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MODIFICATIONS IN GEAR TO CURTAIL THE DESTRUCTION OF UNDERSIZED FISH IN OTTER TRAWLING

By WILLIAM C. HERRINGTON

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MODIFICATIONS IN GEAR TO CURTAIL THE DESTRUCTION OF UNDERSIZED FISH IN OTTER TRAWLING[1]

By William C. Herrington, *Aquatic Biologist, United States Bureau of Fisheries*

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INTRODUCTION

The destruction of undersize haddock did not become a problem of importance to the New England fishery until fairly recent years, for as late as 1900 the total haddock catch hardly reached 50,000,000 pounds and was taken mainly by line trawls. Following the introduction of the otter trawl into the commercial fleet in 1905, the landings slowly increased as the result of a gradual growth in the otter-trawl fleet.

The increasing use of the otter trawl met considerable opposition among the line and dory fishermen because of the belief that it was unduly destructive. As a consequence, Congress, in 1912, provided funds to enable the Commissioner of Fisheries to investigate beam and otter trawl fishing and report "whether or not this method of fishing is destructive to the species or is otherwise harmful or undesirable." Following an extensive investigation the Bureau's committee reported their conclusions in 1915. They found that the

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principal valid objection to the otter trawl was the large number of undersized food fish captured and destroyed by the nets. During the period of the investigation this amounted by *weight* to 40 percent for cod and 38 percent for haddock during June to December, and 3 percent for cod and 11 percent for haddock during January to May. Converted to numbers, the proportion of haddock destroyed amounted to about 77 percent and 40 percent, respectively. At that time, however, the recent introduction of the otter trawl and small size of the fleet made it impossible to reach any conclusion as to whether or not this additional strain would have any appreciable effect on the abundance of fish. Consequently, the committee recommended that otter trawling be restricted to certain banks and that developments during the following years be observed closely to determine what

FIGURE 1.—Setting the trawl after a good catch, Brown's Bank, March 1932, *Kingfisher* trip III.

effect this fishing would have on the abundance of groundfish over a long period of years. The committee also warned: "We emphatically state it to be our opinion that this regulation will prove futile and an unnecessary imposition on American fishermen unless Canada, particularly, and possibly Newfoundland and France will take such action as will prevent or restrict the use of the trawl on the banks in the western North Atlantic" (Alexander, Moore, and Kendall, 1915). The industry did not see fit to support these recommendations; consequently, at that time, neither the United States nor other Governments took further action.

During the following years there were a number of new developments in the groundfish industry. Improved processing methods resulted in an expanding market which led to a rapid increase in the otter-trawl fleet until in 1930 there were 323 such boats fishing out of Boston, Gloucester, Groton, and Portland.[2] This fleet landed nearly 3 times as much fish as the 142 liners and dory vessels fishing from the

[2] These ports receive all New England groundfish landings except a relatively small amount landed at local ports from inshore fishing grounds.

same ports. Although the expanded fishery was based mainly on haddock, the supply showed no alarming signs of decline until 1929 and 1930; in fact, the catch in 1927 (catch per boat per day)was the best within the modern records of our fishery (since 1915). But in 1929 haddock began a rapid decline from the high level reached in 1926, 1927, and 1928. This trend created considerable concern in the industry and was largely responsible for the allotment of funds to the Bureau of Fisheries for the study of the haddock fishery. The investigation was designed to determine the cause of the decline in the haddock catch and whether any effective measures could be devised for its relief.

The study of the fishery begun late in 1930 has demonstrated that the scarcity of marketable haddock during 1929 to 1931 arose principally from two causes. First, haddock spawning during 1925 to 1928 failed to produce more than negligible quantities of small fish, with the result that the stock of haddock of marketable size received few additions of upgrowing young to replace those taken by the fishery and natural mortality.[3] Second, the greatly expanded fishing fleet was removing haddock from the banks at a rate more rapid than ever before in the history of the fishery. Consequently, the marketable stock, with negligible recruitments of young fish, was reduced rapidly by an annual commercial catch which in 10 years had more than trebled in quantity.

Failure of the annual spawning, the first condition named above, appears to be beyond control, for no practical method has yet been developed by which the spawning success on the great offshore banks can be appreciably influenced by man. The second condition offers greater promise, for if means can be found to lessen considerably the strain on the stock without detriment to the fishery, a distinct saving will be achieved.

WASTAGE OF SMALL FISH IN NEW ENGLAND FISHERY

The published figures of haddock landings do not provide an adequate picture of the greatly increased strain on the fishery in recent years, for in addition to the threefold increase in the commercial catch it is an uncontroverted fact that each year large numbers of fish too small for market are taken by the trawls and thrown back into the sea dead. The trawler investigation in 1913 to 1914 showed how large was the proportion of undersized haddock and cod destroyed by the otter trawls, particularly during the summer and fall months. But at that time few boats were using this gear and the additional strain thus imposed on the population by the destruction of young had not caused any noticeable decrease in abundance.

The great increase in the trawling fleet since 1915 not only caused a tremendously augmented drain on the commercial stock through the catch of fish of marketable sizes (this strain would be equally great if the same quantity were caught by any other gear) but in addition imposed an equally serious but less obvious drain from a similar increase in the destruction of small fish. The magnitude of this destruction usually is not fully appreciated even by the most severe critics of the otter trawl. A few hundred or a thousand small haddock, because of their insignificant size, will attract little notice when

[3] The data upon which this statement is based will appear in a later report on the haddock fishery.

scattered about in a haul of several thousand pounds of trash and market fish. It is only when their numbers greatly surpass the large fish that the small haddock become particularly noticeable.

Quantitative records of the destruction of undersized haddock are available for two short periods, 1913–14 and 1930–32. The extensive series of observations made during the first period by Bureau observers engaged in the trawler investigation showed that of the total *number* of haddock caught between June and December, about 77 percent were unmarketable, and of those caught between January and May, about 40 percent. During the study of the haddock fishery in 1930, 1931, and 1932, length-frequency data collected by observers on 20 sea trips aboard commercial trawlers provide more recent information. Between September 1930, and May 1931, the percent of undersized haddock was approximately as follows: South Channel, 50 percent; Northern Edge, 67 percent; Southeastern Georges, 75 percent. During the last part of 1931 and in 1932 the proportion dropped off to 20 percent or less on Georges Bank, but on Browns Bank and eastward it amounted to nearly 75 percent. Thus it is evident that the proportion of undersized haddock in the catch varies with the season, the bank fished, and the year. The destruction is great during years following good spawning seasons, for the young fish then are present on the banks in large numbers; but after a series of poor seasons the number wasted is relatively low. Nevertheless, whether members of good or poor year classes, young haddock are subject to extensive decimation by the trawlers during the time they are growing from about ¼ to 1½ pounds (22 to 42 centimeters). On Georges Bank this growth requires about 1½ to 2 years. Consequently, before reaching marketable size each must run the gauntlet of the commercial fishery for nearly 2 years and the millions that fail to get through reduce the stock of haddock on the banks to the same degree as the capture of an equal number of large, commercially valuable fish.

EFFECT OF DESTRUCTION OF UNDERSIZED FISH ON STOCK

Before proceeding further it may be well to consider the effect on the stock caused by the destruction of millions of small fish. The subject has received considerable attention in Europe and in the case of certain species, notably the plaice, there still exists some difference in opinion. The negative argument is based principally on the "thinning theory" developed in Europe from results obtained in certain studies of the plaice fishery in the North Sea, Belt Sea, and western Baltic. The theory maintains that thinning out a stock of fish is desirable, especially for the smaller sizes, as it leaves a greater amount of food available for the survivors, which by their increased growth more than compensate for the weight of fish removed. Certain writers have transferred this argument from the plaice to other species and at one time it was held by several to be the solution of the overfishing problem. Petersen (1920) and Garstang (1926) argued that through an increase in the growth rate of its members a stock of fish would adjust itself to the strain upon it. The evidence in favor of the argument has come almost entirely from the plaice fishery but even for this species has been more or less discounted by the investigations of recent years (Blegvad, 1932; Hjort, 1932; Jensen, 1932).

The keystone of the "thinning theory" is the increase in growth rate which results from a decrease in the density of any species. However, in the case of roundfish such as the European haddock, cod, and herring, it has been definitely established that the density of the population has no perceptible effect on the growth rate (Bowman, 1932; Hjort, 1932; and Graham, 1933). Sufficient evidence also has accumulated to show that the wide fluctuations in haddock abundance on the North American banks are not accompanied by corresponding changes in growth rate. Consequently, there appears to be no question but that we can eliminate from consideration any such justification for the destruction of undersized fish of these species. In the absence of any favorable reaction in growth rate we are forced to the conclusion that the destruction of undersized haddock, caused by the nets now used in the otter-trawl fishery, is reflected in full as an increased strain on the stock.

Summarizing this discussion, we may point out, first, that under our present fishery great numbers of unmarketable haddock and cod are destroyed annually—a destruction which will become relatively greater with the increasing intensity of the fishery—and, second, the destruction of young fish serves no useful purpose. On the other hand, this destruction removes from the banks each year millions of small fish which if left at liberty another year or two would increase the commercially-valuable stock available to the fisherman thereby improving his catches during good years and, more important, providing a larger reserve to tide over the periods of scarcity which result from a series of poor spawning years. Furthermore, if a means can be developed which entirely or in part will prevent the destruction of undersized fish without curtailing the productivity of the trawling fleet, a clear gain will be achieved, for millions of potentially valuable fish will be saved without detriment to the commercial fishery.

Although it is certain that the extensive destruction of undersized haddock by the otter trawls accelerates the depletion of the stock, it can by no means be concluded that the prevention of all or a large part of this destruction will suffice to restore the fishery to its 1926 to 1928 level. But there can be no doubt that by avoiding such waste we shall obtain better fishing in the future than can be possible if present methods continue.

A review of the factors involved leaves no question of the desirability of avoiding the capture of undersized food fish, particularly haddock and cod. Our problem, therefore, is reduced to the question as to whether any method has been developed or can be developed to prevent the destruction of small fish without seriously affecting the operations of the trawling fleet. If a practical solution cannot be found, the future of our fishing banks may be that of the North Sea where an intensive and destructive fishery has so reduced the population in some of the most important regions, that during 1923 to 1931 the catch of marketable haddock averaged but 80 pounds per hour's trawling, and of these about 85 percent weighed less than three-fourths pound apiece (area C 13, Bowman, 1932). A catch of 80 pounds per hour amounts to about 1,200 pounds per day as trawling is done in our fishery (1½-hour hauls, 10 hauls per day). Compare this to the 13,500 pounds per day averaged by our large trawlers (91 net tons and over) on Georges Bank during the same years. (This catch per day is for marketable sizes of 1½ pounds and over.)

REVIEW OF LITERATURE ON "SAVINGS GEAR"

European investigators for nearly half a century have struggled for a practical solution of the problem of eliminating fish below commercial size from the catches of the beam and otter trawls. T. W. Fulton was one of the first to describe experimental tests of "savings gear" (using this term in its generally accepted sense covering any gear designed to permit the escape of small fish below a predetermined size). At about the same time, E. W. L. Holt was engaged in somewhat similar work which was described in 1895. Following these authors, a considerable amount of data has been published on the subject, especially in recent years when the question of saving small fish has been a live one.

The late T. W. Fulton, of the Scottish Fishery Board, was a pioneer in the field of savings gear with the publication in 1893 of an account of "Mesh experiments with beam or otter trawls." He used a 25-foot beam trawl with a covered cod-end and in his paper gives the number of fish of each size held in the cod-end and in the cover for mesh sizes of 1½ inch, 2 inch, 2½ inch, and 3 inch. Unfortunately, for our purpose his data for roundfish (haddock, cod, and whiting) either are too few or are concentrated in a narrow range of sizes so that, although the results indicate that the use of large mesh caused an increase in the size of escaping fish, no definite relationship can be obtained.

Holt in 1895 described experiments with an otter trawl using a cod-end of square mesh netting. He also tried a wooden frame enclosing square mesh, laced across the rear end of the cod-end, and other methods of spreading the cod-end such as wooden poles laced across the back and belly and wooden rods laced to the sides at the rear end. Holt records that the rigid frame effectively reduced the catch of small trash and that the square-meshed cod-end gave good results when new, but when thoroughly stretched the mesh pulled out of shape and was no better than diamond. It also required twine of double strength, therefore of increased weight, and was not recommended. He gives no data on the selection of the various gears tested.

Following the work mentioned above, experiments by other investigators were described from time to time. Gilson (1904) gave results obtained with an 8- to 10-meter beam trawl using a cod-end mesh of 1½ to 2 inches. His data are principally for flatfish. Heincke (1905), used a 90-foot otter trawl with a cod-end mesh of 3 to 3.5 centimeters. His data are for plaice and dabs. Redeke (1906) gave results for plaice, dabs, and whiting from experiments with a covered cod-end using 3-centimeter mesh.

In 1911, Todd published an account of extensive experiments with a 45-foot beam trawl and a 90-foot otter trawl. Fine-meshed covers were used on the cod-ends for all hauls and on the batings (belly tops) and square for part of the hauls. He gives data for the escapement through the square and belly tops as well as through the cod-end. Todd found that although the mesh in the square was about twice the size of that in the cod-end, and the mesh in the belly tops tapered from approximately the size of that in the square to a size somewhat larger than that in the cod-ends, yet of the total escapement but ½ percent of the plaice and dabs and 2.5 percent of the haddock and whiting escaped through the square, and 1 or 2 percent of the plaice and about 11 percent of haddock through the belly tops. Thus, the cod-end accounted for a very large proportion of the escaping fish. Todd, therefore, concluded that the square was of negligible importance for the escape of small fish, the belly tops of little importance, and the cod-end of predominant influence. He also made one series of experiments with the beam trawl using a rigid oval hoop in the rear end of the cod-end to hold the mesh open. This cod-end made of about 2¼-inch mesh, single twine, gave slightly sharper selection for haddock than the unsupported, 2¾-inch mesh, double twine, cod-end used on the otter trawl (fig. 2). The cod-end used with the hoop also gave considerably sharper selection for plaice than the same cod-end without, and the fish length at which 50 percent selec-

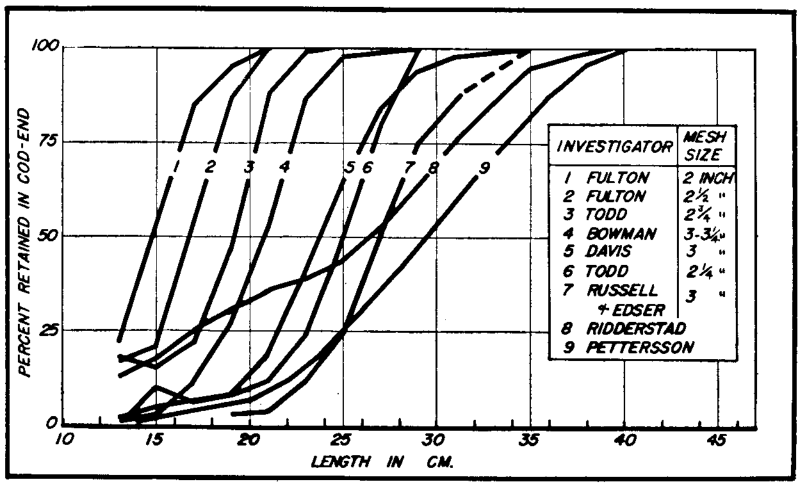

FIGURE 2.—Selection curves showing the proportion of fish retained in cod-end of total that entered, calculated from data published by European investigators shown in table. Data are not for haddock, except Ridderstad and Pettersson which also include cod, whiting, and herring. All investigators used diamond mesh except the last two.

tion occurred was more than 3 centimeters higher than in the latter case.

