NEW ZEALAND MARINE DEPARTMENT
FISHERIES BULLETIN No. 11

M. W. Young

The Escapement of Small Fish from Trawl Nets

and

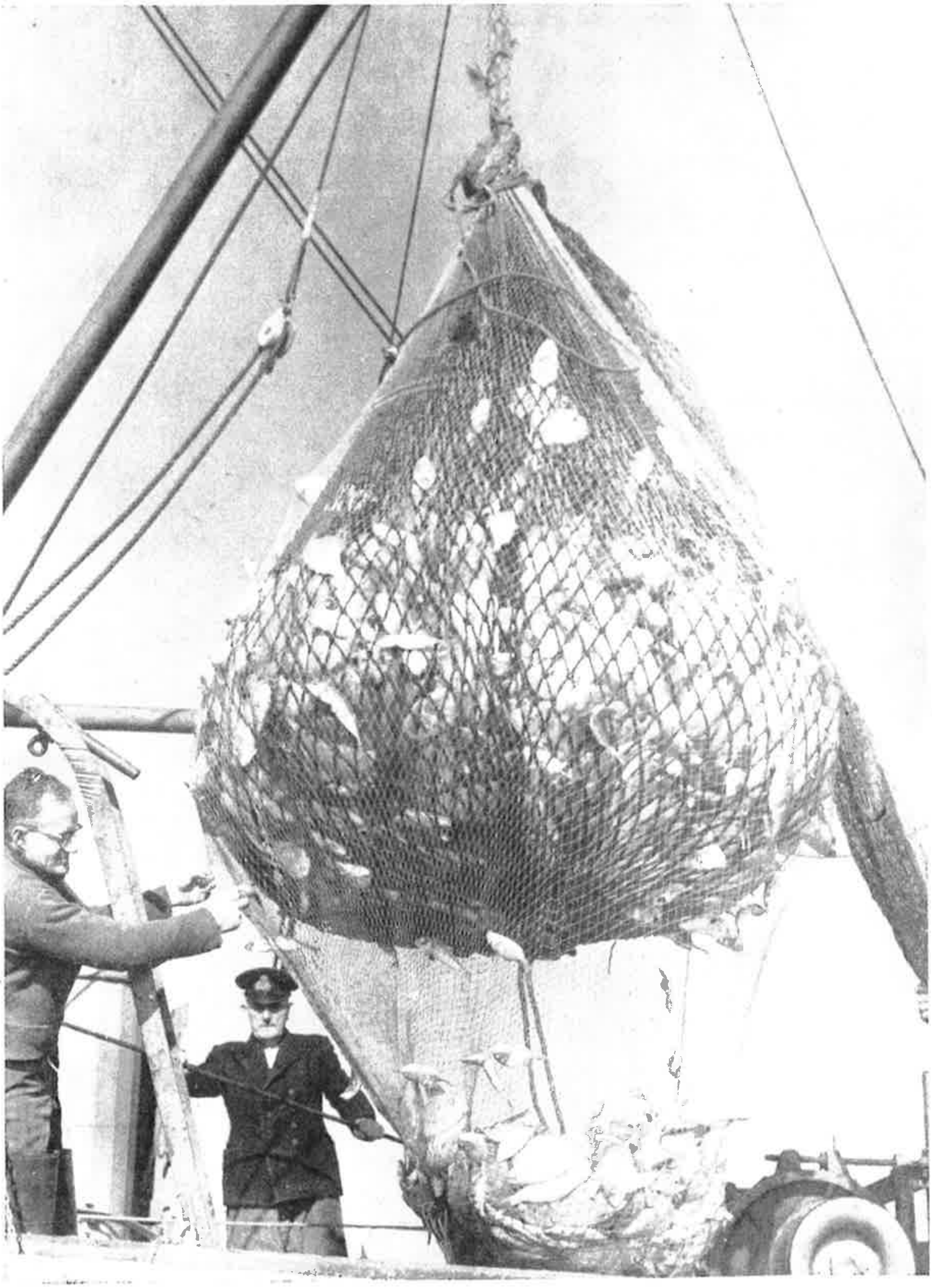
Its Application to the Management of the New Zealand Snapper Fisheries

by

R. Morrison Cassie,
Biologist (Marine), Marine Department

Wellington, New Zealand
1955

R. E. OWEN, GOVERNMENT PRINTER, WELLINGTON.



FRONTISPIECE. The cod-end and cover being taken aboard after a covered-net experiment. There are over 1,000 snapper in the cod-end, weighing three-quarters of a ton

NEW ZEALAND MARINE DEPARTMENT
FISHERIES BULLETIN No. 11

The Escapement of Small Fish from Trawl Nets

and

Its Application to the Management of the New Zealand Snapper Fisheries

by

R. Morrison Cassie,
Biologist (Marine), Marine Department

Wellington, New Zealand
1955

CONTENTS

4. DISCUSSION OF RESULTS—*continued*

LIST OF TABLES

LIST OF FIGURES

Frontispiece: The cod-end and cover being taken aboard after a covered-net experiment.

The Escapement of Small Fish from Trawl Nets

and

Its Application to the Management of the New Zealand Snapper Fisheries

1. INTRODUCTION

THIS series of investigations was commenced in 1948 on the snapper grounds of the Hauraki Gulf, near Auckland, New Zealand. The fishery for the snapper (*Chrysophrys auratus* Forster) extends on the east coast of New Zealand from North Cape to East Cape, and to a lesser degree down the west coast to about 43° S. latitude. The peak of production for this species was reached in 1948, when some 149,000 cwt. were landed, amounting to 28 per cent of the total commercial value of all species taken. Since then the yield has steadily decreased until in 1951 only 108,000 cwt. were landed and the snapper for the first time took second place to the tarakihi (*Cheilodactylus macropterus* Forster), which yielded 110,000 cwt. The same trend has continued in 1952, with snapper 97,000 cwt. and tarakihi 119,000 cwt. These two species together account for slightly over 50 per cent by weight of total fish landings in New Zealand and slightly under 50 per cent by value. The Hauraki Gulf has been subject to a series of closures and other conservational measures, but since 1903, when minimum mesh sizes were prescribed for trawls throughout New Zealand, there has been very little change in the regulations concerning the type of trawl gear which may be used. It has been recognized for some time that a certain quantity, perhaps a very large quantity, of snapper under the legally marketable length of 10 in. is caught at times in the trawl when the present minimum mesh size (4 in. for cod-end) is used. These fish, although they are returned to the sea, are almost invariably dead or dying and thus are a source of loss to the industry.

These investigations were begun with the original object of determining firstly how serious these losses were, and secondly how they might be reduced by certain modifications to the trawl net. It became evident in the early stages of the work that the labour involved in making even an approximate estimate of the wastage of small snapper in New Zealand would be very great. At the same time, the ultimate figure, if it were obtained, would be related in such a complex manner to the potential gain which could be achieved by avoiding such wastage that it would have little or no real value. For this reason the final results may not appear at first sight to answer the original questions, and more emphasis has been placed on gain in the future than loss in the past. The objects of the investigation have thus been revised during the initial part of the work and appear in their final form in the following section. Some of these objects have not been completely achieved, but it is hoped that a set of basic information has been supplied upon which further research as well as administrative action may be founded.

1.1. OBJECTS OF THE INVESTIGATION

1. To ascertain whether small fish escape more readily through a cod-end which is slung so that the meshes hang in a square rather than the normal diamond shape.

2. To verify under New Zealand conditions the claim made by overseas workers that an increase in the size of the mesh of the cod-end will reduce the number of smaller fish caught in the trawl.

3. To determine for the snapper (and for other species when convenient) the relationship between size of cod-end mesh and proportion of fish at any size which will escape.

4. To fit these results to a mathematical law and to express them as simple parameters which are as nearly as possible universal in application.

5. To obtain some estimate of the escapement which occurs in parts of the net other than the cod-end, and how this is affected by mesh size.

6. To determine how the escapement process is affected by other factors such as size of catch or accumulation of bottom debris.

7. To make some preliminary estimate of the size of mesh which will be required in the trawl to give the greatest sustained economic yield of fish flesh, having due regard both to the necessity for maintaining an adequate spawning stock and to the catches of other species of fish which may be important commercially.

8. If any change of mesh size is considered desirable, to estimate what the *immediate* effect on the size of trawl catches will be as opposed to the ultimate long-term effect. (To avoid the possibility of temporarily withholding the livelihood of fishermen who might well be profitably employed again after the fish stock had adjusted itself to the change.)

9. To find a reliable and consistent method of measuring mesh size.

10. To make an estimate of the approximate quantity of snapper less than 10 in. in length destroyed each year by trawlers using the standard 4 in. mesh.

1.2. THE "SAVINGS GEAR"

The design of a trawl net which will release small fish while still catching those of marketable size has been the concern of a number of fisheries workers since the end of last century. The literature up to 1935 has been reviewed by Herrington (1935), and this work should be referred to for more detailed bibliography. The term "savings gear" has been coined to describe any modified form of trawl which successfully achieves the release of small fish. The Swedish savings trawl (Ridderstad, 1915; Pettersson, 1925) and the Gelder cod-end (Buchanan-Wollaston, 1929) both had rigid frames and specially constructed netting, and though effective to some extent, were too cumbersome for general commercial adoption. Several workers have attempted to make use of a "square-meshed" cod-end (see Fig. 2), on the assumption that the meshes would not tend to close up under strain. As a rule this has shown little or no advantage (e.g., Herrington, 1935), even when supported by a rigid frame (Holt, 1895). The Swedish and Gelder trawls both used a rectangular mesh, but in these two cases the framework and other factors in the design probably contributed to their effectiveness. Davis (1934) made some experiments with a cod-end in which alternate rows were braided on different sized spools, producing a "kite-shaped" mesh. This was apparently designed to combine in one and the same net, mesh sizes suitable for both flat and round fish, but the results were not considered valid. The "Liberator", a recent development by the Grimsby nautical school, uses a specially braided panel of nylon netting set into the batings of the trawl.

However, it is now generally agreed that an ordinary trawl with no further modification than an increased mesh size in the cod-end can act as an effective savings gear. Recent underwater observations of trawls in action made by the Fisheries Laboratory, Lowestoft (Margetts, 1952) have confirmed this conclusion, showing that the meshes of a trawl remain wide open when being towed. This is directly contrary to the belief once held by many that the meshes of a trawl close up under strain and prevent any fish from escaping. Davis (1934) and Herrington (1935) both independently introduced what may be a further practical improvement by lacing several longitudinal rope stringers to the cod-end. Such a device would be quite a simple and unobjectionable one to the fisherman, but so far the advantages have not been demonstrated conclusively.

1.3. REVIEW OF PREVIOUS METHODS OF INVESTIGATION

Several different methods have been used in the past to obtain detailed information concerning the escapement of fish from trawls and its relation to fish size and mesh size. Most of the work has concentrated on the cod-end, probably because this portion of the trawl lends itself best to experimental work, and because any conclusions reached could presumably be extended, at least in a modified form, to the remainder of the net. Experimental methods can conveniently be separated under four headings:

Covered net method.
Replicate hauls method.
Trouser trawl method.
Underwater observation method.

1.3.1. THE COVERED NET METHOD

This is the oldest of the methods described, being introduced by Fulton (1893). Part of the trawl, usually the cod-end, is enveloped in a loose cover of netting which is sufficiently fine-meshed to retain all the fish which would normally escape, or at least all those in the size range with which the investigator is concerned. Fulton demonstrated for the first time that—

(a) Fish do escape from the cod-end of a trawl by passing through the meshes.

By comparison of the numbers and lengths of fish retained in the cover with those in the cod-end he estimated for different lengths the percentage which would escape. By repeating this experiment for different mesh sizes he showed further that—

(b) An increase in mesh size in the cod-end produces a proportional increase in the size and number of fish escaping.

Todd (1911) working with a beam trawl was probably the first to present his data in the graphical form now generally used (cf. Fig. 6) and to summarize his result by giving quartiles (i.e., the lengths at which 25 per cent, 50 per cent, and 75 per cent of the fish escape). He also made use of a cover on parts of wings, belly and batings, and square as well as the cod-end. A similar experiment designed to investigate escapement from all parts of the net has been conducted more recently by Margetts (unpub.) using a modern otter trawl. Davis (1934) used a modification of Todd's method to investigate an objection frequently raised, viz., that small fish may not escape while the trawl is being towed, but only when the ship is hove to to pick up the trawl. This, of course, would mean that most of the released fish would have been towed for a long period in the trawl first and would be almost as badly damaged as those which were landed on the ship and later thrown overboard. A throttling device was used to close the rear portion of the cover while the trawl was being towed so that it could receive no more fish during the raising of the trawl. It was found that this throttled part of the cover still contained a large number of small fish, showing that—

(c) Escapement of small fish can actually take place while the trawl is being towed.

Davis (1934), Herrington (1935), and others observed that most of the fish caught in the cover were still lively and apparently undamaged, in spite of the ill treatment they had received. This strongly supported the conclusion that—

(d) Fish which escape through the meshes are not usually damaged seriously and have a very good chance of survival after the experience.

The covered-net method has been subject to criticism on the grounds that the small-meshed cover may affect the performance of the cod-end by reducing the flow of water and preventing the escape of some fish which would normally pass through the meshes. This effect is sometimes referred to as "masking". Both Johnstone

(1910) and Davis (1934) concluded that results of such experiments were invalid, except for making rough comparisons, and recommended the replicate hauls method. In spite of these objections, the covered-net method has been chosen for this series of investigations. While the possibility of bias due to masking must be admitted, it is believed that the error can be reduced to negligible proportions by suitable technique. The following points are claimed in its favour:

(1) Each shot is in itself a complete experiment and repeated shots are needed only to estimate and reduce the magnitude of the sampling error.

(2) Results are independent of the catching efficiency of the trawl. Catching efficiency may be defined as the proportion of fish in the path of the trawl which are captured, and is quite a distinct matter from releasing efficiency, though both may be effected by different meshes and experimental attachments. With the covered net there is no need for scaling results of different catches to allow for assumed variations in catching efficiency.

(3) This is the only method, apart from underwater observations, which shows beyond all possibility of doubt that fish have actually escaped through the cod-end, rather than through other parts of the trawl or by swimming back out of its mouth.

(4) It is also the only method in which the condition of escaping fish can be critically examined after the experiment.

(5) Results are less affected by variations in the size composition of the fish population sampled, and it is probably for this reason that they usually give a better fit to a definite mathematical expression than those from any other method.

(6) Absolute rather than comparative estimates of escapement are given for each mesh.

1.3.2. THE REPLICATE HAULS METHOD

This method was first recommended by Johnstone (1910), but no data were given. The two nets to be compared (usually cod-ends) are used, preferably alternately, under conditions which are made as nearly identical as possible. Borley and Russell (1922), Wallace (1923), and Borowik (1930) all record fish size distribution data obtained using various meshes and show that the larger meshes catch fewer small fish, though no particular efforts appears to have been made to make trawling conditions strictly comparable other than to make a large number of shots.

Most workers have concentrated their experiments on the cod-end. Clark (1936), however, reversed the procedure, retaining the same cod-end but varying the mesh of the remainder of the trawl. Borley and Russell and Borowik also used a number of different combinations of mesh in all parts of the trawl.

Davis (1934) introduced a refinement to this technique in his "North Shields" experiment, where two commercial trawlers of the same class fitted with identical trawls except for the cod-end carried out twelve simultaneous fishing voyages "in the closest possible company". One vessel was fitted with the normal commercial cod-end of about $2\frac{1}{2}$ in., the other with a larger mesh of about $3\frac{1}{2}$ in. After each voyage, cod-ends were exchanged. Herrington (1935) conducted similar experiments using $3\frac{1}{4}$ in. and 5 in. cod-ends alternately from the same commercial trawler. Both of these workers computed percentage escapement by length from the catch ratio of the large to the smaller mesh. Herrington found it desirable to scale the two catches so that the number of larger fish (i.e., those which would have no chance of escaping from either mesh) was the same for both catches. Davis, on the other hand, used the catch numbers as they stood. It is difficult to say which method will give the truer result, but it will be shown in section 4.3.7. that if Davis had used Herrington's method of analysis his conclusions might have been significantly different.

This doubt as to the interpretation of results appears to be the principal disadvantage of the method, though further difficulties may be introduced by the relatively high variations in catch size and composition in even the most carefully standardized replicate trawl shots. For these reasons the method has not yet been used in the Hauraki Gulf investigations, though it is realized that it has certain advantages and may when properly handled produce information which is obtainable in no other way:

(1). The work can be conducted from a commercial fishing vessel with the very minimum of interference with normal working procedure.

(2) Since the size of mesh almost certainly influences the flow of the trawl through the water, it may also affect the number of fish which pass into the mouth of the net in the first place. For instance, a larger mesh may not only retain fewer small fish, but it may catch *more* larger fish. Replicate hauls seem to be the best, if not the only, means of estimating this factor.

(3) Regardless of what the controlling factors may be or the ultimate effect on the fishery, this method gives the only practical estimate of what immediate profit or loss to the fisherman is likely to be produced by any change in mesh size.

(4) Even though the information obtained may be difficult to interpret, the method does give an independent approach to the problem and cannot be ignored. Certainly no conclusions reached by other means should be accepted if they cannot be reconciled with the results of replicate hauls.

In view of the above considerations, it would seem that the replicate hauls method is best employed when an estimate of any desirable change in mesh has already been determined. At this stage an experiment similar to the North Shields investigation would serve the dual purpose both of making a final check on the covered net curve and of estimating the immediate economic effect of the proposed change.

1.3.3. THE TROUSER TRAWL METHOD

This is in effect a modification of the replicate hauls method. Both cod-ends are attached to the same trawl after the manner of a pair of trousers so that there can be little doubt that the two samples are taken from the same population of fish and under as nearly identical conditions as possible. Russell and Edser (1926) first used this technique, and concluded that their results were " sufficiently definite to give clear indications as to how further experiments should be devised, and this is the main use of the trouser trawl ". Davis (1934), though agreeing that good preliminary data could be obtained, pointed out that the two sides of the trawl did not fish identically, the after side usually catching significantly more fish. A trouser trawl was tested in the first stages of the work in Hauraki Gulf, but it was found that whichever bag caught the most fish initially tended by its weight to close the mouth of the other. Herrington (1935) largely overcame this difficulty by placing a carefully designed central septum of netting from the fork of the trousers to the bosoms of the head and foot ropes. Any discrepancy between the two catches was corrected by the same method which he used for replicate hauls.

Although this method would seem at first sight to overcome one of the disadvantages of replicate hauls, viz., the difficulty in standardizing trawling conditions, the final interpretation of results seems just as doubtful. Though the trouser trawl may be a useful subsidiary or preliminary method, it appears that it lacks both the precision of the covered net and the convincing practical demonstration given by replicate hauls.

1.3.4. THE UNDERWATER OBSERVATION METHOD

This is a supplementary method which can be most valuable in interpreting certain aspects of the behaviour of both trawl and fish, though it does not produce any quantitative data. The recent underwater observations and films taken by the Ministry of Agriculture and Fisheries (United Kingdom) and the Scottish Home Department have apparently been designed principally to examine and improve the general efficiency of the trawl and danish seine without any particular emphasis on escapement. Nevertheless, they have confirmed the views of other workers that the meshes can and do open while the trawl is in action. The idea of watching the trawl under water is not a new one. Mr J. Crapper, of Nelson, says that he has tested a small trawl from his boat by towing it at the surface using a long wooden beam slung athwartships to keep the wings apart and watching the net through the clear water. Probably many fishermen have used similar methods to observe and improve the " flow " of their trawls. Herrington (1935) used a large model cod-end slung on a ring with bridles and towed near the surface by one boat while another observed the cod-end, both empty and full of fish, and with and without experimental attachments.

The development of modern observation equipment, including the frogman and other diving outfits, underwater photography, television, and sonic detection, may well lead to a new era in trawl experimentation and design.

1.4. THE MEASUREMENT OF MESH SIZE

Various workers have used different means of measuring mesh sizes and of expressing their results. Some have tended to rely on the nominal mesh of the netting as supplied from the factory, or on the size of spool on which it was braided. Others have used standards common in the fishing industry, such as number of rows per yard, or distance from knot centre to knot centre (either between adjacent or opposite knots). More recently it has been fairly generally recognized that the most significant and useful measurement is the distance between *opposite* knots *inside* the knots instead of between centres, and taken with the mesh stretched to its largest dimensions. Davis (1929) actually gave full-scale shadow photographs of the meshes he used. Clark (1952a) introduced a flat, wedge-shaped gauge incorporating a spring which exerted a pressure of 12 lb. However, many published results seem to lack some or all of the following details:

(*a*) How much tension was applied to the mesh when it was measured.
(*b*) Whether the net was wet or dry when measured.
(*c*) At what time during the course of the experiments the measurements were taken.

It will be seen in the discussion of results that all these factors can be most important and if not defined can seriously affect the validity of conclusions.

1.5. THE ACTION OF THE TRAWL

Recent underwater observations and cine films by the British Ministry of Agriculture and Fisheries have given a very good indication of the shape taken by the trawl while in action. Margetts (1952) reports that—

> The meshes of the nets were open. Such was the case in all parts of the net from wings through to the cod-end and under all conditions tried. In the square the meshes were nearly as broad as they were long and in the cod-end were in the shape of wide diamonds. They were equally well open in the standard 3½ in. mesh cod-end and in a 5 in. mesh cod-end. The partial filling of the cod-end with old netting to simulate a catch of fish only bulged out the tail end of the cod-end, opening the meshes even wider than normal, and slightly constricted the fore part of the cod-end where the meshes still remained open.

Herrington (1935), using a large-scale model cod-end towed near the surface, made similar observations, showing that when a mass of dead fish was placed in the cod-end the meshes immediately in front of the "catch" were actually wider open than when the cod-end was empty.

Neither of these two sets of observations give any clear indication of the behaviour of fish in the trawl. However, underwater work by the Scottish Home Department along similar lines to the M.A.F. investigations but using a danish seine has given some useful information on this question. Though the actual method by which the fish are guided into the seine is somewhat different, by the time they reach the after part of the net conditions would probably be almost identical, since both nets are of similar shape and are being drawn through the water at comparable speeds. The report (Marine Laboratory, Torry, Aberdeen, 1952) states:

Fishing commenced from the time the net began to move through the water. All species of fish showed the same general behaviour pattern, which consisted of a movement over the sea bed in the direction of movement of (i.e., away from) the net and at approximately the same speed. This behaviour was maintained over considerable distances by some individuals, and even by some individuals at some distance (up to 5–10 yards) in front of the groundrope. In very few instances were fish actually seen to escape the net in this way. Capture seemed to be effected whenever the fish rose above the groundrope. Most of these fish still retained their orientation in relation to the direction of movement of the net, but seemed to move more slowly and passed back into the funnel. In very few instances were fish seen to swim out of the mouth of the net once they had moved above the level of the groundrope. A number of shots showed fish well back in the funnel, and even the cod-end, but still heading in the direction of tow.

The greatest concentration of fish always appeared in the centre of the U of the groundrope. It is difficult to assess to what extent this was due to a general movement inwards of fish disturbed by the groundrope along the wings, or to a smaller number of escapes in this central region under the groundrope, which observation showed to be in closer contact with the sea bed than in the wing sections. This point will be investigated.

On entering the cod-end most of the fish appeared to seek or to be forced towards its extremity, with the result that many became closely applied to the meshes, forming a bag of increasing size. For all that, numbers of small flatfish were seen escaping from the wide open meshes of the cod end. The escapes took place most rapidly (within about $\frac{1}{4}$ second) and the escaping fish were seen to swim away from the net, apparently quite unharmed.

Direct observations have not yet given any definite indications as to the behaviour of fish in relation to the forward part of the trawl (though the seine observations may be applicable). However, Todd (1911), after covering various parts of a beam trawl with fine netting, came to the conclusion that 98 per cent of the escapement occurred through the cod-end. On the other hand, Borley and Russell (1922) and Borowik (1930), comparing catches for different combinations of mesh size, both report much higher escapement from other parts of the net, as much as 50 per cent in Borowik's work on flatfish. Clark (1936) compared the results of hauls with small otter trawls using alternatively $1\frac{1}{2}$ in. and 5 in. mesh, except for the cod-end, which remained $1\frac{1}{2}$ in. He found that 87 per cent to 97 per cent more fish were caught by the finer mesh, " the majority of them small ". The two conflicting sets of evidence seem to be more or less reconciled by the recent work of Margetts (unpub.), who has shown for a modern type of trawl (using a method similar to Todd's) that although fish do escape from square and batings the number is very small in relation to the number released by the cod-end, *except* in the case of the after batings, where sometimes the same or even greater escapement occurred. Since the after batings are in effect only a forward extension of the cod-end, it seems reasonable to assume that the boundary between the two for escapement purposes is not necessarily the same as the arbitrary boundary of the netmaker. In fact, the dividing line is probably not a sharp one and may vary from trawl to trawl and even in the same trawl under different conditions. In Clark's experiment it is quite possible that the very much finer cod-end mesh caused the after batings to carry more than their normal share of escapement.

Altogether, experimental evidence seems to indicate that small fish tend to delay their efforts at escaping until they reach the after part of the trawl. Further evidence in support of this conclusion is gained by a consideration of the design of certain types of commercial net. Most of these have evolved through the experience of fishermen over a great many years. Although the trial and error method is not infallible, it is certain that any design which failed to catch fish in satisfactory numbers would soon be abandoned. It is very common, almost a general rule, for a larger mesh to be used in those parts of a net which the the fish encounter first, and where they are least restricted.

The master of the trawler *Konini,* of Nelson, New Zealand, has recently been experimenting with larger meshes in all parts of his trawl, but particularly in the forward portions. The wings have been increased to as much as 3 ft. in the mesh, as compared with about 6 in. in the cod-end. A 3 ft. mesh is big enough to release even the very largest of the fish encountered, but apparently catches have not been adversely affected. An even more extreme case is the lampara net, which may have a wing mesh as great as 6 ft. yet still catches sardines or even sprats in the fine-meshed cod-end. Sometimes, indeed, the initial "fishing" is accomplished not by a net at all, but by a single rope or wire as in the warps of the danish seine or the sweeps of the V.D. trawl. Though the principle of the lampara or the seine is somewhat different from that of a trawl, nevertheless there is abundant evidence that various devices which produce some form of disturbance in the water may be effective in directing the movements of fish even though they do not appear to present an impenetrable physical barrier.

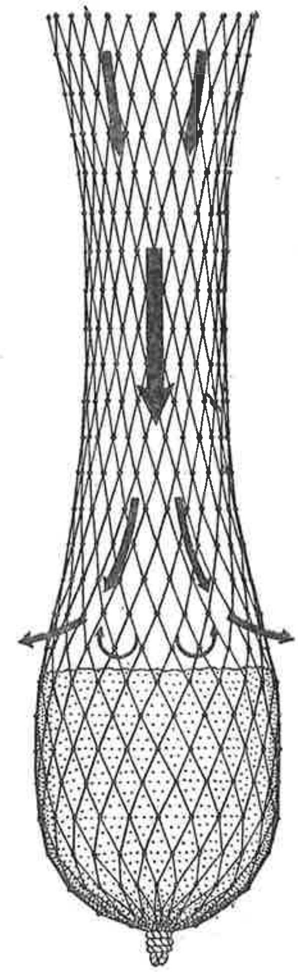


FIG. 1. The probable shape of the cod-end when in action

The following partly hypothetical account may now be given of the behaviour of fish in the trawl.

The fish are herded together by the sweeps and wings, which they tend to avoid, and it is not until the foot-rope of the trawl has passed under them that their main reaction to the net as a physical barrier begins to take place. At first relatively few fish encounter the walls of netting and thus few are in a position to pass through the mesh. Further back they become packed more closely together, more and more impinge on the walls, and the number of escapes increases. At the same time, the funnel shape of the bag tends to accelerate the backward flow of water,* so that the passage through the after belly and batings is fairly rapid, with only occasional momentary contact with the netting. Figure 1 illustrates the probable shape of the cod-end and the flow of water in relation to it, the relative velocity of the water being indicated by the thickness of the arrows. The current from the belly and batings becomes greatest at the most constricted part of the net. After this the space widens and the flow of water is arrested and deflected outward as it strikes the solid plug of fish at the bottom of the cod-end. Both the open mesh and the deflected current give a fish, now literally fighting for its life, a last chance of escape if it is small enough to squeeze through the meshes.† It is important to note the part played by the fish *already caught*. The first few fish which are captured will probably be deposited fairly abruptly and pressed against the almost closed meshes at the end of the cod-end, and only the smallest (or perhaps the strongest) will be able to pass through. Thus the first caught literally build with their bodies a deflecting mechanism assisting the more fortunate later comers to escape.

Some part of the above account may require modification in the light of further observations, but it is at least a useful hypothesis which is consistent both with previous observations and with the experimental evidence which will be shown below.

1.6. THE HISTORY OF REGULATIONS CONTROLLING MESH SIZE IN NEW ZEALAND

The need for controlling the minimum size of trawl meshes in New Zealand waters was first recognized in 1903, when regulations were gazetted prescribing a minimum of 4 in. for the cod-end and 5 in. for the remainder of the trawl. The cod-end mesh has remained the same up to the present day, but that for the belly and batings was reduced to "4½ in. down to 100 meshes", and the square to 4½ in. in 1906. The same regulations were applied to danish seining when it first came

* Strictly speaking, it is the trawl which moves through the water, not the water through the trawl. Water inside the net is tending to remain stationary, and if anything it is probably being dragged forward with the trawl. Nevertheless, it is convenient to think in terms of a stationary net with a stream of water passing through it at a speed which varies in different parts of the trawl.

† It is often assumed that fish will only escape from the upper side of the net. This is probably true when false bellies and other chafing gear is used, or when the whole underside drags on the bottom. However, in New Zealand, particularly in the smaller motor trawlers, it is quite common for the trawl to be used without any such protection, and to adjust it so that the after part of the net, or even the whole net, tows clear of the bottom. In such a case there seems to be no reason why fish should not escape from the underside.

Some aspects of the behaviour of the fish which may be pertinent to this discussion are presented by Kerr (1953) in the account of an investigation of various types of fish screen for use in freshwater streams. It was found that fish (salmon and bass) were reluctant to pass through the vertical boundary separating two bodies of water travelling at different velocities. A minimum velocity of 2·5 ft./sec. (about 1½ knots) is mentioned as a requirement for an effective barrier. Although the different rates of flow inside and outside a trawl are not known, it is not unlikely that velocity gradients of this order are produced by a trawl travelling at 2 to 3 knots, and that this is one of the factors which deter fish from escaping until they are actually forced against the netting or aided by a favourable current.

into operation in the Hauraki Gulf in 1923, but in 1926 the minimum mesh size for the cod-end of the seine was raised to $4\frac{1}{2}$ in. for the last 6 yards (reduced to 3 yards in 1928). In 1936 this was once again raised to 5 in.

Since 1936 there has been no amendment to the mesh size regulations for either of these two methods of fishing, but particularly since the 1939–45 war there has been a marked change in the relative fishing efforts applied by trawl (4 in. cod-end) and danish seine (5 in. cod-end).

Whereas in 1937 trawlers contributed only 44 per cent of the combined catch for the two methods, in 1952 this figure had risen to 91 per cent, so that the larger mesh of the danish seine has gradually lost most of its effect.

