best solution for this type of work. The bottom side bars were made of rather heavier material than the middle upper bar in order to ensure that they reached the bottom first. The sloping portion was intended to promote the passage of the grapnel over irregularities of the sea bed. An extra notch was welded on in order to trap the *Laminaria* stipes, and two saws, which were intended to cut the stipes and so provide almost complete plants, were fixed across the bottom. One of our aims was to secure a complete specimen at each haul so that it could be weighed and a closer approximation thus made to the total tonnage of the bed.

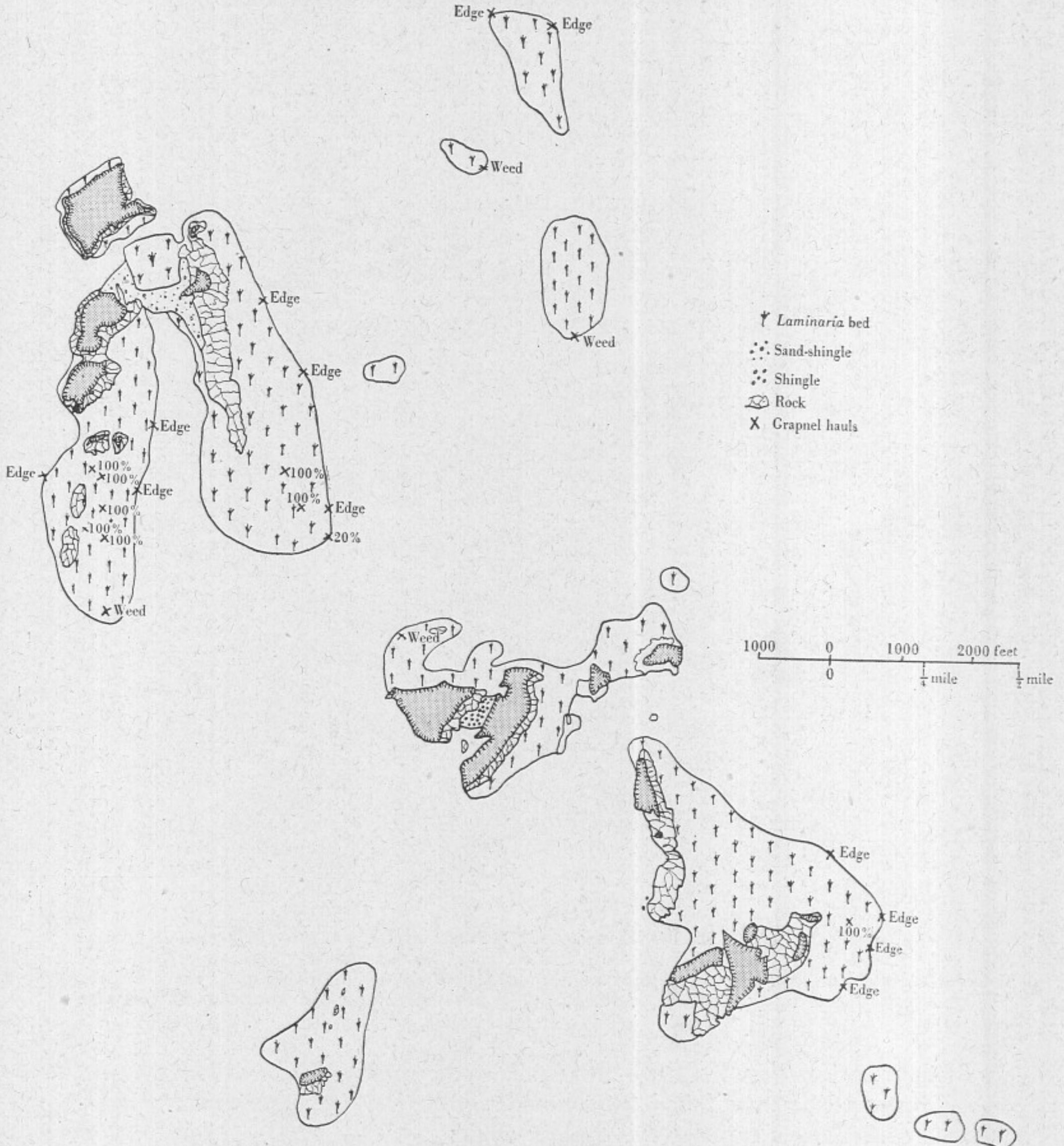


Text-fig. 5. Map illustrating how the use of a boat and grapnel can provide a plan of a weed bed. Additional assistance is also obtained from the Admiralty Chart (inset) where it was evident that the outer limit of the weed bed closely followed the 3-fathom line. (Reproduced by permission of H.M. Stationery Office and the Hydrographer of the Navy.)

Many and various were the boats that were employed on this survey, and as a result of our experience, the following points may be suggested as important in selecting a boat for this type of work:

(1) The boat must be seaworthy and of stout build. The stern is the most suitable place for conducting the grapnel operations and it should have a low free-board. A small mechanically driven winch in this part of the ship materially lightens the arduous labours of the man with the grapnel.

(2) The boat should be about 30–40 ft. long so that there is easy communication between the skipper and the man with the grapnel.



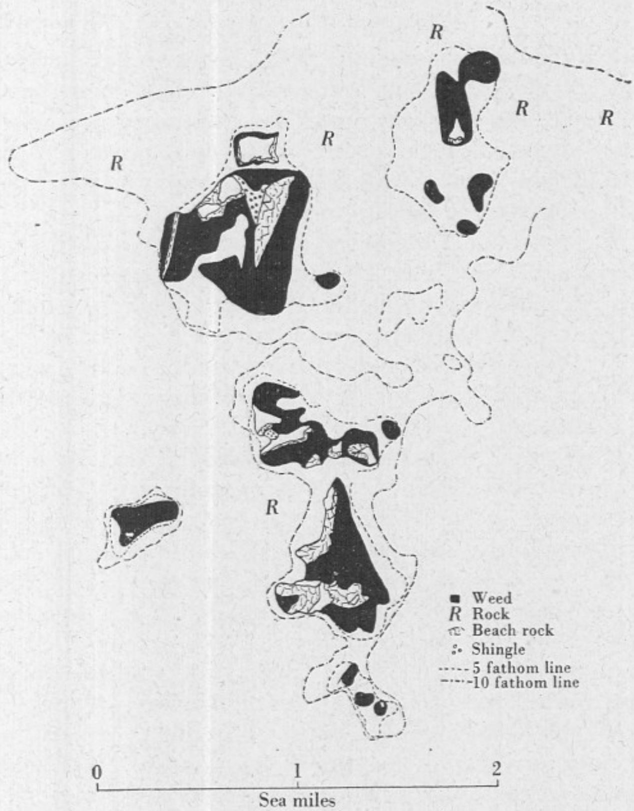
Text-fig. 6. Map illustrating how a difficult area can be surveyed using relatively few observations. (Reproduced by permission of H.M. Stationery Office.)

(3) The engine should be capable of idling for some time in neutral without stopping. It should also possess a reverse.

(4) The engine must be powerful. A 30 h.p. engine is desirable though a 20 h.p. will do in an emergency. Great speed is not an essential, but the boat should be capable of going for a long time at slow speeds.

(5) A shallow draught is an obvious requisite; it should never exceed 7 ft. and preferably should not be more than 5 ft.

(6) The boat must be very manœuvrable, as much of the work may have to be carried out close inshore.