Johnstone, in 1911, described experiments with cod-ends made of mesh of different sizes and covered with fine-mesh netting. From his data he concluded that good results were not possible with a covering net as the draught of water through the net was seriously affected. He recommended the use of a series of hauls with alternate nets, but did not state that he had tried this method.

A unique trawl modification for saving small fish was described by Ridderstad in 1915. A rigid iron framework secured in the net between the cod-end and the belly supported rectangular mesh with uneven axes, the longer axis athwart the trawl. A special arrangement of "leading nets" forced the fish to pass near the windows of rectangular mesh before entering the cod-end. The author claimed a number of advantages for this type of trawl but most of them do not appear to be unique. The one which may turn out to be the most valuable contribution to savings gear design is the use of fixed rectangular mesh with unequal axes. This construction makes it possible to adjust the mesh to independent size limits for round and flatfish, a decided consideration if both groups are important in the catch. However, the Ridderstad gear appears rather unwieldy, and Pettersson (1925) cites this and its cost as the principal arguments against its use. The data given in Ridderstad's account indicate that the selective characteristics of the gear were very poor (fig. 2), but haddock, cod, and whiting were lumped together in his data, and this gives a greater spread to the selection curve because of the different body proportions of these species. But poor selection also is shown by his data for flatfish.

Fulton in his "Report on herring trawling investigations" (1921), gave data on the destruction of small fish and on the selection obtained with covered cod-ends using mesh of various sizes between 1¼ and 3 inches. No haddock measurements were given for the 3-inch mesh and those for the 1¼-inch, 1½-inch, and 1¾-inch are not significant owing to the absence of sufficiently small fish. Selection curves for his data for 2- and 2½-inch mesh are shown in figure 2.

In another report on herring trawling, Borley and Russell (1922) present data on the catch of haddock and whiting obtained with nets using different combinations of mesh sizes in the cod-end, belly, and batings (belly tops). Their results for haddock and whiting indicate that an increase in the size of cod-end mesh reduces the catch of small fish and that the mesh size in the batings is of considerable importance for the escape of small fish. The evidence does not seem conclusive.

Wallace (1923) reported on the results of experimental hauls with small trawls using different mesh sizes. His results in general indicate that an increase in size of mesh allows more small fish to escape. Data are given for soles, plaice, and dabs.

In 1925 Pettersson described a simplified method for using rectangular mesh in the batings of the trawl. This gear was designed to overcome the principal objections to the rather cumbersome Ridderstad trawl—unwieldiness and cost. The new design used a long window of rectangular mesh in the top of the batings, with the long axis of the mesh running athwart the trawl. Cane struts at the forward and rear ends of the window served to keep the mesh extended laterally and leading nets were provided to force the fish to pass near the window before entering the cod-end. The leading nets were of mesh similar to that in the window, and served as additional area for escape. Pettersson's data indicate that although the selection obtained with this gear was considerably sharper than with the original Ridderstad trawl, it still was decidedly poorer than that obtained by the use of a normal cod-end with large mesh throughout (fig. 2). However, Pettersson has lumped together all roundfish, as did Ridderstad, and this may have flattened out the selection curve.

A new method for determining the effects on the catch from the use of cod-end mesh of different sizes, was described by Russell and Edser in 1926. They proposed the use of the "trouser trawl" (trouser cod-end), an ordinary otter trawl with the cod-end divided into 2 legs as in a pair of trousers. The mesh sizes to be compared were used one in each of the 2 legs of the cod-end. The authors offered the following objections to the customary methods used for comparing the effect of mesh of different sizes: i. e., by the use of nets with fine-mesh covers or by alternate hauls on the same ground. The covered trawl offers an increased resistance to water flow and the cover may hinder the escape of small fish through the large mesh of the inside cod-end, while the alternate use of 2 nets requires a long series of hauls to give reliable results. Data are given for plaice caught in a trouser trawl using 3½-inch mesh in one leg and 4½-inch in the other, and for haddock caught in cod-end legs of 2-inch and 3-inch mesh, respectively (fig. 2). Single twine was used in both cases. In each case the leg with larger mesh caught fewer small fish, but more large. The authors recognize the difference between the size of mesh on the spool measured dry, "nominal" mesh, and the size of the mesh after use, "actual" or "effective" mesh. A conical gage was used for the measurements. They, therefore, used mesh circumference measured inside the twine instead of mesh diameter or mesh side measured between knot centers.

Bowman (1928) gave the sizes of haddock caught in a 3 to 3¼-inch cod-end with a fine-mesh cover. He reported that the use of larger mesh allowed larger fish to escape but did not give data for more than one mesh size. His length frequencies from hauls with a Vigneron-Dahl trawl and otter trawl using similar cod-end mesh indicate that there is little difference in the selection exercised by these two nets. But a Danish seine was found to capture fewer undersized haddock probably owing to the escape of small fish through the ballooned wings.

Davis (1929) in a continuation of the work described by Russell and Edser, reported the preliminary results of trawling with cod-end mesh of different sizes. The effect of different sized twine, single and double, on the effective mesh size, is discussed briefly, a subject of considerable practical importance entirely neglected by earlier authors. Davis concluded that the trouser cod-end is useful for providing rough data on mesh sizes, at small cost, but is not reliable for precise results. His chief objection is that the after leg—i. e., inside leg—of the cod-end shows a tendency to take considerably greater amounts of fish. For determining the escapement of small fish, he favors the use of a cod-end with a well-fitted cover rather than the use of alternate nets. Data are given which support his contention that a well-fitted cover with cane supports does not materially affect the selection of the net. He also gives the haddock escapement curve obtained with a covered cod-end of netting knitted on a 10-centimeter spool (mesh diameter about 3 inches). (See fig. 2.)

Hefford (1929) discussed the effect on the New Zealand snapper fishery of protective regulations made in 1926. The use of cod-end mesh measuring less than 4½ inches was prohibited for Danish seines and the most important spawning ground was closed to fishing between November 15 and February 1. The author ascribed the improved fishery in 1927 and 1928 to these regulations, but gives no supporting data.

Borowik (1930) presented data bearing on the relation between mesh size and catch, for flounder (*Pleuronectes flesus*) and dab (*Pleuronectes limanda*). He concluded that (1) the catch of undersized fish depends primarily on the size of mesh used; (2) the chances of retaining or losing undersized fish depend on the number of meshes, therefore, not only the cod-end but also the front part of the trawl are of great importance; and (3) the undersized fish try to escape not only through the meshes in the sides of the trawl but also through those in the upper and even in the bottom part, the last being especially important for the smallest fish. His data consist of measurements of many thousands of fish taken by different boats using nets made up with several combinations of mesh sizes. The catches of the different nets can be compared on the assumption that the length frequency composition of the population fished was the same in all cases. Such comparisons indicate that the cod-end and the front part of the net are of about equal importance for the escape of small fish; i. e., an increase from 30 millimeters to 45 millimeters in the size of cod-end mesh reduced the catch of flounder below 20 centimeters to the same degree as an equal increase in the size of mesh in the front part of the trawl. Inasmuch as there are many more mesh in the front part than in the cod-end, the chances of losing undersized fish do not appear to depend directly upon the number of mesh, but are a function of the number of mesh and their position. Thus a mesh in the cod-end is of much more importance than one in any other part of the trawl. The fact that the data were not obtained from parallel or alternate hauls and the nets using small mesh were of a somewhat different design than those using the larger mesh, leaves a little uncertainty as to the significance of these comparisons. However, they indicate that the front part of the trawl is of more importance for the escape of small fish than appears from Todd's experiments. Borowik described another series of experiments with nets using fine-mesh covers, which demonstrated that the bottom parts of the net are of importance for the escape of small dabs and flounders. These sections accounted for about 20 percent of the total escapement and the sides for 50 percent.

The Gelder cod-end described in literature of the Savings Trawl Net Co. is an elaboration of the cod-ends used by Holt and Todd which were supported in one end by a rigid frame or hoop. The Gelder cod-end has a rigid iron frame at either end which serves to hold open the square mesh on the top of the cod-end and the diamond mesh on the sides. Results indicate that this gear gives sharper selection for plaice than any of the other nets described (Buchanan-Wollaston, 1929). We have seen no data for roundfish.

A recent paper by F. M. Davis (1934) gives the results of tests of 2 cod-ends, 1 of "normal" mesh (24 rows per yard when fishing: i. e., 24 mesh sides per yard or an average mesh side of 1½ inches); and 1 of larger or "abnormal" mesh (about 21 rows per yard when fishing). They were fished on sister ships on the same ground and the cod-ends were exchanged after each of the 12 trips. The "abnormal" cod-end caught about 46 percent less unmarketable haddock than the "normal" cod-end and actually more haddock of marketable sizes. The results of this experiment covering more than 1,200 hours' trawling indicate that the larger mesh not only reduced the quantity of trash and undersized haddock, but caused an increase in the catch of marketable fish.

Of the above investigations those pertaining to roundfish and even more specifically to haddock are of most importance for our present purpose. The haddock catch is of preponderating influence in our otter-trawl fishery and this species has been one of the chief victims of small-fish destruction. Furthermore, a savings gear based on mesh selection which will retain all marketable haddock, also will hold (with present commercial size limits) all marketable cod, flounders, and hake, the species of next importance in the otter-trawl catch. This is a matter of considerable practical importance for although a savings gear must be designed primarily for the most important species, it will not prove acceptable if it loses appreciable amounts of other commercial fish.

In spite of the rather considerable amount of work that has been done on savings gear by a long series of investigators, not a great amount of this available material provides more than a qualitative comparison of the methods or gear used. The scarcity of significant data probably is caused by the numerous practical difficulties which arise as the result of weather, gear, or the failure to find fish of the sizes necessary for an adequate test of the mesh under observation. We have found that a satisfactory program of observations is much more readily planned at a laboratory desk than executed from a trawler's deck. Furthermore, until recent years the various authors have generally failed to mention the size of twine used in their experiments or whether the mesh was measured new or after use, and these factors can make a considerable difference in the actual mesh opening, especially in the cod-end where heavy, double twine ordinarily is used.

For the present problem concerning the effect of mesh size or trawl construction on the capture of small roundfish, particularly haddock, but nine series of data have been found in the literature which are suitable for effective statistical comparison. These are from the experiments described by Todd (1911), Ridderstad (1915), Fulton (1921), Pettersson (1925), Russell and Edser (1926), Bowman (1928), and Davis (1929, 1934). Some information on the effect of large mesh in the forward part of the net (wings, square, belly, belly tops) is also available from work described by Todd (1911), Borley and Russell (1922), and Borowik (1930).

The results of the experiments with cod-end mesh of different sizes indicate a definite relationship between the mesh and the size of fish which escape. The dividing line between those held and those that escape is not an absolute one, but for any size and kind of mesh a fairly definite proportion of the fish can be expected to escape. This proportion is greatest for the smallest sizes and grows progressively less for larger fish until a size is reached where none escape. The proportions, plotted as percentages, form the selection curve for the gear and usually appear in the shape of a drawn out S (fig. 2). The sharper the selection of the net—i. e., the greater the percentage of fish below a certain size which escape without loss of fish above that size—the more nearly vertical is the selection curve. In order readily to compare the curves for different mesh sizes or trawl construction, the selection constants have been calculated from these curves (table 1). Q_1 is the length at which 25 percent of the fish escape the net; *Mdn* is the 50 percent escape point; Q_3 is the 75 percent escape point; C_s is the coefficient of selection which is a measure of the effectiveness of the net in releasing small fish without the loss of large. (See p. 19 for method of calculation.) If selection were perfect—i. e., if all of the fish below a given size escaped and all above that size were retained—C_s would equal 100, while if there were no selection, C_s would equal 0.

TABLE 1.—*Selection obtained by different sizes of cod-end mesh in European investigations as indicated by the percent of each size of fish retained*

[Data are for haddock except for Ridderstad (1915) and Pettersson (1925), which also include cod, whiting, and herring]

Lengths in centimeters and selection constants	Investigator, kind of gear, and sizes of mesh in cod-end								
	Todd, 1911		Ridderstad, 1915	Fulton, 1921		Pettersson, 1925	Russell and Edser, 1926	Bowman, 1928	Davis, 1929
	Otter trawl, 2¾-inch, double twine	Beam trawl with hoop, 2¼-inch, single twine	Swedish trawl, 1-inch by 3½-inch and 1⅕-inch by 4-inch	Herring trawl, 2-inch	Herring trawl, 2½-inch	Swedish trawl, 1-inch by 3⅜-inch [1]	Trouser trawl, 3-inch, single twine	Otter trawl, 3-3¼-inch	Otter trawl, 3-inch, double twine
LENGTHS	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1-13	18	0	13	22	17	1		1	2
14-15	15	10	18	54	21	3		3	5
16-17	22	6	25	85	53	5		11	6
18-19	47	8	31	95	87	7	3	27	9
20-21	88	12	36	100	100	12	4	53	19
22-23	99	24	39			20	12	87	41
24-25	100	50	44			31	25	98	65
26-27		80	53			42	52	99	84
28-29		100	64			54	75	100	94
30-31			76			66	87		98
32-33			86			77			99
34-35			95			88			100
36-37			98			96	100		
38-39			100			100			
40-41									
SELECTION CONSTANTS									
Q_1	17.3	23.1	17.0	13.2	15.3	24.9	25.0	18.7	21.5
Mdn	19.1	25.0	26.3	14.7	16.8	29.3	26.9	20.8	23.7
Q_3	20.4	26.7	30.8	16.3	18.3	33.7	29.0	22.3	26.0
C_s	84	86	48	79	82	70	85	83	81

[1] Pettersson grouped his data in odd-numbered class intervals (15–16, 17–18, etc.); in this table they have been moved down one-half interval; that is, the percent value for 15–16 centimeters has been tabulated opposite 14–15, etc.

The selection curves for the 9 experiments mentioned above show some discrepancies but in general indicate that there is a relationship between the mesh size in the cod-end and the size of fish which escape; i. e., an increase in mesh size causes an increase in the escapement of small fish. Most of the curves have about the same steepness of slope indicating that diamond mesh, irrespective of size, gives a characteristic type of selection.