Thus the effective *average* cod-end mesh in power-hauled nets has decreased since 1937 from about $4\frac{1}{2}$ in. to little more than the 4 in. prescribed for trawlers.

In 1937 a Sea Fisheries Investigation Committee with powers of judicial inquiry was appointed by the Governor-General to investigate and report upon matters pertaining to the sea fishing industry in New Zealand. With regard to trawl fisheries the following two recommendations were made, to apply to New Zealand as a whole:

1. That the size of the mesh in the cod-end of all trawls be raised to 5 in. immediately, exemption being granted to those vessels operating at present to allow them to use up the gear in hand.

2. That all research carried on abroad as to the escapement of under-sized fish from trawls be studied and adopted if found satisfactory under our conditions of fishing.—(Thorn, Young, and Sheed, 1937–38.)

2. EXPERIMENTAL PROCEDURE

2.1. HISTORY OF THE HAURAKI GULF INVESTIGATIONS

This work was begun in 1948, shortly after the author had commenced duties with the Fisheries Branch. The research vessel *Ikatere* had recently been recommissioned under command of Captain A. Duthie after the 1939–45 war. Captain Duthie had been asked early in 1948 to set up a trawl suitable for experiment with different sizes and types of mesh, particularly in the cod-end, and to endeavour to produce a cod-end which would release more undersized fish than the standard 4 in. mesh. The first experiments were made using a 4½ in. manila cod-end set "on the square", which was compared with a cod-end of similar mesh and construction but set in the usual way "on the diamond". (See Fig. 2; 3 and 4.) It had been suggested that the square mesh might remain open better and thus be more efficient in releasing small fish. Two types of experiment were carried out. Firstly the two cod-ends were attached to form a trouser trawl, and secondly the square cod-end, after being somewhat reduced in size, was placed inside the diamond. The trouser trawl was not very successful, since one leg or the other usually caught all the fish. However, it was reported that, using the second method, a number of fish passed through the square-meshed cod-end but were retained in the diamond-meshed cover.

In December 1948 the author first took part in the investigations. The first work was to study more carefully the square meshed cod-end. This was done by repeating the second experiment, and, as a control, reversing the relative positions of the two cod-ends, the length frequency as well as the numbers of fish in inner and outer cod-end being recorded in each case. Fourteen shots were made in this way. It was then decided that the square mesh showed no signs of being more effective than the normal mesh, and the investigation was diverted to a study of the effects of different sizes of cod-end mesh.

During the remainder of this month a 5 in. cod-end was used, with a loose cover of ½ in. "bully netting" about one and a half times the size of the cod-end both in length and circumference and laced to the bottom of the belly and batings. (See Fig. 2; 1.)

These shots were made during a cruise from Auckland to the Bay of Plenty, and the catches are rather too heterogeneous to be of any value for estimating snapper escapement, but a small amount of data for the tarakihi was obtained during the cruise. Some difficulty was found in repairing the ½ in. mesh when it was torn, and during January 1949 shots 20 to 26 were made using the same 5 in. cod-end but with a cover of light 2 in. meshed cotton (actually about 1¾ in. when shrunk). In February and March a return was made to the repaired ½ in. cover, using a 4 in. double cotton cod-end. In April 1949 it was decided that the 2 in. mesh was sufficiently small to capture all the fish in the size range which was being taken. Although only a very light netting was available, it was more easily mended and cheaper to replace when worn out. Thus the 2 in. cotton was used for all shots with a variety of cod-ends up to the end of January 1950, when sufficient data had accumulated for experimental work to be halted for the time being.

Once this data had been fully examined and analysed it became apparent that, although generally quite consistent and satisfactory results had been obtained, there was still the possibility that the trawl with cover attached was behaving differently from a normal trawl without experimental attachments, i.e., that "masking" was taking place. Accordingly a series of paired shots was commenced in January 1950, each two shots of a pair being as nearly as possible on the same ground and at the same time. In one shot the cover was attached, in the other it was omitted. The order of shots was reversed for each succeeding pair. For a few shots the same light cotton covers were used until they were worn out. Some heavy cotton herring cod-ends were then substituted for the original covers. From March to September 1950 work was continued as opportunity arose. During this period there seemed to be a dearth of small fish in the Hauraki Gulf grounds, so that the few pairs of shots which were successful in other ways did not cover a sufficient range of sizes to allow an escapement curve to be computed. In addition, it was found that consecutive shots very frequently seemed to have sampled different populations of fish, so that it was often impossible to draw any parallel at all between the size distributions or the total numbers of fish caught. Whether this was due to a fault in the sampling technique or to the contagious distribution and capricious movements of the fish is not clear, but the high variability in trawl catches of snapper has proved a very real problem in this and other sampling work.

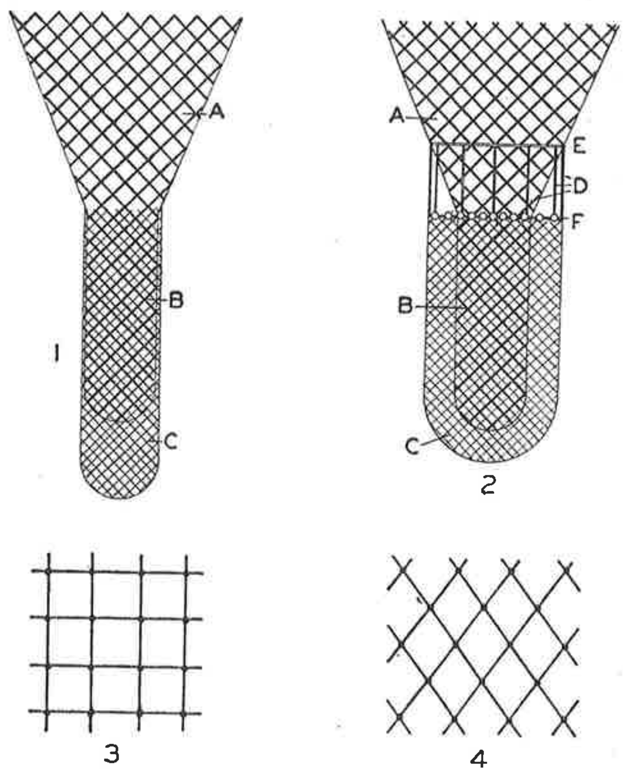


Fig. 2. 1. Method of attaching cover, series 2. 2. Method of attaching cover, series 5. 3. The "square" mesh. 4. The "diamond" mesh. A. Belly and batings. B. Cod-end. C. Cover. D. Rope toggles. E. Rope strop. F. Rope strop with corks above and leads below.

From March to August 1951 a further series of shots was made in a similar manner, but making a greater effort to standardize the trawling conditions both as regards place and time of day in each pair of shots. Here again the same difficulties were encountered, only one pair of catches (shots 167, 168) giving at the same time a satisfactory escapement curve and comparable catches. At this point it was decided to abandon this particular phase of the investigation in favour of a different approach.

It was assumed that if any difference in the catch were made by the cover, it would be in the direction of fewer rather than more fish escaping from the cod-end. If this were the case, it should be possible to detect such an effect by improving the construction of the cover in such a way as to reduce if not eliminate masking. In the first covered-net experiments no particular precaution had been taken to keep the cover from pressing against the cod-end. Accordingly a suspension was designed which should keep the cover at all times a foot or more from the sides of the cod-end. (See Fig. 2; 2.) In order to allow the maximum flow of water the cover was made of No. 36 hemp trawl twine, which has a lesser bulk than cotton of corresponding strength. Further, the mesh was increased to a nominal 3 in. (actually $2\frac{1}{2}$ in. when shrunk), as previous results had suggested that this would not release more than about 1 per cent of 7 in. fish and virtually none above that size, so that the main range of the escapement curve would be unaffected.

The new cover, which was first used in October 1952, functioned for the most part very satisfactorily and the full expected escapement level was realized in nearly all cases. The difference from previous results was indeed so marked that it was at first treated with some suspicion. The trawl used in this case was not the original, but one of somewhat lighter construction. To make certain that the improved results were due to the new cover rather than to the new trawl, a cover of light cotton identical with that originally used was constructed and attached to the trawl as in the original series. Three shots were made using the same 5 in. single manila cod-end which had been used before both for the original and the improved cover. The results obtained were found to duplicate very closely the original 5 in. escapement curve. Unfortunately, the improved cover was lost before a complete range of cod-ends could be tested. However, sufficient results are available to give satisfactory curves for 4 in. double and 5 in. single and double twine. A series of five shots was made in January and February 1953 using the same type of suspension but a " 2 in." (actually about $1\frac{3}{4}$ in.) hemp cover on a 4 in. single manila cod-end. The results were in agreement with the previous three sets in spite of the smaller mesh, suggesting that the new type of suspension rather than the mesh size was the main factor in producing the improved result.

A synopsis of the experimental work is given in Table 1. All *Ikatere* trawl shots are numbererd in sequence, regardless of their purpose, so that the numbers of shots in the table are not necessarily consecutive. The work is divided into five series:

(1) Square mesh experiments, 1948.
(2) Original covered net experiments, 1949.
(3) Paired shot experiments, 1950.
(4) Paired shot experiments, 1951.
(5) Modified covered net experiments, 1952–53.

2.2. THE MEASUREMENT OF MESH SIZE

In the initial part of the investigation the need for an accurate and critical definition of mesh size was not fully realized. In series 1 no measurements were taken at the time, though since the two cod-ends being compared were from the same sheet of netting and gave the same measurement on a later check it was assumed that comparison of the two would be valid. In series 2, reliance was placed initially on the nominal mesh size of the netting together with a rough check by ruler, but it was soon realized that this measurement was inadequate, particularly since, with the exception of the commercially made 5 in. single manila and the 4 in. double cotton, the cod-ends were made by different members of the crew with varying proficiency in braiding. Two of the cod-ends had been lost or could not be identified, but the remainder were still available for measurement fairly soon after the experiment.

A 1 lb. lead weight of an elongated cylindrical shape with a hook at one end was constructed.* In each cod-end 100 meshes were chosen at random. Each mesh was held in one hand just above the knot nearest the mouth of the net. The pound weight was hung from the opposite knot and the distance between the two knots (i.e., inside the knots, not from centre to centre) was measured with a ruler to the nearest $\frac{1}{16}$ in. It was found necessary, particularly with the double twine cod-ends, to apply by hand a tension of considerably more than 1 lb. to extend the mesh fully. Thus, strictly speaking, the weight did not "produce a fair strain or extension",* though it did as a rule serve to hold the mesh in an extended position once it had been stretched.

In series 3 and 4 no accurate measurements were taken, since the type of experiment did not require them, though naturally the same cod-end was used for both shots in every pair.

In series 5 a new system of measurement was introduced. Meshes were measured as soon as possible after the completion of a shot while the net was still wet. Though measurements were not necessarily made after every shot, they were repeated whenever a change in mesh size through shrinkage or other means was suspected. A special measuring apparatus was constructed and is illustrated in Fig. 3. The material is brass throughout, except for the weights, which are lead. Weights of 1 lb., 5 lb., and 10 lb. may be used, but it was found that the 10 lb. weight was by far the most satisfactory one for giving a comparable degree of stretch to all types of trawl twine. The 10 lb. weight was eventually adopted as the standard.

---

* The Fisheries Regulations (1950), paragraph 8, specify as follows: " . . . the size of mesh of a net shall be the size ascertained by measuring the length between knot and knot of opposite corners with the mesh closed, the net being first wetted and stretched and having been tanned, barked, or otherwise prepared for use. If the net is dry, the part to be measured shall immediately before measuring be soaked in either fresh or salt water for not less than ten minutes. In case of dispute or doubt a weight of 1 lb. in the case of a trawl net, . . . , shall be slung or attached to the lower knot of the mesh to produce a fair strain or extension, and the mesh shall be measured whilst the weight is in position."

The method of measuring described here does not follow the regulation strictly, since it was more convenient at the time to measure the nets dry.

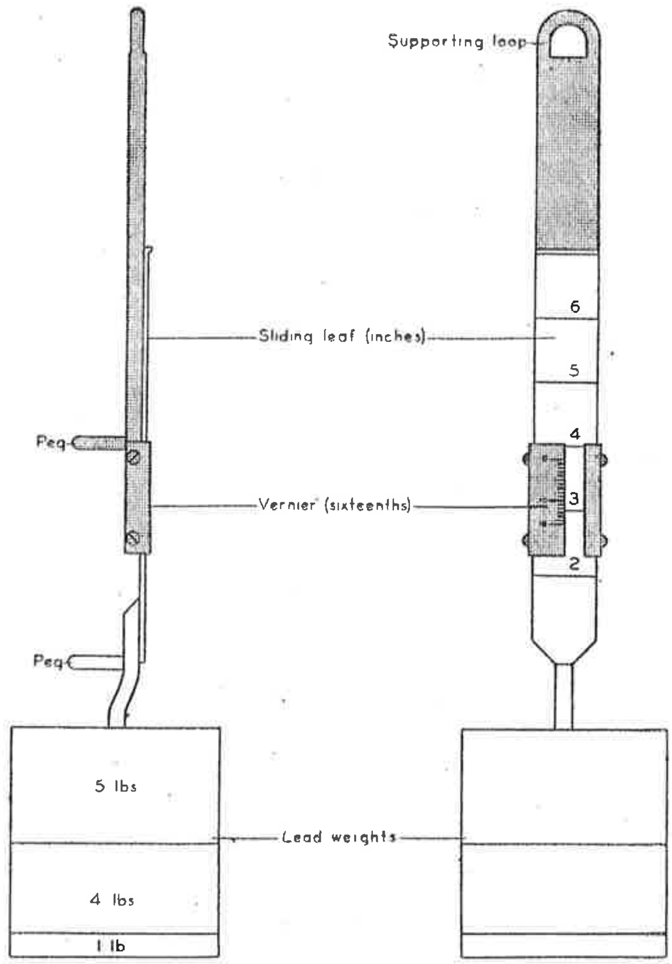


FIG. 3. Apparatus for measuring mesh size

The apparatus was held in one hand by a lanyard attached to the supporting loop with the weight resting on a hatch cover. A mesh was attached by placing one knot over the upper peg and the opposite knot under the lower peg. Raising the upper (stippled) portion so that the weight was just off the hatch cover allowed the lower (unstippled) part of the apparatus to slide down and separate the pegs to the fullest extent allowed by the mesh. The measurement was then read, whole inches from the calibrated sliding leaf and sixteenths from the vernier. Care was taken that any netting below the mesh being measured was supported either by hand or by resting on the hatch cover so that it could not contribute to the stretching weight. Every mesh was measured in each of four complete rows (taken from front to rear) spaced evenly around the circumference of the cod-end.

2.3. RECORDING AND PRELIMINARY ANALYSIS OF RESULTS

The standard trawl data sheet employed for all types of trawl work by *Ikatere* is shown in Figs. 4 and 5. The front of the sheet (Fig. 4) gives all data relevant to the handling of the trawl as well as details of weather, gut contents of fish, etc. The back (Fig. 5) is ruled into columns into which length frequency data can be

FISHING GROUND *Between Kawau and Tiri*

Date 1-10-52 .... Haul No. 238 ....

Time trawl reached bottom 1015 ...... Time picked up 1215 ....

Position at; commencement of haul B6 .... End of haul A6 ....

Course W10°S .... Engine speed 350 ....RPM

Trawling speed measured at 1200 ..... hrs 3.2 .... knots

Wire angles: Dip. 11° .... Spread. 19° ...... Length of wire. 70 f. ....

Average depth of bottom: Chart .15 f. .... Sounding ....

Net used No. 3 Hemp .... Cod end mesh 5" single manilla

Experimental gear attached 3" False cod-end with toggles ....

Weather: Wind WSW .... Sea Sl. ....

Tide Flood ...... Clouds 10/10 Sc .....

Remarks ....

Sea surface temperature at 1200 .... hrs .14.6 .... °C

Birds, porpoises, whales, surface fish, etc., seen Nil ....

....

Nature of bottom (sand, mud, rock, etc.) mud ....

Bottom material found in trawl (shellfish, seaweed, etc.) Nil ....

....

Gut contents:

Species examined	Predominant food: Stomach	Predominant food: Lower gut	Other food
Snapper	Salps	Crab	
Gurnard	Crab	Crab	

Details of any damage to equipment, particularly tears or broken bars in net: Nil ....

....

Further Remarks:

FIG. 4. Trawl data sheet—front

SPECIES OF FISH AND LOCATION IN NET.

Length (inches)										
4	SN/5			SN/3					GN/3	GN/5
5										
6										
	II			III						
7	I			II						
				III						
8	II			卌 II					I	
	I			卌 卌 卌	II					
9	卌			卌 卌 卌	卌 卌 卌	卌 卌 卌	III			
	III			卌 卌 卌	卌 卌 卌	卌 卌 III				
10	卌 II			卌 卌 卌	卌 卌 卌	卌 IIII			I	
	卌 卌			卌 卌 卌	卌 卌 卌	卌 卌 卌	卌 卌 卌	卌 卌 II		
11	卌 卌 卌	卌 卌 IIII		卌 卌 卌	卌 卌 卌	卌 卌 卌				
	卌 卌 卌	卌 卌 卌	卌 II	卌 卌 卌					I	II
12	卌 卌 卌	卌 卌 卌	卌 IIII	卌					II	
	卌 卌 卌	卌 IIII		II					II	II
13	卌 卌 卌	II								I
	卌 卌 III								II	I
14	卌 卌 卌	卌 II								I
	卌 IIII			I						I
15	卌 III			I						III
	卌									I
16	卌 II									
	卌									
17										I
18	I									
19	II									
20										
	I									
21										
22	I									

Details of other fish not recorded above:

Trevally 18 14½ 14 14½ 13 19½ 13 12½

Yellowtail 卌

Warehou I

FIG. 5. Trawl data sheet—back

entered under various headings. The forms are reproduced from typed stencils on good quality duplicating paper and information is entered in pencil, a carbon copy being retained on the ship's file, while the original is forwarded by mail to the laboratory.

The columns on the back of the sheet were divided into different headings as required. For each species of fish occurring in appreciable numbers at least two columns were used, one for the fish in the cod-end, another for those in the cover. Provision was also made for recording fish "meshed"* in the wings, square, belly, or batings. These were not included in the escapement calculations as there was some difficulty in ensuring uniformity of recording owing to the fisherman's normal practice of shaking down all fish, meshed or otherwise, into the cod-end when hauling in the net. However, such meshed fish were usually few in number, seldom more than a dozen, and would not be enough to produce any significant difference in the results. In series 5 an attempt was made to keep a record of fish meshed in the cod-end and in the cover, but here again uniformity was not always certain. However, fish meshed in cod-end or cover were invariably recorded in the final results as being caught in cod-end or cover respectively. Again these did not usually form a significant part of the results, but in one case (shot 241) a sufficient number of meshings was observed with sufficient accuracy to be worth recording.

The results of each shot were tabulated and plotted separately as they came in, and at the end of each group of similar shots the results were pooled and a mean curve for the group computed. In cases where individual shots had obviously produced widely divergent results from their fellows (perhaps owing to some accident in the experimental procedure), these were omitted from the pooled totals. In a few cases it was found desirable to subdivide groups in order to show two significantly different types of result. The method of tabulation may be seen in Tables 7 to 21.

* "Meshing" refers to the trapping of fish in the meshes of the trawl. This may occur when a fish of a girth about the same as the mesh circumference is unable to pass through the mesh, but remains trapped part way through.

3. EXPERIMENTAL RESULTS

3.1. THE THEORY OF THE ESCAPEMENT CURVE

It has usually been the practice to plot the results of escapement experiments on a linear scale as in Fig. 6, and by linear interpolation to obtain the mean and first and third quartiles, i.e., the lengths at which 50 per cent, 25 per cent, and 75 per cent escapement takes place (Mi, Q_1, Q_3 in Fig. 6). This method often provides quite a satisfactory comparison between the performances of different nets, but the data could undoubtedly be put to much fuller use if a suitable mathematical curve could be fitted.

Buchanan-Wollaston (1927) recognized this and fitted to three (or sometimes more) of the central points the parabola expressed by the equation—

$\log_e \Delta p / \Delta L = a + bL + cL^2$

where $\Delta p / \Delta L$ = difference between escapement percentages at successive lengths, L

a, b, c = constants.

Apart from the fact that this method is a somewhat laborious one and gives an unnecessarily complex solution, the curve obtained does not usually fit the data well, except for the few central points originally chosen. It is, in fact, quite possible to obtain obviously impossible values by extrapolating the curve.

However, Buchanan-Wollaston recognized the close similarity between the escapement curve and the curve of the normal integral. A relatively simple test for normality for such data is obtained by plotting against L the value t

$$\text{where } p = 100/\sqrt{2\pi} \int_{-\infty}^{t} e^{-t^2/2}\, dt$$

Corresponding values of p and t may be obtained from tables in most statistical textbooks, but the transformation is more readily made graphically by plotting on probability paper, using the linear scale for L and the probability scale for p. If the data is normally distributed, the points will then be arranged in a straight line. In Fig. 7 the same data used in Fig. 6 has been plotted on probability paper. It will be seen that, with the exception of a few points at the extremities, a straight line may be readily fitted to the data. The lighter lines on either side of the curve in Fig. 7 represent the 5 per cent confidence limits for individual points (i.e., where $\chi^2 = 3{\cdot}841$). The four points at the upper extremity are obviously widely divergent. It will be seen that the majority of escapement curves show this feature, so that it must be assumed that the higher escapement values cannot be described by the same mathematical expression as those nearer to the middle regions of the curve. On the other hand, only one point at the lower extremity does not fit the curve. An examination of the data (Table 8) shows that the divergence here arises from five fish only, all of them caught in shot 86, so that it is possible that the high escapement is an accidental one due possibly to an undetected tear in the net or an error in observation. Figure 8 shows the same data plotted on a linear scale again, the curve fitted to the data corresponding to the straight line in Fig. 7.

From consideration of this and other similar data it was concluded that the cumulative normal curve can be fitted to the escapement curve at least in the middle regions and often toward the lower extremity as well. Thus results were analysed by plotting on probability paper and fitting a straight line by eye to those points which appeared to be linear. It would perhaps seem more precise to use regression analysis rather than purely graphical methods. However, the apparent gain in accuracy would not necessarily have any direct bearing on the validity of the curve, since the solution depends so largely on the initial decision as to which points to consider and which to ignore, a decision which can only be made in the first place by eye.

The two parameters of the curve, *mean* and *standard deviation,* will be known as the *escapement index* and the *selection index* respectively, since the former gives a standard measure of the fish which escape, while the latter shows the sharpness of the selective action. The two indices may be determined from the curve as shown in Fig. 7 where—

Escapement index $= E =$ length at which the curve intersects the 50 per cent escapement level.

Selection index $= S =$ Difference between E and the length at which the curve intersects the 15·87 per cent or 84·13 per cent escapement level.

A third value, the *Coefficient of Selection C,* might also be added where—

$$C = 100S/E$$

However, it will be seen in section 4.3.2. that this coefficient gives no additional information, and it will be omitted from the tabulations.

The two indices serve the same purpose, but are not exactly equivalent to those used by Davis (1934) and Herrington (1935). The standard deviation is used in preference to the quartiles partly to be in line with more recent statistical procedure and also to distinguish the fact that they are determined by a somewhat different method. For most purposes the following conversions may be used for comparison:

Davis	Herrington	R. M. C.
Q_1	Q_1	$E-1{\cdot}5S$
Mi	Mdn	E
Q_3	Q_3	$E+1{\cdot}5S$
X	Cs	$3C$
$(Q_3-Q_1)/3$		S

Herrington's *Cs is* quite distinct from that computed by Buchanan-Wollaston (1929). The latter represents the gradient of the curve at the point of inflexion and would vary in value according to the class interval employed in measuring the fish.

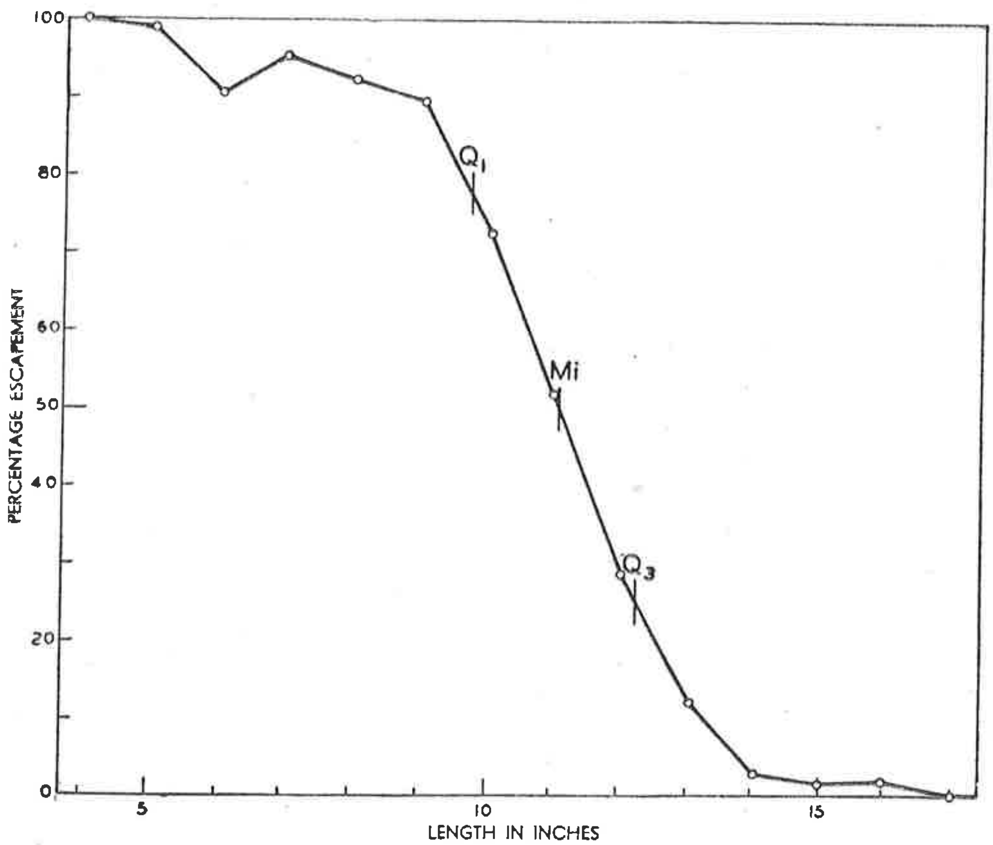


FIG. 6. Escapement curve, linear scale (Table 8)

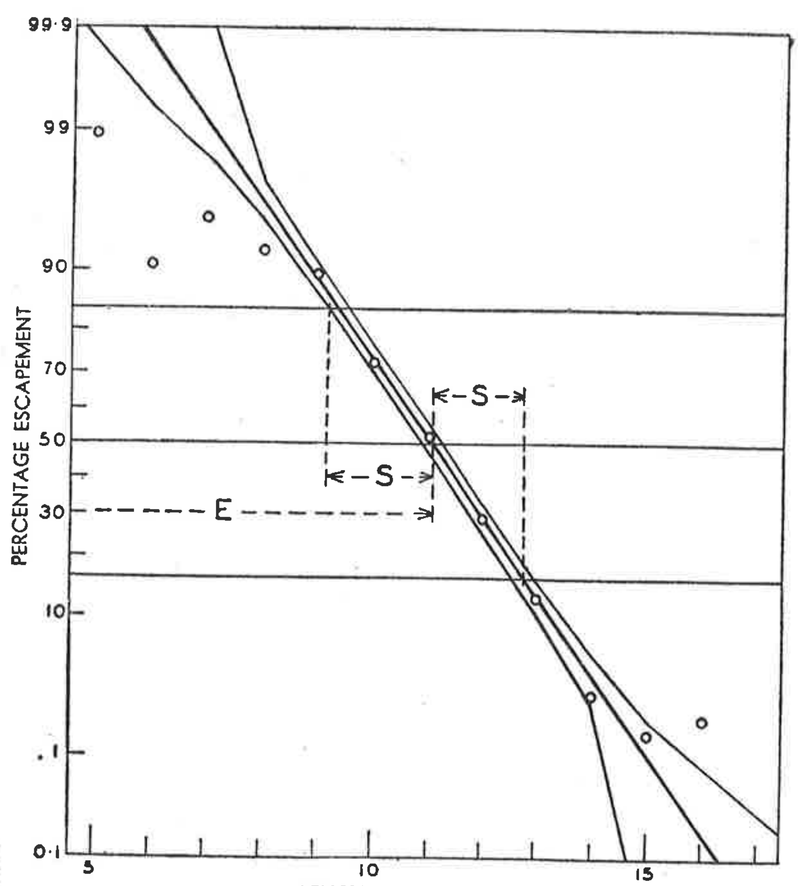


FIG. 7. Escapement curve, same data as in Fig. 6, plotted on probability paper

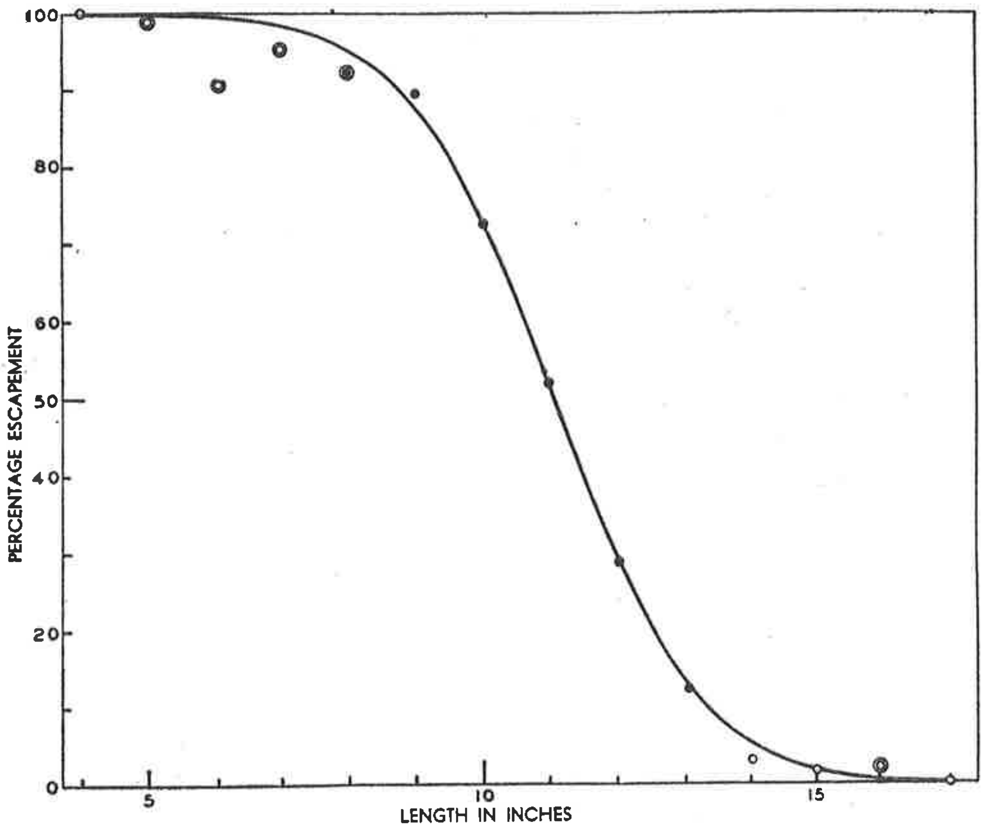


FIG. 8. Escapement curve, linear scale, same data as in Fig. 6, with curve of normal integral fitted

3.2. TESTS OF SIGNIFICANCE AND FIDUCIAL LIMITS

Table 2 shows in detail the method used to test goodness of fit and to estimate the standard error of the escapement index. The data used is the same as that shown in Figs. 6, 7, and 8 and in Table 8 (5 in. single manila cod-end, series 2). It was noted when the curve was first drawn that it obviously did not fit the data at some points toward the extremities. For this reason a test of goodness of fit is applied only to that part of the curve between 9 in. and 15 in.