Text-fig. 7. Admiralty Chart of the same area as Text-fig. 6 illustrating how the outer limits of the bed approximate to the 3-fathom line and hence enable the outline to be plotted. (Reproduced by permission of the Hydrographer of the Navy.)

The usual practice when surveying solely by grapnel was to traverse the area of the bed systematically unless the bed was very large; then the outer edge would be traversed systematically and additional hauls subsequently made in the centre and near the shore in order to establish percentage cover. An example of the use of this method is shown in Text-fig. 5. Text-figs. 6 and 7 illustrate the type of result that can be obtained by combining a study of an Admiralty Chart with the grapnel records. This island group was not an easy area in which to operate, but sufficient hauls on the grapnel were obtained in order to determine the average depths to which heavy weed cover descended, and the remainder of the area was then plotted from the fathom lines on the charts. Substantial confirmation of the total result was obtained by cruising around all the islands, and as the day selected was fortunately very favourable the beds showed up to an observer on the deck of the boat and some further additional positions were fixed.

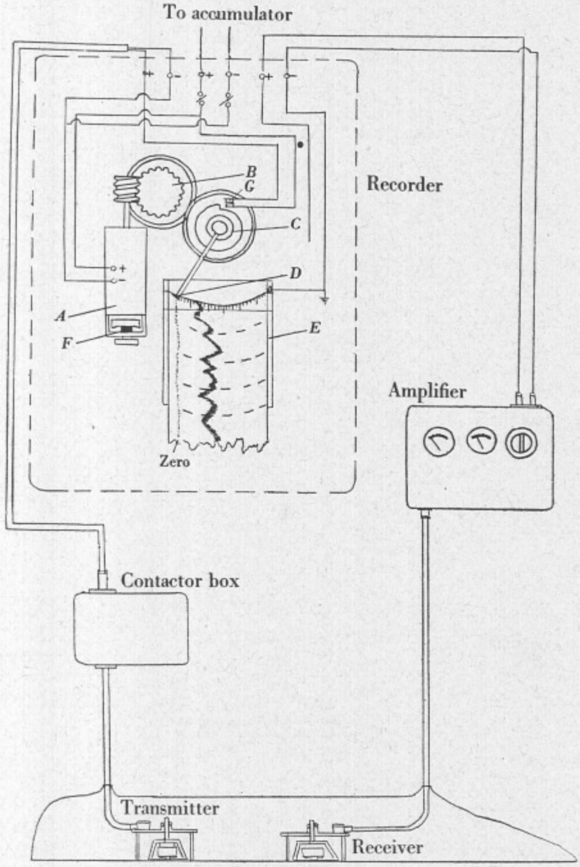
Boat and Echo-sounder

It was known that an echo-sounder fitted into a small boat had been used with great success for surveying the bottom of Lake Windermere. In the course of the Lake Survey it was noted that the presence of submerged lake weeds could be detected on the charts, and it was considered that plants of *Laminaria* would also leave a special mark on the charts so that an echo-sounder could profitably be used to indicate the beds.

The type of echo-sounder employed was the portable M.S. 12 designed by Messrs Henry Hughes and Son. The essence of the apparatus is the sending out of a short pulse of sound (which in fact is audible to the human ear) that is reflected from the sea bottom and on its return is picked up by a receiving system with an amplifier. The time required for the sound wave to travel to and from the bottom of the sea is presented by the machine in the form of a depth measurement.

The general lay-out of the apparatus is depicted in Text-fig. 8. The cam (*C*) with the stylus arm (*D*) is driven through a gear train by the electric motor (*A*). The necessary power in our apparatus was provided by a 12-volt car accumulator. It is desirable to have two of these, and in order to secure the best results the one that has been used should be recharged at the end of a day's working and the spare employed the following day. Each time the stylus arm revolves it passes over the surface of the specially prepared recording paper, a roll of which is fixed in a tank (*E*), a single roll sufficing for two or three days' intensive work. Once in every revolution the cam (*C*) operates the transmitting contacts (*G*) which cause a pulse of sound to be sent out from the transmitter. At approximately the same instant that the pulse of sound is sent out the stylus passes the zero of the scale and leaves a mark on the paper. The recording paper is treated chemically, so that when a current passes through the paper from the stylus to the plate (*E*) forming the front of the tank containing the recording roll, a brown mark is made. If a steady current is passing the stylus will leave a brown mark right across the paper, but if only a short pulse passes at a definite point during the passage of the stylus, the mark will only appear at that position.

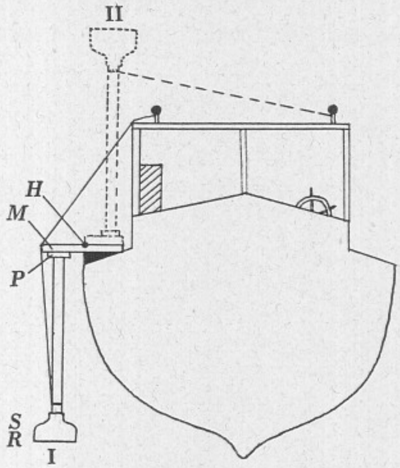
The zero mark is made by the transmitting pulse and the amplified echo is made to supply a short pulse of current at the moment of its arrival. As the boat travels into deeper water the stylus moves farther across the paper before the echo is received. All the time the paper is moving slowly vertically downwards (at right angles to the movement of the stylus), so that with each passage of the stylus the successive echoes form a contour of the sea bed. The chart is calibrated in feet or fathoms, and by varying the rate of the stylus different scales can be produced. Our apparatus was fitted with both a shallow and a deep scale, but as we were usually operating in waters of less



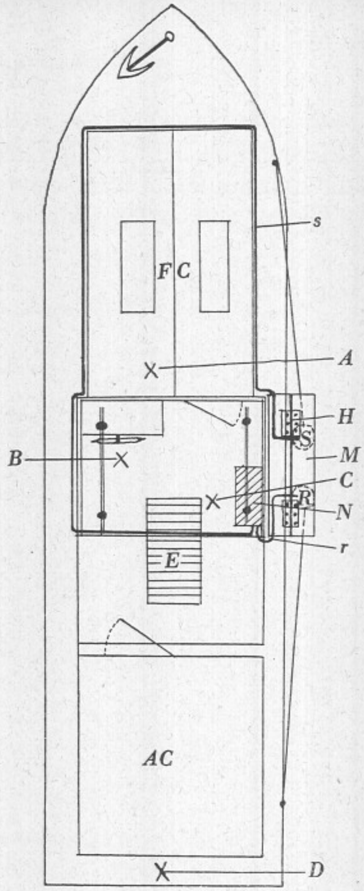
Text-fig. 8. Lay-out of echo-sounding apparatus. *A*, electric motor; *B*, interlocking wheels; *C*, driving cam; *D*, recording arm; *E*, front plate of paper tank; *F*, governor; *G*, contacts. (Reproduced by permission of Messrs Hughes and Son.)

than 10 fathoms we did not have occasion to use the deep scale. Whatever the scale it is essential that the speed be kept constant, and so the apparatus is fitted with an automatic governor (*F*).