The importance of the forward part of the net for the escape of small fish remains uncertain, for the results obtained by Todd (1911), Borley and Russell (1922), and Borowik (1930), are conflicting. Todd's experiments appear to be the more significant for he determined the actual escapement by means of covering nets whereas Borowik compared the catch of different boats using nets with various combinations of mesh sizes. In the latter case, the nets using the larger mesh were of somewhat different construction than those of small mesh, and the hauls were not parallel or alternate (p. 9). Todd found that very few fish escaped through the square and about 9 times as many escaped through the cod-end as through the belly tops (batings). The data from Borley and Russell indicate that there was some escapement of fish through the forward parts of the net but do not provide any good comparison of the relative importance of these parts and the cod-end. The most logical conclusion would seem to be that the cod-end is of primary importance but that the value of the forward part by no means can be dismissed from consideration.

The value of an increase in mesh size for improving the escapement of small fish has been generally accepted for many years by European investigators and the results of the work reviewed here show that there is considerable justification for this view. But a diamond mesh does not give perfect selection, for a size of mesh which retains all marketable fish also retains considerable numbers just below market size, or a mesh size which retains few fish below market size also loses fair numbers of fish just above it. Hence, the attempts of investigators to improve the selective characteristics of the net by the use of various innovations. Among the first of these were the square mesh cod-end, the rigid wooden frame across the rear of the cod-end, and the wooden poles across the back and belly of the cod-end, described by Holt in 1895. The purpose in each case was to keep the mesh more fully extended and thus permit the escape of a larger proportion of small fish.

Following Holt's work a number of other gear modifications have been described. The most unusual of these was the Swedish savings trawl (Ridderstad, 1915; Pettersson, 1925; pp. 7, 8), while the most effective rig was the Gelder cod-end (p. 10). However, none of these special rigs, except the Gelder cod-end, gave appreciably better selection than the cod-ends using unmodified diamond mesh, and all suffered from practical disadvantages. Although no data are available for the selective action of the Gelder cod-end on haddock or other roundfish, the results obtained on flatfish indicate that this gear gives considerably sharper selection than unsupported diamond mesh. The special construction by which it is achieved, however, considerably complicates the handling and maintenance of the gear and makes it very doubtful whether such a net would prove practical in our fishery.

The results of the various experiments furnish information of considerable value for determining the method of attack on the problem of young-fish destruction in the New England otter trawl fishery. We have found that the forward part of the otter trawl is of some value for the escape of small fish but that the cod-end probably is of greater importance. We have found that a cod-end constructed of standard diamond mesh of 2 to 3 inches permits the escape of a large proportion of the small fish below one-fifth to one-half pound in weight, a proportion that progressively increases as the size of fish decreases. We have found considerable evidence that an increase in size of mesh results in the escape of fish of larger sizes. We have found that "savings gear" of special construction, using square mesh netting, rigid frames, or other modifications in the cod-ends or bellies, has not given results for roundfish appreciably superior to, and in many cases as good as, cod-ends of standard diamond mesh. The Gelder cod-end is an exception, but it suffers certain practical disadvantages which at present apparently more than outweigh its advantages. In brief, this review indicates that diamond mesh of the proper size is the most practical solution yet devised for the saving of undersized roundfish.

PRINCIPAL PROBLEMS OF THE INVESTIGATION

Bearing the above conclusions in mind we now can intelligently draw up the questions which, if answered, will contribute most toward a practical solution of our young-fish problem. First, can we be sure that the fish which escape through the netting of the trawl are alive and uninjured? Second, will an increase in cod-end mesh to such sizes as 5 or 6 inches produce a corresponding increase in size and percentage of young fish which escape? Third, if the second be true, then what size of mesh will result in the escapement of the greatest numbers of undersized fish without losing appreciable quantities above the minimum commercial size (1½ pounds)? Fourth, can a savings gear be readily devised which will give a sharper selection than that obtained from standard diamond mesh, without introducing into the net a type of construction which will materially complicate its handling or maintenance? Fifth, what is the value of the forward part of the net (wings, square, belly, and belly tops) for the escapement of small fish?

EXPERIMENTAL PROCEDURE

METHODS

To determine the effectiveness of any type of net it is necessary that we have some satisfactory method for ascertaining the number or percentage of fish of each size which escape through the meshes of the gear under test. A comparison of such numbers or percentages then will indicate the effectiveness of the different types of gear or of increases or decreases in the mesh size. General observations of the catch are ordinarily of little value and frequently may prove misleading for shifts in the position of the boat or movements of the fish may cause a change in the character of the fish population sampled. This will affect the size distribution of the fish taken in the trawl and may lead to wrong conclusions.

There are three methods which have been used successfully by previous investigators for determining the number and size of fish escaping from the net. The first is the use of a light, fine-meshed covering net secured to the trawl proper so that it holds all of the fish which escape through the mesh of the part of the trawl under test. This method was used by Fulton in 1893 and by many others since. The principal objections have been that the cover, by its increased resistance, seriously affects the draught of water through the net; it also may lie close against the inside net and thus hinder the escape of small fish (Johnstone, 1911; Russell and Edser, 1926). However, Davis, in 1929, described a well-fitted cover supported clear of the cod-end by cane hoops, which he showed had little effect on the selective action of the trawl.

The second method of evaluating the escapement of small fish is indirect. It consists of the alternate use of two trawls, one with mesh of the usual size, the other of similar construction except for the size of mesh in the section of the trawl to be tested (Johnstone, 1911). The difference in size composition of the catch then can be ascribed to the change in mesh size or trawl construction in the second net. When working on a homogeneous population this method may give good results from a moderate number of hauls. It is the least complicated of the three.

The third method was proposed and described by Russell and Edser in 1926. It makes use of the "trouser trawl" or "trouser cod-end" (p. 8). In this method one leg of the cod-end is made of small-meshed netting, the other of the mesh size to be tested. As the two legs are of equal size, the fish that enter the mouth of the trawl can be expected to enter the two legs of the cod-end in about equal numbers and the difference in the amount of small fish retained in the large and small mesh legs indicates the number which has escaped through the large mesh. Davis (1929) remarks that the trouser cod-end is useful for providing rough indicative data at small cost but is not reliable for fundamental experiments. His objections are that "in addition to its obvious limitations, as compared with a normal commercial cod-end, it shows a tendency for the after leg (inside leg) to take a considerably larger amount of fish."

Each of the above methods has certain advantages and disadvantages. The covered cod-end, although probably providing the most precise results, involves practical difficulties of handling and maintenance which can be tolerated during experimental work on a research vessel but would be objectionable aboard a commercial fisherman. The use of alternate nets is the least complicated of the three and provides the final test of a full-sized, normally-fishing net, but chance variations in the catch from haul to haul may make necessary an excessively long series to obtain an accurate comparison. The trouser cod-end lacks the precise characteristics of the covered cod-end but can be more readily handled. Also, it is more accurate than alternate nets, at least for a limited number of hauls, for in effect it provides two nets fishing simultaneously and side by side through the same school of fish. No final decision is possible as to which of the above methods is definitely superior, for the choice must hinge on the conditions to be met.

In the present case the gear experiments were to be handled on board commercial fishermen through the cooperation of the owners and crews. Consequently, it was necessary to adopt methods which would offer the least interference to the normal fishing operations of the boat. For this reason, the use of the trouser cod-end was adopted for preliminary experiments on mesh size and alternate nets with full-size cod-ends for final trials of commercial gear. The trouser cod-end work would add few complications to the normal handling of the gear while the use of alternate nets would offer none except for changing over more frequently than usual and occasionally on big hauls, delaying the cleaning and stowing of the catch while measurements were completed. Some of the objections to the use of the trouser cod-end given by Davis (p. 9) were overcome by modifications in the construction of the net and by the methods used in the analysis of the data.

The trouser cod-end used in our experiments was constructed along the following lines. In order to make its action as nearly comparable as possible to that of a normal net, it was constructed so that the cross sectional area and surface area of each leg was equal to one-half that of the commercial cod-end it was replacing on the 7A Vigneron Dahl net used on the *Exeter*. A vertical partition first was placed in the

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net running from the crotch between the two legs of the cod-end forward, on the bottom to the foot rope, and on the top to the after-end of the square (fig. 3). The purpose was to secure an equal division of the catch between the two legs and to prevent mixing of fish which worked forward from the cod-end into the belly of the net during the haul back and landing of the catch. The latter function at times was of considerable importance as no flapper is used in these nets to hold the catch in the cod-end. The forward end of the partition first was made about 12 feet high, according to the best infor-

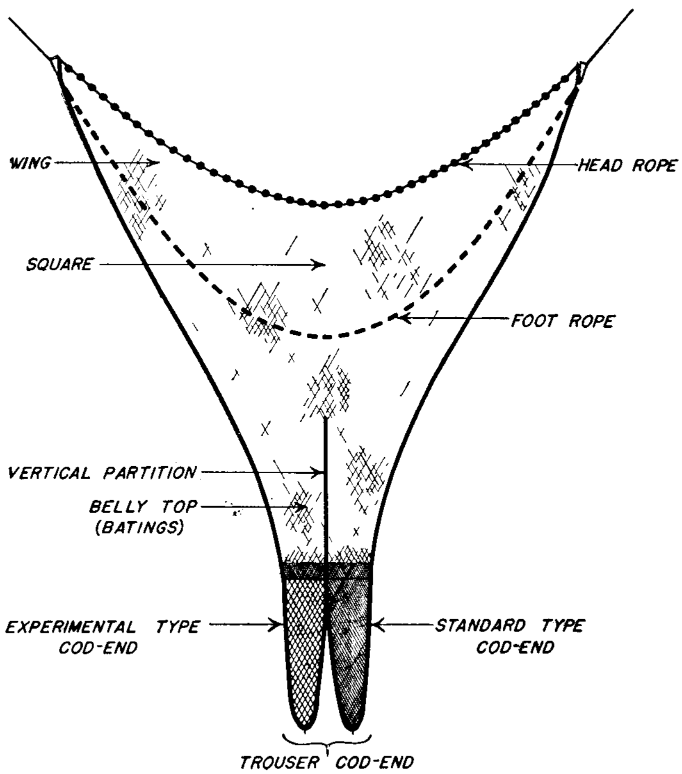

FIGURE 3.—Diagram of a trawl with a trouser cod-end such as was used for testing effect of different kinds of mesh or construction. A cod-end similar to the commercial one now in use was used on one leg while the experimental gear was attached to the other.

mation which could be obtained from the makers and users of the net. However, with this rig, one leg consistently caught several times as much fish as the other, indicating that the partition was so slack that the flow of water swept it considerably to one side where it deflected most of the catch into the opposite leg. Later this partition was cut down considerably in height and to about two-thirds of its former length, and the forward end was given a V shape. Thereafter, the catch in the two legs was much more nearly equal. As first used, the cod-end had a single splitting strap which encircled both legs. When a large catch of small fish or trash was made the leg with the smaller mesh retained more of the small material. This caused it to bulge out until it tightened the splitting strap and sometimes considerably constricted the other cod-end. The difficulty was corrected by the use of individual splitting straps connected by a 5-foot bridle to the center of which the bull rope was attached.

ANALYSIS

Trouser cod-end experiments.—We have described the construction of the trouser cod-end and some of the modifications in its design that were made to give an equal fishing capacity to the two legs; i. e., so that their catches would be about equal. In spite of these precautions usually there was more or less difference in the two catches.

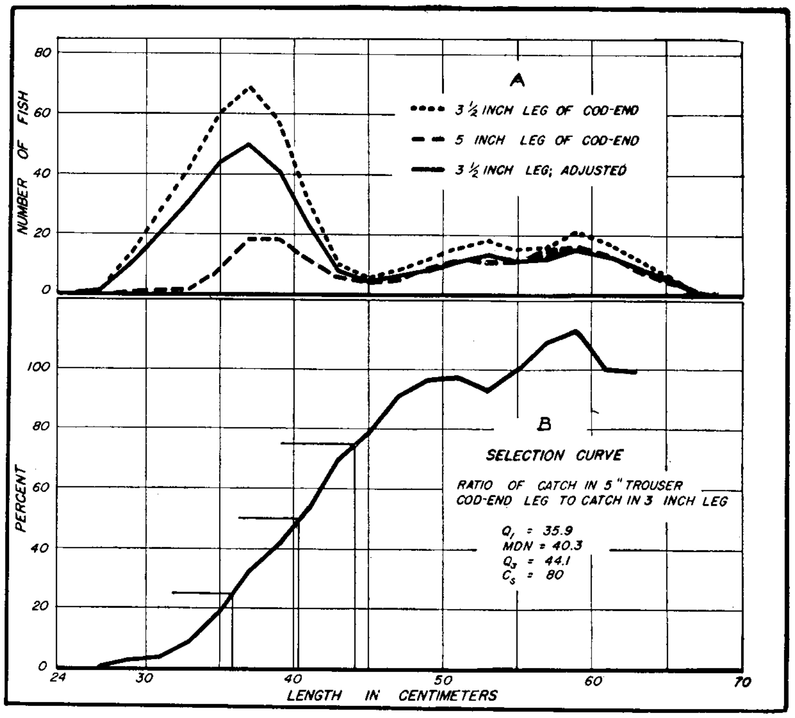

FIGURE 4.—A, length frequencies of haddock caught in the two legs of the trouser cod-end *Exeter* trip I, haul 57; B, selection curve for the 5-inch leg.

This might be due to differences in the adjustment of the towing warps, to greater clogging of the small-mesh net on some hauls than on others, or simply to chance.

In the course of a long series of hauls made from the same population of fish, most of the differences in the catch of the two cod-end legs probably would average out and the totals for the two would be approximately equal. However, if we are to obtain results from series limited to 5 to 20 hauls of a similar type it becomes necessary to utilize other methods. The analysis used in this paper is based on the assumption that the small fish entering the mouth of a net will tend to distribute themselves to the right or left of the center line, in the same proportion as do the large fish of the same species. In the present case a considerable fraction of the small fish that enter the large-meshed cod-end will escape, but few or none of those (above a certain size) that enter the small-meshed cod-end. However, we cannot compare the catch of the two for we cannot be sure that equal numbers entered the two legs.

If we now consider only those fish which are of a size sufficient to preclude escapement through the larger-mesh leg, we can obtain a measure of the relative number which entered each cod-end leg. For example: If we find 150 large haddock in leg 1 and 100 in leg 2, we can assume that all haddock entered the two legs in the proportions of 150 to 100. If we multiply the catch of both large and small haddock, in leg 1 by the ratio of $\frac{100}{150}$, it is adjusted to the level of the second and the number of small then can be directly compared to the catch of small in leg 2, for it has been reduced to the number that would have been caught had equal numbers of fish entered the two legs. The method is illustrated in table 2 showing the calculations for haul 57 made on the first *Exeter* trip. The first 2 columns give the number of haddock of each size caught in the 2 trouser legs. (Throughout this paper lengths given in even centimeters represent the centimeter class interval, i. e., 45 centimeters=45.0 to 45.9, etc. The midpoints of the intervals have been used in all graphs.) The next 2 columns give the same data smoothed by a moving average of 3. The next column gives the catch of the 3-inch leg adjusted by the ratio of $\frac{101.1}{139.9}$ to give the same number of large fish as was taken by the 5-inch leg. The dividing line between large and small was taken as 45 centimeters. The length frequencies are shown in figure 4 *A*, both adjusted and unadjusted. The close agreement of the curves from 45 centimeters up justifies the assumption that practically no haddock above that size escaped through the 5-inch mesh.