The total χ^2, 3·20, has three degrees of freedom, one each for the six individual values computed, less one each for escapement index, selection index, and total number of fish. The probability of a higher χ^2 is found to be approximately 0·4, showing that there is no reason to doubt that the curve fits the data within the range tested.

In computing the standard error of E it is assumed that p has a linear relation to L. This is not strictly correct, but for the narrow range concerned it is sufficiently accurate for our purposes. The 0·05 confidence limits plotted in Fig. 7 are obtained from s_p.

$$P_1, P_2 = \hat{p} \pm 1 \cdot 96 s_p$$

3.3. RESULTS

3.3.1. MESH MEASUREMENTS

Details of all mesh measurements are given in Tables 3, 4, and 5 for series 1, 2, and 5 respectively. In all cases the measurements are of cod-ends only, except in the last two columns of Table 4. Two cod-ends used in series 2 are not specified, the 5 in. double twine and the 6 in. single twine. However, hand measurements taken at the time indicated that both meshes were only slightly under nominal size, and for purposes of comparison they are taken as 4·9 in. and 5·9 in. respectively. In series 1 and 2, measurements were taken after all shots had been completed with dry nets and a 1 lb. stretching weight, while in series 5 the method of measuring is specified at the top of each column. Further details of series 5 are given below:

5 in. Single.—The same cod-end used in series 2—

(*a*) Measured dry before shot 238; meshes chosen at random.
(*b*) As for (*a*), but this and all following measurements are taken systematically for four complete rows equally spaced round the circumference of the cod-end.
(*c*), (*d*) Measured wet immediately after shot 242.

5 in. Double.—A brand-new untanned manila cod-end—

(*e*), (*f*), (*g*) Measured immediately after shot 242.
(*h*) Measured immediately after shot 243.

4 in. Single.—Two different cod-ends were used, both nominally 4 in., though the actual measurements after shrinkage were somewhat different—

(*i*) Measured after shot 251.
(*j*) Measured after shot 268.

4 in. Double.—Measured after shot 254.

Belly and Batings.—Measured after the last shot in series 5. The trawl had been tanned and had been used for about a dozen shots before the series commenced, so that the mesh size may be assumed to have been fairly constant during the series.

3.3.2. DATA FROM ESCAPEMENT EXPERIMENTS

The results of series 1, the square mesh experiment, are given in Table 6 and Fig. 9. The method of preliminary tabulation and analysis is as described in section 2.3, but the fitting of the compound curve follows a slightly different procedure to that outlined in section 3.1 and will be further discussed in section 4.2.

Series 2 and 5 are recorded in Tables 7 to 21 and Figs. 10 to 16, while Table 22 and Fig. 20 refer to the control shots which link the two series, in that, though the series 5 trawl was used, the cover and method of attachment were identical with series 2.

Series 3 and 4 were on the whole unsuccessful and little is to be gained by recording the data. One pair of shots, Nos. 167 and 168, are shown in Table 23 as a matter of interest, though it must be emphasized that they are not representative results, but happen to be the only pair in which the two catches are more or less comparable.

As mentioned previously, meshing of fish in any part of the trawl was not very frequent, but one instance did occur when accurate records were made of a relatively large number of fish meshed in the cod end (shot 241). These are recorded in Table 24.

4. DISCUSSION OF RESULTS

4.1. MESH MEASUREMENTS

An examination of Tables 3 to 5 will show that the distribution of mesh sizes often departs significantly from normal. This may be due to the fact that different strains are imposed on different parts of the cod-end. For instance, when the catch is being lifted on board, the netting is particularly tightly strained between the top of the catch and the lifting strop, while above the strop the netting is hanging slack. Clark (1952, a, b) showed with four different manila cod-ends that when they had been used for some time the meshes in the after part of the cod-end became up to 10 per cent larger than those in the fore part. The knots may contribute quite an appreciable amount of twine to the mesh if they are subjected to a heavy strain before they have time to shrink. Thus the ultimate size of a mesh depends not only on the amount of strain imposed, but also on which comes first, strain or shrinkage, so that it is not altogether surprising that the distribution of mesh sizes is somewhat complex. For this reason it is desirable that a systematic rather than a random method of sampling mesh size be used, so that all the different parts of the cod-end will be proportionately represented. In studying the changes in mesh size of the same cod-end the greatest efficiency in sampling would be gained if the same individual meshes were measured on each occasion. Such a system was adopted toward the end of series 5, but the improvement was made too late to have any great significance in these results. Making due allowance for all sources of error, it would seem that the measurements given are probably sufficiently accurate to detect any change or variation in mesh size greater than 0·1 of an inch.

It is difficult to account for the fact that in series 5 standard deviations are fairly consistently two to three times as large as in series 1 and 2. This might appear at first sight to be due to the two different measuring techniques used. However, a difference just as large appears between the two 5 in. cod-ends in series 5 where the same technique was used under carefully controlled conditions in both cases. The difference in this case is almost certainly due to the fact that one (the single twine) was an old, the other (the double twine) a new, cod-end.

Some significant differences in the mean mesh size as determined by different techniques of measuring may be seen. Measurements are in general increased by using a heavier weight and decreased by wetting the net. Thus the 5 in. single mesh shrunk nearly 0·2 in. when wet and stretched 0·3 in. again when the weight was increased from 1 lb. to 10 lb.

It is obvious that any mesh measurement can only be an approximation to the actual size assumed while the trawl is subjected to the variable strains of being towed. The technique chosen is therefore dependent mainly on considerations of expediency. Ten pounds was taken as a standard because a lighter weight, say 5 lb., was insufficient to straighten out the mesh, particularly of heavy double twine, while any appreciably greater weight (say 20 lb.) had a tendency to enlarge the mesh permanently. Also, 10 lb. is approximately the pressure which can conveniently be exerted by a normal person stretching the net by hand. A laboratory experiment was set up to determine the effects of varying weights. A piece of well-used 5 in. double twine manila cod-end netting four meshes long and two meshes wide was subjected to a series of different tensions from 1 lb. up to 60 lb., measurements being taken at 10 lb. tension both before and after the experiment. The same piece of netting was treated in three different ways:

(*a*) Wet; knots simply threaded over a hook at either end.
(*b*) Wet; all knots whipped with fine wire to prevent slipping.
(*c*) As in (*b*), but dry.

In general, results were variable and difficult to reproduce, but the following are sufficiently representative for present purposes:

In (*a*) the knots began to be pulled out of shape at about 20 lb. tension, and the mesh size was permanently increased by 5 to 10 per cent.

In (*b*) the knots were not distorted, but the mesh size was permanently increased by about 3 per cent. The twine lost an appreciable amount of water content during the process.

In (*c*) the mesh size was permanently increased by about 1 per cent.

From these results it was concluded that the actual process of measuring may in itself affect the mesh size. At least three factors contribute to this effect:

(*a*) Distortion of the knots.
(*b*) Squeezing of water out of the twine.
(*c*) Exceeding the elastic limit of the twine.

For these reasons the tension applied should not at any time exceed the minimum required to straighten the twine effectively, viz., 10 lb.

It is more satisfactory, both for research and for administrative purposes, to measure wet netting, because that is how it is usually encountered at sea and because it is far easier to wet a dry net than to dry a wet one. In a further experiment the same sample of netting was measured at different degrees of wetness, using a 10 lb. weight. It was found that the mesh size became progressively less as the wetness increased, with a maximum variation of about 5 per cent between thoroughly wet and completely dry.

From the above considerations it is concluded that the method of measuring mesh size must be carefully standardized. The netting should be thoroughly saturated with water immediately before measuring, while the stretching weight should be 10 lb. and no more at any stage before the final measurement is recorded.

It is often very obvious that the nominal mesh of the netting may be greatly changed after shrinkage has taken place. For instance, the second single 4 in. cod-end in series 5 is $\frac{3}{4}$ in. below its specified measurement and almost all the other nets show shrinkage to some degree. It is perhaps coincidence rather than anything else that the meshes in series 1 and 2 are so close to their nominal value. Perhaps they were very loosely braided in the first place. The actual amount of shrinkage that can take place after the first wetting is shown in the 5 in. double cod-end, series 5. This was supplied by a well-known Scottish firm, and when measured dry with the 1 lb. weight proved to be almost exactly 5 in. in mesh and slightly more with the 10 lb. weight. After one shot, more than half an inch shrinkage had taken place. After a second shot the additional difference was barely significant. If anything, a little stretching had taken place, possibly owing to the tightening of the knots by a rather heavier catch. The effect of tanning has so far not been investigated, though it is known that repeated tannings can continue to shrink a net. The 5 in. single cod-end in series 2 was retanned and stored at the completion of the series and was brought into use again for series 5. Apparently about 0·3 in. shrinkage had taken place in the meantime.

There are a number of causes which may contribute to shrinkage and to variations in shrinkage. Sometimes even the spools, though nominally the right size, may vary. Different netmakers with different degrees of skill may wrap the twine more or less tightly round the spool or tie the knot more or less firmly. Different types of twine will doubtless vary in their properties, though this should not apply to any marked degree to the manila cod-ends in these experiments, since the same grade of twine was used throughout. The size of the first or the first few catches may be important. Tanning and even storage may also play their part. As a rule, mimosa bark " cutch " was used in this work, but there is no complete record of the treatment of different cod-ends. Just as in the cod-end, different parts of the trawl may undergo different strains which may cause considerable differences in mesh size. For instance, in the belly and batings of the series 5 trawl, though they were of identical machine-made sheet netting (nominally $4\frac{3}{4}$ in.) and had had the same amount of use, the same tanning, etc., there is a difference of nearly half an inch in their ultimate size.

Conclusion 1.—That significant variations in the size of a mesh may be produced not only by the preservation treatment and conditions of use, but by the method employed in measuring. Of the methods tested, the most consistent and least variable measurement was that taken (inside opposite knots) while the twine was saturated with sea water and the mesh stretched to a tension of 10 lb. This standard may not, however, be applicable to nets of heavier or lighter twine than those investigated.

4.2. THE SQUARE-MESHED COD-END

The experimental method used in evaluating the square-meshed cod-end is perhaps an unusual variation of the covered cod-end method in that the cover instead of being of a very small mesh is actually the same mesh size as the cod-end. Although the cover will not retain all the escaping fish, neither will it release them all. It will have its own escapement curve, not necessarily the same curve that

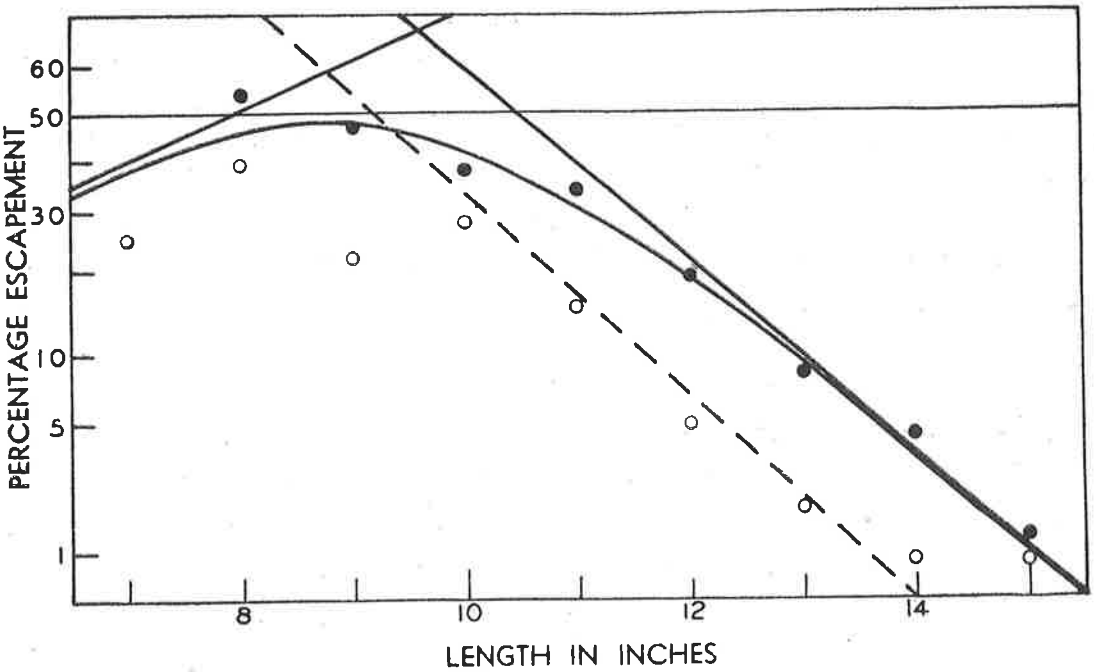


FIG. 9. Escapement curves for the square-meshed cod-end (Table 6)

would operate if it had been used as a cod-end,* but the number of fish retained or released will still be governed by similar laws.

Each fish will have a probability p_1 of escaping from the cod-end and a further probability p_2 of escaping from the cover. The resultant probability p of escaping from the cod-end but not from the cover will be the product:

$$p = p_1 (100 - p_2)/100$$

On probability paper the resultant curve will be hyperboloid with asymptotes formed by the escapement curve of the cod-end and the retention (or inverse escapement) curve of the cover.

The data from Table 6 is plotted in Fig. 9, the circles and broken line referring to " square inside diamond ", the dots and unbroken lines to " diamond inside square ". The range of data is barely adequate to give the cover retention curves accurately, though an attempt has been made to do this for the square meshed cover. The resultant curve for " diamond inside square " gives a good fit to the data, though doubtless quite a wide range of solutions would have been just as acceptable. The " square inside diamond " points are more erratic and a resultant curve has not been fitted though the general trend is much the same. It is clear, however, that the escapement curve for the square-meshed cod-end is significantly (about 1 in.) lower than for the diamond, though the selection index is very much the same.

* In fact, it would appear from Fig. 9 that quite a different escapement operates with the cover, otherwise the curve for the square-meshed cover (unbroken straight line ascending from left to right) would be the mirror image of the curve for the square-meshed cod-end (broken line). This is not unexpected, since a fish which has already struggled through one set of meshes may well be left with depleted strength when it meets a second barrier.

Though the data is perhaps too scarce for an exact quantitative comparison of performance, it shows fairly conclusively that the square mesh releases fewer fish and has no better selective properties than the corresponding diamond mesh. Since the square meshed cod-end also has several practical disadvantages to the commercial fisherman, there seems to be no point in following this line of investigation further. This conclusion is supported by the work of Herrington (1935).

Conclusion 2.—That a square-meshed cod-end is a less efficient releaser of small fish than a normal cod-end of the same mesh size.

4.3. COVERED NET EXPERIMENTS

To facilitate comparisons, several curves have been grouped together in each diagram, Figs. 10 to 14 being for series 2 and Figs. 15, 16 for series 5.

Figure 10 gives the curves for all the single twine cod-ends in series 2; 4, 5, and 6 in. respectively (Tables 7 to 9). It is quite clear that all are of very similar shape and more or less parallel, and that the larger the mesh size the farther the curve moves over to the right.

Figure 11 compares 4 in. cod-ends of single and double twine (Tables 7, 10). The curves are almost identical, except near the upper extremity, where the points for the double twine tend to dip down below the extrapolation of the curve. (Note that the double twine has a separate length scale along the top of the graph.)

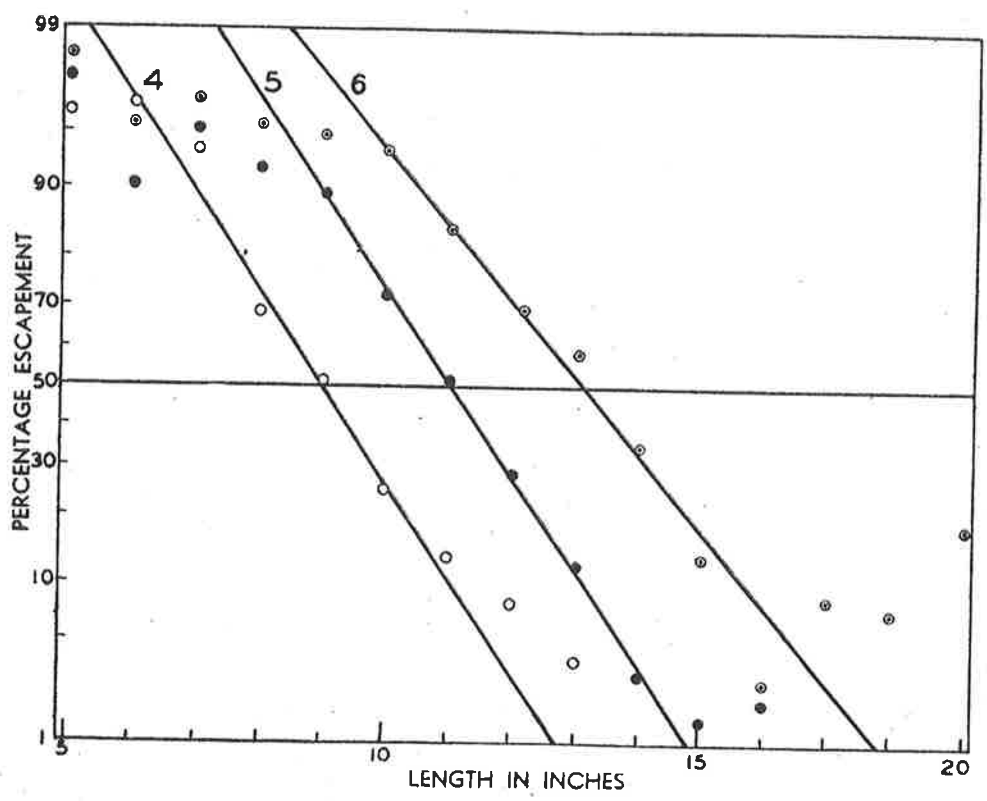


FIG. 10. Escapement curves, 4, 5, and 6 in. single twine cod-ends (series 2, Tables 7 to 9)

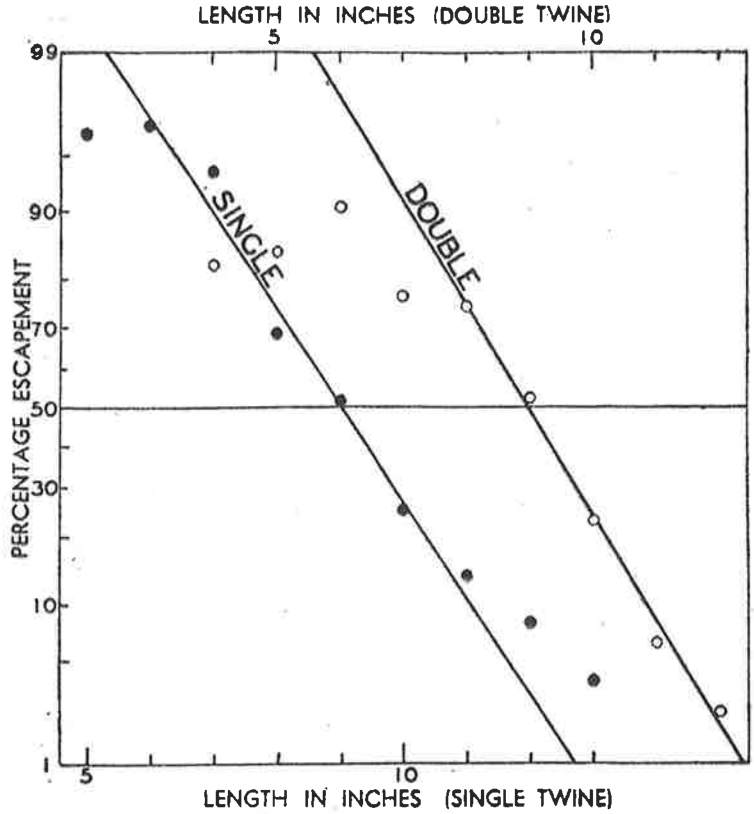


FIG. 11. Escapement curves, 4 in. single and double twine cod-ends (series 2, Tables 7, 10)

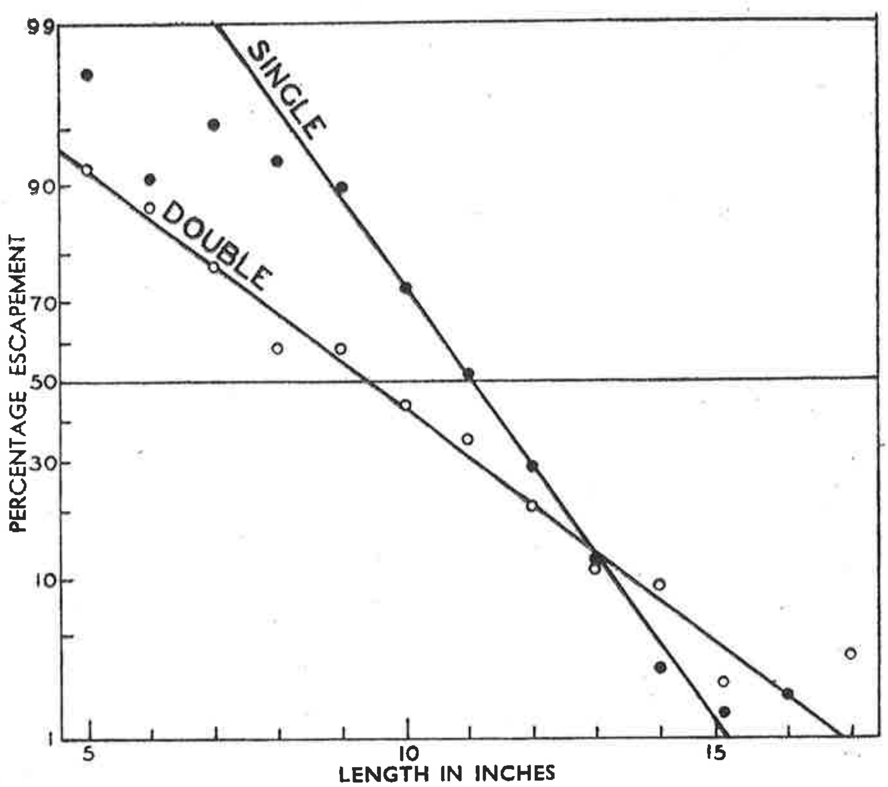


FIG. 12. Escapement curves, 5 in. single and double twine cod-ends (series 2, Tables 8, 11)

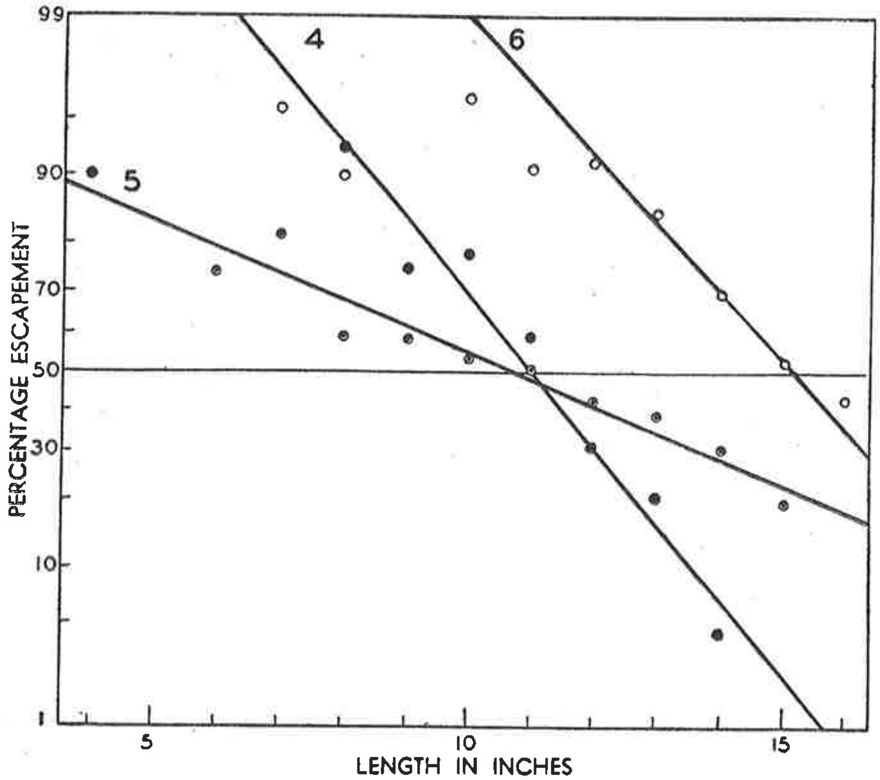


Fig. 13. Escapement curves for gurnard; 4, 5, and 6 in. cod-ends (Tables 12 to 14)

Figure 12 compares the 5 in. single and double twine cod-ends (Tables 8, 11). Here, unlike the previous figure, the difference between the two curves is pronounced. The double twine seems to produce rather anomalous results with escapement index relatively low and selection index high in comparison with the single twine.

Figure 13 gives results for the gurnard (*Chelidonichthes kumu*) using the 4 in. double and 5 in. and 6 in. single cod-ends (Tables 12 to 14). Here again the 4 in. and 6 in. curves are parallel with the 6 in. curve displaced to the right, but the 5 in. curve, instead of occupying an intermediate position as might be expected, leans well over to the left, rather like the apparently anomalous 5 in. double twine curve in Fig. 12.

Figure 14 gives the only data so far available for the tarakihi (*Cheilodactylus macropterus*), using a 5 in. single twine cod-end (Table 15). The data is scarcely adequate to give reliable results, though the points seem to fit the curve quite well in the size range represented.

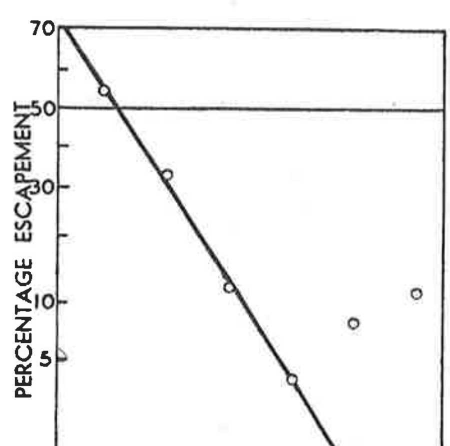


Fig. 14. Escapement curve for tarakihi; 4 in. cod-end (Table 15)

Figure 15 compares the 4 in. and 5 in. single

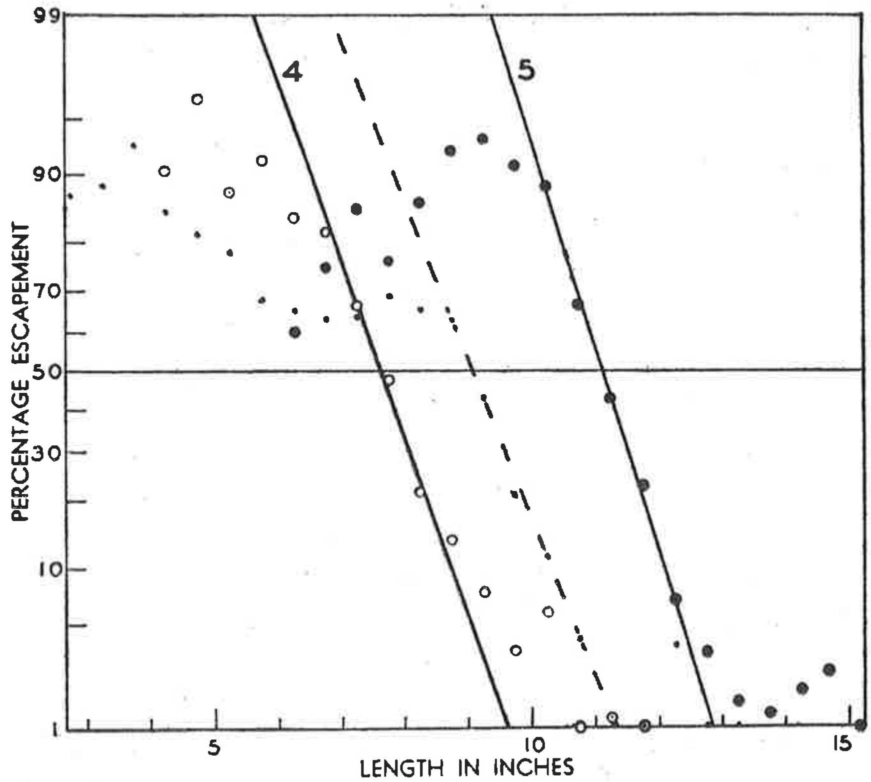


Fig. 15. Escapement curves, 4 in. and 5 in. single twine cod-ends (series 5, Tables 16 to 18)

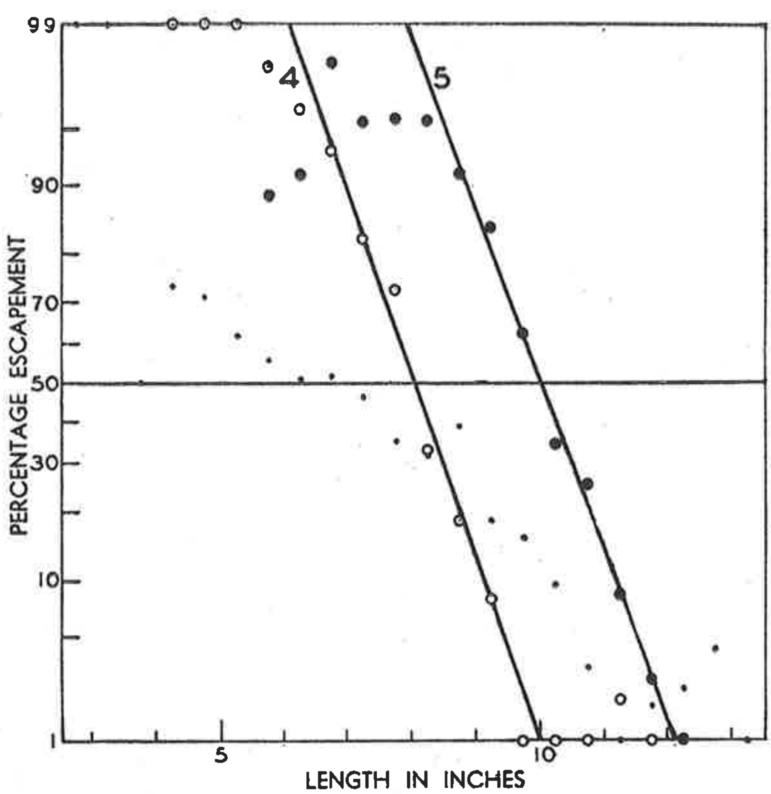


Fig. 16. Escapement curves, 4 in. and 5 in. double twine cod-ends (series 5, Tables 19 to 21)

twine cod-ends in series 5 (Tables 16 to 18). The broken line and small dots represent the first set of data which were obtained for the 4 in. cod-end and which were rejected because they seem to be somewhat anomalous. The second set, which was made to check on this anomaly, appears to be quite normal. The two unbroken lines are very similar and occupy the same relative positions as would be expected from series 2 results. However, the slope is very much steeper in both cases and hence the selection must be sharper than in series 2. A further difference lies in the fact that the curve not only departs from linear for the small sizes of fish, but also tends to dip down again towards the left, suggesting that in this part of the size range escapement decreases instead of increasing with decreasing fish size, as is usually the case.