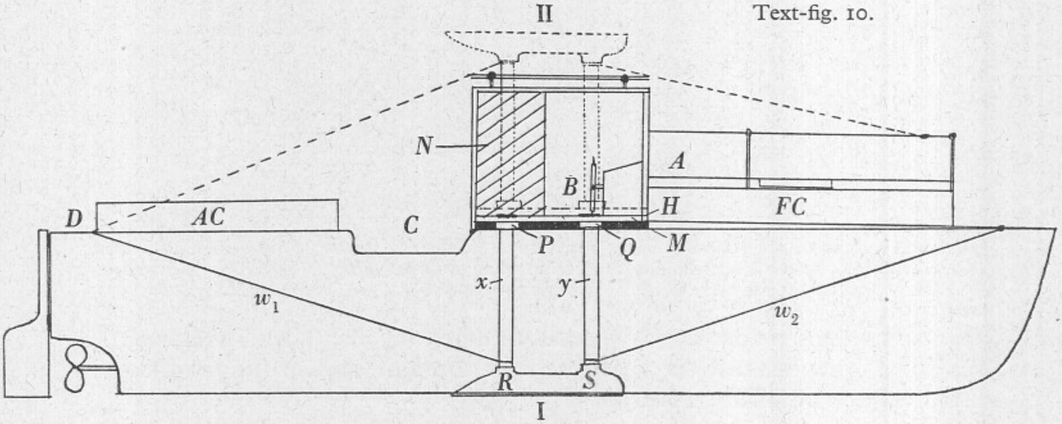
The lay-out of the equipment in the best type of boat for this work is seen in Text-figs. 9–11. The sending and receiving apparatus was contained in a streamlined torpedo-like structure (*SR*), the transmitting portion (*S*) being situated in front of the receiving portion (*R*). This structure was attached by two pipes (*x*) and (*y*) to flanges (*P*) and (*Q*) which were fastened to some stout



Text-fig. 9.



Text-fig. 10.



Text-fig. 11.

Text-fig. 9. Bow view of boat fitted with echo-sounder.

Text-fig. 10. Plan of boat fitted with echo-sounder.

Text-fig. 11. Elevation of a boat fitted with echo-sounding equipment.

I, working position; II, travelling position. *A*, man with box sextant; *B*, skipper; *C*, senior surveyor; *D*, man with grapnel; *E*, engine; *H*, hinge; *M*, plank carrying outboard equipment; *N*, recorder and amplifier; *P*, *Q*, flanges; *R*, receiver; *r*, lead to receiver; *S*, transmitter; *s*, lead to transmitter; w_1, w_2, stay wires; *x*, *y*, piping; *AC*, aft cabin; *FC*, fore cabin.

planking (*M*). This in turn was part of a superstructure firmly bolted to the boat. The outer part of this superstructure was hinged at *H* so that it could be hauled up by the stay wires (w_1 and w_2) into position II when the boat was travelling at speed to reach the working ground. It requires at least two, preferably three, men to haul the apparatus from position I to position II. When the apparatus is down in the working position I a maximum speed of 2–3 knots is the most that is desirable. At higher speeds the outboard part 'shudders', and a great strain is placed upon the superstructure. The recording part of the apparatus and the amplifier were bolted to a strong board which fitted over the side window of the deck cabin because it is important that these two parts should be protected from spray. The accumulator in use was kept on the floor beneath. It is important to keep the leads to the transmitter and receiver as widely separated as possible and so lead (*r*) from the receiver went direct to the recorder, whilst the other (*s*) to the transmitter travelled on deck round the bows of the boat.

For surveying purposes it is desirable to have a complement of five, though the work can be carried out with only four. Under normal conditions the skipper was stationed at *B* and was responsible for steering the boat and controlling the engines. The senior member of the party (in most cases the present author) was stationed at *C* and was responsible for looking after the recording machine, making notes on the record as it appeared, telling the skipper when to change course and where to go, and, by studying the record as it was produced, determining the points where grapnel hauls should be made in order to obtain confirmatory evidence. Each time the course was changed or a haul carried out the man at *C* notified another member, stationed at *A*, who was responsible for fixing the position of the boat by taking a box-sextant reading (cf. p. 43). The third member of the party was stationed at *D* and was in charge of the grapnel. If only two members of the party were out the senior man also made the readings with the box sextant because attending to the grapnel is a whole-time job. The boat also carried an engine-man-cook who occasionally gave some help with the grapnel. The success or otherwise of the echo-sounder depends very largely upon the degree of interpretation which can be given on the spot by the leader together with his estimate of the most profitable course for the boat to take. Upon his skill in interpretation also depends the number of confirmatory grapnel hauls that are necessary. It was found that in each new area to be surveyed it was a good plan to have a number of grapnel hauls during the first day and that fewer and fewer were then required on subsequent days. As we were generally relying upon another method (cf. p. 54) for plotting the shallow in-shore portions of the beds the usual practice was to locate the outer edge of the bed and then to follow it up or down the coast by 'criss-crossing' it at intervals.

It is important to be able to recognize the differences produced in the type of record by variations in the sea bottom because the echo from the weed beds will be superimposed upon that from the sea bottom.

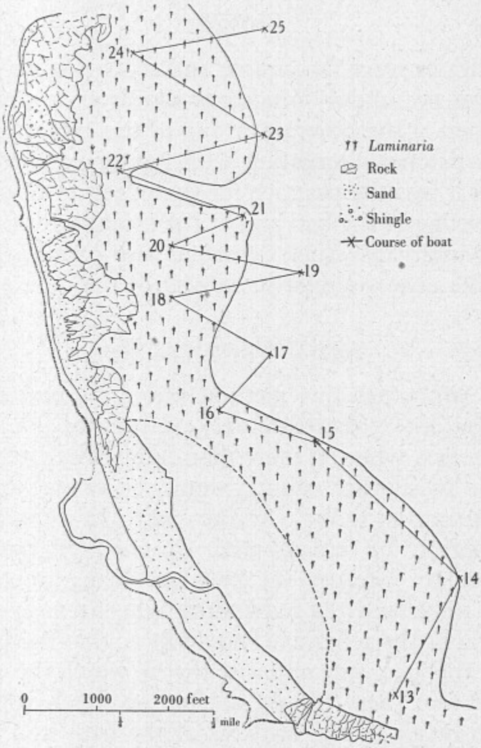
(*a*) *Sand*. Pl. I, fig. 1, represents part of a record from a bare sand or shingle area. It is not always possible to distinguish between a sand or shingle bottom on a record.

(*b*) *Rock*. Pl. I, fig. 2, illustrates rock bottom at 40 ft. where there was no weed, and it is interesting to note the extremely jagged nature of the bottom: some idea of scale is given by the fact that the distance traversed between marks 6 and 7 was 1250 ft. Pl. II, fig. 1, is a good example showing the transition from a weed bed to a bare sand area. It will be observed from these figures that the *Laminaria* appears as a slightly denser band superimposed upon the lighter record of the bottom, and that the individual plants are represented on the record as thin spikes. The thin spiky record is characteristic of *L. cloustoni* beds and each spike probably represents a single plant. The vertical width of the dense band is an indication of the height of the plants, in this case about 3–4 ft. The irregular spiky record of the bed should be compared with the smooth record obtained from the adjoining sandy bottom.

(*c*) *Boulders*. Pl. II, fig. 2, illustrates the transition from a weed bed to a practically bare patch of boulders. The large sharp irregular peaks of the *Laminaria* bed are evident on the left and the shorter and stouter peaks of the boulders on the right. The great irregularity of the peaks produced by a *L. cloustoni* bed is presumably partly due to the plants being attached at various levels on the boulders or rock and partly because they vary themselves greatly in height. Records of what were probably isolated plants are specially marked on the record. It will be noted that in this type of record, where the plants are growing on boulders, the deeper 'fuzz' obtained when they grow on a rocky bottom is not produced.