The selection curve for haul 57 is obtained by dividing the number of haddock caught in the 5-inch leg by the adjusted number caught in the 3-inch leg. To obtain a more regular curve the frequencies were grouped by 2-centimeter intervals before calculating the percentages, which then were smoothed by a moving average of 3. The selection curve is shown in figure 4 *B*. As it is obtained from a comparison of the catch in the large and small-meshed legs of the trouser cod-ends it presumably represents the proportion of the haddock retained by the large-meshed cod-end of the total that entered it. Of course, this does not hold for the very small fish which can escape through the meshes of the small-meshed leg.

TABLE 2.—*Example of the methods used for adjusting the catch in the 2 legs of the trouser cod-end and the calculation of selection percentages, "Exeter" trip I, haul 57*

Length (centimeters)	Length frequencies: Original, 3½-inch leg	Original, 5-inch leg	Smoothed by 3, 3½-inch leg	Smoothed by 3, 5-inch leg	3½-inch leg adjusted to 5-inch leg	Ratio of catch 5-inch leg to 3½-inch leg: Un-smoothed	Ratio: Smoothed by 3
	Number	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*
26	----	----	----	----	----	0	1
27	----	----	1.7	----	1.2		
28	5	----	4.0	----	2.9	3	3
29	7	----	8.7	.3	6.3		
30	14	1	11.3	.3	8.2	5	4
31	13	----	16.0	.7	11.5		
32	21	1	18.7	.3	13.5	4	9
33	22	----	23.3	1.0	16.8		
34	27	2	29.7	2.0	21.5	18	19
35	40	4	30.7	6.0	22.2		
36	25	12	34.7	8.0	25.1	36	33
37	39	8	34.0	10.0	24.6		
38	38	10	31.0	9.7	22.4	44	42
39	16	11	25.7	8.3	18.6		
40	23	4	17.3	6.7	12.5	47	54
41	13	5	13.0	3.7	9.4		
42	3	2	6.7	3.3	4.8	71	70
43	4	3	3.0	1.7	2.2		
44	2	----	2.7	1.7	2.0	92	79
45	2	2	2.3	1.7	1.7		
46	3	3	3.3	1.7	2.4	73	91
47	5	----	4.3	2.3	3.1		
48	5	4	5.0	3.3	3.6	109	96
49	5	6	6.0	5.3	4.3		
50	8	6	6.7	6.0	4.8	105	97
51	7	6	8.3	5.3	6.0		
52	10	4	8.7	5.3	6.3	78	93
53	9	6	9.0	4.7	6.5		
54	8	4	7.7	4.3	5.6	96	100
55	6	3	6.7	5.7	4.8		
56	6	10	7.3	6.3	5.3	127	109
57	10	6	8.3	8.0	6.0		
58	9	8	10.3	7.3	7.4	105	113
59	12	8	10.3	8.3	7.4		
60	10	9	9.7	7.3	7.0	106	100
61	7	5	7.3	5.7	5.3		
62	5	3	6.0	4.3	4.3	90	99
63	6	5	5.3	3.0	3.8		
64	5	1	4.0	2.3	2.9	100	----
65	1	1	2.3	1.0	1.7		
66	1	1	.7	1.0	.5		
67	----	1	.3	.7	.2		
68	----	----	----	.3	----		
Total 20–44	312	63	312.2	63.7	225.7	28	----
Total 45–80	140	102	139.9	101.1	100.9	100	----
Grand total	452	165	452.1	164.8	326.6	----	----

The selection constants Q_1, Mdn, Q_3, and C_s are obtained as follows: Q_1 is the fish length which corresponds to the point on the selection curve where 25 percent of the fish that enter the net are retained; Mdn is the length at which 50 percent are retained; Q_3 is the length at which 75 percent are retained; and C_s, the coefficient of selection, $= 100 \frac{(Mdn-(Q_3-Q_1))}{Mdn}$. This coefficient of selection is used in these experiments as a measure of the sharpness of selection. It is objective, easily caculated, and readily understood. It is equal to 100 for perfect selection; i. e., if all fish below a certain size escape while all fish above that size are retained by the net; and to zero if no selection takes place. Davis used this constant and credits it to Buchanan-Wollaston (Davis, 1929). The latter author in 1927 described a more involved treatment of the selection curve based on his "law of chance selection", but for most of our data this method does not give a good measure of the actual selection involved. It appears to be useful only for quite regular data such as that obtained from a good series of hauls with a covered cod-end. For such cases, however, the method appears to offer a means for evaluating the effects of weather (amount of roll) clogging, etc., on the selection of the mesh.

The above methods were applied to the trouser cod-end experiments as follows: For each series the length frequencies for the individual hauls were adjusted, as described above, to the level of the catch in the 5-inch cod-end, then combined for each leg of the cod-end, and the resultant curves smoothed by a moving average of 3. The selection curve data were obtained from these length frequencies as described above. It was not usually necessary to smooth the selection curves for series of hauls providing numerous measurements. Nevertheless, the same treatment was applied in order to obtain comparable results as smoothing tends to flatten out the curves and give a slightly lower C_s value.

Alternate net experiments.—The analysis of the alternate net data was similar to that described for the trouser cod-end. The length frequencies for the commercial cod-end catch and savings cod-end catch were separately combined, smoothed by threes, and the frequencies of the sizes for 50 centimeters and greater adjusted to the level of the least numerous of the two. The number of small fish of each size caught by the savings cod-end then could be directly compared with the catch of fish of the same size in the commercial cod-end and the difference considered as the number that escaped through the meshes of the savings cod-end. The only assumption involved is that the length-frequency composition of the fish entering the two nets averages the same. The validity of this assumption can be checked by the degree of similarity in the shape of the length-frequency curve from 50 centimeters up. The selection curve and selection constants were obtained from the adjusted length frequencies in the same way as for the trouser cod-end experiments.

EXPERIMENTAL RESULTS

ACKNOWLEDGEMENTS

Throughout the course of this work we have received the generous cooperation of various firms and individuals interested in the New England fishing industry. A considerable part of the experimental gear was furnished by the Linen Thread Co., of Boston, Mass., in cooperation with the Plymouth Net & Cordage Co., of Plymouth, Mass., and L. O. Runkle, of the former firm, assisted in some of the preliminary experiments and on the first, second, and fourth *Exeter* trips. The cod-ends used on the *Kingfisher* were made up by the crew of the net loft of the Portland Trawling Co. at Groton, Conn. The square-mesh cod-end used on the fifth *Exeter* trip was furnished by the Great Grimsby Coal, Salt & Tanning Co., of Great Britain. Through arrangements with W. H. Raye and A. L. Parker, of the Whitman, Ward & Lee Co., the trouser cod-end experiments and some alternate net experiments were carried out on the dragger *Exeter*, of the Whitman, Ward & Lee Co. fleet. John Graham, of the Portland Trawling Co., provided the use of their Groton net loft and crew for making up several cod-ends, and through his cooperation we were able to carry on a series of alternate net experiments on the

steam trawler *Kingfisher* of the Portland Trawling Co. fleet. W. A. Ellison, Jr., of the latter company, assisted us on one *Kingfisher* trip. We wish to express our appreciation for the cooperation of the firms and individuals mentioned, and also to the many others, especially Capt. Sylvester Dunn, of the *Kingfisher*, and Capt. Martin Pedersen, of the *Exeter*, and their crews, whose able and willing assistance greatly expedited our work.

A number of the members of the Bureau of Fisheries scientific staff assisted in various parts of the work. D. Merriman directed several field trips and assisted in part of the analytical work. F. Widerstrom directed one field trip and assisted on most of the others; while Messrs. Dallas, Beakley, and Leupold assisted on one or more field trips. In preparation, this paper has had the benefit of criticism by Messrs. Nesbit, Webster, and particularly by O. E. Sette who has been a friendly critic throughout the work.

PRELIMINARY EXPERIMENTS

Following the careful consideration of European work on savings gear it was decided to confine our first efforts to the determination of the selective characteristics of cod-ends using diamond mesh of sufficient size to release haddock up to 1½ pounds. These experiments were to include the testing of certain modifications in cod-end construction by which it was hoped to achieve some improvements in the selective action of the diamond mesh.

Unfortunately, there appears to be little authentic information on the subject of net and mesh shapes for fishing gear while in operation. In fact, among experienced fishermen there exists a very considerable difference in opinion on such matters as the working shape of the mesh in different parts of the net, the height of the head rope in various types of trawls, etc. Consequently, the effect on the mesh shape of changes in mesh size or trawl construction is a matter of conjecture, yet such information sometimes might prove of considerable aid in devising improved methods for releasing small fish or in demonstrating to a skeptical fishing fraternity how and why certain changes in their gear will produce desirable results.

With the above consideration in mind, preliminary experiments were made with small-scale cod-ends constructed of 5-inch [4] mesh using no. 54 cotton twine double. One cod-end was of normal construction except for the large mesh; the other was similar except for six rope stringers running fore and aft through the cod-end and equally spaced about its circumference. The stringers were securely lashed to each knot to hold the mesh fully open even when a considerable strain was exerted on the cod-end mesh by the catch (fig. 5 *B*). The two cod-ends were rigged to hoops about 4½ feet in diameter and towed behind a motorboat at 2½ to 3 knots with the cod-end just under the surface. The shape of the cod-end and of the mesh was observed from a second boat running beside the net and it was found possible to hold the relationship between boat and net sufficiently steady to obtain direct measurements of the mesh openings. The results show that even a small catch in a normal cod-end opens up the mesh so that in a limited area just forward of the load the open-

[4] Unless otherwise stated, the mesh size used in this paper is the diameter between knot centers, measured diagonally along the long axis of the fully stretched mesh.

ings are sufficiently wide for the escapement of small fish. The second part of the experiment illustrates the effect of stringers in holding the mesh open throughout the cod-end and irrespective of load (fig. 5).

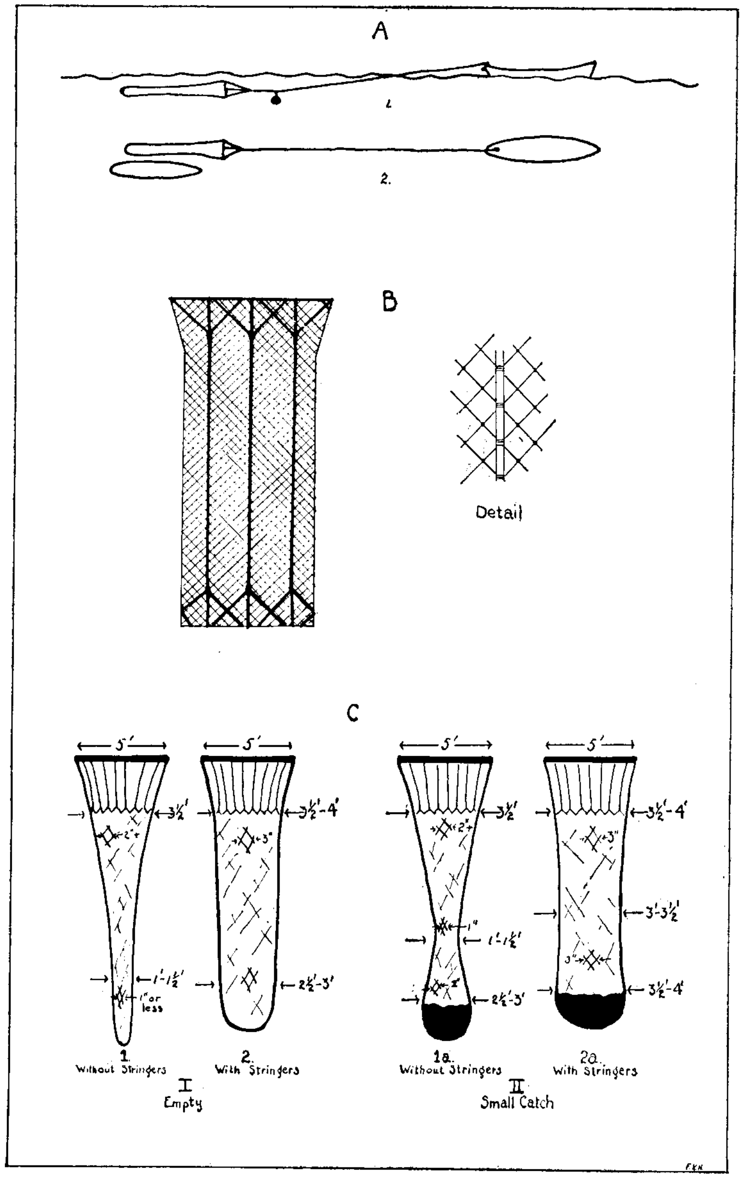

FIGURE 5.—Experiments with small-scale cod-ends. A. Method of observing cod-end: 1, profile view of net and towing boat; 2, top view of net with observation boat alongside. B. Method of attaching stringers to cod-end. C. Shape assumed by two-cod-ends towing empty and with small catch.

The cod-end with stringers, described above, later was attached to a small flounder trawl and fished from the Bureau of Fisheries' research steamer *Albatross II* with a cover of shrimp netting. The gear was too small to obtain large catches of haddock but the results with small hake and with scattered haddock appeared promising (fig. 6), and it was decided to continue the tests on a larger scale. As the small, single-drum winch on the *Albatross II* was inadequate, arrangements were made to continue the work on the commercial trawler *Exeter*.

RELATION BETWEEN LENGTH AND WEIGHT OF HADDOCK

For the most part the sizes of haddock given in the text and tables of this paper refer to the length of the fish. In order that these may be translated readily to equivalent haddock weights as marketed, there is given in figure 7 a length-weight curve showing the relationship between length and weight of gutted haddock for the months during which these experiments were in progress. Measurements were obtained at the Boston Fish Pier from the regular commercial landings. The weights given in this paper refer to gutted weights inasmuch as practically all haddock are marketed in this condition.

TROUSER COD-END EXPERIMENTS

The trouser cod-end was used during three trips on the *Exeter* in May and June 1931. On all trips 3½-inch mesh was used in one leg of the trawl and in the other leg 5-inch mesh, double twine part of the time, and 4¾-inch mesh, single twine the remainder. The large-meshed cod-ends were tested both with and without stringers similar to those used on the small cod-end described in figure 5. A summary of the data on size of mesh and twine, cod-end rig, etc., is given in table 3.

The length-frequency curves are shown in figure 8 for the haddock caught during the three trouser cod-end trips. The solid line curve gives the number of haddock of each length caught by the small-meshed leg of the cod-end while the broken line curve shows the catch of the large-meshed leg. The correction for the chance differences in the numbers caught in the two legs is described on page 18.