Figure 16 compares the 4 in. and 5 in. double twine in series 5 (Tables 19 to 21). Here again part of the 4 in. data appears to be anomalous and the first set (small dots) will be ignored. The downward trend at the left-hand extremity of the curve appears again in the 5 in., but strangely enough it is entirely absent in the 4 in. curve.

4.3.1. GOODNESS OF FIT

The escapement parameters and related statistics are summarized in Table 25. The column headed P shows the results of the χ^2 test for those portions of the curve which have been fitted, while column *d.f.* gives the number of degrees of freedom involved. Twelve values of P are above the 0·05 confidence limits, one is less than

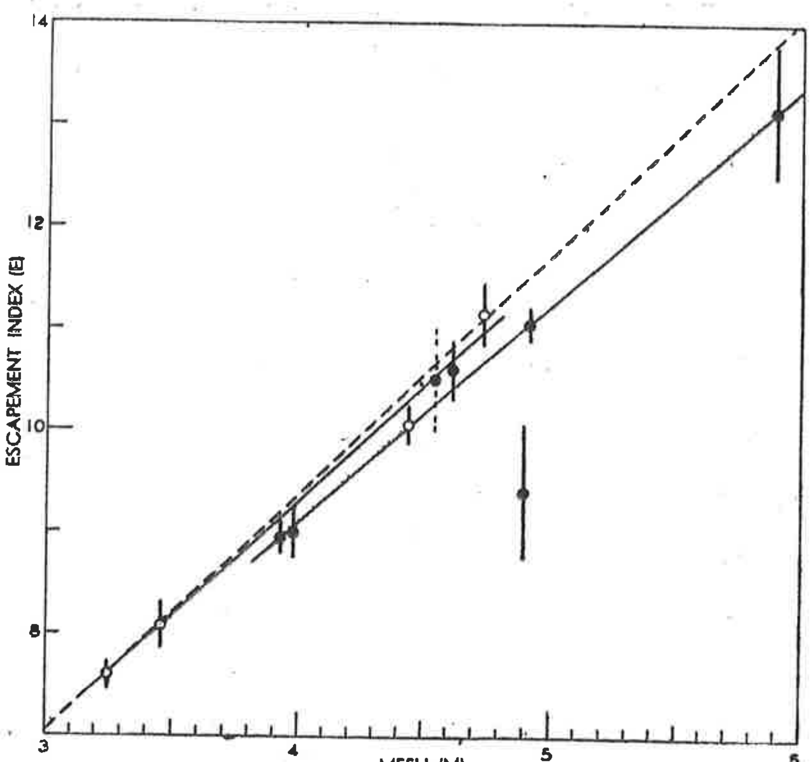


Fig. 17. Regression of escapement index on mesh size (Table 25)

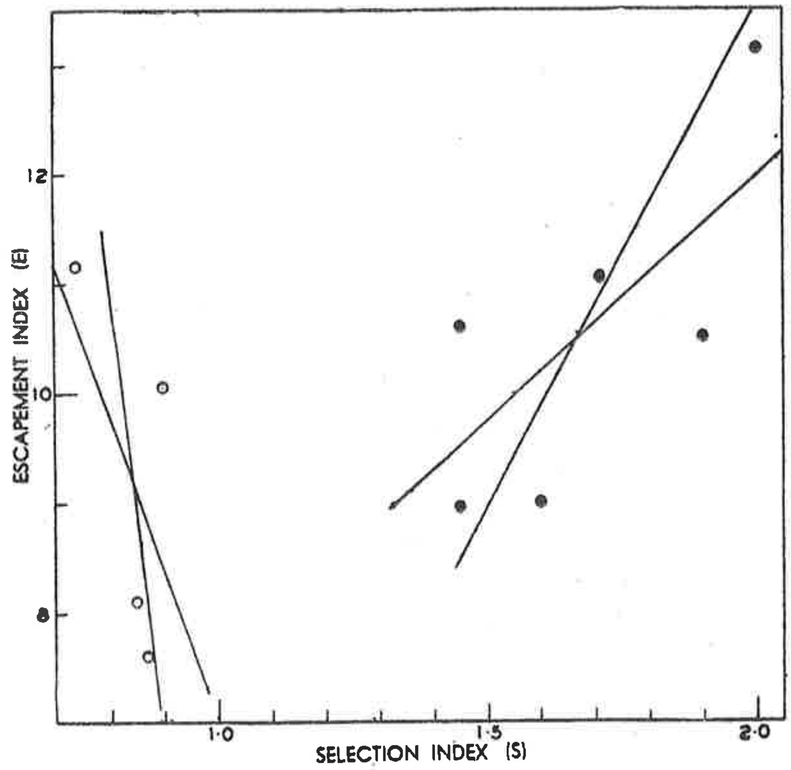


Fig. 18. Correlation of escapement index with selection index (Table 25)

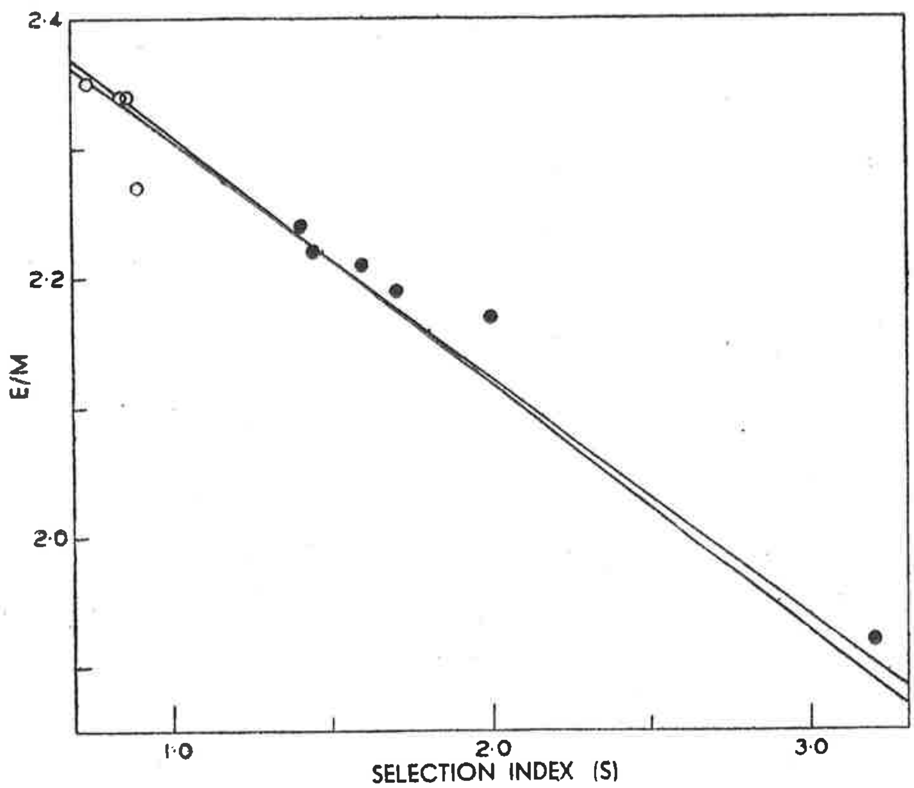


Fig. 19. Correlation of (escapement index)/(mesh size) with selection index (Table 25)

0·05, and two less than 0·01. It is believed the curves as fitted can be taken as valid in spite of these significantly divergent cases. It will be shown below that there is some degree of variation in the escapement and selection indices, particularly the latter, for individual shots, possibly due to an inherent variability in the behaviour of the trawl. This will mean that, unless a large number of shots are made, sampling errors at any one point need not necessarily cancel each other out, and may indeed be cumulative to some degree. For this reason, and also because even the divergent results seem to fit into a general pattern, it is proposed to tolerate in a few cases a somewhat higher deviation than the usual limits of confidence would allow.

Conclusion 3.—That the fitting of escapement data to the normal ogive is valid at least in the 90 per cent to 5 per cent range.

4.3.2. RELATIONSHIP BETWEEN MESH SIZE, ESCAPEMENT, AND SELECTION

In examining Table 25 the most obvious relationship is the apparent correlation between size of mesh (M) and escapement index (E). Figure 17 shows E plotted against M. Series 2 is plotted as dots and series 5 as circles, while the heavy vertical line through each point gives the range $E \pm 2s_e$. The two unbroken oblique lines represent the regression of E on M in the two series. The 5 in. single cod-end control shot (series 5) is plotted as part of series 2, to which it is more akin, and the 1 lb. dry mesh measurement (4·62 in.) is used. The correlation is immediately obvious, with only one aberrant point, the 5 in. double twine cod-end, series 2. This has already been seen to be an anomalous curve. If this one point is ignored the correlation is highly significant, 0·998 for series 2 and 0·996 for series 5.* The regression curves for the two series are parallel, but series 2 gives a slightly lower ratio of escapement index to mesh size. This difference would probably be intensified if the same system of mesh measurement had been used for both series, since the dry measurement using a 1 lb. weight is somewhat lower than the wet measurement using a 10 lb. weight.

The relationship of the selection index (S) to the other indices is less plain. Figure 18 shows E plotted against S, series 2 and 5 being shown again as dots and circles respectively. Series 5 shows a negative correlation of −0·572, while series 2 shows a positive correlation of 0·713 if the aberrant 5 in. double twine is ignored. Both are rejected as not significant at the 0·05 confidence level.

---

* In computing the correlations and the regression curves the weighting factors (W, Table 25) have been applied. W is the number of fish in the four size groups nearest to the 50 per cent escapement level, divided by 100 and expressed to the nearest whole number. The statistics for the two curves are as follows:

Where $E = a + bM$
r = correlation coefficient.

	Series 2	Series 5
a	0·5521	0·1804
b	2·1385	2·2763
r	0·9984	0·9955

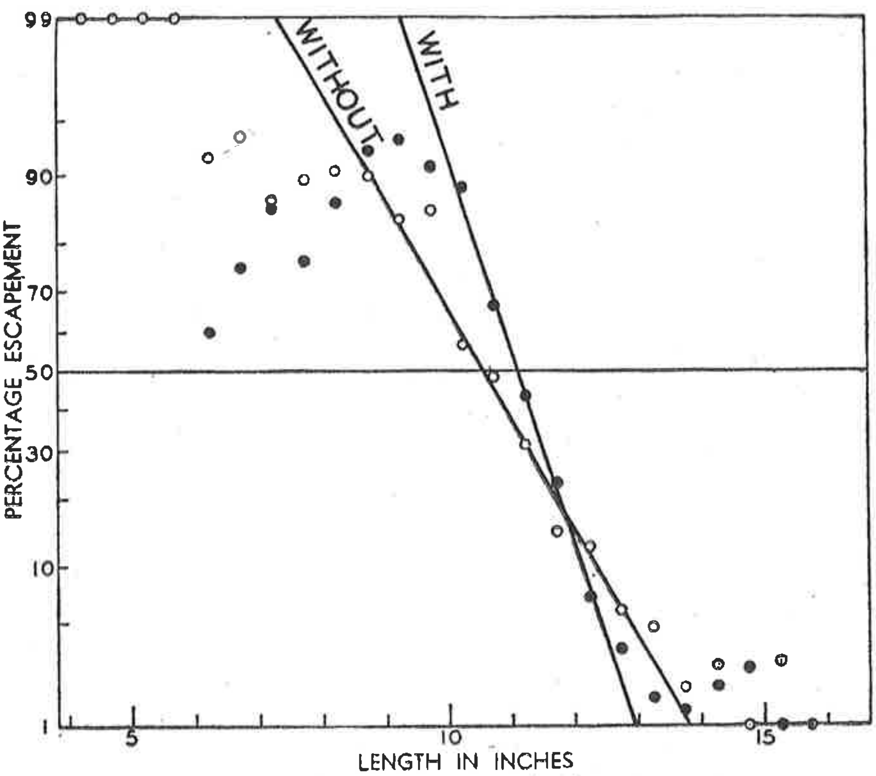


FIG. 20. Escapement curves for 5 in. single twine cod-end, with and without toggle attachment for cover (Tables 18, 22)

In Fig. 19 the value E/M (Table 24) is plotted against S.* When the effect of varying mesh size is thus eliminated there is found to be a highly significant negative correlation of $-0{\cdot}980$.

Conclusion 4.—That there is a positive correlation and very nearly a direct proportional relationship between mesh size and escapement index.

Conclusion 5.—That the type of cover used in series 5 allows a greater number of fish to pass through the cod-end and also has a sharper selective action than that used in series 2.

Conclusion 6.—That when the escapement index is expressed in terms of the mesh size it is negatively correlated with the selection index.

4.3.3. RELATIONSHIP BETWEEN SERIES 2 AND 5

It has already been shown that there are consistent differences between the E and S values determined by the two methods. Figure 20 shows the results of a control experiment which was conducted to ensure that the difference in results was due to the different experimental procedures and not to the fact that a different trawl was used in the second series. The curve " WITH " (toggles) is for the 5 in.

* To compensate for the different techniques of mesh measurement the series 2 mesh sizes are multiplied first by 4·74/4·62, which is the ratio between the measurements by the two methods in Table 5, columns *b* and *d*. The correction is not a very precise one, but it is the best available.

single twine cod-end using normal series 5 attachment (Table 18), while the curve "WITHOUT" is for the same cod-end in a series of shots made immediately after but using the series 2 attachment (Table 22). The two are quite distinct, WITHOUT giving a lower escapement index and a higher selection index, showing that the difference in results by the two methods was at least partly due to the experimental method. The series 2 curve is not exactly reproduced, since the escapement index is still slightly higher and the selection index lower. (See table below.) However, two simple corrections are sufficient to explain this difference. In the first place, although the same 5 in. cod-end was used throughout, in series 5 its previous mesh size of 4·92 in. had been reduced to 4·74 in. Multiply the series 5 escapement index by 4·92/4·74 and it becomes almost identical with the series 2 index. Further, in series 2 a number of very small catches were taken, while in series 5 all catches are large. It will be shown later (section 4.3.8) that the size of the catch may have quite a substantial effect on the escapement index. If, instead of the curve for all series 2 data, we take instead only those catches where over 175 fish were taken (Fig. 30), the selection index is found to be almost identical with that for the control experiment. The following table gives all the data pertinent to the above argument:

	M	*E*	*S*
Series 5	4·74	11·15	0·74
Control experiment	4·74	10·6	1·41
Series 2	4·92	11·05	1·71
Control experiment corrected	4·92	11·0	1·41
Series 2, > 175	4·92	11·05	1·53

Conclusion 7.—That the higher escapement and lower selection index in series 5 is due to the improved method of suspension of the cod-end, and that series 5 results are therefore nearer to the truth than series 2.

4.3.4. COMPARISON OF RESULTS WITH EXPECTATION

In estimating the validity of results at this stage it is useful to consider the type of curve that might be expected. Firstly, regarding the escapement index. The snapper is a fairly smooth fish with few projecting parts which might impede its forward progress through a mesh. It seems that any fish which had a maximum girth equal to the circumference of a mesh would have about an even chance of escaping. The length of this fish would then be equal to the escapement index. Since trawl twine is somewhat elastic, the mesh circumference varies with the tension applied to it and cannot be precisely defined. However, the 10 lb. weight probably gives a fairly close approximation to the maximum extension which could be used effectively by the fish. With greater tension any gain in circumference would tend to be counteracted by the relative inflexibility of the aperture, which would become a rigid diamond, and would not adapt itself so well as before to the oval shape of the fish passing through (Fig. 24). Thus, consideration of the relationship between the length: girth ratio of the snapper and the 10 lb. mesh measurement should give a fairly reliable estimate of the maximum value to be expected for the escapement index. The ratio of length to maximum girth of the snapper has been found to follow very closely the equation:

$$\text{Fork length} = 1{\cdot}174 \times \text{maximum girth.}^{*}$$

This leads to a new estimate of E which will be designated by the symbol E':

$$E' = 1{\cdot}174 \times 2M$$
$$= 2{\cdot}35M.$$

Returning to Fig. 17, this regression is shown by the broken diagonal line. It is seen that points for all the series 2 experiments fall somewhat below this curve. If the 10 lb. mesh measurement had been used they would have been further below. On the other hand, three out of the four series 5 points coincide almost exactly with the curve. The fourth represents the 5 in. double twine cod-end which was brand new and untanned at the time and may for this reason have behaved differently from the other more seasoned cod-ends. The general picture suggests a series of estimates, E, all tending toward the corresponding estimate E', but only reaching this ultimate value under the improved conditions of series 5.

As regards the selection index, it is not so easy to set any precise expected values, but it is possible nevertheless to make some useful deductions. The following table shows for three selected cod-ends the respective lengths at which 90 per cent, 50 per cent, and 10 per cent escapement occurs, while the last column, E', shows the expected escapement index:

	90 Per Cent	50 Per Cent	10 Per Cent	E'
(1) 5 in. single, series 5 ..	10·2	11·2	12·2	11·2
(2) 5 in. single, series 2 ..	8·8	11·0	13·2	11·8
(3) 5 in. double, series 2 ..	5·3	9·4	13·5	11·8

Every inch added to or subtracted from the length of a snapper makes a corresponding difference of 0·86 in. to its girth.† Subtracting E' from each of the lengths and multiplying by 0·86 gives the difference between the girth of the fish and the circumference of the mesh as follows:

	90 Per Cent	50 Per Cent	10 Per Cent
(1)	0·9	0·0	−0·9
(2)	2·6	0·7	−1·2
(3)	5·6	2·1	−1·5

*The statistics upon which the equation is based, taken from a sample of 134 snapper, are as follows:

Where X = fork length,
Y = maximum girth,
If $Y = a + bX$,
$b = 0{\cdot}8038$,
$a = 0{\cdot}3007$,
Standard error of regression, $s_{y.x} = 0{\cdot}4657$,

Since a does not differ significantly from zero, the regression may be expressed in the simpler form:

$Y = b'X$,
Where $b' = 0{\cdot}8521$,
Maximum girth = $0{\cdot}8521 \times$ fork length,
or Fork length = $1{\cdot}1736 \times$ maximum girth.

† Since these figures remain constant regardless of the size of the fish, it will not be surprising to find the conclusion reached in the following section that the selection index also tends to remain constant.

All the figures in the 10 per cent column appear reasonable, i.e., a fish with a girth 1 in. to $1\frac{1}{2}$ in. greater than the mesh circumference would be expected to have a fairly low chance of escape, though about one in ten might struggle through. On the other hand, the 90 per cent figures vary considerably in their apparent likelihood. Here 0·9 in. seems a far more likely figure than 5·6 in. or even 2·6 in. for the amount of clearance that would be required to allow nine out of ten fish to escape. The 50 per cent escapement has been discussed already, and it will be seen in the table that the degree of agreement with expectation is in the same descending order as the 90 per cent column, though the range is less extreme.

If this process of reasoning is applied to all the curves (including those rejected as anomalous), it is found that as a general rule the escapement of larger fish is near to expectation, but that at the other end of the curve the solution is increasingly unlikely as the selection index becomes larger. This is undoubtedly a manifestation of the " masking " effect of the cover referred to by various authors. It would seem, therefore, that the lowest estimates of S are those nearest the truth. This is to be expected, since it has been shown that E and S are negatively correlated and that the best estimates of E are the highest ones.

Conclusion 8.—That the escapement index, E, as determined by the covered net method is an estimate of the true escapement index (which may be designated as ε), but tends to be biased towards a lower value. This bias has apparently been reduced to a negligible value by the improved technique used in series 5.

Conclusion 9.—That the escapement index, E', which is the average length of a fish having its maximum girth equal to the mesh circumference, is also an estimate of ε. For the snapper, $E' = 2{\cdot}35 \times$ mesh measurement. This estimate may also be biased, but only to a very slight degree. Provided that the same method of measuring mesh size is used, E' will always bear the same proportional relationship to M.

Conclusion 10.—That S is an estimate of the true selection index σ, but tends to be biased toward a higher value. The lowest value of S will be the nearest to the correct estimate and normally occurs in conjunction with the truest estimate of E.

4.3.5. ANOMALOUS CURVES

In several instances in previous sections certain sets of data have been rejected, or partly rejected, because they do not fit in with the pattern of other data. Four such cases must be considered:

(*a*) 5 in. double, series 2 (Fig. 12).
(*b*) 5 in. single, series 2, gurnard (Fig. 13).
(*c*) 4 in. single, series 5, first set (small dots, Fig. 15).
(*d*) 4 in. double, series 5, first set (small dots, Fig. 16).

In series 2, although the author was present when most of the shots in question were made, it was not realized until later, when a more critical analysis was made, that the figures were in any way unusual. Thus it was not possible to assess variations in setting up of the gear with this particular type of anomaly in mind. In the case of the 5 in. double twine, the cover had been slightly reduced in size by cutting out torn netting, and this may have increased its "masking" effect. The gurnard curve is less readily explained, since the snapper data obtained from the same shots were quite normal. It is possible that the setting of the cover was such that, while it allowed sufficient freedom for snapper to escape, the gurnard, a comparatively angular and in some respects "awkward" fish, were rather more seriously hampered in their efforts at escapement.

In series 5 some anomalies were anticipated, and with a better knowledge of the results to be expected it was possible to detect unusual results as soon as they appeared. The author was not present when the first set of shots was made with the 4 in. single cod-end, but when the results were noted the experiment was repeated taking greater care in attaching the cover, and results agreeing more closely with expectation were achieved on the second trial. The first shot with the 4 in. double twine was analysed during the second shot while the trawl was actually in the water. The curve was found to be anomalous, and when the trawl was raised at the end of the second shot the condition of the cover was noted before hauling aboard. The toggles were seen to be badly kinked by shrinkage, a condition which was not so obvious when the cod-end was on deck. This was rectified in the remaining shots, and the anomaly disappeared completely from the results.

Thus, although in only one case was the actual cause of unsatisfactory data traced to some definite cause, it is reasonable to assume that in other cases some cause was present, but was not detected. It will be noted that in each of the four cases considered the anomaly is of the same type: a depressed escapement at the left-hand extremity of the curve. In section 4.3.2 it has been shown that the 5 in. double twine cod-end, series 2, though it does not appear consistent with other results in its own series, can quite readily be reconciled with the other data when the three indices, E, M, and S are taken into account. The same could probably have been done with the gurnard curve if sufficient data had been available to correlate.

Series 5 experiments were conducted under the assumption that all estimates of escapement probabilities were subject to a variable negative bias. Hence any set of experiments producing consistently higher percentage escapements would be nearer the truth and all others should be rejected. The two anomalous curves are somewhat irregular, so that accurate escapement and selection indices are difficult to determine. Nevertheless, such estimates as can be made are not inconsistent with the correlation of E/M and S (Fig. 19), so that these two sets of data, though they are not in keeping with the remainder of series 5, do not in any way constitute exceptions to the general rules for escapement indices, which will be summarized in the next section.

Conclusion 11.—That although certain results have been ignored for the sake of convenience, they do not conflict in any way with the conclusions reached.

4.3.6. THE TRUE VALUES OF ESCAPEMENT AND SELECTION INDICES

Some of the conclusions reached above may now be expressed in equation form:

Conclusions 4 and 9:

$$E' = 2\cdot35M \doteq E \quad \ldots \quad (1)$$

Conclusions 6 and 8:

$$E/M = a + b/S \leq \epsilon/M \quad \ldots \quad (2)$$

(where a and b are constants).

Conclusion 10:

$$S \geqslant \sigma$$

In the ideal case, when $E = E' = \epsilon$ .. .. (3)

$$\text{from (1)}\ \epsilon = 2\cdot35M$$

$$(2)\ \epsilon = (a + b/S)M$$

$$\text{subtracting}\ 0 = [2\cdot35 - (a + b/S)]M$$

$$S = b/(2\cdot35 - a)$$

$$= \text{a constant}$$

Since in series 2 there are three cases in which E and E' are identical and may be assumed to be very close to the true value ε, the corresponding selection indices will be equally close estimates of σ. These estimates are:

	S
4 in. double twine cod-end	0·87
4 in. single twine cod-end	0·85
5 in. single twine cod-end	0·74

Conclusion 12.—That the escapement of snapper from single or double manila cod-ends is fully described, at least within the limits 90 per cent to 5 per cent, by the indices of escapement and selection where—

Escapement index $= 2\cdot35 \times$ mesh size.
Selection index $= 0\cdot8$ in.

4.3.7. THE ANOMALOUS EXTREMITIES OF THE CURVE

Outside the 90 per cent to 5 per cent limits the shape of the curve sometimes deviates significantly from the curve expressed by the above indices. There is a tendency for escapements less than 5 per cent to be too high and for escapements beyond 90 per cent to be too low.

Dealing first with the lower extremity: the anomaly here is less marked, and though sometimes statistically significant, it is at other times completely absent. It was frequently noted in this series of experiments (and indeed may be seen in almost any trawling) that when the net is hauled to the surface some fish, almost invariably the larger ones, are swimming actively forward and may escape from the mouth of the net. Now, a large fish, once having passed through the cod-end into the cover, is hardly likely to return to the cod-end. On the other hand, if it has remained in the cod-end it still has an opportunity of escaping without passing through any mesh at all. In doing so it will decrease the catch in the cod-end, and accordingly increase the apparent percentage of fish at that size which have escaped into the cover. This would be quite sufficient to explain the anomaly at the bottom of the curve. As a rule, it would only be necessary to assume that a relatively small number of fish (not more than ten) had escaped in this way, and the lower portion of the curve may therefore be fairly confidently extrapolated.*

The anomaly at the upper extremity of the curve is nearly always much more pronounced. In series 2 it usually takes the form of a general flattening out of the curve toward the horizontal, commencing at or above the 90 per cent level. In series 5 the effect is even more pronounced, since the curve often not only flattens out, but actually descends again for the smallest sizes of fish. There are several possible reasons for this:

(1) The " masking " effect of the cover, though substantially eliminated in the lower escapement levels, may be still effective above the 90 per cent level.

(2) Certain of the smaller fish may have escaped from the cover.

(3) The trawl may have a sorting effect on smaller fish before they reach the cod-end. This sorting will operate mainly for size in the central regions of the escapement curve, but among the very small fish, size may not be so critical as the varying physical and " psychological " make-up which may exist among fish even of the same size, giving some a greater tendency to escape than others. The smaller fish which reach the cod-end will be those which have the lowest tendency to escape, and the curve will be depressed accordingly.

(4) The true escapement cannot be fitted to the normal curve above the 90 per cent level.

The first explanation does not appear very likely, since in series 2, where some masking undoubtedly did occur, the anomalous values are less extreme than in series 5, where improved technique had greatly reduced masking. The second, too, is not consistent with results. For instance, in series 5 the 4 in. double twine cod-end has no anomaly at all, although the cover mesh was relatively large ($2\frac{1}{2}$ in.), while in series 2 the same cod-end has a fairly high anomaly, even though the $\frac{1}{2}$ in. cover could not have allowed any fish at all to escape. The third explanation would require that the number of fish which escaped before reaching the cod-end should be added to the cover catch. Taking as an example the 5 in. single twine, series 5, we find that about one thousand more fish below 8 in. in length would be sufficient to raise the whole of this part of the escapement curve to 90 per cent. In view of present knowledge of the size distribution of the snapper population, this does not seem an unreasonable figure. On the other hand, the number of fish required to make the whole curve a straight line would be well over a million, which seems a most improbable figure. Thus it seems that none of the first three suggested explanations can fully account for the departure of the curve from normal, though the tendency for the left-hand extremity to descend below 90 per cent may well be due to one or more of the three suggested causes.

---

* It might be possible to make more certain of this conclusion by repeating the experiments using a " floppa " or non-return valve at the mouth of the cod-end.

Conclusion 13.—That the curve described by the escapement indices is probably valid from 90 per cent to zero. For fish beyond the 90 per cent limit, escapement cannot be described by the normal curve, though it is probable that the effective proportion of fish escaping will always be 90 per cent or more in this range.

4.3.8. THE MASKING EFFECT OF THE COVER

The term "masking" has been used to describe the probable effect of the experimental cover on the cod-end. It is presumed that the effect, if any, will be that of reducing the number of fish which will pass through the cod-end, thereby shifting all or part of the curve to the left of its true position. It has been concluded in a previous section that this effect has been reduced to an insignificant level in certain more successful experiments, but it is useful at this stage to mention some of the views and results of Davis (1934).

Davis has attempted to estimate the error due to masking by two methods, firstly by the use of control shots under similar conditions but without the cover, and secondly by comparing results with those obtained by the replicate hauls method. In the control shot series he found that the ratio of the catch of uncovered to covered cod-end varied progressively with the size of fish. At 50 per cent escapement it was approximately unity, decreasing for larger and increasing for smaller sizes. This, he suggests, is a graded masking effect which varies inversely with the size of fish. This is, of course, in agreement with the conclusion reached in section 4.3.3. In correcting for masking, Davis applied (in effect) the following equation

$$p' = (rF - 2f'' + f''^2/rf')/rF$$

where p' = corrected probability of escapement.
f' = frequency of fish in covered cod-end.
f'' = frequency of fish in control shot.
F = frequency of fish in covered cod-end and cover.
r = $\Sigma_0^{10\%} f'' / \Sigma_0^{10\%} f'$

His uncorrected curve for haddock, using a $3\frac{1}{2}$ in. mesh, can be fitted for all values below 90 per cent with an escapement curve with $E = 9{\cdot}3$ in., $S = 1{\cdot}3$ in. (dots, Fig. 21). The corrections (circles, Fig. 21) increase E slightly (9·5 in.), but the slope is unaffected except above 90 per cent, where the anomalous points come more or less into line with the rest of the curve. This is quite contrary to the *Ikatere* results, where decreased masking produces a steeper curve and actually seems to intensify the anomalous nature of the upper extremity. In view of the somewhat arbitrary nature of these corrections just shown, it seems that little significance can be attached to them. In fact, Davis himself rejected them, though on somewhat different grounds.