In addition to recognizing the various types of bottom a marked effect is also obtained on the chart when there is too much wave action, and for this reason we did not survey with the echo-sounder unless the sea was moderately calm. An example of the type of record produced by excessive wave action is seen in Pl. III, fig. 1, and although at first sight the record has the appearance of a *Laminaria* bed it differs from it in that the peaks are more regular in height and spacing. Soon after this record was made the boat passed over a *Laminaria* bed and the difference in the type of record can be noticed. Rolling, however, is not readily distinguishable from a boulder bottom on a chart, and hence if it is desired to have some indication of the sea floor a calm day is essential. Excessive irregular rolling would also make it very difficult to distinguish a *Laminaria* bed.

So far we have only been concerned with records of *L. cloustoni* beds which produce characteristic irregular sharp peaks. *L. digitata* normally grows too close to the shore to make it safe to venture so near, but we obtained some evidence at one place which indicated that this species gave the same type of record. The specimen chart has unfortunately faded to such an extent that it will not reproduce satisfactorily. The habit of the *L. digitata* plants would in any case lead one to expect that they would give the same type of record as plants of *L. cloustoni*. Beds of *L. saccharina* were also encountered, and it was soon evident that their method of growth, with the frond lying extended along the sea bed, was not such as to give a reliable indication with the echo-sounder. The apparatus cannot therefore be used with any degree of certainty to detect this particular species. Pl. III, fig. 2, illustrates the type of record obtained



Text-fig. 12. Map illustrating the plotting of the record shown in Pl. III, fig. 3, on to the relevant 6 in. O.S. map. The numbered points correspond to the numbered lines on the record. (Reproduced by permission of H.M. Stationery Office.)

over a bed of *L. saccharina*, and although it shows some slight irregularities as compared with bare ground nevertheless these might well be taken for large stones. There is no dark 'fuzz' in the case of a bed of this species.

Text-fig. 12 illustrates the method of plotting the records on to a map, the relevant record being shown in Pl. III, fig. 3, and the plotted map in Text-fig. 12. These two should be compared carefully. The point on the chart where the record changes from bare ground to weed bed or vice versa between two stations is estimated by eye. Variations in the speed of the boat made it very difficult to be more accurate, but it is not believed that any appreciable error is involved.

View-box and Sextant

Sometimes it was found convenient to use a view-box in order to see if weed was present; it was, however, employed more often to ascertain the density of the cover. In such cases it was always worth while to take a reading with the box sextant in order to establish the position of the boat.

Visibility

If the sun conditions were favourable and work was proceeding in an area where the water was not unduly muddy or too deep, it was often possible for an observer stationed at the bows or on top of the cabin to see the *Laminaria* beds as deep blue patches alternating with lighter patches of sandy bottom. On such occasions it was the practice for the observer to direct the course of the boat along the edge of the bed and at the same time to take readings with the box sextant at intervals. Such occasions also proved useful for checking the behaviour of the echo-sounder in respect of the type of record.

Aerial Photography

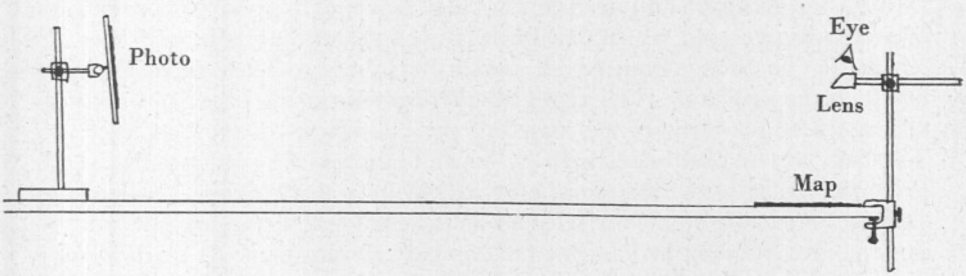
Owing to certain difficulties this method was not employed until relatively late in the investigation. It therefore only proved possible to use it in certain of the detailed surveys, where it more than fulfilled expectations. Any future preliminary survey in another country could be carried out most profitably and in the shortest time by flying over the coast. In using aerial photography certain points require to be remembered. In northern waters it is important to have bright sunlight because the beds are being photographed through varying depths of water and the maximum light intensity is essential. When taking the photographs the aeroplane should fly so that the sun is either behind or, even better, on the wing side opposite that to which the camera is attached. It is also desirable that there should not be too much wind because ripples and waves tend to break up the outlines of the beds and also there is more reflexion of light from a broken than from a calm sea. A small amount of wave action, however, is not unduly deleterious. It may not be possible to secure good photographs the day after an on-shore gale because the water is often muddy with torn-up weed. The best altitudes for securing the most satisfactory results range from 1500 to 2000 ft., although the number of photographs required at such altitudes are considerable. Quite satisfactory results can be obtained up to 4000 ft., but the degree of accuracy in the plotting decreases at altitudes above 2000 ft. In securing the photographs it is important to use an aeroplane type in which there is ready intercommunication between pilot, observer and photographer.

Two types of photograph may be secured:

(*a*) *Obliques*. Experience proved that the beds showed up best in this type of photograph (cf. Pl. IV, fig. 1), but they take somewhat longer to plot.

(*b*) *Verticals*. This type includes near verticals where the angle of deviation is not more than 5°. The beds do not always show up so well, and the depth limit to which they can be detected is apparently less than with obliques. This type of photograph, however, is very easy to plot (cf. Pl. IV, fig. 2).

Successful interpretation of the photographs depends upon a sharp line of distinction between the seaweed bed and the surrounding bare area. The best contrast is provided if the adjoining bare areas are sandy: if the sea bottom is rocky throughout but only a portion of the rocks is covered with *Laminaria* it is more difficult to interpret the photographs. It may be argued that one is really photographing the rocks rather than the beds of weed, but this is not so, because even with partially populated rocks a definite deepening in colour can be seen where a bed exists. The outline of a bed becomes sharper the shallower the water, but under good conditions a bed can be observed to a



Text-fig. 13. Apparatus for plotting verticals and near verticals. The photograph is affixed to a board on a ball bearing. The board can then be adjusted so as to compensate for any small angle of tilt.