TABLE 3.—*Summary of data concerning the effect of cod-end mesh size on selection, obtained from haddock caught in the trouser cod-end experiments*

Trip	Gear specifications						Selection curve constants			
	Small-meshed cod-end		Large-meshed cod-end							
	Mesh size	Twine	Mesh size: New	Mesh size: Used	Twine	Rig	C_s	Q_1	*Mdn*	Q_3
	In.		*In.*	*In.*				*Cm*	*Cm*	*Cm*
Exeter I	3½	3 thread, 1200, D [1]	5	4¼	3 thread, 1100, D	Without stringers.	85	35.7	38.4	41.6
Do	3½	do	5	4¼	do	With stringers	87	36.6	39.6	41.6
Exeter II	3½	do	4¾	4⅝	4 thread, 750, S [2]	Without stringers.	82	38.8	42.6	46.6
Do	3½	do	4¾	4⅝	do	With stringers	80	37.3	40.8	45.3
Exeter III	3½	do	(3)	4⅝	do	Without stringers.	88	39.0	41.8	44.1
Do	3½	do	(3)	4⅝	do	With stringers	94	41.2	42.6	43.8

[1] Double twine. [2] Single twine. [3] The same cod-end was used on *Exeter* III as on II.

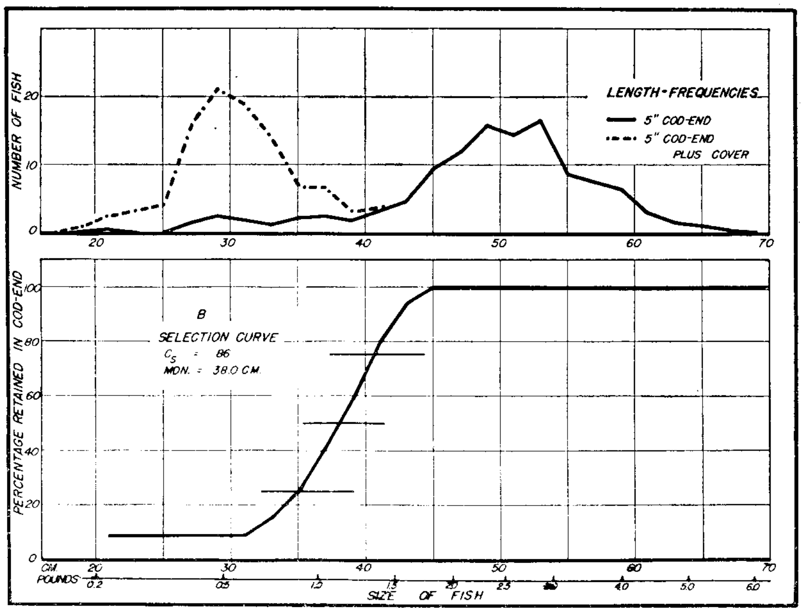

FIGURE 6.—Result of several hauls with a small flounder trawl using a cod-end of 5-inch mesh supported by stringers.

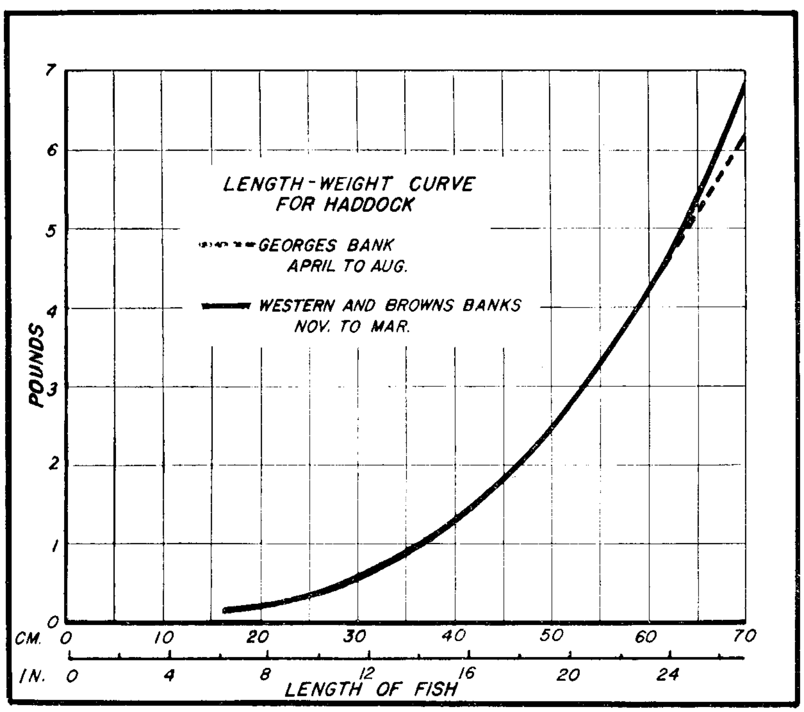

FIGURE 7.—Relation between length and weight of gutted haddock for months shown.

TABLE 4.—*Length frequencies of haddock caught in the large-and small-meshed leg of the trouser cod-end*

[The catches of the 2 legs were adjusted as described (p. 18)]

Length (centimeters)	*Exeter* I				*Exeter* II				*Exeter* III			
	5 hauls without stringers		11 hauls with stringers		12 hauls without stringers		21 hauls with stringers		20 hauls without stringers		9 hauls with stringers	
	3½-inch mesh	5-inch mesh	3½-inch mesh	5-inch mesh	3½-inch mesh	4¾-inch mesh	3½-inch mesh	4¾-inch mesh	3½-inch mesh	4¾-inch mesh	3½-inch mesh	4¾-inch mesh
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
21[1]											1	
24			1				1					
25	2		1		1		1					
26	6		1		1		2				2	
27	4		1		2		1		1			
28	5		11	2	3		2		1		4	
29	15		21	2	2		4		1		4	
30	20	2	38	1	3	2	12	2	10		5	2
31	31	2	53	1	9	1	4	1	8		12	
32	52		86	4	18	1	11	2	11	3	19	1
33	80	7	103	3	13		14	1	7	2	20	
34	80	18	146	12	22	2	9	2	15	1	16	3
35	81	11	150	24	18	3	16	1	19	3	30	1
36	89	24	162	46	20	5	17	5	20	4	36	3
37	74	33	169	44	24	2	19	6	16	3	29	1
38	67	29	139	53	11	2	19	4	8	3	24	1
39	38	30	103	54	19	4	16	6	16	1	18	2
40	23	22	85	51	16	9	13	5	8	5	24	4
41	14	11	57	38	14	3	6	4	8	4	22	5
42	11	7	38	31	9	5	8	8	10	4	14	4
43	4	5	21	24	9	4	14	10	6	3	11	4
44	9	3	12	19	4	7	22	12	3	5	3	6
45	4	8	12	18	18	8	21	19	8	9	7	7
46	7	17	15	23	18	17	37	25	6	6	3	7
47	10	8	32	18	24	22	52	42	19	18	6	8
48	15	13	32	30	49	30	68	58	31	14	4	5
49	14	18	23	34	51	39	78	76	16	35	10	11
50	24	25	40	37	49	59	113	102	38	28	12	8
51	34	31	45	43	54	76	118	97	47	30	15	16
52	29	33	44	45	86	72	133	127	38	37	24	22
53	20	37	44	44	63	65	118	126	36	34	15	13
54	37	31	55	46	84	74	153	145	27	23	20	17
55	33	31	41	48	83	88	169	151	17	31	15	16
56	21	20	45	51	94	84	130	144	28	30	16	13
57	26	22	48	40	89	78	119	145	29	29	11	22
58	32	24	48	50	89	65	146	146	25	25	15	10
59	19	26	42	42	68	79	118	135	10	13	27	22
60	33	20	38	50	56	74	92	106	13	19	21	25
61	17	13	41	30	47	49	69	66	17	12	25	16
62	10	9	30	33	48	45	53	56	8	11	21	21
63	18	10	29	28	32	31	58	53	1	5	23	15
64	8	11	20	16	30	31	44	33	2	5	8	19
65	8	5	8	8	14	16	23	19	6	4	8	10
66	6	5	7	6	9	10	13	14		3	12	5
67	1	8	7	8	9	8	7	6		1	4	6
68		4	3		7	5	6	8	1	1	3	5
69	5	4	4	2	4	3	5	5				1
70			2	2		3		3		1	3	4
71	2		1	2		2	1	1			4	4
72				1			1	1				3
73		1					1	1				
76				1								
77	1				2							
Total 0–44	705	204	1,398	409					168	41	294	37
Total 45–77	434	434	756	756					423	424	332	331
Total 0–49					378	166	467	289				
Total 50–77					1,017	1,017	1,690	1,690				
Grand total	1,139	638	2,154	1,165	1,395	1,183	2,157	1,979	591	465	626	368

[1] The 21-centimeter length includes all measurements from 21 to 21.9, etc.

The most noteworthy feature of the curves shown in figure 8 is the difference in the number of small haddock caught in the large- and small-meshed cod-ends. This is especially striking for the first trip because of the large number of small haddock encountered. Similar differences were found in trips II and III data but are not so significant as small haddock were scarce on the second trip and both scrod and

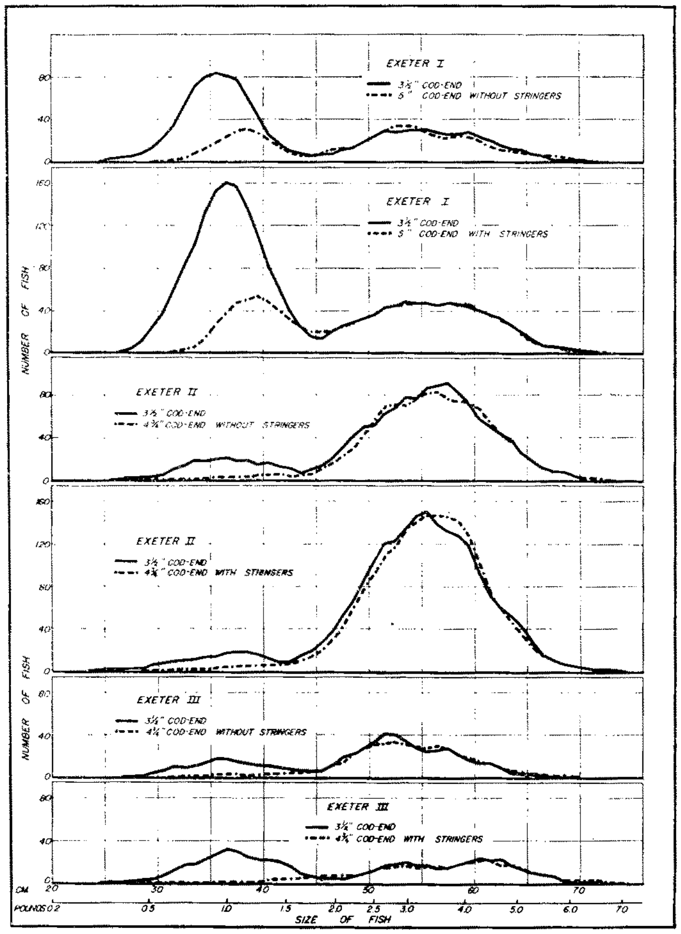

FIGURE 8.—Length-frequency curves for all trouser cod-end experiments. The large mesh cod-end used on trip I was of double twine; those used on trips II and III were of single twine.

large on the third. The data from trip II would appear to be the least representative because of the great preponderance of large haddock.

A better comparison of the effectiveness of the gear used on the different trips can be obtained from the selection curves in figure 9. These curves simply show the number of fish of each size taken by one net as a percentage of the number of fish of the same size taken by the other. With 5-inch mesh, double twine, most of the haddock below 1 pound in weight escaped (area above the selection curve), and only a few weighing more than 1½ pounds. The 4¾-inch mesh, single twine, released most of the haddock up to 1¼ pounds in weight, and only a few above 1¾ pounds. Poor results were obtained from the 4¾-inch cod-end on the second trip, probably a result of the very small pro-

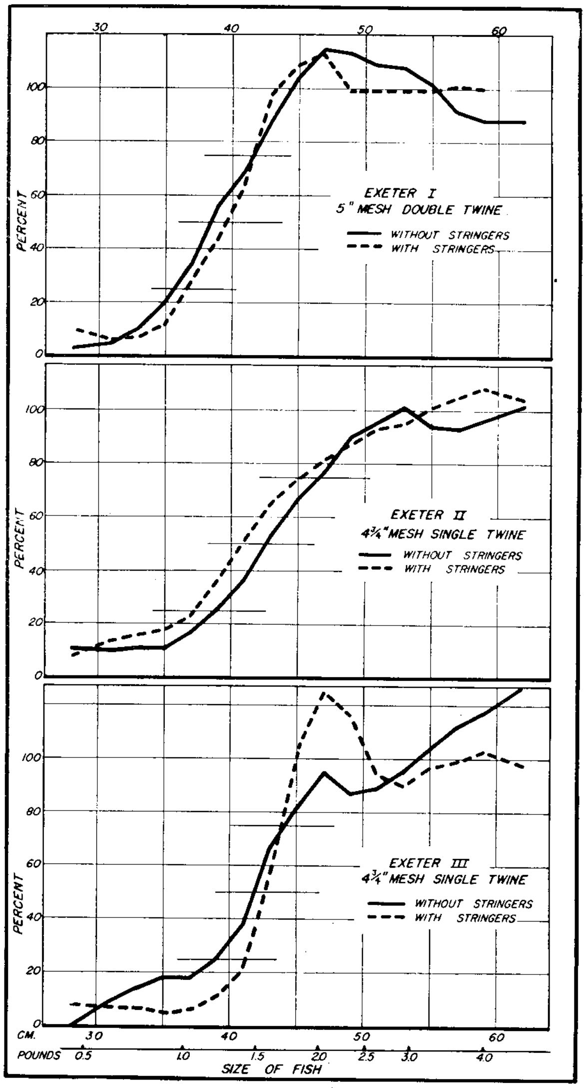

FIGURE 9.—Selection curves for all trouser cod-end experiments.

portions of undersized haddock in the population sampled. For both the first and third *Exeter* trips the large-meshed cod-end with stringers gives somewhat sharper selection than the same cod-end without. For trip II the stringered cod-end indicates somewhat poorer selection but the above-mentioned disproportions between the numbers of large and small haddock cause this result to be of uncertain significance.

TABLE 5.—*Selection resulting from the different sizes of cod-end mesh used in trouser trawl experiments, as indicated by the relative number of haddock caught by the large- and small-meshed legs of the cod-end*

Lengths in centimeters and selection constants	*Exeter* I		*Exeter* II		*Exeter* III	
	5-inch mesh double twine		4¾-inch mesh single twine		4¾-inch mesh single twine	
	Without stringers	With stringers	Without stringers	With stringers	Without stringers	With stringers
LENGTHS	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
20–29	3	10	11	8	0	8
30–31 [1]	5	6	10	14	9	7
32–33	10	7	11	16	14	7
34–35	20	12	11	18	18	5
36–37	34	28	17	23	18	6
38–39	56	44	26	36	25	11
40–41	69	64	37	51	38	21
42–43	88	98	54	65	67	58
44–45	104	109	67	74	82	103
46–47	115	113	77	81	95	125
48–49	113	99	90	87	87	116
50–51	109	99	96	93	89	94
52–53	108	99	101	95	95	99
54–55	102	99	94	101	104	97
56–57	91	101	93	105	112	99
58–59	88	100	97	108	117	103
60–80	88	100	102	104	127	98
SELECTION CONSTANTS						
Q_1	35.7	36.6	38.8	37.3	39.0	41.2
Mdn	38.4	39.6	42.6	40.8	41.8	42.6
Q_3	41.6	41.6	46.6	45.3	44.1	43.8
C_s	85	87	82	80	88	91

[1] The lengths 30-31 centimeters represent the interval from 30 to 31.9, etc.