In his replicate hauls experiments for a similar cod-end he obtains the curve shown (dots) in Fig. 22, giving an escapement index of 10·0 in. Davis points out that this is a minimum value, since the smaller mesh will not catch all the fish in the escapement range of the larger mesh. Thus the escapement index appears

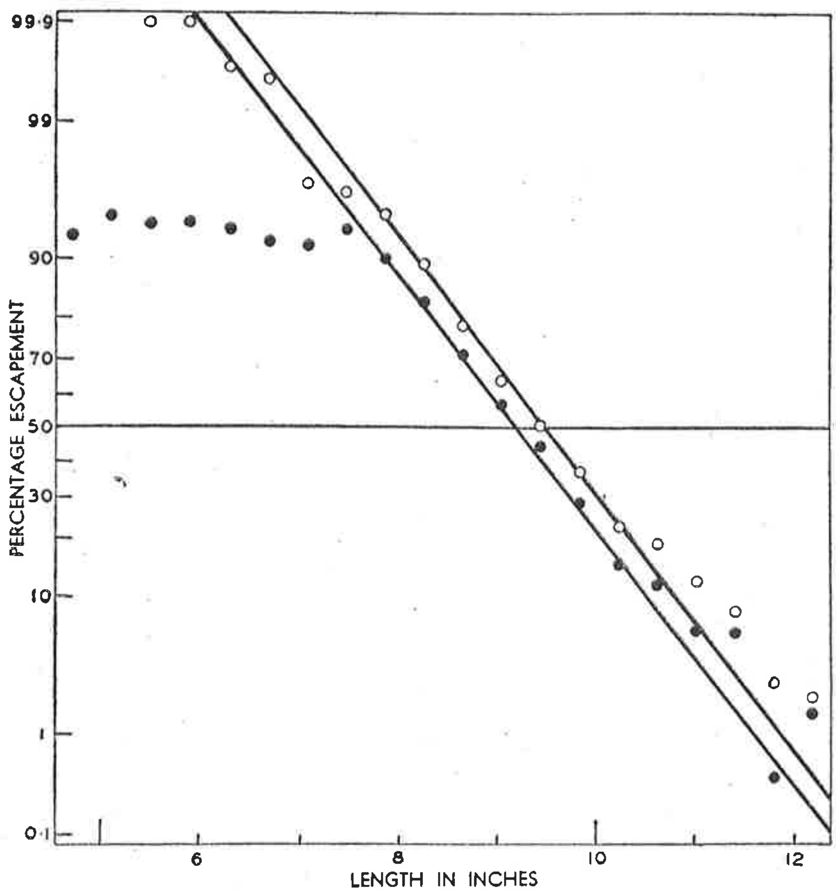


Fig. 21. Control experiment with covered cod-end (Davis, 1934) showing escapement curve (dots) with correction for masking (circles). Data from columns F and U of Davis's Table 14

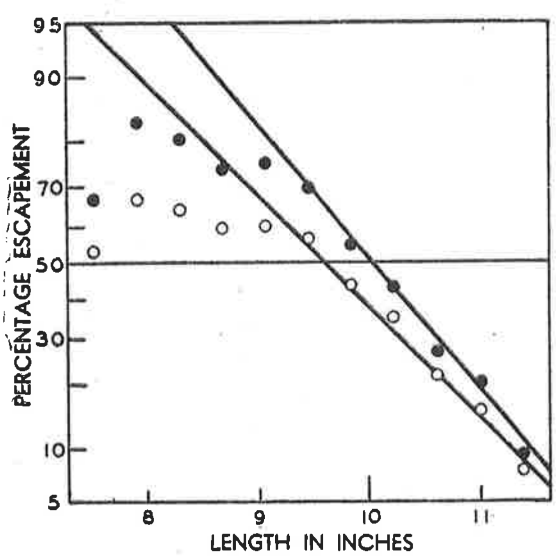


Fig. 22. Escapement curve (Davis, 1934) from replicate hauls experiment. Data (dots) from Davis's Table 5, column E. For circles see text, p. 52.

to be at least $\frac{3}{4}$ in. higher than even the corrected value for the covered net method. For this reason he decided that covered net experiments are unreliable for any accurate determination of mesh performance.

There are, however, two methods of reconciling the two sets of data. Firstly, it is not clear whether the same cod-end was used in both experiments, and, if not, whether any precautions were taken to ensure that the mesh sizes did not differ significantly. It is, however, mentioned that the $3\frac{1}{2}$ in. cod-end varies from 18 to 21 rows to the yard when new. This variation in itself is sufficient to explain discrepancies of up to $1\frac{1}{2}$ in. [10(21 — 18)/21] if different cod-ends were used in the two experiments. Secondly, it seems doubtful whether it is correct to express the large mesh catch as a percentage of the small without any correcting factor. In both cod-ends there is virtually no chance of a fish over 14 in. long escaping. In this size range the smaller mesh has caught only 80 per cent of the number in the larger mesh, suggesting that a correction of 80 per cent might be applied to the escapement percentages as was done by Herrington (1935). The curve corrected in this way (circles, Fig. 22) gives the indices $E = 9{\cdot}6$, $S = 1{\cdot}3$, which are almost identical with the corrected values for the covered cod-end.

Conclusion 14.—That the evidence examined does not appear to prejudice the assumption that the covered net method under suitable conditions can give a true quantitative estimate of escapement.

4.3.9. VARIABILITY OF RESULTS AND EFFECT OF VARYING CATCH SIZE

In order to obtain some estimate of the variation in results likely to arise, eighteen shots were made with the series 2, 5 in. single manila cod-end. Half of these shots took only small catches of fish (less than 175) and thus were not adequate for individual analysis, but the remaining nine were plotted separately and the escapement and selection indices determined in each case. The results are given in Table 26. E is more or less constant, varying from 10·9 to 11·3, giving a mean and standard error of about 11·0 and 0·1, both of which agree well with the values obtained from the pooled data. S is rather more variable and sometimes cannot be determined with sufficient accuracy, but there is nevertheless quite a significant difference apparent between the values for small and large catches. Though in individual catches of over 175 fish S varies from 1·2 to 1·65, in no case does it approach 2·35, which is the mean value for the smaller catches. The pooled data for large (>175) and small (<175) catches are plotted together in Fig. 23, showing this marked difference in slopes. This is quite in keeping with the theory of the action of the trawl already outlined, the plug of fish in the bottom of the cod-end tending to hold meshes open, so that a partly full cod-end has a sharper selection than an empty one. It is difficult at first to see why more small fish but fewer large ones are released by the open mesh. Figure 24 offers a possible explanation. When the mesh is taut and well open (a), the small fish, A, can escape more readily, but the larger fish, B, becomes a " round peg in a square hole " and cannot pass

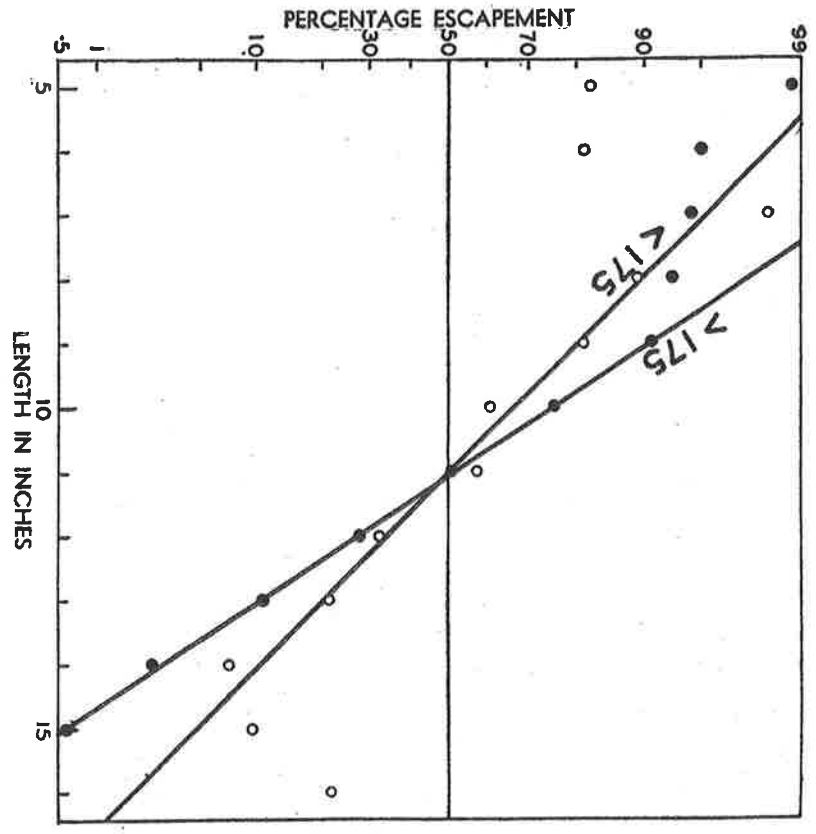


Fig. 23. Escapement curves, 5 in. single twine cod-end (series 2), for catches of greater and less than 175 snapper (Table 26)

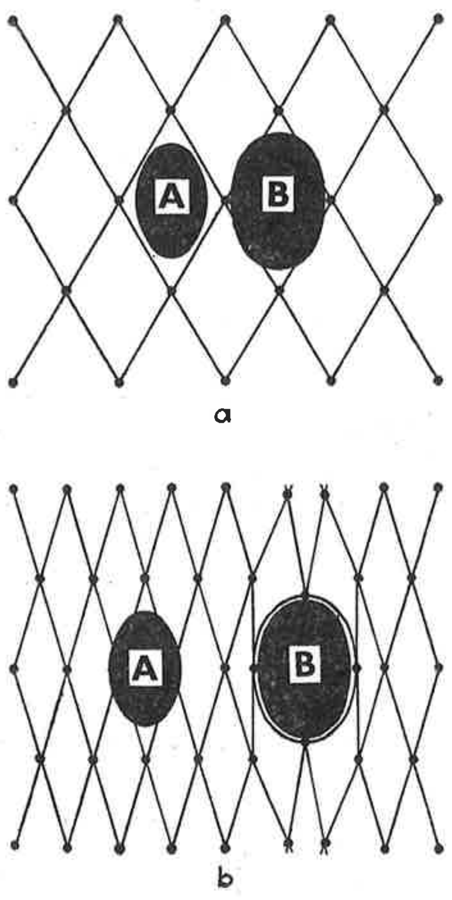


Fig. 24. Relationship of small (A) and large (B) fish to open, tightly stretched mesh (*a*) and partly closed slack mesh (*b*)

through owing to the shape and rigidity of the aperture. On the other hand, when the meshes are slack and partly closed, the smaller fish is faced by a narrow slit through which it is too weak to force a way, though the larger, stronger fish can adapt the mesh by force to its own shape and thus pass through. Table 27 gives similar though less comprehensive data for the 4 in. single twine cod-end in series 2, showing that the same relationship exists between large and small catches.

It is not possible to obtain any detailed test of correlation between selection index and catch size, since in all the smaller catches and in some larger catches the data are not sufficient to determine the selection index accurately. There does not appear to be any such correlation in the larger catches, which suggests that a threshold effect takes place, i.e., selection is improved as the first few fish collect and form a plug at the bottom of the cod-end, but once the plug reaches sufficient size to open the meshes to their fullest extent no further improvement can take place.

Conclusion 15. — That the selective action of the cod-end becomes sharper after some fish have accumulated, but the escapement index remains more or less constant. The sharpness of selection reaches a maximum when sufficient weight of fish has accumulated to hold the meshes fully open. In the trawl used by *Ikatere* the critical weight is about 300 lb. (the weight of 175 fish) or less.

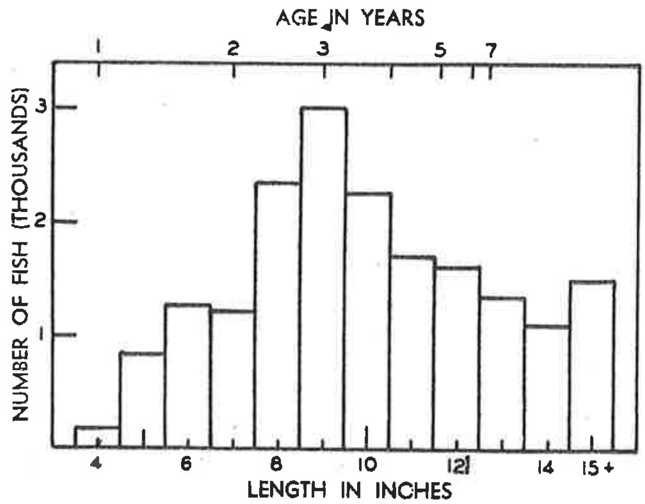


FIG. 25. Size distribution of all snapper caught in series 2 experiments

4.4. SOME OTHER CONSIDERATIONS

4.4.1. ESCAPEMENT FROM OTHER PARTS OF THE TRAWL

No direct attempt was made in these experiments to estimate what escapement takes place from other parts of the trawl beside the cod-end. However, the size distribution is known for all but the very smallest fish which pass into the cod-end, regardless of whether they eventually escape or not. If some estimate were available of the size frequency of all fish which initially pass into the mouth of the trawl it would be possible to calculate the numbers which escape before they reach the cod-end.

The following estimates are based on the assumptions—

(1) That the age frequency of the fish passing into the trawl is similar to the age frequency of the fish population, in that the number of fish will be less in each successive year class.

(2) That (if due allowance is made for fluctuations in annual recruitment) the number of fish will decrease by roughly the same proportion (or mortality rate) from any one year class to the next.

It is true that neither (1) nor (2) can be proven absolutely, and in fact there is good reason to believe that no trawl catch is truly representative of the fish population. Nevertheless, it would appear from consideration of a considerable number of catches, both with commercial and with small-meshed biological trawls, that these two assumptions, biased though they may be, explain the size and age distribution of the catch better than any other simple hypothesis.

Figures 25 and 26 show the length frequency of all catches (including cover catches) for series 2 and 5 respectively. Both have a similar shape and the discussion will be limited to Fig. 26, though the same argument can be applied to both. Along the top of the graph is a scale of age. Using this scale, and making appropriate adjustments, it is possible to convert this figure to an age frequency distribution. This has been done in Fig. 27, where frequency has been plotted on a logarithmic scale against age. From four years onward the points fall roughly on the unbroken straight line, representing a constant mortality of about 45 per cent per annum. Extrapolating backwards to one year gives an estimate of the true age distribution of the fish which passed into the trawl. This in turn permits an estimate of the escapement, p, in the range one to four years—

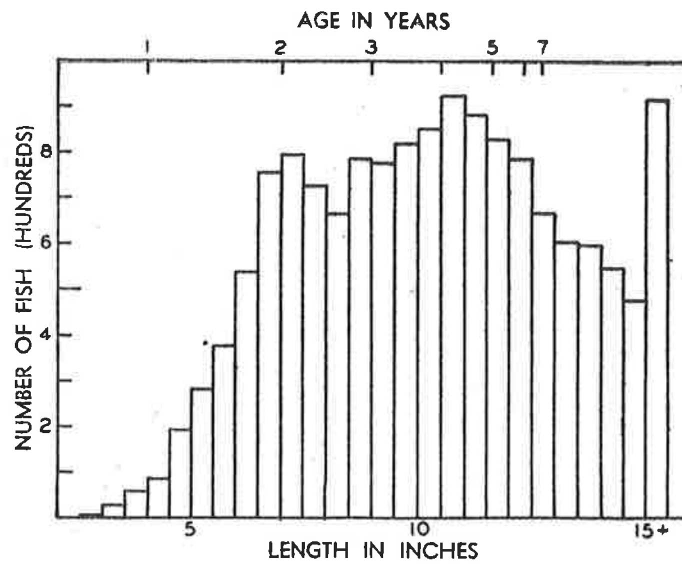


Fig. 26. Size distribution of all snapper caught in series 5 experiments

$$p = 100(F' - F)/F$$

where F = actual catch frequency.

F' = potential catch frequency from extrapolated curve.

The resulting points are plotted in Fig. 28 giving the escapement and selection indices

$$E = 8{\cdot}6$$
$$S = 2{\cdot}9$$

The broken line in the same figure represents the escapement curve which would be expected from a cod-end with a mesh of 4·3 in., which is the average figure for belly and batings of the trawl. The indices are

$$E = 10{\cdot}1$$
$$S = 0{\cdot}8$$

By the reverse process the age frequency curve can be corrected for this estimate of escapement giving the points which are plotted as circles in Fig. 27. The broken

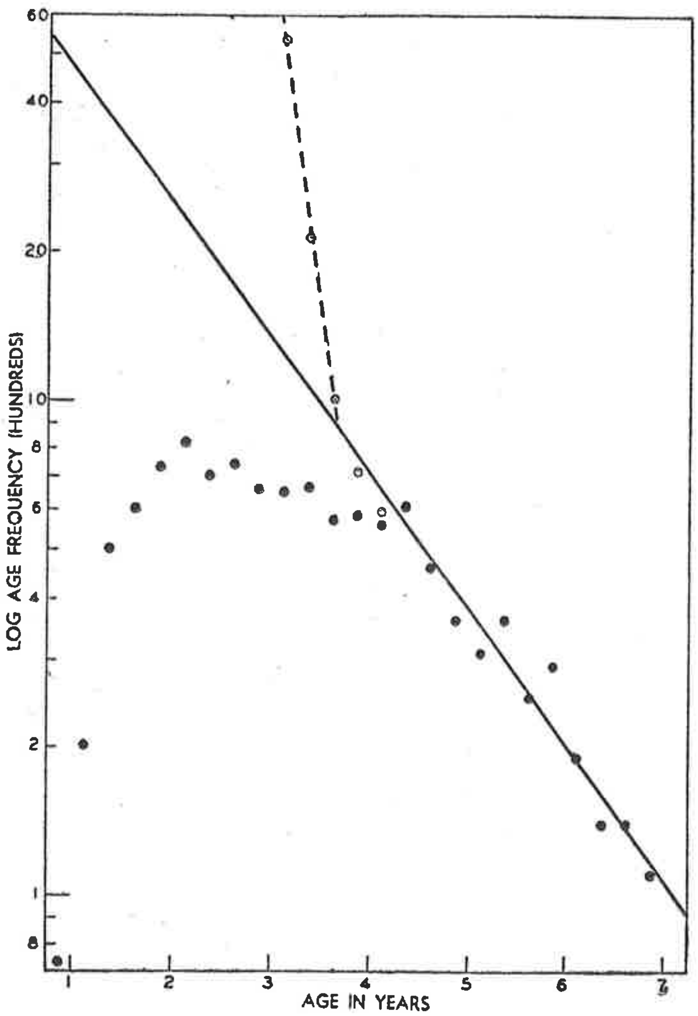


FIG. 27. Log: Age-frequency distribution of all snapper caught in series 5 experiments

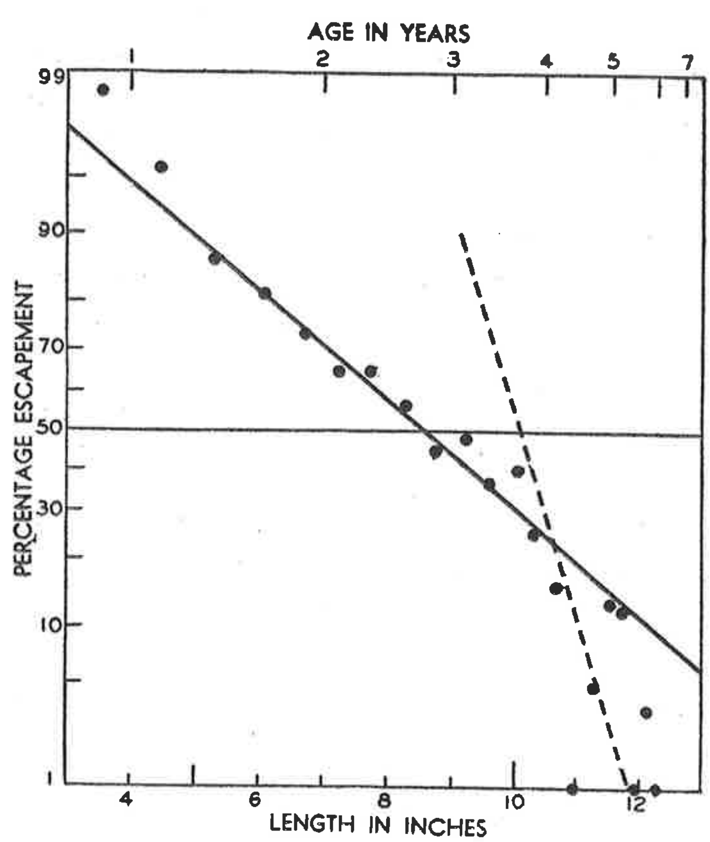


FIG. 28. Hypothetical escapement curves for forward part of trawl (see text, p. 55)

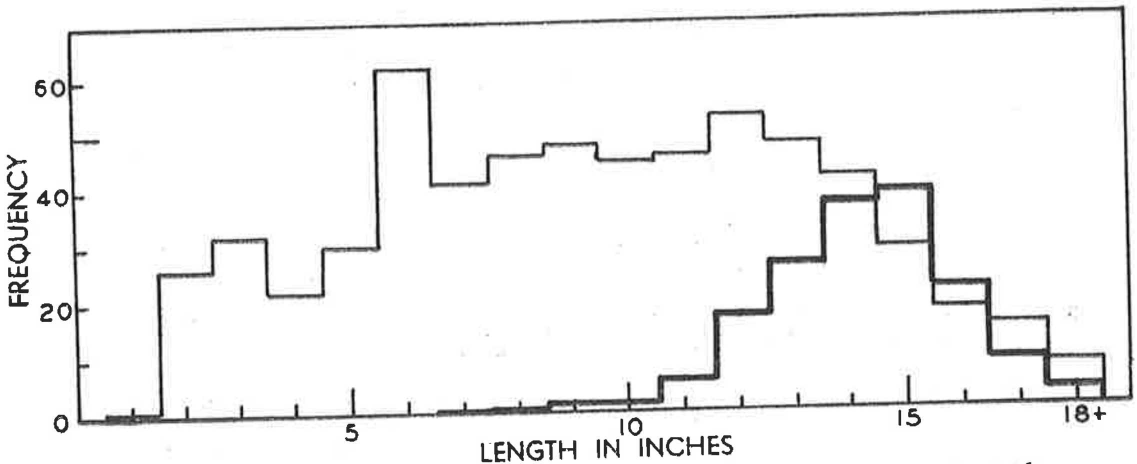


FIG. 29. Effect of the seaweed *Carpophyllum* on length frequency of catch

line showing the resultant trend of these points corresponds to a mortality rate of 96 per cent per annum. While such a high mortality is not impossible, it is highly improbable even in the light of the most pessimistic estimates which have been obtained for the first four years by other means, and the second escapement curve in Fig. 28 must therefore be rejected.

Conclusion 16.—That although quite a considerable number of fish escape from the fore part of the trawl, the escapement index is lower and the selection less sharp than would be expected from a cod-end of similar mesh. If optimum escapement and selection are to be achieved in a trawl, the size of all meshes, not only those of the cod-end, should be considered. The mesh in the fore part should be at least as large as in the cod-end, and preferably somewhat larger,* particularly in those parts farthest from the cod-end.

4.4.2. THE EFFECT OF SEAWEED ON ESCAPEMENT

On very few occasions during the mesh escapement work was any quantity of seaweed or other bottom material picked up, and on no occasion were the results in any way noticeably affected by such foreign matter. However, in February 1953 a series of four shots were made with the same trawl as that used in series 5, except for the cod-end, which had a nominal mesh of 6 in. The last shot, No. 272, was made in a sheltered bay and very large quantities of the brown alga *Carpophyllum flexuosum* were collected. This seaweed, with its long membraneous "leaves", clings very readily to netting. In this particular case the whole trawl was described as being "like a blanket" and several hours were taken cleaning it afterwards. The effective way in which the meshes were blocked is shown in Fig. 29. The light line represents the size frequency of this catch, while the heavy line gives the average size frequency of the three preceding shots where no *Carpophyllum* was encountered.

* On the other hand, too large a mesh in the fore parts of the trawl, particularly the belly and batings, is inclined to produce a number of "stickers" or meshed fish. This is probably due at least in part to the fact that the twine is finer, and hence "sharper", than in the cod-end. Stickers are usually more common among tarakihi than snapper, but when they do occur the added labour in removing fish from the net may be scarcely justified by the small improvement in escapement.

Without the seaweed the catch is quite consistent with the escapement to be expected for a 6 in. cod-end. Since the true mesh size was approximately 5½ in., the escapement index would be about 13 in. The 13 in. level on the histogram is about half-way down the left flank of the curve, while no fish at all were taken below 6 in. In shot 272, however, a very large number of small snapper was caught, extending down the scale as far as 1 in. Although it is quite possible that these small fish were associated with the *Carpophyllum* in the first place and hence might have been available to the trawl in greater numbers, it is fairly certain that the majority of these would have escaped if the meshes had been free of obstruction.

This case is a very definite exception to the rules of escapement so far derived, but it is probably one of fairly uncommon occurrence. Although commercial fishermen are perhaps prepared to take greater risks with their gear than were taken by the master of *Ikatere* in these experiments, large quantities of seaweed are usually avoided not only because of their effect on escapement, but because they add considerably to the labour of trawling and may even be a danger to net and ship. Not all seaweed will cling to the net in this fashion. For instance, the bull kelp *Durvillea antarctica* may be taken in large quantities (though not in Hauraki Gulf), but it usually drops to the bottom of the cod-end. There seems to be no reason why seaweed or bottom debris of any kind which settles in a compact mass in the cod-end should have any more adverse effect on escapement than the equivalent mass of fish.

Conclusion 17.—That the presence of large quantities of certain species of seaweed, notably *Carpophyllum flexuosum* (and probably other species of the same genus), may impair the escapement properties of the trawl, though such a situation is usually avoided by fishermen whenever possible.

4.4.3. THE EFFECT OF MESH SIZE ON SIZE OF CATCH

If any substantial alteration is to be made in the size of mesh to be used in commercial fishing it is desirable to know not only the change in releasing power of the trawl, but also the change, if any, in total catching power. Although any such measure would be designed to increase the fisherman's ultimate catch, there must inevitably be a transition period during which the number of small fish released by the larger mesh is not balanced by a corresponding number of larger fish in the population. Unless there is some compensating factor, a fisherman who is working on a low profit margin at the time of the change may well be put out of business by a relatively small decrease in catch, even though the decrease is only temporary. Fortunately, a compensating factor may exist in that a larger meshed trawl, though releasing more small fish, may also capture more larger fish at the same time.

Such a difference in catching power can, of course, only be demonstrated convincingly by an experiment of the replicate hauls type. Possibly the best known and one of the most intensive set of results of this type is that of Davis (1934), who showed in his North Shields experiment that the marketable catches of 2½ in. and

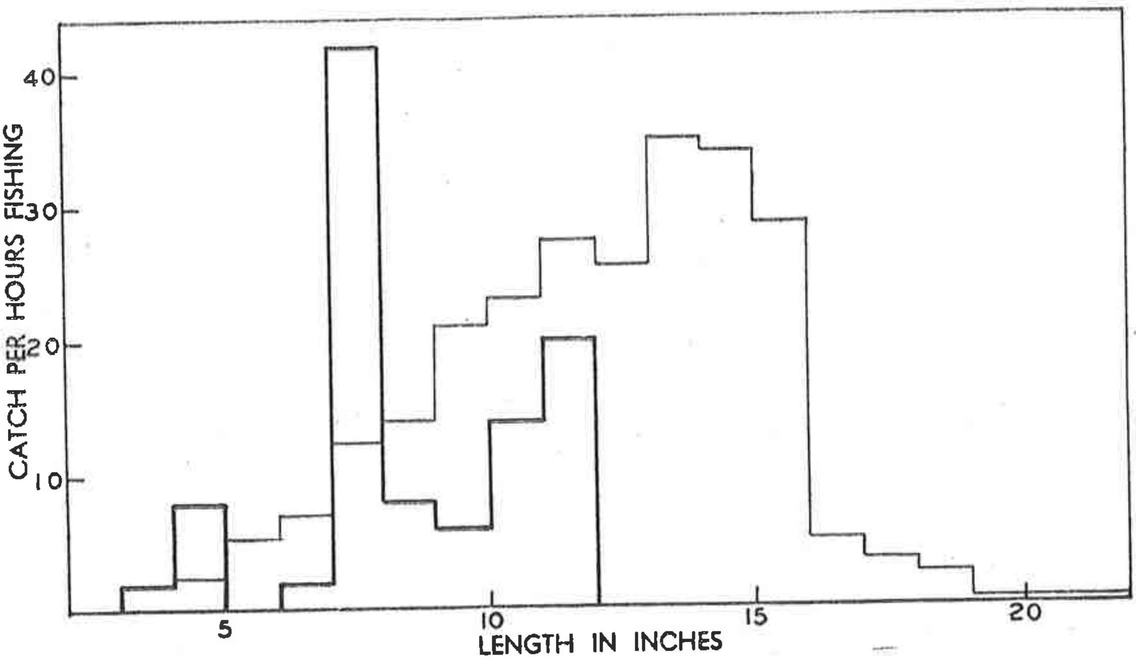


FIG. 30. Comparison of catches of large and small-meshed trawls

3½ in. meshed cod-ends differed by an insignificant amount over the same period of time. The smaller mesh gave a cash yield of £1,265, while the larger mesh, though taking fewer small fish, made up for this by a greater weight of large fish, giving a cash yield of £1,276. This suggests that the trawl does not engulf all fish in its path, but has an upper as well as a lower size limit, both of which are in direct proportion to the mesh size. It is generally assumed that this is because a larger mesh allows a better flow of water through the trawl, thus sweeping in larger fish. Further rather striking evidence for this supposition is given by the two histograms in Fig. 30.* The two catches of snapper were taken on the same day over as nearly the same trawling path as possible. The heavy line is the catch per hour of a small trawl of approximately 1½ in. mesh throughout, while the light line is the catch per hour of a commercial trawl of about 3½ in. mesh in the cod-end and 4½ in. in the fore part. It is not possible to estimate the relative catching powers of the two trawls, but the small trawl figures should probably be multiplied by a factor of the order of 10 to allow for the disparity in size of gear. The 3½ in. meshed cod-end will presumably release virtually no fish above 11 in. in length, so that from this point onward the two curves should be similar in shape. However, the 1½ in. mesh, though it has taken 20 fish between 11 in. and 12 in., has taken *no fish at all* above that size. Even allowing for the difference in catching power of the two trawls, it is obviously highly improbable that the two curves from 11 in. onward are both unbiased samples of the same fish population.

* This is a typical example taken from a series of experiments being conducted at the time of writing. It is not yet possible to give a detailed summary of results, but the size distributions have in all cases followed a similar pattern to that shown in Fig. 30.

Conclusion 18.—Certain evidence suggests that an increased mesh size in the trawl may result not only in smaller catches of small fish, but also in larger catches of large fish. This is, of course, by no means proven, and further investigation may be desirable.

4.4.4. MESHING

The occurrence of meshing in the trawl is of importance for two reasons. Firstly, a meshed fish may be difficult to remove from the net, and if large numbers occur a considerable loss of time to the fisherman is involved. Secondly, it seems probable that the size of fish which mesh may be related in some way to the escapement curve. In the case of the snapper, meshing rarely if ever seems to be a serious practical problem, though it has been reported as a cause of delay in certain tarakihi fisheries on some occasions. In the *Ikatere* investigations a few fish were almost invariably meshed in the body of the trawl, but were usually easily shaken out. In a double twine cod-end it was rare for any fish to remain in the meshes when the catch was emptied on deck. With the single twine appreciable numbers were sometimes meshed, but here again they were so easily shaken out that they presented no practical problem, and, in fact, it was difficult to keep them separate from the rest of the catch.