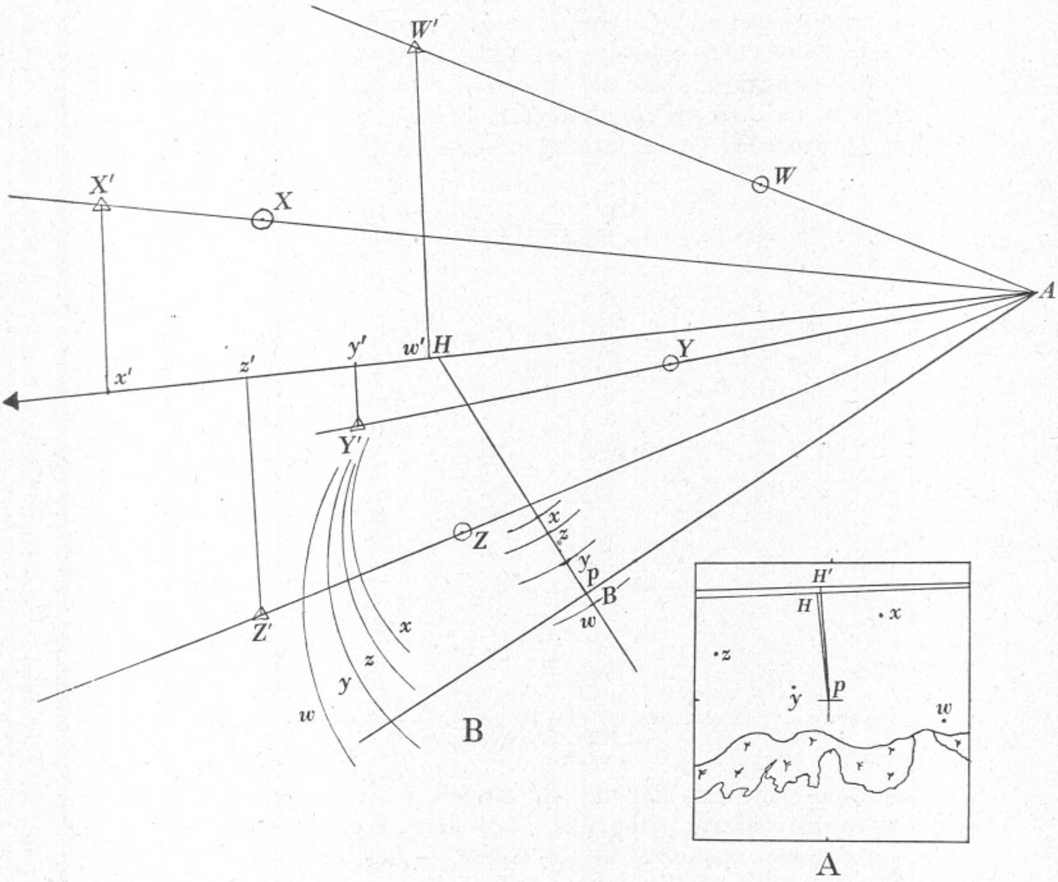
depth of 5 or 6 fathoms. Confirmatory proof of the existence of these beds was obtained by the use of the echo-sounder and the grapnel. Cloud shadows can be mistaken for beds of weed unless great care is taken: the beds of weed can be distinguished by virtue of the sharper outline. It is desirable, however, to take photographs on cloudless days.

Vertical photographs with an angle of tilt less than 5° can be plotted by means of a simple prism and mirror apparatus. The photograph is attached to a board (Text-fig. 13) which can swivel on a ball-bearing in any direction. By this means adjustments can be made which will compensate for any small angle of tilt. Four fixed and easily identifiable points are selected and marked on the photograph and the same points are marked on the relevant map. The map is then placed in position vertically beneath the eyepiece. On looking through the eyepiece the photograph is seen superimposed upon the map. The marked points of the photograph may be made to coincide with the corresponding ones on the map by moving the board nearer to or farther from the eyepiece. If the fit is not quite perfect it can usually be made so by slightly tilting the board one way or another. The distance of both map and photo from the eyepiece can also be pre-calculated from the ratio

$$\frac{\text{Distance apart of two points } AB \text{ on photo (in.)}}{\text{Distance apart of two points } AB \text{ on map (in.)}} = \frac{\text{Distance of photo from lens}}{\text{Distance of map from lens}}.$$

When the points on the photograph coincide with the same points on the map the outline of the beds can be drawn in directly on to the map. Recognition of the beds is materially assisted if they are outlined beforehand in white ink on the photograph. It is also important to select four identification points which are well scattered over the photographs and not confined to any one part.

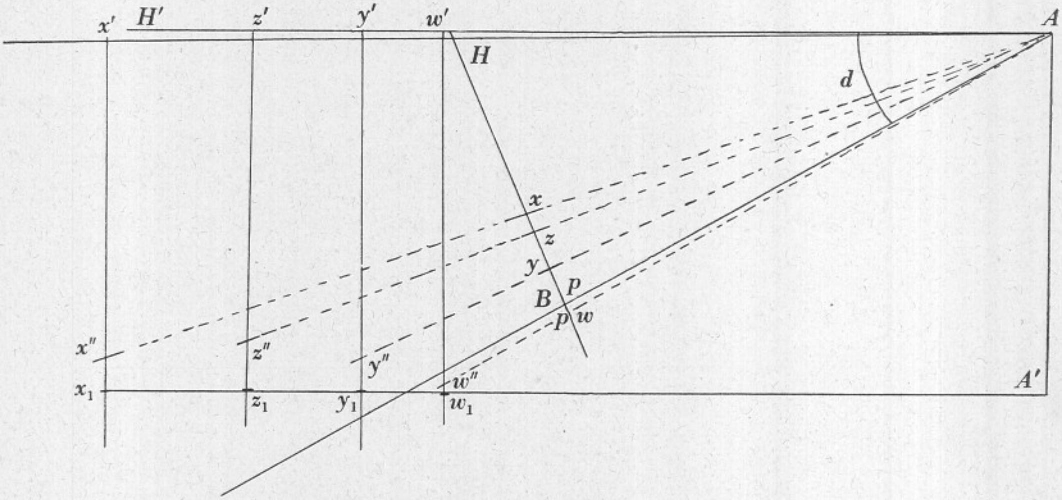
The oblique photographs were plotted by means of a geometrical construction which is Trorey's modification of Cohn's described in any text-book on photogrammetry. Without discussing the principles involved it is perhaps worth while giving an outline of this method. It depends upon the construction of a perspective grid which can be laid over the photograph, and then the outline of the beds is transferred square by square to a corresponding grid based on the map scale. The map grid is drawn on tracing paper so that it can ultimately be placed over the map and the boundaries of the bed traced in. The beds are first outlined carefully in white ink on the photograph and the principal centre of the photograph is marked by a circle. Four scattered and easily recognizable points are selected on the photograph and marked, and the same points are identified and marked on the relevant map. If the horizon is visible on the photograph it is marked in by a straight line, but if not the photograph is firmly attached to a sheet of paper and the position of the horizon is estimated and drawn in: this is known as the 'trial' horizon. A perpendicular pH is drawn from the principal point to this trial horizon (Text-fig. 14). A sheet of kodatrace is taken, and on it is drawn a line AB the length of which is equal to the focal length of the camera lens (Text-fig. 14). At B a perpendicular pH is erected equal in length to the line joining the principal point of the photograph to the trial horizon. A, H are joined and produced. With H as centre and with a radius equal in length to a perpendicular from one of the selected points on the photograph to the trial horizon the line pH is cut at x. Then with x as centre and the same radius an arc x is drawn on the side of pH remote from A. This process is then repeated for all the remaining three selected points so that a series of four arcs (w, x, y, z) is obtained. The kodatrace is then laid over the photograph so that the line AH lies over the line pH on the photograph (the line from the principal point to the trial horizon), and the kodatrace is gently moved up until the trial horizon makes a tangent with the first arc w. Whilst in this position a prick (W) is made in the kodatrace at the selected point w in the photograph that corresponds to the arc w resting on the trial horizon. This procedure is repeated for the other three points so that now all four points have been transferred to the kodatrace (W, X, Y, Z). The point A is joined up to each of these points and the lines are produced beyond them. The kodatrace is now removed and placed over the relevant map and moved about until the lines from *A* to the selected points pass over the corresponding points on the map. The point *A* must be on that side of the selected points from which it was evident that the photograph was



Text-fig. 14. A, photograph with principal point *p*, trial horizon *H* and true horizon *H′*. The four selected points are *w*, *x*, *y*, *z*. The *Laminaria* bed is also marked. B, geometrical construction on Kodatrace (cf. text for explanation).

taken. When a fit for at least three lines has been obtained, the four points on the map are pricked on to the kodatrace (*X′*, *Y′*, etc.) and perpendiculars are drawn from these points to the line *AH* produced, e.g. *X′x′*. Although it is of no immediate interest the position of *A* on the map marks the position on the ground immediately beneath the aircraft when the photograph was taken.