The general results of the 3 trouser cod-end trips indicate the following: A cod-end of 5-inch mesh, 3 thread, no. 1100 twine double, permits the escape of a large proportion of young haddock below marketable size but it also loses a small proportion of the scrod between 1½ and 2 pounds. Netting made of 4¾-inch mesh, 4 thread, 750 twine single, gives somewhat sharper selection than 5-inch mesh of 3 thread, 1100 twine double (C_s of first is 85 and 87 against 88 and 94), and slightly increases the size of fish that escape. (*Mdn* of first equals 38.4 centimeters and 39.6 centimeters against 41.8 centimeters and 42.6 centimeters for second.) Third, the use of stringers in the cod-end gives somewhat sharper selection. For the first trip without stringers $C_s=85$, with stringers $C_s=87$; third trip without stringers $C_s=88$, with stringers $C_s=94$; second trip without stringers $C_s=82$, with stringers $C_s=80$. The reversed effect on the second trip does not appear significant due to the low proportion of small haddock mentioned previously.

ALTERNATE NET EXPERIMENTS

The results from the third *Exeter* trip indicated that heavy, single twine might give sharper selection than double twine and that mesh of the size used, 4¾-inch (new), 4 thread, 750 twine single, permitted the escape of considerable numbers of small scrod. Consequently, the first full-size cod-end made up for the alternate net experiments was of single twine of the same weight but with the netting more tightly knit so that although the mesh measured 4¾ inches new, as did the large-meshed *Exeter* III net, it shrank down to 4¼ inches after use. (The *Exeter* III net after use measured 4⅝ inches.) The full-size cod-end was attached to a net of the same size and type as those used for the trouser cod-end experiments but using larger mesh in the wings, square, and belly. The mesh sizes (compared to stand-

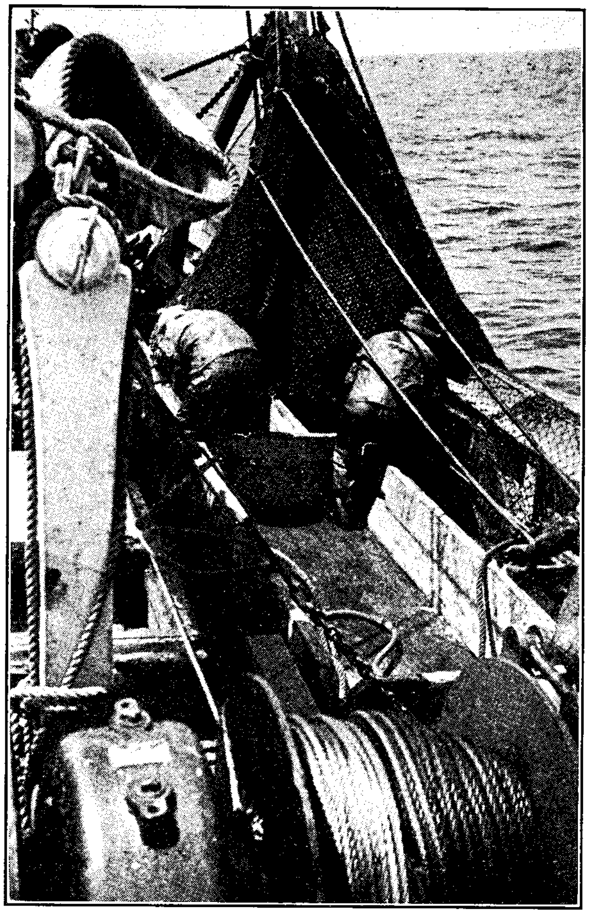

FIGURE 10.—Landing trouser cod-end. View shows cod-end bellies covered by chaffing gear. Apparent difference in size of two cod-ends is due to small trash caught by small-mesh leg. South Channel, June 1931, *Exeter* III.

ard mesh used in commercial trawls) were: Wings and square, 6 inches (5 inches); belly and belly tops, 5 inches (5 to 3 inches).

Bureau observers accompanied the *Exeter* on the first trip on which the large-meshed net was used but as most of the time was spent on flounder fishing, few haddock were caught. However, measurements of whiting (*Merluccius bilinearus*) and hake (*Urophycis chuss* and *U. tenuis*) indicated that small fish were effectively eliminated from the catch. For a series of 12 hauls with the commercial net and 9 with the large-meshed net, the selection coefficient C_s for hake was 86. This is in the same range as the values obtained for haddock from the trouser trawl experiments. Furthermore, the large-meshed net caught only about 2 percent as many whiting below 50 centimeters in length as the commercial trawl.

The large-meshed cod-end continued to give satisfactory results during the two trips it was used on good bottom but on the third trip the *Exeter* worked a rough area and the cod-end tore up a number of times. This evidence of weakness indicated that much heavier twine would be necessary to obtain sufficient strength. Experience with the previous nets indicated that it would be impractical to make up such heavy twine into uniform mesh which would not loosen up badly before using, thus producing uneven mesh size, and that whatever improved selection single twine might give would thereby be lost. Consequently, double twine was used in the remainder of the experiments.

One other test of abnormal gear will be described before returning to a discussion of results from cod-ends of diamond mesh, double twine. The gear in question was made of large-size square mesh.

On first consideration square mesh appears to offer much better opportunity for the escape of small fish than diamond mesh of the same size. This develops from the well-known fact that diamond mesh tends to close when subjected to a longitudinal strain while square mesh does not. Apparently this was the thought of one of the earliest investigators, for Holt tested a cod-end of such construction prior to 1895. His results were not favorable and since that time investigators have not considered rectangular mesh except in gear of special construction such as the Gelder cod-end and Swedish savings trawl where rigid supports are used. The principal reasons for the neglect of square mesh are: First, the greater part of the load is carried by the longitudinal bars of the mesh making it necessary to use twine of approximately double strength to obtain a cod-end with the same lifting capacity as with diamond mesh. (Average of three tests made for us by Mr. Tucker, of the American Net & Twine Co., gave diamond mesh breaking point as 172 percent that of square mesh made of the same sized twine and mesh.) Second, the strain comes principally on the longitudinal bars of the mesh, thereby causing the knots to pull unevenly so that the mesh is pulled out of shape with the longitudinal axis becoming longer than the transverse.

Because of these characteristics, square mesh had not been included in the present experiments but in the fall of 1931 an opportunity arose to obtain first-hand information on the action of such mesh. At the behest of interested parties a square-meshed cod-end was made up and used on the *Exeter* in November 1931. The mesh was of 4-thread, 1100 twine double, and constructed the same as diamond but with the netting hung so that the mesh sides ran parallel to the longitudinal and transverse axes, respectively, of the cod-end. Two Bureau observers were present on the trip but, unfortunately, very few small haddock were encountered and neither the standard commercial net nor the net with the square-meshed cod-end took appreciable numbers of small haddock. Consequently, no reliable results could be obtained on the selective action of the square mesh but the rather scattered data do not indicate that selection was better than for diamond mesh of the same size. A set of measurements was obtained to show the effect of use on the shape of the square mesh. The mesh when new averaged about 4¼ inches between knot centers, stretched, or 2⅛ to 2¼ inches on each side. At the end of the trip (21 hauls with this net) the mesh averaged 3.7 inches stretched, with the longitudinal side averaging 2.3 inches and the transverse side 1.6 inches.

Subsequent to the trial of the square-mesh cod-end, one trip was made on the *Exeter* and several on the *Kingfisher* to test full-size cod-ends made of large, diamond mesh and double twine. The construction of the cod-ends used on all of these trips was modified because of the difficulties encountered from torn netting in the cod-end bellies and rear end of the cod-end tops of the large-meshed gear used on the previous *Exeter* trips. Thereafter, the cod-end bellies and 3 feet on the rear end of the cod-end tops were made of small-mesh netting. The remainder of the top was made of large

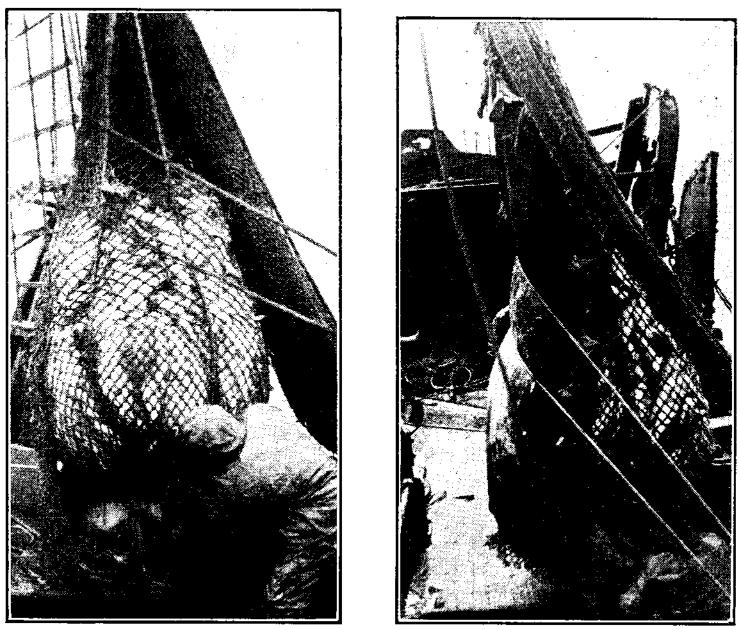

FIGURE 11.—Use of savings gear on Brown's Bank, March 1932, *Kingfisher* III. On the right: Landing of catch with a "savings" cod-end. The contrast between large mesh in cod-end top and normal commercial mesh in belly and rear part of top is easily seen. On the left: Cod-end with stringers attached. Note the mesh is held wide open throughout in spite of weight of catch.

mesh which was attached to the other sections in such a manner as to cause it to hang slack longitudinally and tight laterally. This construction served several purposes. The use of standard mesh in the underside and after end of the top side eliminated any unfavorable comparisons with the commercial nets (whether justified or not) as to strength and durability, especially in the rear end where a tear might lose the entire catch; the amount of specially constructed large mesh was materially reduced; and the adjustment of the large mesh in respect to small helped to keep the mesh open.

The data on mesh and twine size for the large-mesh sections used in the three *Kingfisher* cod-ends are given in table 6. The mesh of the first cod-end (*Kingfisher* I) was not as uniform as on the later trips, nor were the knots as tight. This probably accounts for the increase in mesh size when the gear was used (average 5⅛ inches new, 5¼ inches at end of trip). On all three trips the cod-ends were used on German trawls with 90-foot head ropes and 120-foot foot ropes. The alternate nets used for comparison were the same type but using 3- to

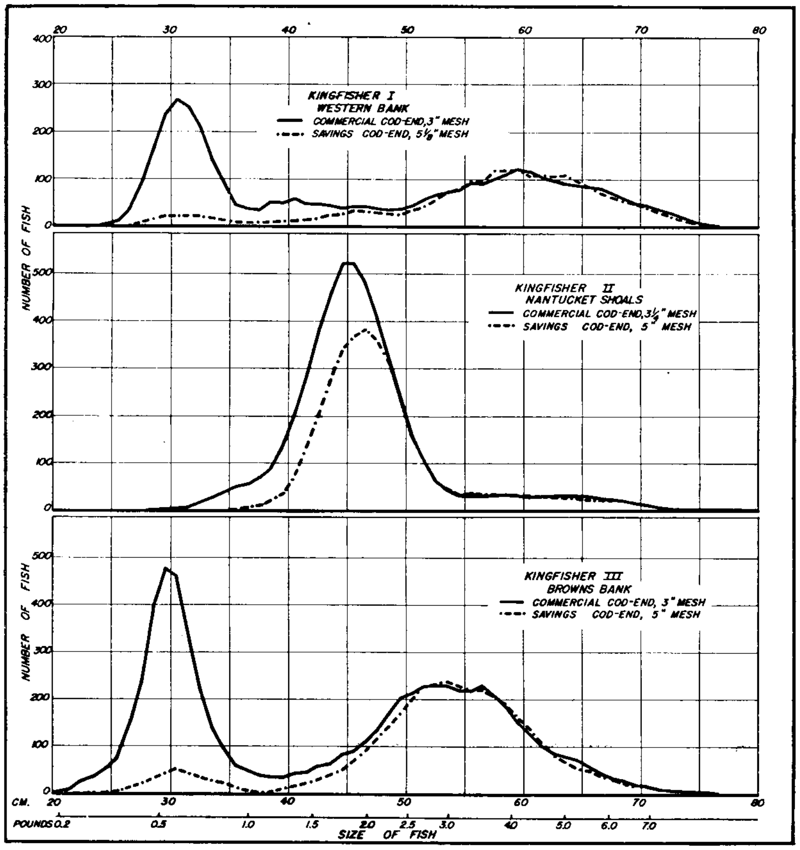

FIGURE 12.—Length-frequency curves for all alternate net experiments. All cod-ends were of double twine

3¼-inch mesh in the cod-ends. The mesh in the wings measured 5½ inches, in the square 5 inches, and in the belly 5 inches tapered down to 3¼ inches.