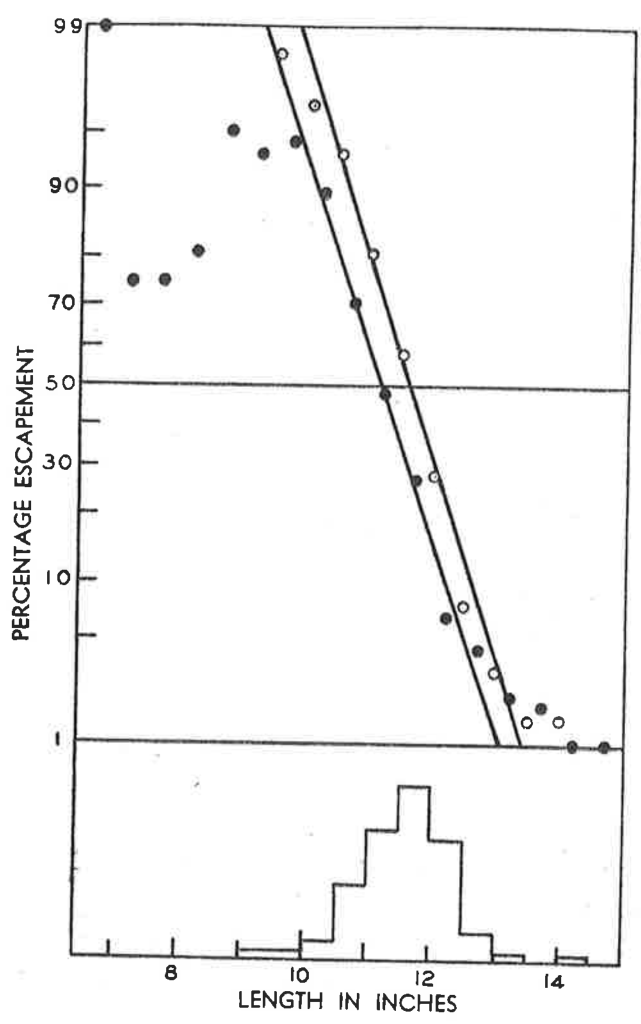


FIG. 31. Relationship between length frequency of meshed fish (circles and histogram) and escapement curve (dots) (Tables 18, 24)

In shot 241, however, particular care was taken, and some 63 fish meshed in the cod-end were collected and measured (Table 24). To test the relationship with the escapement curve the cumulative frequency of these fish has been plotted on probability paper (circles, Fig. 31) using the method described in previous papers (Cassie, 1950 and 1954). At the bottom of the figure is given a histogram of the same data. The escapement curve (dots) for shot 241 is plotted on the same graph. The size distribution of the meshed fish is very nearly normal, though with a slight positive kurtosis,* but the most striking feature is the manner in which it follows the shape of the escapement curve. The following are the parameters of the two curves:

	Escapement	Meshing
Mean	$E = 11{\cdot}2$	$m = 11{\cdot}6$
Standard deviation ..	$S = 0{\cdot}83$	$s = 0{\cdot}80$
Standard error	$s_e = 0{\cdot}23$	$s_m = 0{\cdot}10$

The close similarity of the two curves is perhaps not surprising, since both are functions of mesh size and elasticity. Applying the t test of significance gives a probability of 0·1 for the null hypothesis that E and m are estimates of the same parameter. Nevertheless, it is quite likely that fish would mesh at a slightly higher average size than the escapement index, and the difference, though not statistically significant here, may be a real one.

Conclusion 19.—That the size distribution of fish which mesh in the trawl may be related to the escapement curve. If further data on this relationship were available, this might lead to a useful means of evaluating the escapement curve.

4.4.5. THE CONDITION OF ESCAPING FISH

Evidence on this question can be only circumstantial, since it is virtually impossible to follow the subsequent history of an escaped fish and to estimate its chances of survival as compared with a fish which has never come in contact with a trawl. Iversen (1934), Davis (1934), Herrington (1935), and many others have noted the condition of small haddock and other fish retained in the small-meshed cover, and found that a substantial proportion were alive and seemed to have a good chance of survival in spite of the fact that they had been dragged along the bottom and otherwise mishandled instead of escaping into their natural element immediately. Herrington kept some of these fish in an aquarium and found that they remained alive for some time. Davis also demonstrated that escapement occurred while the trawl was being towed. This has been verified by the Scottish Home Department's underwater cine film of a danish seine net which at the time was moving through the water in a similar manner to a trawl. The film showed clearly that the passage of a fish through the mesh could take place in a small fraction of a second. This suggests that it would not suffer any prolonged abuse before it escaped and that its subsequent chance of survival would not be prejudiced to any great degree.

In the *Ikatere* investigations the condition of fish in the cover was usually found to be good, except when particularly large catches caused those at the bottom to be crushed. It was also noted that the smaller the fish the better its condition. One- and two-year-old fish (approximately 4 in. and 7 in. long respectively), unless

* It is interesting to note that this kurtosis may be accounted for by setting up two normal distributions with the same mean but different standard deviations. The fish are thus divided into two groups, one with a narrow size range which may correspond to those fish tightly held by the mesh fitting behind the operculum, and another with a wider size range for the fish loosely held either by the tip of the snout or by some part of the body (Cassie, 1954).

crushed by the weight of other fish, were almost invariably able to swim away quite normally if thrown over the side. On one occasion two 4 in. and one 7 in. snapper were transferred to a bucket of water and later to a small aquarium, where they survived for a week. Their ultimate death seemed to be due to poor aquarium conditions rather than to damage sustained in the trawl. The main cause of disability in larger fish seems to be the distended belly owing to gas released in the body cavity. Fish swim upside down and are unable to dive, though this condition can be relieved by puncturing the belly. The pressure of gas internally seems to be due partly to the rough treatment received in the net and partly to decompression when the trawl is raised from some depth. Neither of these would occur if the fish escaped through the mesh soon after it encountered the cod-end.

Conclusion 20.—That fish escaping through the meshes of the trawl are not often seriously damaged, and though there is no absolute proof that their chance of subsequent survival is not slightly reduced, there is undoubtedly still a very substantial saving of small fish, particularly in the smaller sizes, which seem to sustain the least damage even when not released.

4.4.6. THE WASTAGE ENTAILED BY THE USE OF A 4 IN. MESH

As pointed out in the introduction, it would be a laborious procedure to estimate the total number or weight of snapper under marketable size which are destroyed in New Zealand waters by trawls using the standard 4 in. cod-end mesh. Such an estimate would require a sampling programme conducted on the commercial fishing boats and sufficiently intensive to reduce to the required confidence limits the variability in catch composition arising from different areas, seasons, boats, and weather conditions, as well as from the inherently contagious distribution of the fish population. The figure, once obtained, would probably help little, if at all, in finding a management procedure which would convert this present loss into gain.

Nevertheless, the question is frequently asked, and it is of some value to give an answer, if only in very approximate terms, so that an idea may be gained of the order of magnitude of the problem. A series of thirty trawl shots, using 4 in. manila cod-ends (both single and double twine), were made by *Ikatere* in the Hauraki Gulf during the year 1952. The number of snapper under 10 in. in length, i.e., not legally marketable, was found to be 2,521 out of a total of 12,340. This gave an average wastage of 20 per cent, though in individual shots this varied from 0·6 per cent to 68 per cent. Converting numbers to weights gave an average wastage of about 10 per cent. Since about 50,000 cwt. of snapper are landed by trawlers in New Zealand each year, this would represent an annual wastage of 5,600 cwt. The market value of these fish is, of course, not known, since they cannot be sold, but if converted to the same weight of larger fish they would bring, at £2·3 per hundredweight, a price to the fishermen of about £13,000. Assuming that the average undersized fish weighs 4 oz., the total number of fish would be about 2·5 million. If the range of sizes of these fish is between 4 in. and 10 in., it can be computed from the escapement curves that at least 40 per cent of them will be saved by the use of a 5 in. cod-end, i.e., about 1 million fish. Though these figures are only very approximate, it is none the less plain that numbers of fish of the order of a million and money counted in thousands of pounds are entailed in the question of mesh size, so that the matter is one worthy of serious consideration.

Conclusion 21.—That the approximate number of small snapper less than 10 in. in length which are annually destroyed by trawlers in New Zealand waters may be of the order of 2·5 millions, of which at least 1 million might be saved by the use of 5 in. cod-ends. The weight of fish involved in this loss may amount to thousands of hundredweight with a potential value of some thousands of pounds to the fisherman.

5. APPLICATION OF RESULTS

5.1. THE SNAPPER

The above results have shown that the size of mesh used in a trawl has a definite and predictable relationship to the size of snapper released. Thus the control of mesh size may serve as an effective limit on the minimum size of fish taken in the trawl. This knowledge does not in itself lead to a more efficient system of fisheries exploitation, but must be considered in conjunction with a number of other factors. An increased mesh size will undoubtedly spare smaller fish, which *may,* if allowed to grow, produce a great yield later on. On the other hand, such a procedure, if carried to extremes, will eventually reach a point where virtually no fish are captured at all, which is certainly not the object of fisheries management. It is necessary to decide not only what is the most suitable mesh size, but whether the regulation of mesh can be supplemented or even perhaps replaced by other means of control.

There are two main factors which may be controlled in the management of a fishery, firstly the size of fish which is taken, and secondly the number which are taken. These will be referred to as *size limit* and rate of *exploitation* respectively, and one cannot be adjusted to best advantage without due regard for the other. Size limits, or more precisely minimum size limits, may be imposed in a trawl fishery in several ways at the various stages in the passage of fish from the sea to the consumer:

(*a*) *Area or Season Limit.*—The capture of small fish is prevented before fishing even commences by the prohibition of fishing in certain areas (sometimes known as "nursery grounds") which are known to contain more than the usual proportion of small sizes. Such a closure may be permanent or only for certain seasons of the year when small fish congregate in the area. If it could be applied, this limit would be the most effective of all, since the protected fish are not subjected to disturbance of any kind. It is known that in certain parts of the New Zealand coast the snapper does tend to form seasonal aggregations of small or large fish (although this does not occur to any marked degree in the Hauraki Gulf). Such movements where they occur are well known to trawler skippers, who, in their own interests, follow the larger fish if they are within boat range. Thereby the fisherman impose upon themselves a voluntary limit, and it is doubtful whether sufficient information is yet available to improve on this by legislation.

(*b*) *Mesh Size Limit.*—This takes place at the actual time the fish are being caught. Though some undersized fish may be disturbed or even damaged, the mesh limit has the advantage that in a population of mixed sizes it retains its selective action.

(*c*) *Market Size Limit.*—Since a fish, once caught, can be measured and sorted with any required degree of precision, this method is much more sharp in its selective action. However, this selectivity is of little benefit in a trawl fishery, since a fish when it is landed on deck is almost invariably dead or dying and, even if it is replaced immediately into the water, little is gained except very indirectly and inefficiently by the return of some organic matter to the aquatic food cycle. In trawling the only value of such a limit is that it encourages the fisherman to apply other size limits, since he will have no desire to waste time and effort in taking fish he cannot sell. In other methods of fishing, such as by hand lines and certain types of net, a market size limit may be profitable, since undersized fish may often be returned undamaged to the sea. In the snapper landings for 1952, 27 per cent of the catch was taken by methods other than trawling or danish seining. It is possible that a market size limit may effect a direct saving of small fish among this 27 per cent, although by no means all the methods concerned necessarily take fish in live condition. On the other hand, in the tarakihi fishery 99·7 per cent of the 1952 catch was taken by trawls and danish seines, so that little saving could be effected in the remaining 0·3 per cent of the fishing represented by other methods.

(*d*) *Consumer Preference.*—This, unlike the previous three limits, is not amenable to direct control, since it is an automatic one imposed by the consumer. It becomes an effective size limit when fish below a certain size cannot be sold for human consumption, either because the buyer prefers a larger size* or because the cost of preparing it for sale is too great in proportion to the amount of food it produces. The consumer preference may be broad and indefinite or may fluctuate with changes in supply and demand, but it is none the less a size limit which may change or modify the effect of other limits.

To achieve the *best possible* sustained yield it is necessary for both size limit and rate of exploitation to be controlled, each at its proper level. The discussion below aims at achieving not the best possible, but a *better,* yield, by adjusting the size limit to suit the existing exploitation rate. Any advance so made will be one step only toward the ideal solution where, with due regard for all factors, biological, economic, and social, the best crop is taken and continues to be taken indefinitely.

It can be shown that in any one age class of fish there is usually a gain in the total weight during the earlier years, owing to the relatively rapid growth of the

---

* Occasionally too there is an upper size limit, where the buyer prefers his fish not to be too big. This is an additional problem outside the scope of the present work, but it could, under certain circumstances, make an appreciable difference to the best value for mesh or other size limits.

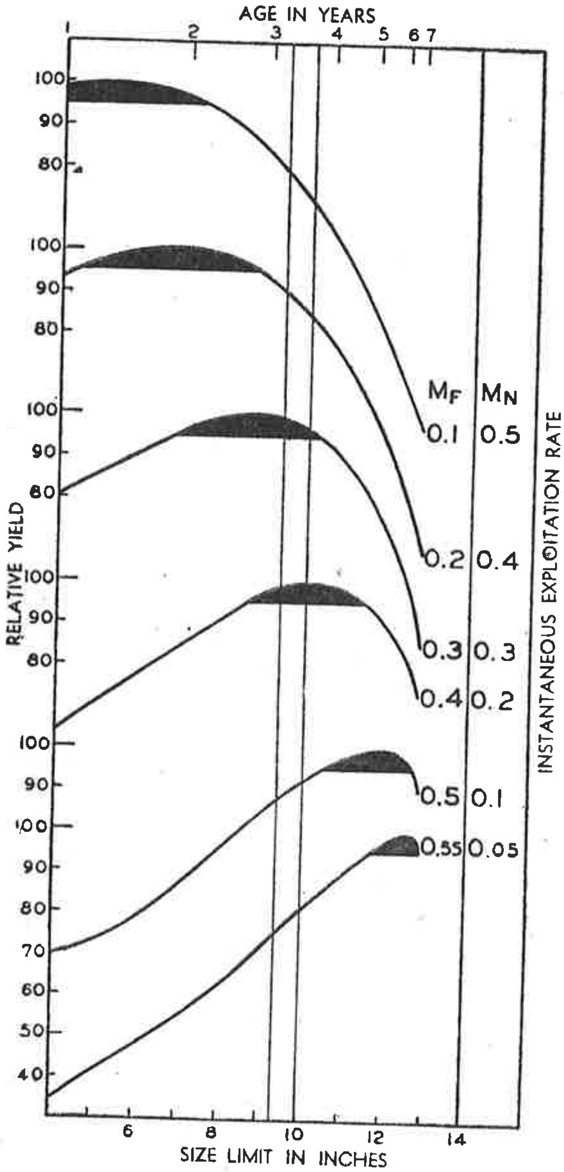


FIG. 32. The snapper: Relationship between yield, size limit, instantaneous fishing mortality (M_F), and instantaneous natural mortality (M_N)

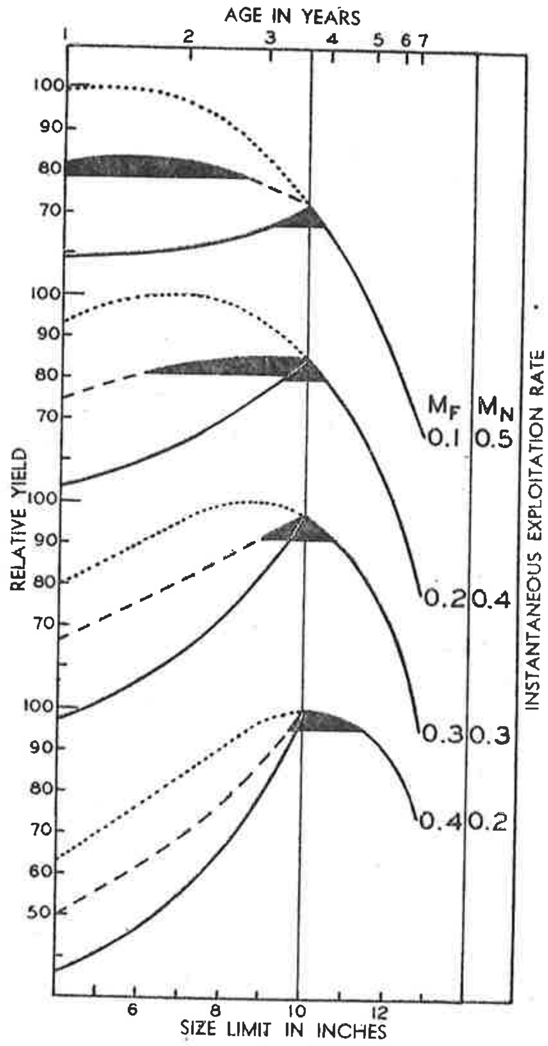


FIG. 33. As in Fig. 32 but with fish below 10 in. unmarketable (unbroken line) or marketable at half normal price (broken line)

young fish. Later, as growth becomes slower, this gain is counterbalanced by natural mortality, so that the total weight of the survivors reaches a maximum and then commences to decline. The age at which this maximum is reached may be called the *critical age*, and the corresponding average size, the *critical size** (Ricker, 1945). Obviously, if every fish were taken immediately it reached this critical size, the maximum possible yield would be obtained. (The question of whether these

* Though this is the usual pattern in the known life-cycle of most fish, it is by no means impossible for the critical age to be at the beginning of the life-cycle, or even for two critical ages to occur in the life of a year class. For instance, in most bony fishes there is an enormous mortality rate in the early larval stages which may more than offset the growth rate, and so induce a second peak in the production curve. In such a case, provided that allowance was made for replacement stocks, it might be just as economical or even more so to take such species at the first peak in the curve. Thus fisheries such as that for the New Zealand whitebait (*Galaxias attenuatus*), where fish is taken almost exclusively in the larval stage, may not necessarily be as wasteful as would at first appear.

fish have had a chance to spawn sufficiently to provide stocks for later years will be deferred.)

It is not possible to achieve this ideal, nor would it be economic to try to do so. The more fish that are caught, the fewer and harder to catch are the remainder, and long before every fish was taken the effort required would have become too great to be profitable. To compensate for this it is necessary to take fish before they reach the critical age. The lower the exploitation rate the earlier it is necessary to start, to obtain the best yield. Ricker (loc. cit.) described the best minimum size limit for any given rate of exploitation as the *optimum size* and demonstrated how this size might be estimated* if the following information were available for the fish stock concerned:

(*a*) The average growth rate.
(*b*) The natural mortality rate.
(*c*) The exploitation or fishing mortality rate.

The growth rate of the Hauraki Gulf snapper (Table 28) is known with a fair degree of confidence up to the seventh year. On the other hand, the two mortality rates are not known separately, though the value of the two combined has been estimated as approximately 45 per cent per annum between the third and seventh year, corresponding to an instantaneous rate of 0·6 per annum.† Although this information is insufficient to estimate an optimum size limit for the present rate of exploitation, the range of possibilities may be reduced to manageable proportions.

Figure 32 (computed after the manner of Ricker, loc. cit.) shows the variations in total yield which would be expected from various combinations of natural and fishing mortality. It is assumed that the fishing and natural mortality rates will remain constant throughout the size range. Although this is not necessarily strictly true, it is probably a sufficiently close approximation to place correctly the more critical parts of the curve.

The two columns of figures at the right-hand end of each curve represent fishing mortality (M_F) and natural mortality (M_N), the two in each case adding up to 0·60. The yield in each case is expressed as a percentage of the maximum, the black area below each curve covering the range 100–95 per cent, while the two vertical lines represent the two existing size limits, mesh limit at 9·4 in. and market limit at 10 in.‡ Not only does the optimum size limit become higher with higher fishing

* Such an estimate will be only a first approximation, unless the optimum size indicated is equal (or very close) to the limit already prevailing. Once a change has been made, the factors concerned will probably change too, and although the new limit will almost certainly be a better one, it may still require further adjustment.

† Growth has been determined from combined scale reading and length frequency mode methods, the two giving reasonably consistent results. The estimate of mortality has been gained from the examination of the size distribution of trawl catches over the past five years. It rests, perhaps, on less certain grounds and is being investigated further. It is believed that, if anything, the true rate is somewhat lower than 45 per cent, in which case optimum size limits will tend to be under rather than over estimated.

‡ The Fisheries Regulations 1950, regulation 107, specify minimum size units as follows: "No person shall take, buy, sell, expose for sale, or have in possession any fish of any of the descriptions included in the table subjoined to this regulation which is of a less size than that set opposite the name of such description of fish in the said table; the measurement . . . being made from the tip of the nose to the posterior end of the middle ray of the tail fin." The lengths given in the table for both snapper and tarakihi are 10 in.

rate, but owing to the decrease in growth rate it also becomes more critical. Thus at $M_F = 0{\cdot}1$ the peak is at 5 in., but the limit can vary $2\frac{1}{2}$ in. either way without reducing the yield by more than 5 per cent. On the other hand, at $M_F = 0{\cdot}55$ the peak is sharp with not more than half an inch latitude either way. The information in the figure may be summarized as follows:

(*a*) If fishing rate is 0·1 or 0·2, the present limits are too high.
(*b*) If fishing rate is 0·3, the present limits are a little too high, but not enough to make a serious difference.
(*c*) If fishing rate is 0·4, the present limits are about right.
(*d*) If fishing rate is 0·5 or higher, the present limits are too low.

So far consideration has been given to the production of a maximum weight of fish without regard to the value in monetary terms, i.e., to the consumer preference. At present this limit is not accurately known and in many cases its presence is masked by a market size limit of 10 in. In Auckland there usually seems to be little difficulty in marketing fish of this size, though in some parts of New Zealand there is a tendency to prefer larger fish, particularly when a good selection of sizes is available. In other cases there is also a marked preference for fish of medium rather than large size, though this seldom constitutes any problem, since large fish are invariably fewer in numbers and there is rarely any great difficulty in disposing of them. At 10 in. a snapper weighs about 12 oz. when caught, 11 oz. gutted, and 6 oz. filleted. A smaller fish, though still quite edible, would scarcely repay the labour of preparing for sale, since it takes nearly as long to clean, say, a 6 in. fish as a 12 in. one, which would yield eight times as much edible flesh. Thus fish appreciably less than 10 in. in length would have less value to the fisherman, even if present regulations permitted them to be sold. Either they will not be bought at all (when the value will be zero) or the merchant will only buy at a lower price per pound to compensate him for the increased cost of cleaning or the lesser value if it is reduced to fish meal or similar by-products.

In Fig. 33 the first four yield curves (those with optimum size below 10 in.) have been redrawn, making allowance for a 10 in. consumer size limit. The unbroken line follows the assumption that all fish under 10 in. are unsaleable. As might be expected, the yield decreases sharply as the size limit falls below 10 in. The broken line allows for a somewhat more involved situation where undersized fish are still saleable but for only half the normal price (say, for the manufacture of fish meal). When fishing rate is very low (0·1) there would be a slight financial gain if the size limit were reduced to 5 in. or 6 in., but for any of the higher rates the maximum yield point remains at 10 in. When the consumer limit is higher than 10 in. the yield curves will be similar in shape, but the maximum will be shifted correspondingly to the right. In such a case no great problem would exist, as the minimum size taken would tend to be adjusted by the fishermen, provided they were fully acquainted with all available means of controlling the size range of their catches and with the advantages to be found in so doing.

Up to this point the discussion has concerned the maximum yield for a single year class, neglecting for the time being the necessity for keeping a spawning stock sufficient to maintain the optimum level of recruitment in later year classes. Though it is generally believed that an unexploited fish population produces eggs far in excess of what is required to maintain itself, it is not yet known to what level the reproduction potential of the snapper can be lowered without reducing subsequent stocks. It would appear, then, that the safest course is to maintain the spawning stocks at least at the highest level that is consistent with the best economic yield per year class. Fortunately the two are not incompatible, at least as far as size limit control is concerned. It can be shown that, once a female snapper reaches maturity, the weight of the ovary, and hence presumably the number of eggs produced, is very nearly in direct proportion to the weight of the fish. Since (assuming that exploitation remains constant) yield is directly proportional to size of stock, the optimum size limit for egg production will be identical with the optimum size limit for yield, provided that the latter is above the maximum size at which sexual maturity is reached. The snapper usually reaches maturity in its third year when its length is about 9 in., and it is rare to find an immature specimen over 10 in., hence the size limit : egg production curve will be very similar to the size limit : economic yield curve (unbroken line, Fig. 33), where all fish under 10 in. were considered unmarketable. This is a similar conclusion to that reached by many of the early conservationists, who maintained that every fish should be allowed to spawn at least once, though it is recognized here as a precaution rather than an inflexible rule.

A further consideration is introduced from section 4.4.3, where it is suggested that increased mesh size may under certain conditions be accompanied by greater catches of large fish. In other words, the higher size limit, though decreasing the exploitation rate for smaller fish, might actually increase the rate for the larger fish which still cannot escape through the mesh. Thus any optimum mesh size limit estimated under present conditions will probably require to be raised still further owing to the increased fishing mortality which it has introduced.

Conclusion 21.—From the above considerations it is concluded that, although sufficient information is not yet available to estimate the optimum mesh size limit for the snapper trawl fishery, a substantial improvement in the sustained economic yield may be expected if the size of mesh is increased to 5 in. throughout the trawl. The following reasons may be given:

(*a*) The effective minimum size limit for trawl-caught snapper will be raised to about $11\frac{3}{4}$ in., thereby ensuring that the absolute minimum of fish below the market size limit of 10 in. will be destroyed. This will remove the present inconsistency between mesh and market size limits.

(*b*) There will be a greater assurance that fish up to the time of first spawning will be protected. Though such a measure may later be found unnecessary, in the meantime it is a worth-while precaution against reduction of recruitment.

(*c*) Although yield would be lowered if the fishing mortality were less than half the total mortality, it does not seem likely that the available stocks could have been reduced as much as landing statistics suggest, by an exploitation rate less than 20 per cent per annum. If, however, exploitation rate is low, it would seem that the way to greater yield lies in increased exploitation, using a larger mesh size as a precautionary measure.

(*d*) The New Zealand trawler fleet, though it is at present controlled as to the number of boats licensed, is nevertheless tending to become more and more efficient every year. Even if the present state of the fishery did not demand a larger mesh size, it would seem a wise precaution to anticipate future trends.

(*e*) The change from 4 in. to 5 in. is not such a drastic one that it is likely to imperil any fisherman's livelihood. There is, in fact, some reason to believe that his catches may be much the same or even greater with the larger mesh, and that larger fish may be taken which were previously immune from the trawl and therefore lost to the industry.

(*f*) On the other hand, the change is of sufficient magnitude to produce some effect which can be observed and measured. Even if it were ineffective as a conservation measure, it would have served a useful purpose as an experiment producing new data. From Fig. 32 six alternative predictions can be made as to the outcome. They range from a sharp drop in yield ($M_F = 0{\cdot}1$) to a sharp rise ($M_F = 0{\cdot}55$). The experiment would show which of these predictions, and hence which of the curves, is nearest to the truth. With this knowledge, future control measures could be planned with far greater confidence.

5.2. OTHER SPECIES

Although the snapper is fairly widespread in its distribution and is the dominant species in most regions where it is caught, nevertheless there are numerous occasions when other important species are taken, if not on the same ground, at least by the same boat and on the same trip. Thus it is not possible to consider the snapper entirely alone in determining the most suitable size of trawl mesh. The following table (abridged from Marine Department, 1953) shows the values of landings for fish in 1952. It will be seen that the first ten species account for 93 per cent of the total, so that the remainder (about thirty species) may be fairly safely ignored in considering the over-all economy of the industry.

Species	Value £1,000	Value Per Cent	Species	Value £1,000	Value Per Cent
Tarakihi ..	263	24	Elephant fish ..	30	3
Snapper ..	223	21	Ling	19	2
Hapuku ..	123	11	Moki ..	13	1
Sole	111	10	All others ..	70	7
Blue cod ..	89	8			
Flounder ..	85	8			
Gurnard ..	53	5	Total ..	1,079	100

Of the nine species beside snapper, the tarakihi is by far the most important. Present knowledge suggests that the tarakihi has a slightly slower growth rate than the snapper. This, coupled with the higher length-girth ratio (1·25), would indicate that a tarakihi has a greater chance of escaping from any given mesh than a snapper of the same age. Though it is not necessarily implied that a smaller mesh is desirable for tarakihi, there does seem to be some likelihood of the two species requiring different treatment. This does not create a very great problem in the South Island, where the ranges do not overlap to any great extent. On the other hand, in the North Island both species are often found very close together. Until about five years ago the range of dominance of the tarakihi was believed to be confined to the east coast south of East Cape in the North Island, the snapper occupying the remaining coastline, with little intermingling. Today this situation has changed, perhaps partly because the ranges have altered, but more probably because trawlers are fishing deeper water and are finding tarakihi on the outskirts of the snapper grounds. Overlapping is particularly common in the Bay of Plenty area, and the effect is intensified by the greater range of trawlers. Where boats once fished near their home ports, they now may steam hundreds of miles and may encounter many different types of ground in one trip. It is clear, therefore, that although a change of mesh size can in some cases be applied to the snapper fishery without affecting the tarakihi, before the full benefits of such a move can be realized it will be necessary to have more information regarding the optimum mesh size for the tarakihi.

Of the remaining eight species, two—hapuku and blue cod—are caught almost entirely by lines and hence would not be affected by mesh size. Three—elephant fish, ling, and moki—are considerably larger fish and mature specimens would be unlikely to escape from any mesh suitable for snapper. The only other fish which might present some problem are the gurnard and the two flatfish, sole and flounder (the last two actually comprising three or more species). The gurnard escapement curves (Fig. 13) and some general observations of flatfish trawling suggest that quite a number of fish of commercial value might be lost through a 5 in. mesh. In the case of flounder and sole this loss is not likely to be as high as the percentage landings would suggest, since at least three-quarters of the catch is landed at ports which have little or no snapper, while of the remaining quarter the majority is not taken by trawl or danish seine. Some significant reduction in catch of gurnard may be inevitable, but since this species seldom constitutes the main part of a trawler's catch it is unlikely that any undue hardship would be caused.

Conclusion 22.—That on grounds where tarakihi, gurnard, or flatfish are caught as well as snapper, some special precautions may be necessary to ensure that the mesh size employed is equally suitable for these other species.

6. SUMMARY AND CONCLUSIONS

Regarding the questions asked in section 1.1, definite answers can be supplied in some cases; in others it is only possible to ask further questions. Dealing with the points one by one:

(1) It has been shown conclusively that there is nothing to be gained by the use of a square-meshed cod-end in place of the diamond mesh. The selective action is no sharper, while the escapement for the same size of mesh is definitely lower.

(2) It has also been demonstrated that increasing the size of the cod-end mesh can be a highly effective measure to reduce the number of smaller snapper caught in the trawl. The same is probably true for other species of fish such as the gurnard and tarakihi, though data for these is less comprehensive.

(3) It is believed that the relationship between the size of mesh and the size and numbers of the fish escaping has been determined with a sufficient degree of accuracy, and that the control of mesh size in trawl fisheries can be used to impose effective minimum size limits at any level considered necessary.

(4) The relationship, fish size : probability of escape, has been successfully fitted to the curve of the normal integral for probabilities below 90 per cent. Curve fitting can be carried out readily by plotting the data on probability paper and fitting a straight line by eye. This line may be fully described by the two parameters mean and standard deviation, which are referred to as

$$\text{Mean} = \text{escapement index} = E.$$
$$\text{Standard deviation} = \text{selection index} = S.$$

For the snapper it has been found that, within the range of mesh sizes investigated, E is directly proportional to the mesh size, while S is a constant. E and S tend to be biased respectively toward lower and higher values than the true ones, but it is believed that in certain experiments this bias has been reduced to a negligible size, so that the two parameters are consistent with what might be expected in view of the general shape and nature of the fish.