A line *AB* is now drawn on a large sheet of paper (Text-fig. 15), equal in length to the line *AB* of the kodatrace. At *B* a perpendicular is erected, equal in length to *pH* on the kodatrace, and *A* is joined to *H* and produced. Along *AH* lengths are marked off equal to the distances on the kodatrace from *A* to the perpendiculars from the selected points (e.g. *Ax′*). Four points on *AH* produced are thus obtained, each one corresponding to one of the four selected points. From these four points perpendiculars are dropped downwards. With *H* as centre the new line *pH* is cut in the same four places as on the kodatrace, using the perpendiculars from the selected points to the trial horizon as radii. These four points on the line *pH* are joined to *A* and produced beyond the line *pH* until they cut the perpendiculars dropped from the four points on the line *AH* produced. Each line will meet a corresponding perpendicular for



Text-fig. 15. Geometrical construction to obtain altitude and angle of dip (cf. text for explanation).

the same selected point, and the spot where each is cut marks the vertical elevation of that selected point (e.g. *x″*). Reference is now made to the map and a correction is applied to all the points for height above sea-level, thus lowering them all by varying degrees. The map scale is used for this purpose as the figure is automatically constructed on the same scale as the map. The four corrected points (x_1, y_1, etc.) are joined up if they form a straight line and the line is produced towards *A*. A perpendicular *AA′* is drawn from *A* to this ground line and its length on the map scale gives the altitude of the aeroplane. If the ground line is not parallel with the line *AH* a new line *AH′* is drawn from *A* which is parallel with it. This line represents the true horizon and is transferred to the photograph and a new perpendicular is drawn from it to the principal point. The angle *H′Ap* is the angle of dip of the camera lens and is measured. If the four points are not in a straight line their positions can be corrected by means of a correction triangle.

The final stage is the construction of a perspective grid to fit the photograph. One of these grids was made for every 200 ft. in altitude and for every 2° in declination of the camera lens. A family of grids was thus built up on this basis, and once the altitude and angle of dip of any photograph had been determined it was only necessary to look out the relevant grid.

The following procedure is followed in order to construct a perspective grid assuming that the map grid is to have sides 300 ft. long. A line is drawn across the top of a sheet of paper, and from a point A near the centre of the line a perpendicular AH is drawn such that

$$AH = \frac{\text{Altitude in feet}}{\text{Sides of map grid in feet}} \sec d = \frac{\text{Altitude}}{300} \times \sec d \text{ (angle of dip of the camera).}$$

At H another line is drawn at right angles to AH and parallel to the first line with H as centre; this line is divided by points each 1 in. apart. These points are joined by rays to A. Two points v and v' on opposite sides and equidistant from A on the original line are found from the formula

$$Av = Av' = f \sec d,$$

where f = focal length of camera lens. On AH a point P is marked off such that AP is equal to pH' on the photograph to be plotted (i.e. the distance from the principal point to the true horizon established by the previous construction). vP and $v'P$ are joined and produced and horizontals are then drawn using the intersections of vP and $v'P$ with the vertical rays as markers. This produces the perspective grid which is then reproduced on to kodatrace. When a photograph is plotted the point P on the grid is placed over the principal point on the photograph and the line AP adjusted so that it lies over the line joining the principal point to the true horizon. When drawing in the outlines of the bed it is necessary to draw in portions of the coast which can be laid over the corresponding portions on the map; these serve not only to orientate the drawing but also act as a check on the accuracy of the construction. If a mistake had been made in determining the altitude of the plane or angle of dip of the camera an incorrect grid will automatically have been used, and the scale of the beds, as drawn from the grid, will differ from the map scale and the guiding portions of the coastline will not coincide.

Summary

Previous methods of survey by American workers are described and the differences between the species of seaweed involved are emphasized. The small stature of the European kelps renders all methods of survey difficult and the results can only be described as the best approximations. The British survey was divided into (1) a preliminary survey in order to determine the regions with the biggest beds, and (2) a detailed survey, when some of these major

beds were mapped in detail. The primary survey was a rapid affair and the results were based on information obtained from (*a*) use of boat and grapnel, (*b*) existence of cast weed, (*c*) lobster fishermen, (*d*) coastguards, fishery officers, borough surveyors, harbour-masters, (*e*) inspection from cliffs, (*f*) a study of Admiralty Charts.

In the section on the detailed survey the different types of grapnel employed and also the method of using the box sextant are described. The use of an echo-sounder to locate weed beds is discussed and the different types of record obtained over various types of bottom or weed are noted. The use of a view-box and personal observation is also mentioned, and finally an account is given of aerial photography as a means of survey. The most suitable conditions for success are noted and also the technique of interpretation for both oblique and vertical photographs. The plotting of these two types of photograph is described in some detail.

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EXPLANATION OF PLATES I–IV

PLATE I

Fig. 1. Echo-sounding record from bare sand and *L. cloustoni*.

Fig. 2. Echo-sounding record of bare rocks.

PLATE II

Fig. 1. Echo-sounding record showing transition from bare sand to *L. cloustoni* bed.

Fig. 2. Echo-sounding record showing transition from *L. cloustoni* bed to boulders.

PLATE III

Fig. 1. Echo-sounding record showing effect of wave action compared with records from beds of *L. cloustoni* and *L. saccharina*.

Fig. 2. Echo-sounding record from *L. cloustoni* and *L. saccharina* beds.

Fig. 3. Part of the record plotted in Text-fig. 12.

PLATE IV

(Reproduced by permission of the Air Ministry)

Fig. 1. Oblique photograph of a *Laminaria* bed.

Fig. 2. Vertical photograph of the same *Laminaria* bed.

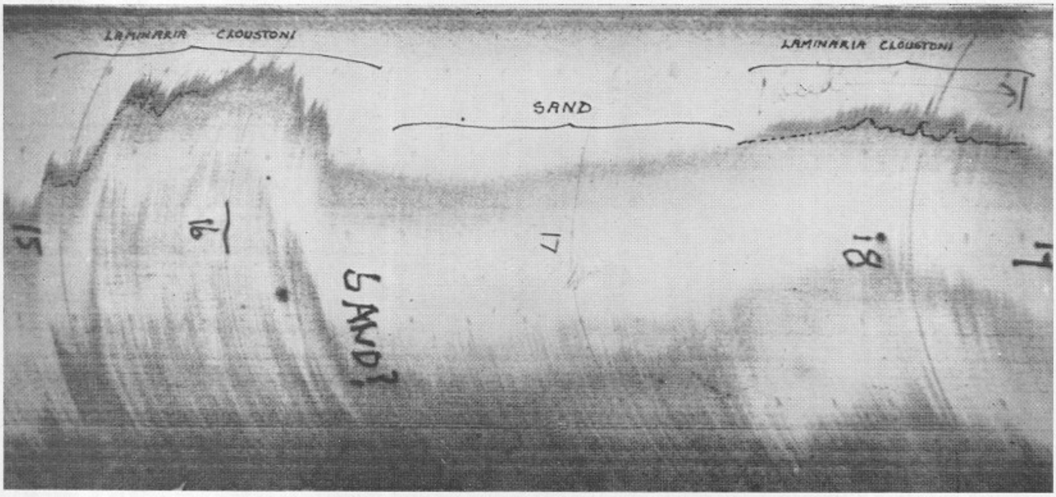

Fig. 1.