TABLE 6.—*Summary of data concerning the effect of cod-end mesh size on selection obtained from haddock caught in the alternate net experiments*

Trip	Gear specifications				Selection curve constants			
	Commercial cod-end mesh size	Savings cod-end			C_s	Q_1	*Mdn*	Q_3
		Mesh size		Twine (doubled)				
		New	Used					
	Inches	*Inches*	*Inches*			*Centimeters*	*Centimeters*	*Centimeters*
Kingfisher I	3	5⅛	5¼	4-thread, 900	79	39.0	43.0	48.0
Kingfisher II	3¼	5	4½±	4-thread, 1,000	83	38.7	42.3	45.8
Kingfisher III	3	5	4⅜	4-thread, 750	83	38.7	42.0	46.0
Kingfisher II and III	3 to 3¼	5			84	39.2	42.1	45.8

Large numbers of small haddock were encountered on the *Kingfisher* I, II, and III trips, and a good series of alternate hauls with large- and small-meshed cod-ends was secured on each. On the other trips few small haddock were found or the fishing was so scattered over a wide area that no series of comparisons could be obtained. Stringers were used on the cod-end during the last part of trip III but the boat was prospecting about on the return to port and the size distribution

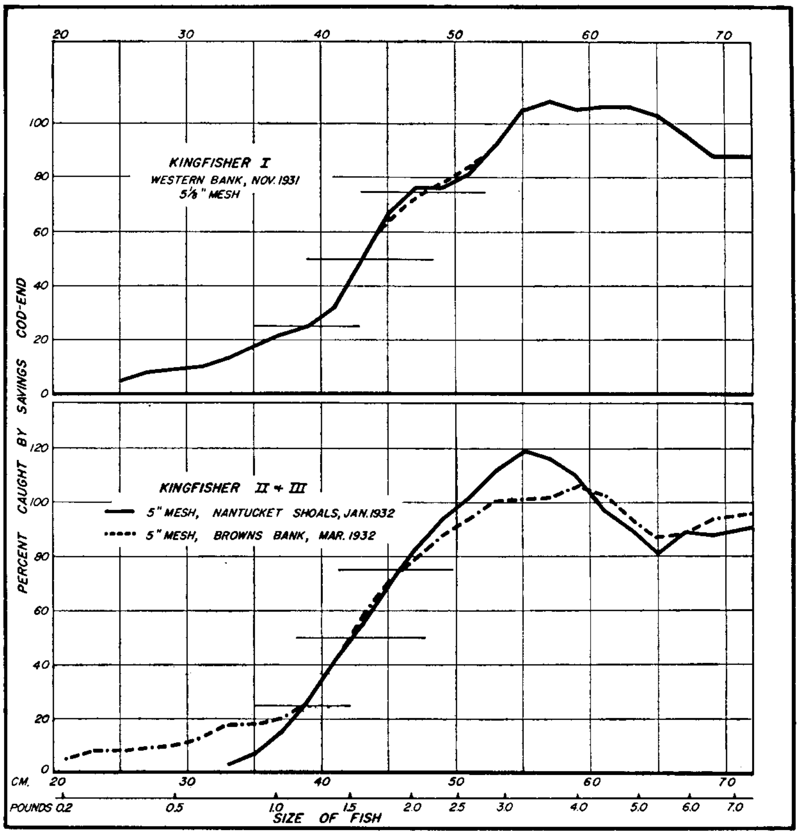

FIGURE 13.—Selection curves for all alternate net experiments.

of the catch changed too rapidly to provide any comparison of the net's effectiveness.

The number of haddock of each size taken by the nets with savings and commercial cod-ends is shown by the length-frequency curves in figure 12 for the three *Kingfisher* trips. The catch of the two nets has been equalized as described on page 18 for the sizes of 50 centimeters and larger so that the number of small haddock taken by the large- and small-meshed cod-ends can be directly compared.

The great difference in the length-frequency composition of the haddock population fished on the three trips makes it impossible to draw from the length-frequency curves any definite conclusion as to the selection achieved by the three nets. The selection curves in figure 13 are much better for this purpose. The net used on the

Kingfisher I trip gave rather poor results probably due to the loose construction mentioned previously, which resulted in unusually irregular mesh when the knots were finally pulled tight by the first few hauls landed. The selection coefficient C_s is 79, the lowest value obtained from any of our experiments. The selection curves for data obtained on the second and third trips are very similar despite the very different size composition of the population fished. The C_s values in both cases are 83, and the 50 percent selection points 42.3 centimeters and 42.0 centimeters, respectively (table 6).

TABLE 7.—*Length frequencies of haddock caught by the savings cod-end and by commercial cod-ends used in alternate net experiments*

Length (centimeters)	*Kingfisher* I		*Kingfisher* II		*Kingfisher* III	
	CC-E [1] 3-inch mesh, 15 hauls	SC-E [2] 5⅛-inch mesh, 12 hauls	CC-E 3¼-inch mesh, 10 hauls	SC-E 5-inch mesh, 10 hauls	CC-E 3-inch mesh, 14 hauls	SC-E 5-inch mesh, 9 hauls
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
14 [3]	------	------	------	------	1	------
15	------	------	------	------	6	------
16	------	------	------	------	3	------
17	------	------	------	------	5	------
18	------	------	------	------	3	------
20	------	------	------	------	4	------
21	------	------	------	------	9	------
22	------	------	------	------	20	3
23	9	------	------	------	61	2
24	6	------	------	------	45	4
25	4	------	------	------	77	5
26	27	3	------	------	135	9
27	79	2	------	------	281	24
28	174	25	------	------	431	27
29	240	22	12	------	666	49
30	301	21	------	------	567	57
31	263	30	9	------	374	48
32	193	21	23	1	233	20
33	173	17	38	------	165	38
34	64	15	57	1	77	24
35	40	7	72	4	73	10
36	32	7	91	3	48	7
37	42	10	74	11	46	0
38	32	12	137	16	34	6
39	78	8	187	36	40	6
40	41	18	277	56	41	18
41	53	13	450	122	60	25
42	51	18	547	215	47	24
43	40	23	706	279	88	39
44	43	38	804	355	79	57
45	38	20	828	379	119	52
46	49	48	705	366	112	97
47	37	32	613	401	154	119
48	29	14	500	308	203	142
49	40	35	333	235	243	160
50	40	27	223	145	264	207
51	54	45	146	91	238	227
52	80	58	92	74	288	243
53	56	68	41	26	273	233
54	84	103	49	43	233	239
55	93	76	42	35	259	214
56	98	109	33	38	266	210
57	78	106	49	34	272	235
58	125	144	52	35	188	168
59	128	109	49	27	180	172
60	109	113	36	35	146	143
61	111	97	41	30	101	105
62	87	121	49	19	100	86
63	95	109	43	30	94	58
64	92	103	53	22	93	56
65	81	76	42	27	65	45
66	82	83	36	18	44	49
67	77	53	34	18	21	17
68	50	53	29	18	24	31

[1] Commercial cod-end.
[2] Savings cod-end.
[3] The 14-centimeter length includes all measurements from 14 to 14.9, etc.

TABLE 7.—*Length frequencies of haddock caught by the savings cod-end and by commercial cod-ends used in alternate net experiments*—Continued

Length (centimeters)	*Kingfisher* I		*Kingfisher* II		*Kingfisher* III	
	CC–E 3-inch mesh, 15 hauls	SC–E 5⅛-inch mesh, 12 hauls	CC–E 3¼-inch mesh, 10 hauls	SC–E 5-inch mesh, 10 hauls	CC–E 3-inch mesh, 14 hauls	SC–E 5-inch mesh, 9 hauls
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
69	54	56	21	22	11	15
70	44	34	16	12	15	8
71	38	32	11	7	3	10
72	27	23	6	5	3	4
73	24	14	7	2	13	10
74	11	5	6	...	...	1
75	2	6	4	2	...	...
76	5	3	9	1	...	...
77	3	2	5	...	...	...
78	5	3	11	5	...	...
79	...	...	...	...	...	3
80	3	2	...	...	...	...
Total 0–49	2,178	459	6,463	2,788	4,550	1,072
Total 50–80	1,836	1,833	1,235	821	3,238	2,789
Grand total	[4] 4,014	2,292	7,698	3,609	7,788	3,861

[4] *Kingfisher* I frequencies are for several series of hauls and were separately adjusted before combined (see p. 18). The totals for unadjusted frequencies were: CC–E, 5,366; and SC–E, 3,053.

TABLE 8.—*Selection resulting from the different sizes of cod-end mesh used in alternate net experiments as indicated by the relative number of haddock caught by the savings cod-end and by commercial cod-ends*

Lengths in centimeters and selection constants	*Kingfisher* I 5⅛-inch mesh [1]	*Kingfisher* II 5-inch mesh	*Kingfisher* III 5-inch mesh	Lengths in centimeters and selection constants	*Kingfisher* I 5⅛-inch mesh [1]	*Kingfisher* II 5-inch mesh	*Kingfisher* III 5-inch mesh
LENGTHS	*Percent*	*Percent*	*Percent*	LENGTHS—con.	*Percent*	*Percent*	*Percent*
20–21 [2]	...	...	5	54–55	105	119	101
22–23	...	...	8	56–57	108	116	102
24–25	5	...	8	58–59	105	110	106
26–27	8	...	9	60–61	106	97	103
28–29	9	...	10	62–63	106	90	94
30–31	10	...	13	64–65	103	81	87
32–33	13	3	18	66–67	96	89	88
34–35	18	7	18	68–69	88	88	94
36–37	22	15	20	70–80	88	91	96
38–39	25	27	26				
40–41	32	42	42	SELECTION CONSTANTS			
42–43	50	55	58				
44–45	67	70	71	Q_1	39.0	38.7	38.7
46–47	76	83	79	*Mdn*	43.0	42.3	42.0
48–49	76	94	88	Q_3	48.0	45.8	46.0
50–51	81	102	94	C_s	79	83	83
52–53	92	112	101				

[1] In all 3 alternate net experiments the cod-ends were of double twine without stringers.
[2] The lengths 20–21 centimeters represent the interval from 20 to 21.9, etc.

The accurate appraisal of the value of any net for the saving of small fish requires more than the record of the percentage escapement above and below market size. For instance, on the January trip the large-meshed cod-end released 71 percent of the haddock below 1½ pounds and 20 percent above, while on the March trip 87 percent below 1½ pounds were released and but 5 percent above. Yet the effectiveness of the nets was almost identical for the two trips and the above percentage differences are due to the length-frequency composition of the population fished. The selection constants C_s and *Mdn*, which we have used for comparing the action of different nets, provide a better measure of the merits of the gear but still do not give a very precise gage of the nets' effectiveness. Probably the most instructive measure is the "escapement index" or average percentage escapement of all the sizes considered. For instance, the escapement index for the sizes from 30 to 40 centimeters would be the average of the percentage which escape at 30, 31, and 32 centimeters, etc. For any type of savings gear and mesh size this index would be constant,

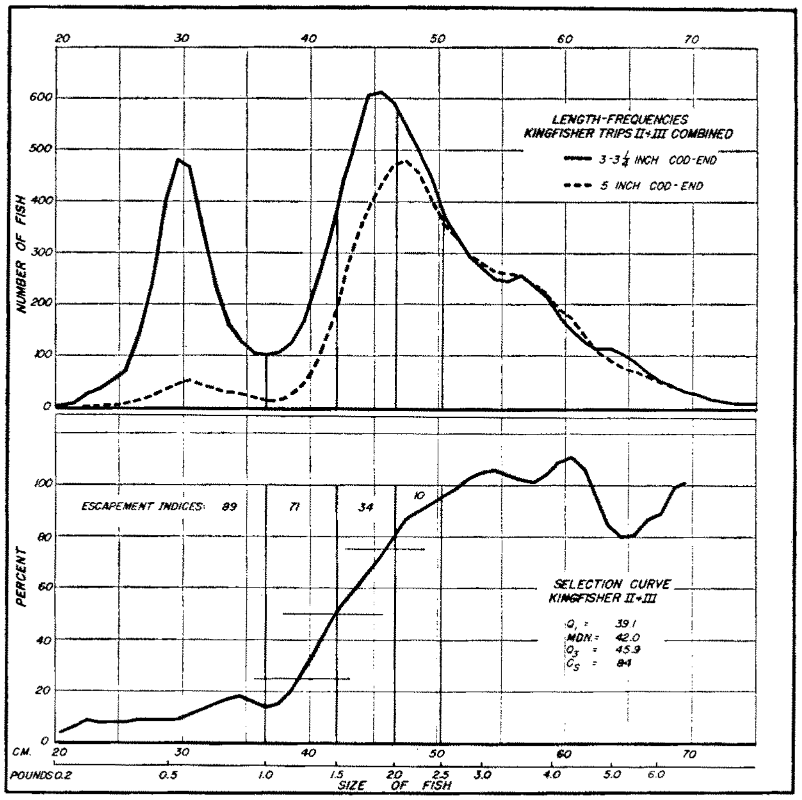

FIGURE 14.—Length-frequency curves and selection curve for *Kingfisher* trips II and III combined.

irrespective of the size composition of the population fished (disregarding the possible effect of variations in mesh clogging from varying quantities of trash or wide fluctuations in amount caught).

The use of the escapement index is limited to those cases where a selection curve can be obtained which is fairly reliable throughout its entire course. It cannot readily be applied to the January trip data for that curve is based on relatively few measurements for lengths below 38 and above 52 centimeters. Likewise, the March curve is best for 25 to 34 centimeters and 46 to 60 centimeters but not as good between 34 and 46 centimeters. As the nets used on these trips were of the same type and mesh size and the selection obtained very nearly identical, the two groups of data have been combined and give us a fairly considerable series of measurements for all lengths from 25 to 65 centimeters (fig. 14). The selection curve calculated from this combined data is the most reliable exposition which our experiments afford of the selective characteristics of 5-inch mesh of 4-thread, 750 to 1,000 twine double. The fluctuations above and below the 100-percent line for the lengths between 50 to 70 centimeters do not represent real differences in the action of the large- and small-meshed cod-ends but are due to chance variations in the size composition of the population sampled by the two nets.

The selection constants for the composite curve, of course, are very much the same as for its two components. The slight increase in the C_s value (84 for the composite curve against 83 for the individual curves) results from the finer smoothing (1-centimeter instead of 2-centimeter grouping) which the larger numbers of the combined data make possible. Two-centimeter grouping has been used on all other data.

The real effectiveness of the 5-inch mesh cod-end for saving undersized haddock (weighing less than 1½ pounds) is revealed by the escapement indices for the composite curve. The index is 89 for fish from 0.2 to 1 pound; 71 from 1 to 1.5 pounds; 34 from 1.5 to 2 pounds; 10 from 2 to 2.5 pounds; and negligible for fish over 2.5 pounds.

TABLE 9.—*Length frequencies of haddock caught by the savings cod-end and commercial cod-end for "Kingfisher" II and III, and selection percentages for the combined data*

[Frequencies combined after adjusting and smoothing]

Length (centimeters)	Commercial cod-end 3-inch mesh	Savings cod-end 5-inch mesh	Relative catch in savings cod-end	
			Unsmoothed	Smoothed
	Number	*Number*	*Percent*	*Percent*
14	2	------	---------	---------
15	3	------	---------	---------
16	4	------	---------	---------
17	3	------	---------	---------
18	3	------	---------	---------
19	2	------	---------	---------
20	3	------	---------	4
21	9	1	11	6
22	26	2	8	9
23	36	3	8	8
24	52	4	8	8
25	74	6	8	8
26	141	13	9	9
27	235	20	9	9
28	397	33	8	9
29	480	44	9	9
30	465	51	11	11
31	343	42	12	13
32	236	35	15	15
33	162	28	17	17
34	128	26	20	18
35	106	17	16	16
36	101	12	12	14
37	105	14	13	15
38	123	25	20	20
39	167	46	28	28
40	245	87	36	37
41	327	153	47	46
42	437	234	54	54
43	521	323	62	60
44	604	387	64	66
45	611	436	71	72
46	590	471	80	80
47	540	477	88	87
48	495	455	92	90
49	440	399	91	93
50	370	355	96	96
51	329	329	100	99
52	291	298	102	103
53	269	286	106	105
54	248	264	106	106
55	245	260	106	104
56	256	255	100	102
57	239	239	100	101
58	217	224	103	104
59	178	193	108	109
60	150	174	116	111
61	128	139	109	107
62	114	109	95	95
63	114	91	80	84
64	103	79	77	80
65	88	72	82	81
66	69	58	84	87
67	53	50	94	89
68	45	40	89	99
69	31	35	113	101
70	26	26	100	---------
71	16	16		
72	11	14		
73	9	7		
74	8	5		
75	7	1	80 (71–80)	80
76	4	1		
77	5	2		
78	3	3		
79	3	3		
80	------	1		
Total 0–49	8,216	3,844	---------	---------
Total 50–80	3,629	3,629	---------	---------
Grand total	11,845	7,473	---------	---------

FACTORS AFFECTING SELECTION AND CATCH

During the trouser cod-end experiments the large-meshed cod-end was used with various gear combinations. It was the inside leg during 61 hauls while the short partition was used; and the outside leg during 22 hauls with the short partition, 10 hauls with the long partition, and 16 hauls with no partition. The long partition (p. 16) had the greatest effect on the distribution of large haddock (45 centimeters and up) between the two legs. The inside cod-end held 29 percent of the total when this partition was used compared to 55 percent when using no partition or the short partition. The series with the long partition is not used in the following analyses.