For all practical purposes the following values may be used:

$$\text{Escapement index} = 2{\cdot}35 \times \text{mesh size.}$$
$$\text{Selection index} = 0{\cdot}8 \text{ in.}$$

The escapement curves for snapper with a variety of meshes are summarized in Fig. 34.

(5) It has been shown that other parts of the trawl beside the cod-end can release fish, although the escapement index is almost certainly lower and the selection

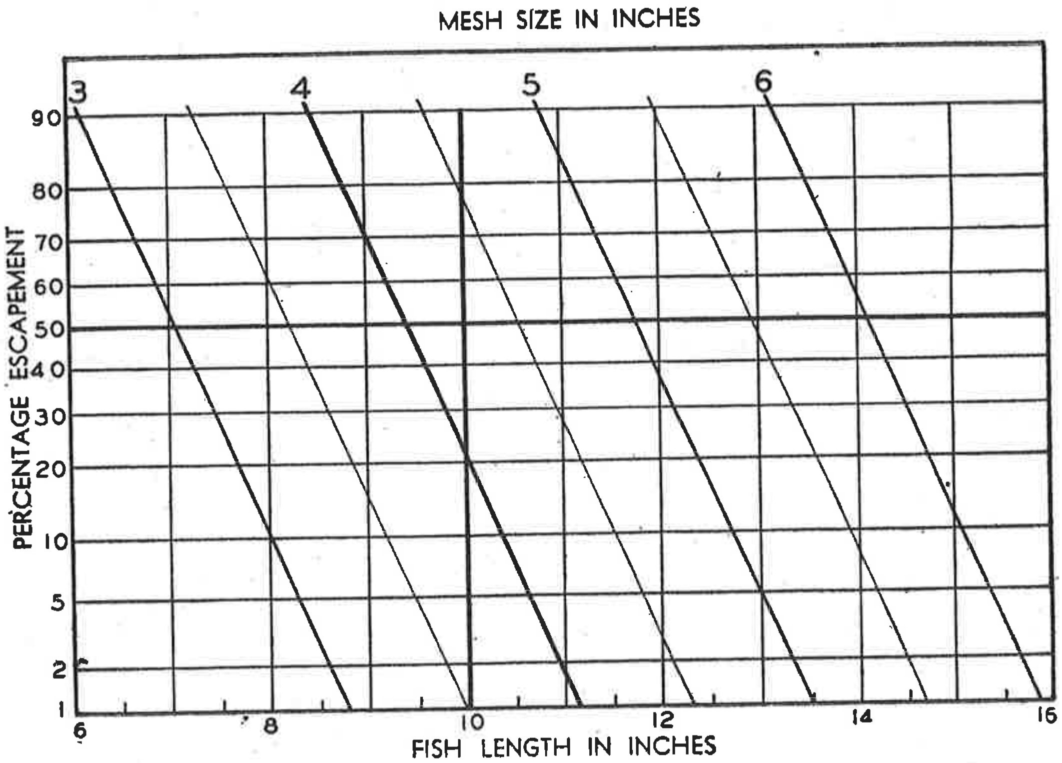


FIG. 34. Summary: Relationship between mesh size, fish length, and escapement

less sharp. In order to supplement to the maximum the releasing action of the cod-end, the mesh of other parts of the trawl should be at least as large as in the cod-end.

(6) The effectiveness of the cod-end as a "savings gear" does not normally decrease as it fills up with fish. The selective action actually improves after a small plug of fish forms at the bottom of the cod-end and holds the meshes open. Certain kinds of seaweed such as the fucoid *Carpophyllum flexuosum* may seriously reduce escapement if present in sufficient quantities, but it is unlikely that the invertebrate fauna and general bottom debris usually collected in the cod-end would have any more serious effect than a similar mass of fish.

(7) Although sufficient information is not available to make a final estimate of the best mesh size to obtain the maximum yield of snapper, it is believed that a marked improvement may be made by increasing the present minimum size to 5 in. This measure, though not absolutely certain, has a good probability of success in increasing the yield or at least in arresting its decline. Even in the event of its not being altogether successful, the results will almost certainly give valuable data which will greatly assist in the preparation of a future conservation programme.

Since certain other species of fish are likely to be affected by the change, some compromise may be required in the application of a new mesh size in New Zealand waters, and adjustments will very probably be needed as further information comes to hand.

(8) The question of the immediate effect of an enlarged mesh on the fisherman's catch needs to be determined by an investigation of similar scope to the North Shields experiment (Davis, 1934) in which the old and proposed new mesh were directly compared under carefully controlled conditions for some 1,200 hours' trawling time. It is believed that the value of catches will not be reduced by a larger mesh, but it is most desirable that this experiment be conducted before any such measure be put into effect so that, if necessary, adjustments may be made to avoid imposing too great a restriction on the fisherman during the transition period.

(9) The standard of mesh measurement found most satisfactory in this investigation is that taken inside opposite knots with the twine thoroughly wet and the mesh stretched to a tension of 10 lb. Where accuracy is essential, the average should be taken of at least one complete row of meshes running fore and aft in the cod-end.

(10) The destruction of snapper under 10 in. in length by New Zealand trawlers using a 4 in. cod-end may be in the order of 2·5 million, weighing 5,000 cwt., and with a potential value to the fisherman of £10,000. Of these, 40 per cent or more might be saved by the use of a 5 in. cod-end. These figures are not necessarily a reliable measure of the gains to be achieved by the increased mesh size, but they do serve to indicate that the matter is not a trifling one in terms either of money value or food resources.

7. ACKNOWLEDGMENTS

I gratefully acknowledge the assistance given by the following:

Captain A. Duthie, master of the research trawler *Ikatere,* who has been responsible for the setting up and working of all trawling equipment used in this project, and whose knowledge of practical fishing has been indispensable in all aspects of the field work.

Mr H. R. Haxell, who, in the absence of the author, has maintained a high standard in recording results, as well as performing his normal duties as mate of *Ikatere.*

The various members of the crew of *Ikatere* who have at one time and another assisted in the practical work.

Trawl fishermen in all parts of New Zealand who have contributed to the background of knowledge required in the investigation.

Miss M. K. McKenzie, who has been responsible for much of the preliminary tabulation and analysis of results.

My wife, Messrs K. R. Allen, A. C. Kaberry, and W. B. Taylor, all of whom have read and made valuable criticism of the manuscript.

Mr W. C. Smith (Secretary of Marine) and Mr M. W. Young (Chief Inspector of Fisheries) for permitting publication of these results as a Fisheries Bulletin.

R. M. C.

8. REFERENCES

BORLEY, J. O., and E. S. RUSSELL

1922 *Report on herring trawling.* Fish. Invest., Lond. (2) 4 (4):57 pp.

BOROWIK, J.

1930 *On what does the catch of undersized fish depend?* J. Cons. int. Explor. Mer 5:197–215.

BUCHANAN-WOLLASTON, H. J.

1927 *On the selective action of a trawl net, with some remarks on selective action of drift nets.* J. Cons. int. Explor. Mer 5:197–215.

1929 *The selective action of the Gelder cod-end and that of other cod-ends compared.* J. Cons. int. Explor. Mer 4:300–308.

CASSIE, R. M.

1950 *The analysis of polymodal frequency distributions by the probability paper method.* N.Z. Sci. Rev. 8:89–91.

1954 *Some uses of probability paper in the analysis of size frequency distributions.* Aust. J. Mar. Freshw. Res. 5:513–522.

CLARK, G. H.

1936 *The California trawl fishery and its conservation.* Calif. Fish Game 22:13–26.

CLARK, J. R.

1952a *Experiments on the escape of undersized haddock through otter trawls.* Comm. Fish. Rev. 14 (9):1–7.

1952b *Further experiments on the escape of undersized haddock through otter trawls.* Comm. Fish. Rev. 14 (12):7–12.

DAVIS, F. M.

1929 *Preliminary note on experimental trawling with cod-end meshes of different sizes.* J. Cons. int. Explor. Mer 4:287–299.

1934 *Mesh experiments with trawls,* 1928–33. Fish. Invest., Lond. (2) 14 (1):56 pp.

FISHERIES REGULATIONS

1950 *The fisheries (general) regulations,* 1950. Order in Council. Ser. no. 1950/147. (Wellington, N.Z.)

FULTON, T. W.

1893 *The capture and destruction of immature sea fish. Part 3. The relation between the size of the mesh of trawl nets and the fish captured.* Rep. Fish. Bd., Scotland 12 (3):302–312.

HERRINGTON, W. C.

1935 *Modification in gear to curtail the destruction of undersized fish in otter trawling.* Invest. Rep. U.S. Bur. Fish. 24:48 pp.

HOLT, E. W. L.
1895 *An examination of the present state of the Grimsby trawl with special reference to the destruction of immature fish.* J. Mar. biol. Ass. U.K. 3:339–448.

IVERSEN, T.
1934 *Some remarks on mesh width and its influence on young fish.* Rapp. Cons. Explor. Mer 90:39–44.

JOHNSTON, J.
1910 *Influence of size of net mesh.* In *Report of measurements of Irish Sea plaice made during year 1909.* Trans. L'pool. biol. Soc. 24:146–151.

KERR, J. E.
1953 *Studies on fish preservation at the Contra Costa steam plant of the Pacific Gas & Electric Company.* Fish Bull., Sacramento 92:52.

MARGETTS, A. R.
1952 *Some conclusions from underwater observation of trawl behaviour.* World Fishing 1:161–166 (Aug. 1952).
Unpub. *The escape of fish from different parts of a trawl.* 4 pp.

MARINE DEPARTMENT
1953 *Annual Report for the year* 1952–53, presented to the House of Representatives. p. 22. (Wellington, N.Z.)

MARINE LABORATORY, TORRY, ABERDEEN
1952 *Underwater photography of the seine net whilst fishing.* World Fishing 1:329–334 (Dec. 1952).

PETTERSSON, O.
1925 *The Swedish savings-trawl.* Svenska hydrogr.-biol. Komm. Skr. 6:6 pp.

RICKER, W. E.
1945 *A method of estimating minimum size limits for obtaining maximum yield.* Copeia 1945:84–94.

RIDDERSTAD, G.
1915 *A new construction of trawl intended to spare undersized fish.* Svenska hydrogr.-biol. Komm. Skr. 6:1–21.

RUSSELL, E. S. and T. EDSER
1926 *The relation between cod-end mesh and size of fish caught. Preliminary experiments with the trouser trawl.* J. Cons. int. Explor. Mer 1:39–54.

THORN, J., M. W. YOUNG, and E. SHEED
1937–38 *Report of the Sea Fisheries Investigation Committee, laid on the table of the House of Representatives.* (Wellington, N.Z.)

TODD, R. A.
1911 *Covered net experiments.* Rep. Mar. Biol. Ass. U.K. 3:177–206.

WALLACE, W.
1923 *Report on experimental hauls with small trawls in certain inshore waters off the east coast of England with special reference to young Pleuronectidae.* Fish. Invest., Lond. (2) 5 (5):30 pp.

9. APPENDIX

GLOSSARY OF TECHNICAL TERMS AND SPECIES OF FISH REFERRED TO IN THE TEXT

Danish seine: A method of fishing which originated in Denmark. In New Zealand it is often known simply as a "seine", while in Australia it is known as a "seine trawl". The net is similar in many respects to a trawl and might be expected to have a similar selective action, though it is claimed by some that the danish seine is a less destructive method of fishing than the trawl.

Fore and *aft* sides of the trawl: The sides which are towed from the fore and aft gallows respectively. The fore side is to port when trawling on the port side of the ship.

Floppa: A small piece of netting attached to the upper side of the mouth of the cod-end and serving to prevent fish from passing forward again.

Mesh: A single aperture in the net, bounded by four *bars* of twine with a knot at each junction. *Mesh size* in this paper refers to the maximum distance between two *opposite* knots, measured *inside* the knots.

Otter boards (see Fig. 35), (also *trawl boards, trawl doors,* etc.): Two rectangular boards, at the ends of the towing warps, one on either side of the trawl, which are suspended like kites so they are forced apart by the pressure of the water and hold the mouth of the trawl open.

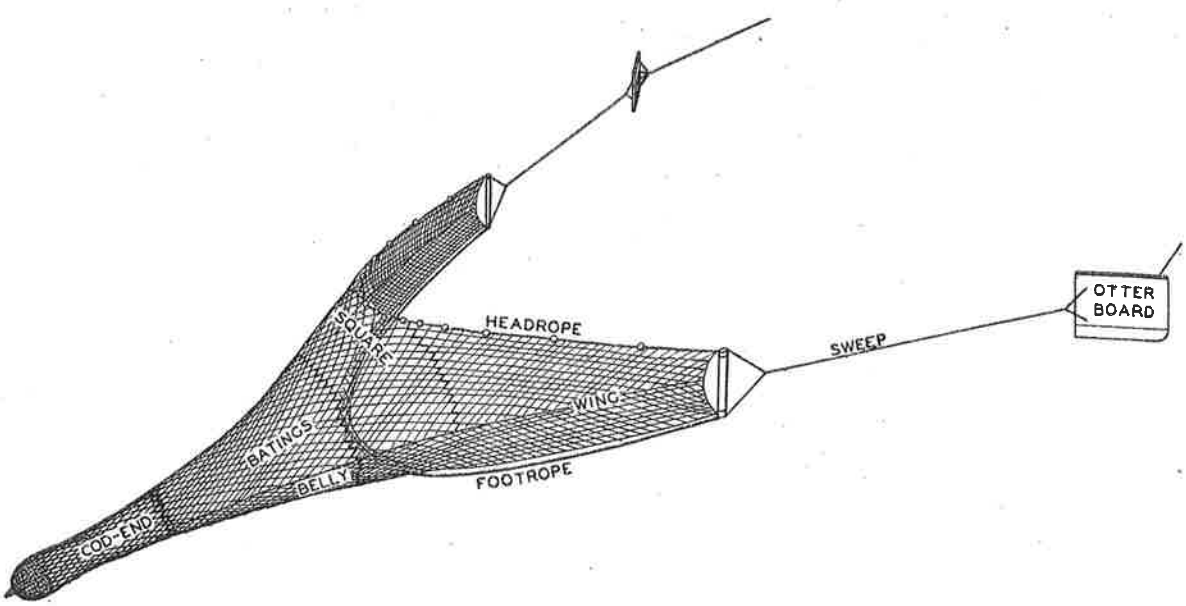


Fig. 35. The approximate shape of the trawl when in action, showing the position of the various parts mentioned in the text

Shot: One single and complete operation with the trawl, from the time the net is placed in the water to the time it is lifted and the fish emptied from the cod-end. The actual towing time is taken from the time the full length of trawl warp has been paid out to the time hauling in commences. In these experiments towing time was normally two hours.

Trawl: In all the experiments described the trawl was of the V-D (Vigneron-Dahl) or "French" type as commonly used in New Zealand, and is of similar size to those used by the larger motor trawlers. The V-D trawl is distinguished from the ordinary otter trawl in that the *otter boards* are attached by long wire *sweeps* (or *extensions*) to the trawl instead of being fastened directly to the wings.

Figure 35 shows the general appearance of the net with parts labelled. The full length of the sweeps is not indicated. The approximate dimensions of the trawl used by *Ikatere* is as follows. All measurements are in feet, unless otherwise specified, and in the case of netting are taken with the meshes fully stretched along the dimension concerned:

	Length	Breadth, Forward Edge	Breadth, After Edge
Headrope	76	..	..
Footrope	96	..	..
Upper wing	33	5	22
Lower wing	42	5	12½
Square	9	61	50
Belly	28	50	16½
Batings	28	50	16½
Cod-end	14	33 (circumference)	33
Total length	84	..	..
Otter boards	6	3 (× 2 in. thick)	..
Sweeps	100	1½ in. (circumference)	..

Length or *fork length* of fish: In all cases the length of the fish given is the maximum distance between the tip of the snout and the V or fork of the tail.

Blue cod: Parapercis colias Forster. (*Parapercidae*—not a true cod.)

Elephant fish: Callorhynchus millii Bory. (*Chimaeridae.*)

Flounder:

Rhombosolea plebeia Richardson. Sand flounder.
R. leporina Guenther. Yellow belly flounder. (*Pleuronectidae.*)

Gurnard: Chelidonichthes kumu Lesson and Garnot. (*Triglidae.*)

**Hapuku* or *Groper: Polyprion oxygeneios* Bloch and Schneider. (*Serranidae.*)

Ling: Genypterus blacodes Bloch and Schneider. (*Ophidiidae.*)

**Moki: Latridopsis ciliaris* Forster. (*Latridae.*)

---

* Names derived from the Maori. Frequently misspelt, e.g., "hapuka".

Snapper (sometimes *schnapper*): *Chrysophrys auratus* Forster. Small snapper are sometimes known as *bream*. (*Latridae.*)

Sole:

Peltorhamphus novae-zeelandiae Guenther. "English" sole.
Pelotretus flavilatus Waite. Lemon sole. (*Pleuronectidae.*)

**Tarakihi:* *Cheilodactylus macropterus* Forster. (*Cheilodactylidae.*)

Trevally: *Carynx lutescens* Jennings. (*Carangidae.*)

---

* Name derived from the Maori. Sometimes misspelt, e.g., "teraki" "terakihi".

10. TABLES

TABLE 1—SUMMARY OF ESCAPEMENT EXPERIMENTS

Series	Commenced	Completed	Shot Nos.	Cod-end	Cover	*
1	8/12/48	15/12/48	1–14	4½ MS90	4½ MS90	Yes
2	17/12/48	23/12/48	15–19	5 MS90	½ C32/9	Yes
	16/1/49	21/1/49	20–26	5 MS90	2 C32/36	Yes
	3/2/49	22/2/49	27–41	4 CD10/45	½ C32/9	Yes
	31/3/49	31/3/49	42	4 CD10/45	2 C32/36	Yes
	2/4/49	5/4/49	43–48	4 MS90a	2 C32/36	Yes
	8/6/49	19/8/49	49–61	6 MS90	2 C32/36	No
	24/8/49	2/9/49	62–68	5 MD90	2 C32/36	Yes
	7/9/49	13/9/49	69–72	5 MD90	2 C32/36	No
	28/9/49	10/11/49	73–86	5 MS90	2 C32/36	No
3	24/1/50	28/1/50	87–92	4 CS10/45	2 C32/36	Yes
	14/3/50	8/9/50	93–125	4¼ CS10/45	2 C10/48	No
4	5/3/51	7/8/51	153–168	4¼ CS10/45	2 C10/48	No
5	1/10/52	2/10/52	238–241	5 MS90	3 H36T	Yes
	14/10/52	18/10/52	242–243	5 MD90	3 H36T	No
	20/10/52	23/10/52	244–246	5 MS90	2 C32/36	No
	5/11/52	13/11/52	248–251	4 MS90b	3 H36T	No
	19/11/52	1/12/52	252–256	4 MD90	3 H36T	Yes
	26/1/53	28/1/53	264–266	4 MS90c	2 H36T	Yes
	3/2/53	12/2/53	267–268	4 MS90c	2 H36T	No

* "Yes" or "No" refers to whether or not the author was present when the shots concerned were made.

Table 2—Goodness of Fit

L	f	F	p	$\hat{p}$	$\hat{f}$	$\hat{f}'$	$(\hat{f}-f)$	χ^2	s_p	$\hat{p}+s_p$	$\hat{p}-s_p$
4	4	4	100·0	100·00	4·0	0·0	0·0	..	..	..	..
5	263 } 1092	269 } 1159	97·8	99·97	268·9 } 1153·7	0·1 } 5·3	5·9 } 61·7	..	..	..	..
6	352	389	90·5	99·81	388·3	0·7	36·3	721	..	..	..
7	473	497	95·2	99·1	492·5	4·5	19·5	..	..	..	..
8	1293	1403	92·2	96·2	1349·7	53·3	56·7	62	..	..	..
9	1538	1718	89·5	88·5	1520·7	197·3	−17·3	1·72	..	..	..
10	820	1132	72·3	72·9	825·2	306·8	5·2	0·12	1·32	..	71·6
11	439	845	51·9	51·2	432·6	412·4	−6·4	0·19	1·77	53·0	49·4
12	246	859	28·6	28·8	247·4	611·6	1·4	0·01	1·56	30·4	..
13	93	759	12·2	12·7	96·4	662·6	3·4	0·14	..	..	..
14	20 } 26	659 } 1051	3·0	4·2	27·7 } 31·6	631·3 } 1019·4	7·7 } 5·6	1·02	..	..	..
15	6	392	1·5	1·0	3·9	388·1	−2·1	..	..	..	..
Total, 9–15	3162	6364	..	..	3153·9	3210·1	−8·1	3·20	..	..	..
15	6	392	1·5	1·0	3·9	388·1	−2·1	..	..	..	..
16	5 } 11	248 } 849	2·0	0·21	0·5 } 4·4	247·5 } 844·6	−4·5 } 6·6	9·9	..	..	..
17	..	117	0·0	0·03	..	117·0	..	..	..	..	..
18+	..	92	0·0	0·00	..	92·0	..	..	..	..	..
Grand totals	5552	9383	..	..	5657·8	3725·2	..	..	..	..	..

Standard Error of E

$$E + s_e = 11 + (53{\cdot}0-50{\cdot}0)/(53{\cdot}0-30{\cdot}4) = 11{\cdot}13$$
$$E - s_e = 10 + (71{\cdot}6-50{\cdot}0)/(71{\cdot}6-49{\cdot}4) = 10{\cdot}97$$

Subtracting $2s_e$ $= 0{\cdot}16$

$s_e = 0{\cdot}08$

L = length of fish, in inches.
f = length frequency of fish in cover.
F = length frequency of total catch.
p = percentage escapement = $100f/F$.
$\hat{p}$ = expected percentage escapement (interpolated from linear curve).
$\hat{f}$ = expected number of fish in cover = $\hat{p}F/100$.
$\hat{f}'$ = expected number of fish in cod-end = $F-f$.
$\chi^2 = F(\hat{f}-f)^2/\hat{f}\hat{f}'$.
s_p = standard error of $\hat{p}$.
s_e = standard error of E.
E = escapement index.

TABLE 3—MESH MEASUREMENTS, SERIES 1

m			Square	Diamond
$4\frac{7}{16}$	..	..	12	3
$4\frac{8}{16}$	..	..	58	41
$4\frac{9}{16}$	..	..	25	15
$4\frac{10}{16}$	..	..	3	8
$4\frac{11}{16}$	..	..	2	2
$4\frac{12}{16}$	..	..	..	7
n	..	..	100	76
M	..	..	4·51	4·55
s_m	..	..	0·05	0·08

m = mesh size, in inches.
n = number of measurements.
M = mean mesh size.
s_m = standard deviation of mesh size.

TABLE 4—MESH MEASUREMENTS, SERIES 2

m		4in. Single	4 in. Double	m		5 in Single
$3\frac{13}{16}$	..	7	4	$4\frac{12}{16}$	..	1
$3\frac{14}{16}$	..	13	25	$4\frac{13}{16}$	..	11
$3\frac{15}{16}$	..	23	47	$4\frac{14}{16}$	..	21
4 ..	..	31	24	$4\frac{15}{16}$	..	14
$4\frac{1}{16}$	..	20	..	5	..	29
$4\frac{2}{16}$	..	5	..	$5\frac{1}{16}$	..	1
$4\frac{3}{16}$	..	1	..	..		..
n ..	..	100	100	..		77
M	..	3·98	3·93	..		4·92
s_m	..	0·08	0·05	..		0·07

Table 5—Mesh Measurements, Series 5

		5 in. Single				5 in. Double				4 in. Single		4 in. Double	Belly	Batings
Stretching Wt Dry or Wet *m*		1 lb. Dry (*a*)	1 lb. Dry (*b*)	1 lb. Wet (*c*)	10 lb. Wet (*d*)	1 lb. Dry (*e*)	10 lb. Dry (*f*)	10 lb. Wet (*g*)	10 lb. Wet (*h*)	10 lb. Wet (*i*)	10 lb. Wet (*j*)	10 lb. Wet (*k*)	10 lb. Wet (*l*)	10 lb. Wet (*m*)
3	..	..	..	..	..	..	..	..	..	..	3	..	..	..
$3\frac{1}{16}$	..	..	..	..	..	..	..	..	..	..	8	..	..	..
$3\frac{2}{16}$	..	..	..	..	..	..	..	..	..	1	27	..	..	..
$3\frac{3}{16}$	..	..	..	..	..	..	..	..	..	15	48	..	..	..
$3\frac{4}{16}$	..	..	..	..	..	..	..	..	..	22	61	..	..	..
$3\frac{5}{16}$	..	..	..	..	..	..	..	..	..	27	39	..	..	..
$3\frac{6}{16}$	..	..	..	..	..	..	..	..	..	30	24	15	..	..
$3\frac{7}{16}$	..	..	..	..	..	..	..	..	..	29	6	28	..	..
$3\frac{8}{16}$	..	..	..	..	..	..	..	..	..	21	2	16	..	..
$3\frac{9}{16}$	..	..	..	..	..	..	..	..	..	15	2	12	..	..
$3\frac{10}{16}$	..	..	..	..	..	..	..	..	..	21	1	1	..	..
$3\frac{11}{16}$	..	..	..	..	..	..	..	..	..	18	..	..	..	1
$3\frac{12}{16}$	..	..	..	..	..	..	..	..	..	16	..	..	..	2
$3\frac{13}{16}$	..	..	..	..	..	..	..	..	..	3	..	..	..	8
$3\frac{14}{16}$	..	..	..	..	..	..	..	..	..	7	..	..	..	18
$3\frac{15}{16}$	..	..	..	..	..	..	..	..	..	3	..	..	..	11
4	..	..	..	..	..	..	..	..	..	1	..	..	..	10
$4\frac{1}{16}$	..	..	1	..	..	..	..	2	..	..	..	..	..	11
$4\frac{2}{16}$	..	..	1	..	..	..	..	2	1	..	..	..	3	15
$4\frac{3}{16}$	..	..	1	1	..	..	..	8	4	..	..	..	4	13
$4\frac{4}{16}$	..	..	3	4	..	..	..	9	3	..	..	..	16	11
$4\frac{5}{16}$	..	1	..	7	..	..	..	9	8	..	..	..	18	3
$4\frac{6}{16}$	..	..	..	10	..	..	..	8	19	..	..	..	16	3
$4\frac{7}{16}$	..	4	5	8	..	..	..	9	13	..	..	..	9	2
$4\frac{8}{16}$	..	6	13	7	1	..	..	9	7	..	..	..	16	3
$4\frac{9}{16}$	..	12	15	6	10	..	..	7	10	..	..	..	11	3
$4\frac{10}{16}$	..	9	13	2	10	..	..	2	13	..	..	..	11	3
$4\frac{11}{16}$	..	3	15	..	22	..	..	1	7	..	..	..	7	2
$4\frac{12}{16}$	..	4	9	2	10	..	..	1	3	..	..	..	6	1
$4\frac{13}{16}$	..	4	5	..	13	..	..	..	2	..	..	..	5	1
$4\frac{14}{16}$	..	4	3	1	13	5	1	..	2	..	..	..	..	..
$4\frac{15}{16}$	..	2	3	..	3	4	2	..	1	..	..	..	1	..
5	..	..	..	..	4	3	7	..	..	..	..	..	1	..
$5\frac{1}{16}$	..	1	..	..	1	3	4	..	..	..	..	..	..	..
$5\frac{2}{16}$	..	..	1	..	..	3	12	..	..	..	..	..	..	..
$5\frac{3}{16}$	..	..	..	..	..	6	5	..	..	..	..	..	..	..
$5\frac{4}{16}$	..	..	..	..	..	2	7	..	..	..	..	..	..	..
$5\frac{5}{16}$	..	..	..	..	..	2	5	..	..	..	..	..	..	..
$5\frac{6}{16}$	..	..	..	..	..	..	3	..	..	..	..	..	..	..
$5\frac{7}{16}$	..	..	..	..	..	..	3	..	..	..	..	..	..	..
$5\frac{8}{16}$	..	..	..	..	..	..	2	..	..	..	..	..	..	..
$5\frac{9}{16}$	..	..	..	..	..	..	1	..	..	..	..	..	..	..
n	..	50	88	48	87	28	52	67	93	229	221	72	124	121
M	..	4·64	4·62	4·44	4·74	5·07	5·19	4·44	4·49	3·48	3·25	3·46	4·46	4·09
s_m	..	0·16	0·18	0·14	0·13	0·14	0·16	0·15	0·17	0·19	0·16	0·06	0·14	0·25

7—Bull. No. 11.

Table 6—Square Mesh Experiments

(a) *Diamond Mesh Inside Square*

L	Diamond							Square							*F*	*p*	χ^2	*P*
	2	3	9	10	11	12	Total	2	3	9	10	11	12	Total (*f*)				
7 ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
8 ..	..	..	1	5	..	..	6	..	..	3	4	..	..	7	13	54	0·27	0·60
9 ..	2	2	14	15	5	2	40	..	..	19	13	1	1	36	76	47	0·00	0·99
10 ..	10	10	33	28	10	7	98	2	5	24	21	6	3	61	159	38	0·87	0·34
11 ..	10	9	9	41	17	18	104	2	9	12	11	5	12	52	157	34	0·58	0·44
12 ..	27	28	21	30	16	27	149	4	2	14	9	3	5	35	184	19·0	0·00	0·99
13 ..	19	30	10	40	13	12	124	2	3	1	5	..	1	11	135	8·2	0·13	0·72
14 ..	16	33	15	33	6	8	111	1	1	3	1	..	..	6	116	5·2 }	0·31	0·58
15 ..	7	26	11	18	13	5	80	..	..	..	..	1	..	1	81	1·2 }		
16 ..	3	15	4	7	6	2	37	..	..	1	1	3	..	(5)	42	..	..	..
17 ..	5	4	2	2	5	2	20	..	..	..	1	1	..	(2)	22	..	..	..
18+ ..	3	8	4	3	13	1	32	..	..	1	..	1	..	(2)	34	..	..	..
	102	165	124	222	104	84	801	11	20	78	66	21	22	218	1019	..	2·16	0·35

(b) *Square Mesh Inside Diamond*

L	Square							Diamond							*F*	*p*
	5	6	7	8	13	14	Total	5	6	7	8	13	14	Total (*f*)		
7 ..	..	..	..	..	..	3	3	..	..	..	..	..	1	1	4	25
8 ..	1	1	3	4	3	2	14	1	..	..	1	6	1	9	23	39
9 ..	10	4	6	9	14	21	64	2	2	3	3	7	1	18	82	22
10 ..	23	32	19	40	22	31	167	9	15	4	10	26	..	64	231	28
11 ..	34	26	34	69	39	87	289	3	4	8	6	27	3	51	340	15
12 ..	44	31	39	59	46	167	386	1	3	3	4	6	3	20	406	49
13 ..	35	21	21	38	46	167	328	..	1	1	..	2	2	6	334	1·8
14 ..	26	31	11	52	31	75	226	..	..	..	1	1	..	2	228	0·88
15 ..	11	15	11	34	16	30	117	..	..	1	..	..	..	1	118	0·85
16 ..	3	8	5	17	6	14	53	..	..	..	..	..	(3)	(3)	56	..
17 ..	1	8	2	14	3	1	29	..	..	..	..	..	(3)	(3)	32	..
18+ ..	2	5	6	7	11	1	32	..	..	..	..	..	(1)	(1)	33	..
	190	182	157	343	237	599	1708	16	25	20	25	75	18	179	1887	..