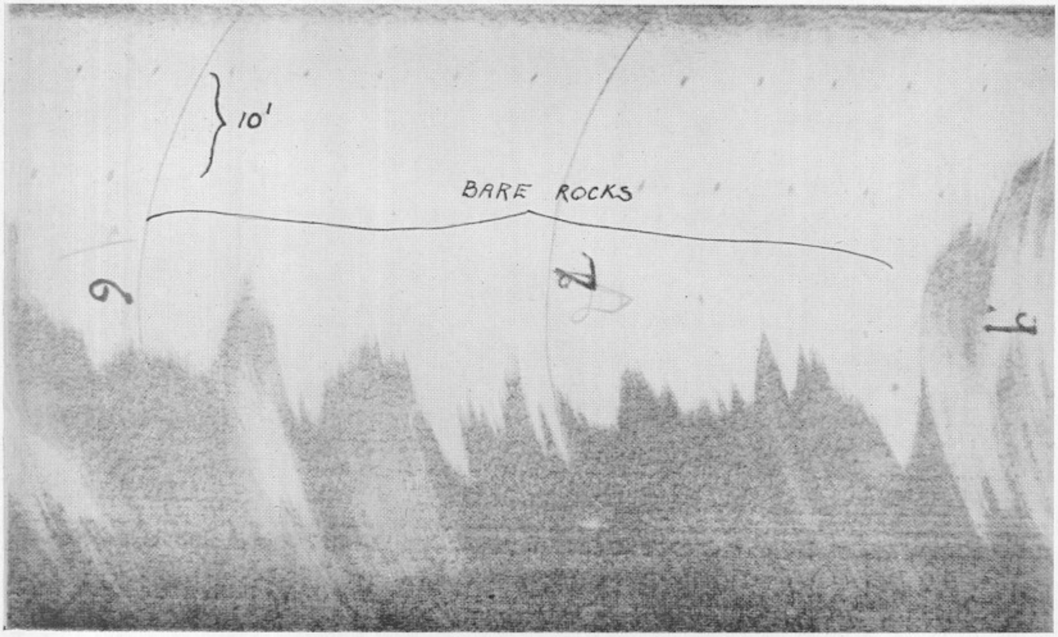

Fig. 2.

Echo-sounding records from *Laminaria* beds.

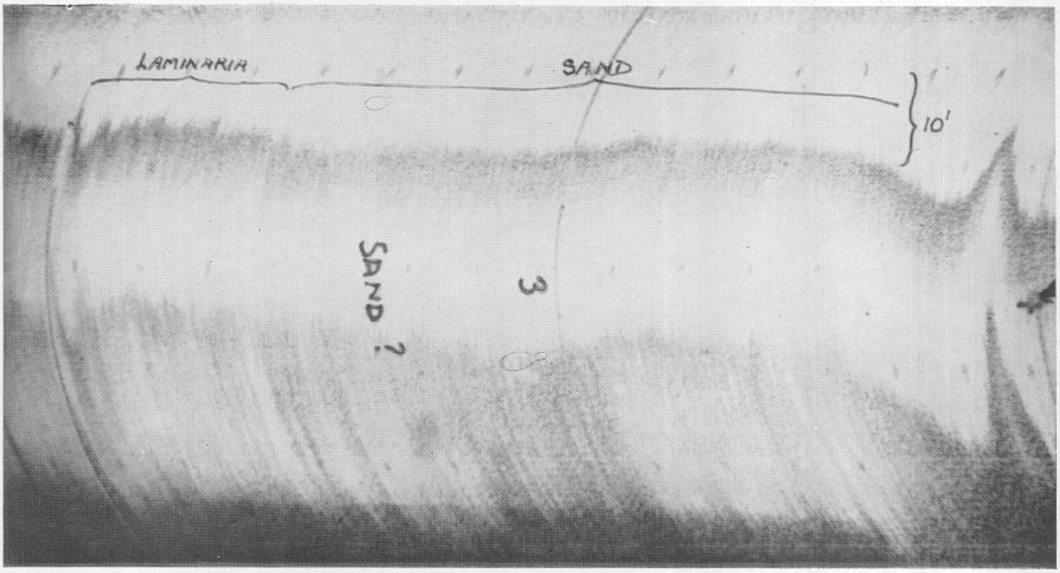

Fig. 1

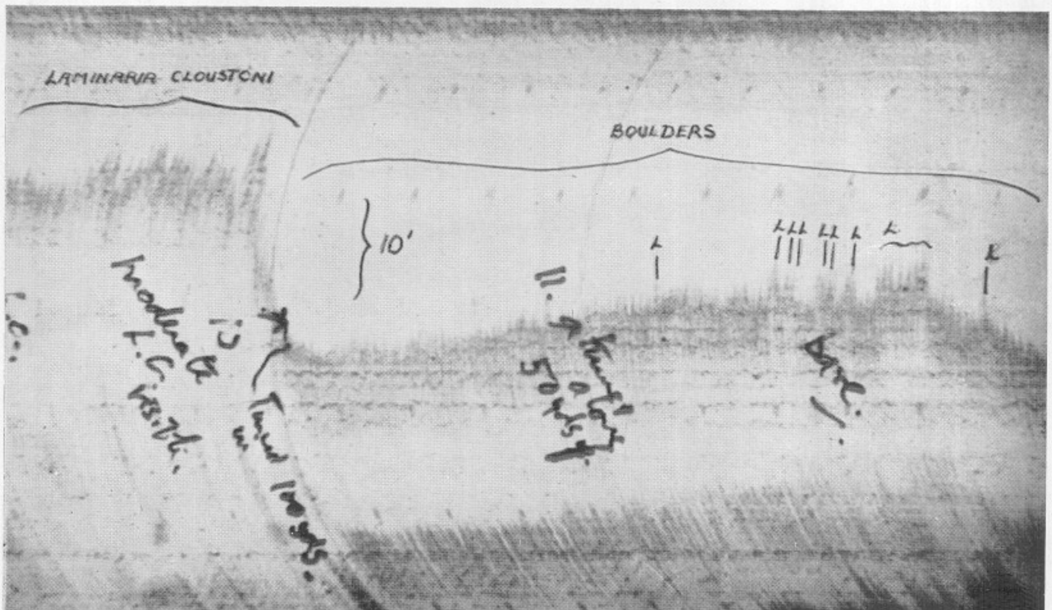

Fig. 2.

Echo-sounding records from *Laminaria* beds.

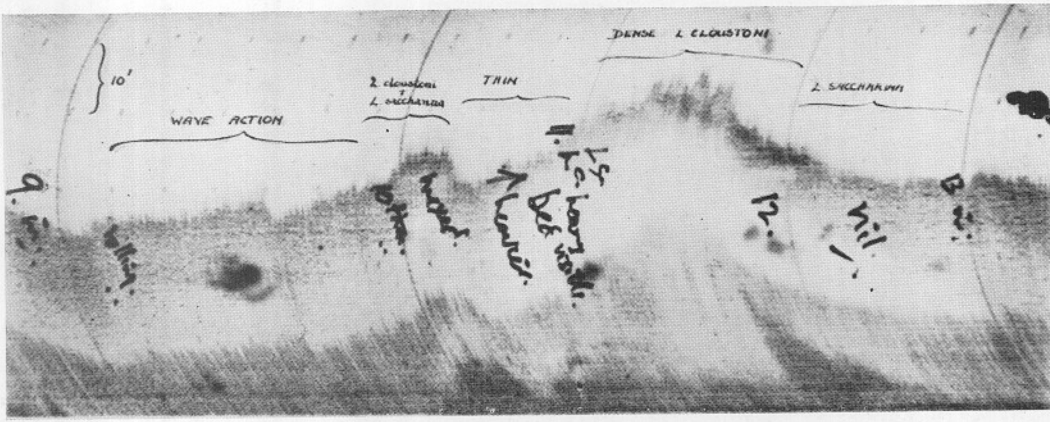

Fig. 1.

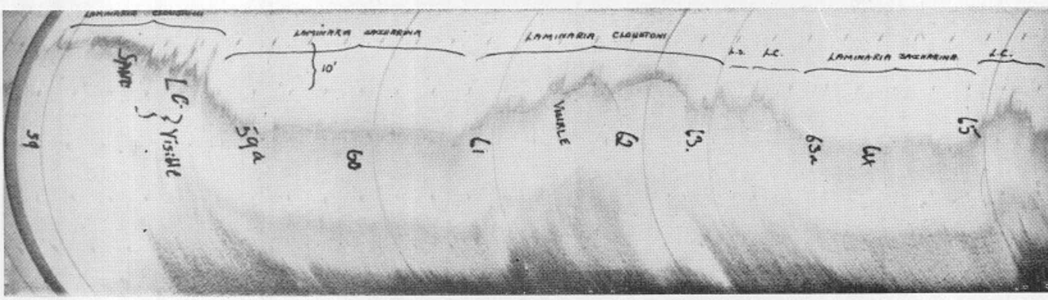

Fig. 2.

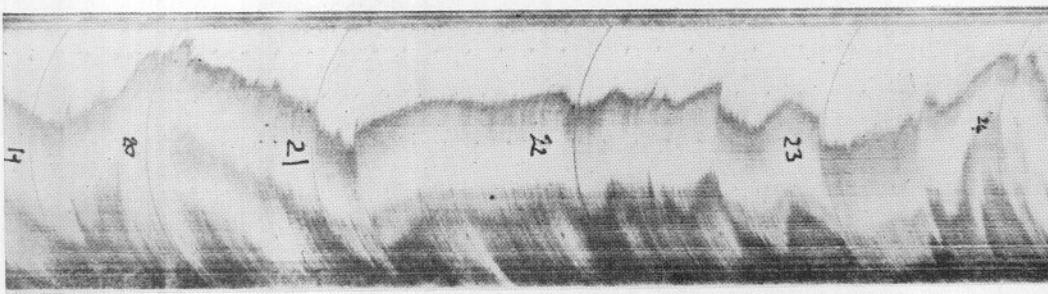

Fig. 3.

Echo-sounding records from *Laminaria* beds.

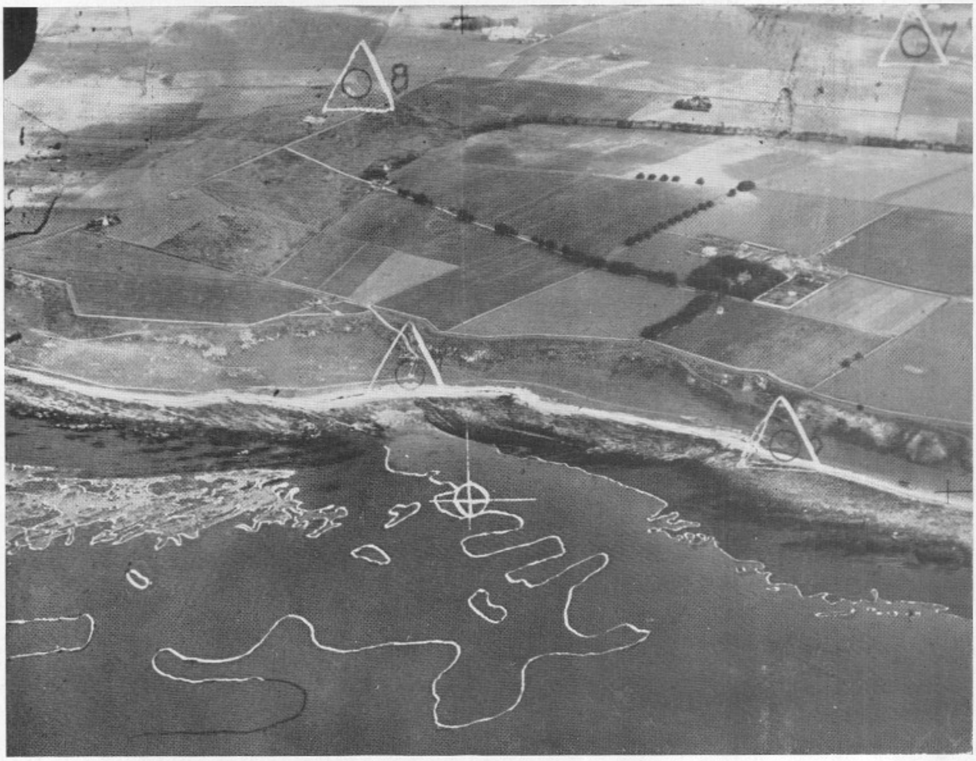

Fig. 1.

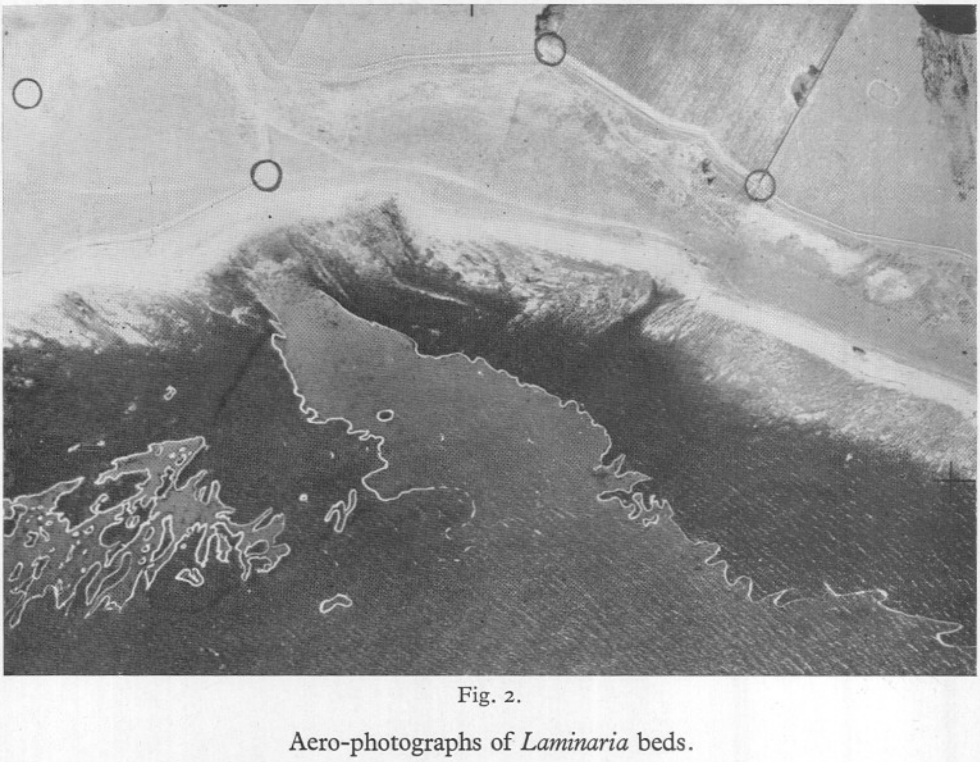

Fig. 2.

Aero-photographs of *Laminaria* beds.