Table 7—Snapper, 4 in. Single Twine, Series 2

L	Cod-end 43	Cod-end 44	Cod-end 45	Cod-end 46	Cod-end 48	f'	Cover 43	Cover 44	Cover 45	Cover 46	Cover 48	f	F	p	χ^2
4 ..	..	..	..	..	..	..	..	2	..	..	..	2	2	100·0	(0·51) (rows 4–6)
5 ..	2	..	..	1	..	3	37	24	..	16	..	77	80	96·2	
6 ..	5	3	..	4	..	12	191	81	2	79	..	353	365	96·7	
7 ..	5	2	..	5	..	12	94	50	1	38	..	183	195	93·8	(4·58)
8 ..	22	21	..	30	..	73	54	40	..	62	1	157	230	68·3	2·87
9 ..	63	60	2	38	..	163	60	45	1	65	4	175	338	51·8	0·42
10 ..	62	67	..	35	7	171	17	16	1	20	4	58	229	25·3	0·16
11 ..	24	29	2	36	12	103	2	2	..	10	2	16	119	13·4	0·83
12 ..	15	29	1	36	11	92	3	..	1	4	..	8	100	8·0	0·072 (rows 12–15+)
13 ..	8	20	2	34	11	75	..	..	..	3	..	3	78	3·8	
14 ..	6	8	1	24	19	58	..	..	..	..	..	..	58	0·0	
15+ ..	15	10	2	48	19	94	..	..	..	..	..	..	94	0·0	
	227	249	10	291	79	856	458	260	6	297	11	1032	1888	..	4·35

L = length of fish, in inches.
f' = totals of cod-end length frequencies.
f = totals of cover length frequencies.
$F = f + f'$.
$p = 100f/F$.
χ^2, P—see Table 2.

Table 8—Snapper, 5 in. Single Twine, Series 2

L	Cod-end 20	21	22	23	24	25	26	73	77	78	79	80	81	82	83	84	85	86	f'
4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
5	2	..	1	..	..	..	..	..	..	..	2	..	..	..	..	..	1	..	6
6	3	..	1	1	..	1	1	1	3	..	9	..	..	2	4	7	2	2	37
7	..	..	3	4	..	4	1	2	6	..	..	..	1	3	..	..	..	..	24
8	9	5	10	15	..	23	10	10	5	..	2	..	..	3	4	9	..	5	110
9	8	10	11	17	..	39	21	17	8	..	6	3	..	12	2	15	2	9	180
10	18	33	14	21	3	37	35	41	13	..	2	23	..	14	5	20	8	25	312
11	17	40	22	48	1	54	52	64	16	..	8	21	4	29	6	12	4	8	406
12	21	70	33	43	13	62	76	95	32	2	10	19	5	69	6	23	19	15	613
13	29	67	55	38	12	67	65	52	65	2	9	11	8	141	2	14	11	18	666
14	27	77	57	60	17	74	43	27	77	1	6	..	7	132	1	12	3	18	639
15	21	43	39	24	9	26	21	13	62	1	2	2	4	99	4	6	4	6	386
16	12	18	24	18	6	14	14	7	59	1	4	3	5	47	2	3	2	4	243
17	5	9	5	10	3	5	5	..	32	2	5	..	..	27	1	..	7	1	117
18+	6	4	4	6	1	6	4	5	37	..	4	..	6	8	1	..	..	..	92
	178	376	279	305	65	412	348	334	415	9	69	82	40	586	38	121	63	111	3831

L	Cover 20	21	22	23	24	25	26	73	77	78	79	80	81	82	83	84	85	86	f		P	χ²
4	..	..	1	2	..	..	1	..	..	..	..	..	..	..	..	..	..	..	4	4	100·0	
5	55	3	24	6	..	45	17	95	..	..	5	..	..	4	1	2	2	4	263	269	97·8	(721)
6	59	12	18	10	..	15	15	103	8	..	7	14	1	8	17	27	18	20	352	389	90·5	
7	58	28	30	33	3	28	60	104	13	1	11	30	5	7	20	9	19	14	473	497	95·2	
8	162	98	82	145	39	231	245	141	17	..	13	25	6	9	6	17	24	33	1293	1403	92·2	(62)
9	93	94	90	134	33	268	228	445	21	..	11	18	3	6	18	6	34	36	1538	1718	89·5	1·72
10	84	89	82	77	38	140	121	55	15	4	19	4	4	18	11	11	18	30	820	1132	72·3	0·12
11	23	36	44	44	11	52	69	55	11	1	7	1	8	16	13	4	20	24	439	845	51·9	0·19
12	11	17	24	11	11	13	32	35	10	2	..	..	4	40	8	1	12	15	246	859	28·6	0·01
13	4	8	4	3	5	6	6	..	3	1	..	..	..	36	..	1	..	16	93	759	12·2	0·14
14	..	2	1	..	1	5	1	..	2	1	..	..	..	4	..	..	..	3	20	659	3·0	1·02
15	..	1	..	..	1	..	..	..	1	1	..	..	..	..	..	..	..	2	6	392	1·5	
16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	5	248	2·0	(9·9)
17	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	117	0·0	
18+	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	92	0·0	
	549	388	400	465	142	803	795	1033	101	11	73	92	31	148	94	78	147	202	5552	9383	..	3·20

TABLE 9—SNAPPER, 6 IN. SINGLE TWINE, SERIES 2

L	Cod-end										Cover										F	p	χ^2
	49	50	51	53	54	55	56	57	59	f′	49	50	51	53	54	55	56	57	59	f			
4 ..	..	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	..	..	..	3	3	100·0	(140) (4–9)
5 ..	..	..	..	1	..	..	..	..	..	1	..	16	..	16	4	3	24	..	..	63	64	98·4	
6 ..	..	4	..	..	..	..	5	..	..	9	4	65	14	20	3	13	66	5	1	191	200	95·5	
7 ..	2	3	1	..	..	..	..	..	..	6	4	70	11	13	2	13	64	8	3	188	194	96·9	
8 ..	1	2	1	..	..	1	1	..	..	6	3	55	10	19	3	3	30	1	3	127	133	95·5	
9 ..	..	9	2	..	..	3	2	..	..	16	16	135	19	57	7	4	52	1	6	297	313	94·9	
10 ..	5	10	4	..	..	1	1	..	..	21	41	119	28	37	4	6	68	5	10	318	339	93·8	0·16
11 ..	6	13	5	1	5	5	4	..	4	43	58	51	24	13	8	4	50	1	32	241	284	84·9	0·30
12 ..	27	6	2	1	7	6	3	2	5	59	32	16	17	6	3	10	27	1	23	135	194	69·6	0·50
13 ..	22	12	6	1	5	4	10	3	2	65	11	12	14	5	6	5	14	3	22	92	157	58·6	1·80
14 ..	27	12	2	..	13	4	6	5	7	76	3	3	6	..	3	2	9	..	15	41	117	35·0	0·10
15 ..	35	6	3	..	14	4	14	..	2	78	..	1	2	..	2	..	2	1	4	12	90	13·3	1·27
16 ..	9	9	9	2	16	4	9	3	11	72	..	..	..	1	..	..	..	..	1	2	74	2·7	2·69
17 ..	8	3	3	..	21	..	6	1	2	44	..	..	..	..	..	..	2	..	2	4	48	8·4	(32) (17–23)
18 ..	..	..	1	1	5	1	2	..	3	13	..	..	..	..	..	..	..	..	1	1	14	7·1	
19 ..	1	..	2	1	2	..	..	..	3	9	..	..	..	..	..	..	..	..	2	2	11	18·2	
20 ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	100·0	
23 ..	1	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	1	0·0	
	144	89	41	8	88	33	63	14	39	519	172	546	145	187	45	63	408	26	126	1718	2237	..	6·82

TABLE 10—SNAPPER, 4 IN. DOUBLE TWINE, SERIES 2

L	Cod-end													
	27	28	29	30	31	32	33	35	36	37	38	39	40	f'
4	..	..	..	..	..	..	..	..	..	20	9	1	1	31
5	..	..	..	..	..	..	..	..	..	28	34	2	5	69
6	..	..	..	..	..	..	..	..	..	4	15	..	3	22
7	2	..	5	1	1	6	..	..	..	10	16	4	3	48
8	..	6	11	13	..	21	5	..	..	9	34	25	5	129
9	2	5	29	17	2	28	15	..	1	18	70	17	37	241
10	2	6	10	12	3	38	7	..	2	18	68	31	42	239
11	1	2	6	9	5	18	8	7	..	21	50	43	44	214
12	2	7	7	8	4	11	9	8	1	19	62	54	61	253
13	1	6	9	11	7	10	4	9	2	17	43	50	58	227
14	..	3	2	2	8	13	..	14	3	13	14	43	38	153
15+	..	3	7	6	10	14	2	23	10	5	19	32	38	169
	10	38	86	79	40	159	50	61	19	182	434	302	335	1795

L	Cover														F	p	χ^2
	27	28	29	30	31	32	33	35	36	37	38	39	40	f			
4 ..	..	..	..	1	..	1	4	..	2	79	45	2	10	144	175	82·3	
5 ..	4	3	19	25	1	6	9	..	5	88	163	4	46	373	442	84·4	(2170)
6 ..	3	5	25	12	3	1	3	..	1	12	94	9	38	206	228	90·4	
7 ..	3	5	20	22	2	4	2	..	1	28	35	17	17	156	204	76·5	(52)
8 ..	8	25	59	80	1	25	3	..	3	30	78	34	27	373	502	74·3	0·01
9 ..	3	7	31	43	6	11	15	2	..	19	66	17	47	267	508	52·6	2·84
10 ..	3	3	4	8	2	2	2	..	1	3	18	5	21	72	311	23·1	0·03
11 ..	1	1	..	2	..	2	..	..	..	2	2	..	4	14	228	6·1	0·96
12 ..	..	..	2	2	..	..	..	..	..	1	1	..	..	6	259	2·3	
13 ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	227	0·0	0·06
14 ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	153	0·0	
15+ ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	169	0·0	
	25	49	160	195	15	52	38	2	13	262	502	88	210	1611	3406	..	3·90

TABLE 11—SNAPPER, 5 IN. DOUBLE TWINE, SERIES 2

L	Cod-end						Cover						*F*	*p*	χ^2
	67	68	69	70	71	*f′*	67	68	69	70	71	*f*			
4 ..	..	1	..	..	..	1	..	..	..	..	..	..	1	0·0	
5 ..	..	..	1	..	..	1	..	11	..	..	..	11	12	91·7	
6 ..	..	8	1	2	1	12	1	75	..	..	5	81	93	87·1	0·0001
7 ..	..	11	..	13	7	31	6	82	3	4	10	105	136	77·2	
8 ..	2	6	..	10	16	34	1	12	1	17	17	48	82	58·6	2·70
9 ..	1	13	..	17	25	56	1	17	4	24	32	78	134	58·2	0·64
10 ..	..	19	1	55	71	146	..	10	11	53	40	114	260	43·8	0·14
11 ..	4	11	13	62	62	152	..	2	25	35	20	82	234	35·1	1·96
12 ..	2	14	19	57	62	154	..	..	20	9	11	40	194	20·6	0·00
13 ..	5	28	11	39	40	123	..	..	9	1	5	15	138	10·9	0·70
14 ..	4	31	18	32	26	111	..	..	6	4	1	11	122	9·0	
15 ..	7	23	10	23	14	77	..	..	..	..	2	2	79	2·5	
16 ..	8	15	6	15	6	50	..	..	..	..	..	..	50	0·0	
17 ..	3	13	3	3	4	26	..	..	..	..	1	1	27	3·7	0·003
18 ..	3	6	..	2	1	12	..	..	..	..	..	..	12	0·0	
19+ ..	3	11	..	5	..	19	..	..	..	..	..	..	19	0·0	
	42	210	83	335	335	1005	9	209	79	147	144	588	1593	..	6·15

Table 12—Gurnard, 4 in. Double Twine, Series 2

L	*F*	*f*	*p*	χ^2
4	10	9	90·0	1·60 (4–9)
5	10	10	100·0	
6	5	5	100·0	
7	4	4	100·0	
8	14	13	92·9	
9	12	9	75·0	
10	27	21	77·8	0·92
11	51	25	49·0	0·02
12	68	21	30·9	0·00
13	39	8	20·5	0·17 (13–15+)
14	23	1	4·4	
15	8	..	0·0	
15+	2	..	0·0	
	273	126	..	2·71

Table 13—Gurnard, 5 in. Single Twine, Series 2

L	*F*	*f*	*p*	χ^2
5	120	..	0·0	(600)
6	104	77	74·1	(1·44)
7	255	209	81·9	(9·2)
8	501	296	59·0	(17·1)
9	458	266	58·1	2·15
10	353	188	53·3	0·33
11	331	167	50·5	0·79
12	668	284	42·5	0·40
13	797	308	38·6	5·17
14	805	244	30·3	0·90
15	532	102	19·2	5·05
16	108	19	17·6	1·30 (16–18)
17	27	..	0·0	
18	4	..	0·0	
	5063	2160	..	16·09

TABLE 14—GURNARD, 6 IN. SINGLE TWINE, SERIES 2

L	*F*	*f*		χ^2
6	15	15	100·0	
7	23	22	95·7	
8	20	18	90·0	
9	13	13	100·0	(10·2)
10	25	24	96·2	
11	32	29	90·7	
12	46	42	91·3	0·16
13	80	68	85·0	0·07
14	79	55	69·6	0·03
15	44	23	52·2	0·02
16	26	11	42·3	
17	5	..	0·0	0·02
18	2	..	0·0	
	410	320	..	0·30

TABLE 15—TARAKIHI, 5 IN. SINGLE TWINE, SERIES 2

L	*F*	*f*	*p*	χ^2
9	2	2	100·0	
10	3	3	100·0	0·18
11	3	3	100·0	
12	11	6	54·5	
13	9	3	33·3	0·002
14	25	3	12·0	
15	103	4	3·9	
16	87	7	8·0	
17	35	4	11·4	(21)
18	3	..	0·0	
19	2	..	0·0	
	283	35	..	0·18

TABLE 16—SNAPPER, 4 IN. SINGLE TWINE, SERIES 5 (REJECTED)

L	Cod-end					Cover					*F*	*p*
	248	249	250	251	*f′*	248	249	250	251	*f*		
2¾ ..	1	..	..	..	1	7	..	..	..	7	8	87·5
3¼ ..	3	..	..	..	3	22	..	2	..	24	27	88·9
3¾ ..	2	..	1	..	3	38	..	1	1	40	43	93·0
4¼ ..	4	1	..	1	6	29	..	3	2	34	40	85·0
4¾ ..	5	..	1	2	8	25	2	7	1	35	43	81·4
5¼ ..	9	1	2	..	12	26	..	14	3	43	55	78·3
5¾ ..	13	..	8	3	24	20	1	22	8	51	75	68·0
6¼ ..	22	3	11	5	41	26	7	33	12	78	119	65·5
6¾ ..	20	5	19	12	56	22	32	26	18	98	154	63·6
7¼ ..	28	7	22	4	61	27	29	38	15	109	170	64·1
7¾ ..	22	5	15	3	45	20	40	27	12	99	144	68·7
8¼ ..	16	3	19	5	43	19	29	21	14	83	126	65·9
8¾ ..	20	4	27	8	59	12	35	33	22	102	161	63·3
9¼ ..	29	9	31	9	78	3	13	25	19	60	138	43·5
9¾ ..	19	12	39	20	90	..	3	8	13	24	114	21·0
10¼ ..	20	13	31	13	77	..	1	3	5	9	86	10·5
10¾ ..	29	19	35	11	94	1	1	..	2	4	98	4·1
11¼ ..	22	13	38	9	82	..	..	1	..	1	83	1·2
11¾ ..	18	16	55	9	98	..	..	..	1	1	99	1·0
12¼ ..	21	20	44	15	100	1	1	2	..	4	104	3·8
12¾ ..	27	26	38	11	102	..	..	1	..	1	103	1·0
13¼ ..	34	18	40	11	103	..	..	..	..	..	103	0·0
13½+ ..	145	137	160	23	465	..	..	..	..	..	465	0·0
	529	312	636	174	1651	298	194	267	148	907	2558	..

TABLE 17—SNAPPER, 4 IN. SINGLE TWINE, SERIES 5

L	Cod-end						Cover						*F*	*p*	χ^2
	264	265	266	267	268	*f′*	264	265	266	267	268	*f*			
3¾ ..	2	..	..	..	..	2	1	..	..	..	..	1	3	33·3	
4¼ ..	1	..	..	1	..	2	10	..	..	8	1	19	21	90·4	
4¾ ..	2	..	..	..	..	2	36	5	..	8	3	52	54	96·2	
5¼ ..	4	..	..	4	..	8	33	6	..	20	..	59	67	87·9	(112)
5¾ ..	..	..	1	3	..	4	8	1	3	27	4	43	47	91·6	
6¼ ..	3	2	5	8	1	19	15	3	11	45	27	101	120	84·1	
6¾ ..	21	8	7	19	8	63	107	35	11	94	39	286	349	81·8	1·45
7¼ ..	39	19	7	28	22	115	98	28	4	78	19	227	342	66·3	0·00
7¾ ..	63	22	9	48	20	162	70	15	1	55	8	149	311	47·8	1·94
8¼ ..	47	21	9	29	24	130	14	4	1	14	3	36	166	21·7	0·74
8¾ ..	25	13	28	23	32	121	2	3	1	12	1	19	140	13·6	2·37
9¼ ..	48	22	52	28	35	185	5	..	..	8	2	15	200	7·5	(12·1)
9¾ ..	51	27	45	36	39	198	3	..	..	4	..	7	205	3·4	
10¼ ..	40	23	35	29	47	174	7	1	..	2	1	11	185	5·9	
10¾ ..	23	13	34	35	39	144	..	..	..	..	..	..	144	0·0	
11¼ ..	33	13	32	57	30	165	1	..	..	1	..	2	167	1·2	(102)
11¾ ..	32	15	29	38	31	145	..	..	..	..	..	..	145	0·0	
12¼ ..	33	27	52	29	38	179	..	1	..	..	..	1	180	0·6	
12½+	200	146	175	268	151	940	..	..	..	..	..	..	940	0·0	
	667	371	520	683	517	2758	410	102	32	376	108	1028	3786	..	6·05

TABLE 18—SNAPPER, 5 IN. SINGLE TWINE, SERIES 5

L	Cod-end			Cover			F	p	χ^2
	238	241	f'	238	241	f			
6¼ ..	2	..	2	3	..	3	5	60·0	
6¾ ..	1	..	1	2	1	3	4	75·0	
7¼ ..	..	1	1	3	3	6	7	85·7	
7¾ ..	2	2	4	7	6	13	17	76·5	
8¼ ..	1	5	6	17	21	38	44	86·4	(193)
8¾ ..	5	2	7	48	38	86	93	92·5	
9¼ ..	3	3	6	43	42	85	91	93·5	
9¾ ..	7	5	12	39	82	121	133	91·0	
10¼ ..	10	10	20	70	84	154	174	88·6	0·27
10¾ ..	29	41	70	43	97	140	210	66·6	0·30
11¼ ..	37	74	111	15	69	84	195	43·1	0·00
11¾ ..	39	86	125	5	32	37	162	22·8	0·71
12¼ ..	24	97	121	2	7	9	130	6·9	0·00
12¾ ..	17	67	84	..	3	3	87	3·4	
13¼ ..	13	47	60	..	1	1	61	1·6	
13¾ ..	22	54	76	..	1	1	77	1·3	
14¼ ..	9	44	53	1	..	1	54	1·9	2·55
14¾ ..	9	29	38	1	..	1	39	2·6	
15¼ ..	5	22	27	..	..	..	27	0·0	
15½+ ..	17	56	73	..	..	..	73	0·0	
	252	645	897	299	487	786	1683	..	3·83

TABLE 19—SNAPPER, 4 IN. DOUBLE TWINE, SERIES 5 (REJECTED)

L	Cod-end			Cover			F	p
	252	253	f'	252	253	f		
2¾ ..	..	..	..	1	..	1	1	100·0
3¼ ..	..	..	..	2	1	3	3	100·0
3¾ ..	5	1	6	4	2	6	12	50·0
4¼ ..	5	..	5	8	6	14	19	73·7
4¾ ..	9	3	12	19	10	29	41	70·8
5¼ ..	14	5	19	19	12	31	50	62·0
5¾ ..	19	4	23	12	17	29	52	55·8
6¼ ..	18	11	29	8	22	30	59	50·8
6¾ ..	12	17	29	22	9	31	60	51·7
7¼ ..	19	24	43	18	19	37	80	46·2
7¾ ..	18	19	37	13	7	20	57	35·1
8¼ ..	16	18	34	12	4	16	50	32·0
8¾ ..	20	13	33	19	2	21	54	38·9
9¼ ..	29	24	53	12	..	12	65	18·5
9¾ ..	23	15	38	7	..	7	45	15·6
10¼ ..	26	22	48	4	1	5	53	9·4
10¾ ..	34	27	61	2	..	2	63	3·2
11¼ ..	30	38	68	..	..	..	68	0·0
11¾ ..	22	32	54	1	..	1	55	1·8
12¼ ..	19	23	42	..	1	1	43	2·3
12¾ ..	24	23	47	2	..	2	49	4·1
13¼ ..	30	14	44	..	..	..	44	0·0
13½+ ..	77	75	152	..	..	..	152	0·0
	469	408	877	185	113	298	1175	..

TABLE 20—SNAPPER, 4 IN. DOUBLE TWINE, SERIES 5

L		Cod-end			Cover			*F*	*p*	χ^2
		254	256	*f′*	254	256	*f*			
3¾	..	..	..	..	..	2	2	2	100·0	
4¼	..	..	..	..	..	4	4	4	100·0	
4¾	..	..	..	..	6	42	48	48	100·0	3·35
5¼	..	2	..	2	67	30	97	99	98·0	
5¾	..	6	1	7	146	27	173	180	96·1	
6¼	..	9	1	10	93	51	144	154	93·5	0·07
6¾	..	6	3	9	17	25	42	51	82·4	0·01
7¼	..	12	3	15	20	20	40	55	72·7	1·82
7¾	..	45	9	54	13	14	27	81	33·3	1·72
8¼	..	46	29	75	7	10	17	92	18·5	0·24
8¾	..	26	20	46	1	3	4	50	8·0	0·00
9¼	..	20	19	39	..	..	..	39	0·0	
9¾	..	21	23	44	..	..	..	44	0·0	
10¼	..	12	25	37	..	..	..	37	0·0	0·002
10¾	..	19	29	48	1	..	1	49	2·0	
11¼	..	23	20	43	..	..	..	43	0·0	
11½+	..	124	175	299	..	..	..	299	0·0	
		371	357	728	371	228	599	1327	..	7·21

TABLE 21—SNAPPER, 5 IN. DOUBLE TWINE, SERIES 5

L		Cod-end			Cover			F	*p*	χ^2
		242	243	*f′*	242	243	*f*			
5¾	..	1	..	1	8	..	8	9	88·9	
6¼	..	5	..	5	50	1	51	56	91·1	
6¾	..	2	..	2	92	10	102	104	98·1	(64)
7¼	..	3	1	4	76	7	83	87	95·4	
7¾	..	2	1	3	44	23	67	70	95·7	
8¼	..	4	3	7	79	70	149	156	95·5	
8¾	..	11	10	21	100	117	217	238	91·2	0·23
9¼	..	13	13	26	63	76	139	165	84·2	1·62
9¾	..	6	51	57	24	71	95	152	62·5	0·00
10¼	..	16	94	110	17	41	58	168	34·5	2·23
10¾	..	21	123	144	15	34	49	193	25·4	1·72
11¼	..	22	141	163	7	8	15	178	8·4	0·10
11¾	..	17	125	142	1	3	4	146	2·7	
12¼	..	31	129	160	..	..	..	160	0·0	0·20
12½+	..	322	481	803	..	..	..	803	0·0	
		476	1172	1648	576	461	1037	2685	..	6·10

TABLE 22—CONTROL EXPERIMENT, SERIES 5: 5 IN. SINGLE TWINE, WITHOUT TOGGLES

L	Cod-end				Cover				F	p	χ^2
	244	245	246	f'	244	245	246	f			
4¼	..	..	..	..	1	1	1	3	3	100·0	
4¾	..	..	..	..	2	3	2	7	7	100·0	
5¼	..	..	..	..	7	4	1	12	12	100·0	
5¾	..	..	..	..	8	5	1	14	14	100·0	
6¼	1	1	..	2	13	8	2	23	25	92·0	
6¾	1	1	..	2	18	10	3	31	33	93·9	(34)
7¼	3	4	..	7	23	16	8	47	54	87·0	
7¾	1	2	2	5	20	17	5	42	47	89·5	
8¼	2	..	1	3	14	10	5	29	32	90·5	
8¾	2	3	..	5	20	18	7	45	50	90·0	
9¼	5	5	3	13	22	33	13	68	81	84·0	0·03
9¾	9	7	3	19	43	45	21	109	128	85·2	9·35
10¼	33	25	6	64	35	34	16	85	149	57·0	0·81
10¾	27	33	27	87	23	35	24	82	169	48·5	0·10
11¼	33	45	23	101	15	17	15	47	148	31·8	0·38
11¾	49	68	41	158	10	10	7	27	185	14·6	6·61
12¼	40	53	27	120	8	7	2	17	137	12·4	0·12
12¾	40	42	13	95	3	4	..	7	102	6·9	0·06
13¼	29	33	20	82	1	2	1	4	86	4·7	
13¾	38	40	24	102	1	1	..	2	104	1·9	
14¼	23	29	19	71	..	2	..	2	73	2·7	
14¾	19	25	8	52	..	..	..	..	52	0·0	2·43
15¼	15	12	6	33	..	1	..	1	34	2·9	
15½+	27	24	8	59	..	..	..	..	59	0·0	
	397	452	231	1080	287	283	134	704	1784	..	19·89

TABLE 23—CONTROL EXPERIMENT, SERIES 4

L	167			168
	f	*f'*	*p*	*f'*
2	12	..	100·0	..
3	42	..	100·0	..
4	80	..	100·0	..
5	58	..	100·0	..
6	45	..	100·0	..
7	56	..	100·0	1
8	69	1	98·6	4
9	28	3	90·3	6
10	12	9	57·2	18
11	3	20	13·0	28
12	1	13	7·1	30
13	1	17	5·0	27
14	..	21	0·0	40
15	..	20	0·0	36
16	..	7	0·0	11
17	..	2	0·0	1
18+ ..	..	..	..	3
	407	113	..	205

L = length of fish, in inches.
f = length frequency in cover.
f' = length frequency in cod-end.
p = $100f/(f+f')$.

TABLE 24—LENGTH FREQUENCY OF SNAPPER MESHED IN 5 IN. COD-END, SHOT 241

L			f
9¼	..	..	1
9¾	..	..	1
10¼	..	..	2
10¾	..	..	8
11¼	..	..	14
11¾	..	..	19
12¼	..	..	13
12¾	..	..	3
13¼	..	..	1
13¾	..	..	..
14¼	..	..	1
	Total	..	63
	Mean	..	11·61
	Standard deviation		0·80

TABLE 25—SUMMARY OF ESCAPEMENT STATISTICS

Species	Series	M_n	$M \pm s_m$	$E \pm s_e$	S	E/M	E'	P	$d.f.$	N	N_s	W
Snapper	1	4½ S	4·55±0·009*	10·5	1·9	2·25	11·0	0·15	1	1019	6	2
	..	4½ Sq	4·51±0·005*	9·1	1·8	1·96	10·9	..	..	1708	6	..
	2	4 S	3·98±0·008*	9·0±0·12	1·6	2·21	9·6	0·1	2	1888	5	9
	..	4 D	3·93±0·005*	8·95±0·08	1·45	2·22	9·5	0·15	2	3407	13	15
	..	5 S	4·92±0·008*	11·05±0·08	1·71	2·19	11·8	0·4	3	9383	18	36
	..	5 D	(4·9)	9·4±0·37	3·2	1·87	11·8	0·3	5	1593	5	7
	..	6 S	(5·9)*	13·15±0·32	2·0	2·17	14·2	0·15	4	2237	9	6
	5	4 S	3·25±0·011	7·6±0·06	0·87	2·34	7·6	0·03	2	3786	5	12
	..	4 D	3·46±0·007	8·1±0·12	0·85	2·34	8·1	0·2	5	1327	2	3
	..	5 S	4·74±0·014	11·15±0·16	0·74	2·35	11·15	0·3	3	1683	2	7
	..	5 D	4·44±0·018	10·1±0·08	0·90	2·27	10·4	0·2	4	2685	2	7
	5 (2)	5 S	4·74±0·014	10·6±0·15	1·41	2·24	11·15	<0·01	6	1784	3	6
Gurnard	2	4 D	3·93±0·005	11·0±0·37	2·0	2·8	..	0·2	2	273	10	..
	..	5 S	4·92±0·997	10·7	5·9	2·2	..	<0·01	5	5063	16	..
	..	6 S	(5·9)	15·2±0·18	2·2	2·6	..	0·8	2	410	4	..
Tarakihi	2	5 S	4·92±0·008	12·2±0·8	1·6	2·5	12·6	..	..	293	3	..

* Apply correction factor × 4·74/4·62 in computing E/M and E'.

M_n = nominal mesh size, in inches.
M = true mesh size, in inches.
s_m = standard error of M.
E = escapement index, experimental estimate.
s_e = standard error of E.
S = selection index.
E' = escapement index = $2 \cdot 35M$.
P = goodness of fit.
$d.f.$ = number of degrees of freedom in fitting curve.
N = total number of snapper, etc., caught.
N_s = number of shots.
W = weighting factor.

Table 26—Snapper, 5 in. Single Twine Cod-end: Results of Individual and Grouped Shots

Shot		E	S
20 ..	..	11·3	1·5
21 ..	..	10·9	1·65
22 ..	..	..	1·6
23 ..	..	11·0	1·2
25 ..	..	11·0	..
26 ..	..	11·1	1·45
73 ..	..	11·0	..
77 ..	..	10·9	..
82 ..	..	11·0	..
>175 ..	..	11·05	1·53
<175 ..	..	11·00	2·35
Total	..	11·05	1·71

Table 27—Snapper, 4 in. Single Twine Cod-end: Results of Individual and Grouped Shots

Shot		E	S
37 ..	..	9·1	1·5
38 ..	..	8·7	1·5
39 ..	..	8·5	1·5
40 ..	..	9·2	1·4
>175 ..	..	9·05	1·25
<175 ..	..	9·0	1·7
Total	..	8·95	1·45

Table 28—Growth Rate of the Snapper

t		l	w	i
1 ..	..	4·0	0·85	2·7
1½ ..	..	5·7	2·3	1·5
2 ..	..	7·0	4·1	0·96
2½ ..	..	8·05	6·2	0·70
3 ..	..	9·0	8·4	0·54
3½ ..	..	9·8	11	0·42
4 ..	..	10·5	13	0·34
4½ ..	..	11·1	15	0·27
5 ..	..	11·6	17	0·22
5½ ..	..	12·0	19	0·16
6 ..	..	12·3	21	0·13
6½ ..	..	12·55	22	0·11
7 ..	..	12·7	23	0·08

t = age, in years.
l = fork length, in inches.
w = weight, in ounces.
i = instantaneous rate of gain in weight per annum.

R. E. OWEN, GOVERNMENT PRINTER, WELLINGTON—1955

1,400/6/54—32856 H