The inside cod-end took slightly more than half of the total catch of large haddock irrespective of whether the large- or small-meshed leg was in this position. When of large mesh, this leg took 53 percent of the total, and when of small mesh, 57 percent, giving an average of 55 percent. Davis (1929) reports the same effect for he found a persistent tendency for the inside cod-end to receive more than half of the catch. The figures given above also indicate that the large-meshed cod-end averaged slightly smaller catches than the small-meshed leg; i. e., 48 percent against 52 percent.

EFFECT OF SIZE OF CATCH ON SELECTION

Todd and others have mentioned the influence that the weather (amount of roll) and size of catch exert on the selection produced by cod-end mesh. Little additional information on this subject is available from these experiments for whatever influence these factors may have exerted cannot be segregated from that of other conditions. The average catch per haul [5] for *Exeter* I was about twice as great for the hauls in which no stringers were used on the cod-end (1,820 pounds) as for the hauls with stringers (970 pounds), yet the selection coefficient C_s is nearly as high, 85 compared to 87, and the difference is more probably owing to the use of stringers than to the size of catch. On the second *Exeter* trip the catches averaged about the same (1,200 pounds) for the two series of hauls and at a level between the first and second trip I series. On trip III both series averaged about the same (880 pounds) at a level lower than those for the two previous trips, but the high C_s values are probably due more to the use of single twine than to the slightly lower catch level.

The hauls made on the second and third *Kingfisher* trips gave nearly identical selection coefficients, yet the catch of marketable fish on the second trip averaged 1,000 pounds per haul and on the third trip 1,820 pounds per haul. On the first trip when the poorest selection was obtained the catch averaged 1,500 pounds per haul.

The influence of the size of catch does not appear to have been sufficiently great to make itself evident above other factors affecting selection. Neither does the weather appear to have exerted a dominant influence although possibly a detailed analysis of the data bearing on this question might give some results. Precise evaluation of the influence of these two factors requires more extensive experiments, preferably with covered cod-ends.

[5] Hauls averaged 1⅓ hours.

EFFECT OF WEIGHT OF TWINE AND SHRINKAGE IN REDUCING THE EFFECTIVE MESH SIZE

During the progress of our experiments it has become evident that an accurate and consistent description of the netting used is necessary for any precise comparison of the position of the selection curves for different gears. It is customary to designate mesh size simply by the distance between knot centers along one side of the mesh (mesh side) or between knot centers measured diagonally along the stretched mesh (mesh diameter). But the really important dimension, insofar as the size of fish held is concerned, is the mesh opening inside of the knots. This measurement is affected in its relationship to knot-center measurement by the size of twine used and tightness of the knots. Furthermore, the mesh size of new netting is not necessarily equal to the size of the same netting after use, and different batches of new netting may shrink or stretch more or less, according to how loose the knots were when the nets first were measured. The importance of these factors can be appreciated if any precise comparisons between mesh size and median selection point are attempted for the selection data from European experiments (table 1, fig. 2).

It may be argued that a difference of one quarter or one-half inch in mesh size is not important, but our data indicate that a difference of one-half inch will raise or lower the position of the selection curve as much as 4 to 6 centimeters. Therefore, if we expect to designate a mesh size which will place the selection curve as close as possible to the lower boundary of the marketable sizes, an error of 4 centimeters plus or minus either will cause the capture and waste of many small fish or permit the loss of a large proportion of the fish just above the lower limit of market size.

Unfortunately, the importance of these factors was not fully realized when this work was begun, and the data collected are not as extensive as might be wished. However, for all but one of the large-meshed cod-ends we have a series of measurements of the mesh when new and again at the end of the trip. Each of the following figures is the average of from 2 to 4 separate series of measurements. The average shrinkage for 4- to 5-inch mesh (diameter between knot centers, new) of 3-thread, 1100 and 1200 twine double, was 0.5 inch; that for 4¾-inch mesh of 4-thread, 750 twine single, was 0.3 inch; and that for 5-inch mesh of 4-thread, 750 and 900 twine double, was over 0.6 inch. In one case (*Kingfisher* I) the mesh averaged 5⅛ inches new and actually increased to 5.31 inches by the end of the trip. The large mesh in this cod-end was a special job by a net man whose experience had been in building nets rather than in making up netting. As a result, although the mesh was made up as 5⅛ inches diameter, the knots were sufficiently loose so that when pulled tight in use, the slack more than counteracted the shrinkage.

In addition to the change in size of new mesh when used, there is a difference in the diameter of the mesh in the forward and rear sections of the cod-end. On the third *Kingfisher* trip this averaged between one quarter and one-half inch. Consequently, for consistent comparisons, measurements must be made in the same section of the cod-end especially when the gear is fairly new. The greater diameter of the rear-end mesh is due to the strain to which it is subjected when the catch is landed by the splitting strap or with the landing strap secured about the midsection of the cod-end.

The thickness of the twine is another factor of some importance in reducing effective mesh size. If the same mesh and twine size is used throughout, this influence cancels out, but if either is considerably altered, the effect must be considered. The following figures are the average differences for mesh diameters measured between knot centers and inside of knots, stretched mesh. Each value given is the average of differences obtained from 2 to 4 series of measurements taken between hauls with the various nets. In all cases the cod-ends had been used for 40 to 60 hauls before the measurements were made.

These data were obtained from the nets used on the *Exeter* and *Kingfisher* trips. For 3- and 4-thread, no. 1100 and 1200 twine double, the average difference between diameters measured between knot centers and measured inside knots was 0.57 inch. The 4-thread, and 3-thread twine gave the same difference but the catches in the 4-thread net averaged considerably larger and the knots were pulled up more tightly than in the 3-thread net. The 4-thread, 750 twine single gave a difference of 0.56 inch. The 4-thread, 750 twine double gave an average difference of 0.78 inch. For new netting the differences were considerably higher, averaging from 1 inch to 1¾ inches. The mesh did not stretch out to a fairly permanent size until at least 5 to 10 good-size hauls had been landed. The selection coefficients (C_s) for the first half dozen hauls on all three *Exeter* trips are 4 to 5 points below those for the same gear for the remainder of the trip. The median selection points also are 2 to 3 centimeters lower for the first hauls.

A practical difficulty was encountered in cases where the stringers had been attached to the new cod-ends. The weight of the catch when landed was carried principally by the stringers rather than by the netting, as a result the knots were not pulled tight even after landing several hauls. It was found necessary to fish the net for at least 5 to 10 hauls before attaching the stringers. Any cod-end supported by rigid frames would appear to be subject, to some extent, to the same drawback. For small mesh where lighter twine can be used there is less difficulty but for the heavy double twine necessary for 5-inch mesh, the knots did not become permanently tightened until a series of good catches had lubricated the twine with fish slime and subjected it to the fluidlike pressure of several tons of fish.

EFFECT OF VARIABILITY IN MESH SIZE ON THE SHARPNESS OF SELECTION

For any savings gear depending on mesh selection the variability in mesh size puts a practical limitation on the selection that can be achieved. For specially made netting the variability might be reduced considerably but for commercial gear this refinement does not appear practical. Indeed, there is some question whether netting made of double twine as heavy as 4-thread, 750 could be permanently stretched at the factory without considerable additional expense. If not permanently tightened, the knots work loose when the netting is handled before using, and when finally pulled tight there is considerable variation in mesh size. Some day, perhaps, a new material will be developed for cod-end construction which will help to solve this difficulty.

A considerable series of mesh measurements was obtained at various times for the large-meshed netting used on the third *Kingfisher* trip. The maximum range in mesh diameters measured between haul 24 and haul 87, was 1¼ inches, but 54 percent of the measurements lay within a ¼-inch range. The differences were greatest at the first of the trip and became less as the knots became more uniformly tightened. This variability in mesh makes it necessary to specify mesh size as an average, preferably of a series of 10 or more consecutive meshes.

CONDITION OF THE FISH WHICH ESCAPE

That the fish which escape through the meshes of the otter trawl are liberated in good condition apparently has been taken for granted in savings gear work, for if the question has appeared in the literature, it has not come to our attention. The assumption is difficult to prove definitely but appears logical, for there seems to be no good reason why many small fish should be injured by their passage through the more or less distended meshes of the net, except possibly for the border-line sizes which can just squeeze through. The potential swimming speed of most fish is so much greater than the usual 2½ to 3 knots of the trawl that it is difficult to visualize the fish being carried helplessly about and forced up against the mesh by the relatively slow water stream. The flow of water through the mesh should assist rather than retard the escape of the fish and the blocking of the mesh by larger fish would prevent all escapement rather than force out small fish in an injured condition. The roundfish which escape from the trawl after it has neared the surface, probably suffer a heavy mortality because of their inability to return to the bottom inasmuch as the release of pressure has caused them to become distended, but this number is ordinarily a very small percentage of the total escapement.

In 1931 an experiment was performed to determine the condition of the fish which escaped from the trawl. A cod-end of 5-inch mesh was attached to a small flounder trawl and a second and larger cod-end of shrimp netting was secured over it. Thus, small fish which escaped through the large mesh of the inside cod-end were held in the outside cover of fine mesh. These fish were landed in tanks of water on deck and remained alive and in good condition during the time they were held. It is obvious that complete escape from the trawl, while the latter still is on the bottom, must be an immeasurably lesser ordeal than that to which the fish were subjected in this experiment. Consequently, their condition can have been little affected by escape through the large mesh of the inside cod-end. Moreover, it is known that haddock and cod can survive fairly rough treatment, for a considerable number used during our tests of experimental tags were kept for 1 to 2 years in a live car measuring 18 by 14 by 7 feet, and removed for observation several times a year. This operation subjected the fish to impounding with a small seine, removal with a dip net, measurement of length, and observation of the tag (sometimes 2 or 3) during which the fish sometimes squirmed loose and flopped about before it could be recaptured and returned to the live car. The haddock used in this experiment ranged in size from 1 pound to 5 or 6 pounds. Inasmuch as this treatment was not fatal, there appears to be little question but that the experience of slipping through the meshes of the cod-end of a trawl usually would be survived successfully.

DISCUSSION OF RESULTS

HADDOCK

A recapitulation of available data bearing on the relation between cod-end mesh and the size and proportion of haddock which escape reveals several significant results. An average selection constant of 83 is obtained for all European experiments considered here, exclusive of the Swedish savings trawl. This is precisely the same as the value obtained for *Kingfisher* II and III experiments if 2-centimeter length

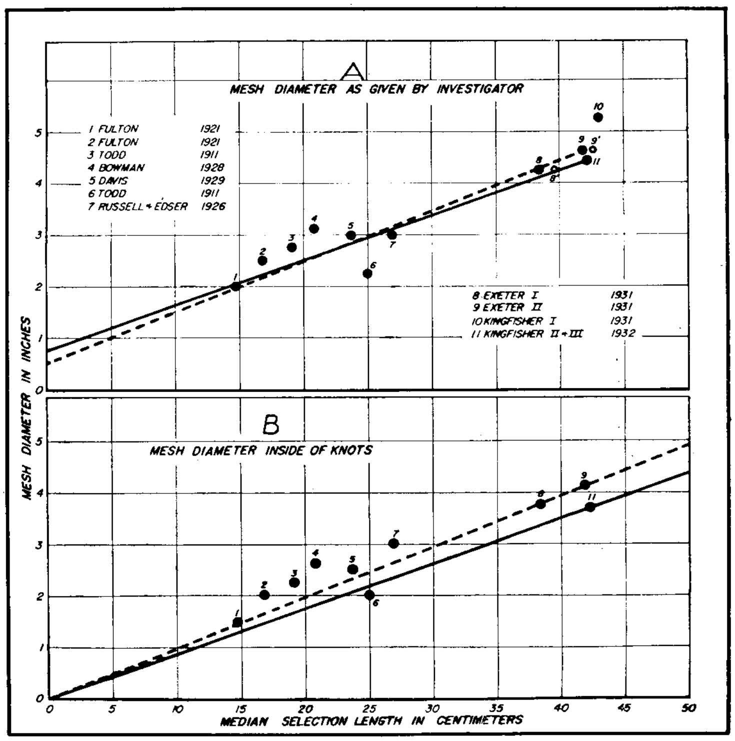

FIGURE 15.—A. Relationship between diameter of mesh used in cod-end and length at which 50 percent of haddock escaped (median selection length). Mesh diameter is that given by various investigators. Points 8′ and 9′ are for cod-ends with stringers. B. The data shown are similar to A except that mesh diameter measured inside of knots is used.

grouping is used as in the case of the European data (table 1). The average C_s value for the *Exeter* I, II, and III cod-ends without stringers is 85 (86.5 for *Exeter* I and III), the same as that for the data obtained by Russell and Edser with a trouser cod-end. These remarkably good agreements for mesh differing widely in size provide strong evidence for the belief that the selective action of diamond mesh remains approximately the same throughout the range of mesh sizes covered (2 to 5 inches).

In figure 15 *A* the length at which median selection occurs is plotted against mesh size for the experiments mentioned above. For our experiments we have used for this purpose the average diameter of the mesh after 30 to 40 hauls as the best value for the size of the mesh "in use." A straight line drawn from the point for the *Exeter* III stringerless cod-end to the point on the Y axis corresponding to the knot thickness for the size of twine used (the mesh size at which theoretically no fish could escape due to the effect of knot and twine thickness) also passes approximately through the point for the *Exeter* I cod-end, which had the same knot thickness. The point for the Russell and Edser trouser cod-end also falls near this line but the mesh size given by them is measured inside of knots. If adjustment is made for thickness of knot (3-ply, 100 twine single) the mesh diameter would be about 3⅗₁₆ inches and would fall a little above the line we have drawn. The median lengths for *Exeter* I and III large-meshed cod-ends with stringers lie about 1 centimeter higher than the same cod-ends without stringers, a difference that reasonably can be ascribed to the effect of the stringers.

The data from our alternate net experiments and European covered cod-end experiments are not particularly consistent. The results for *Kingfisher* I differ considerably from *Kingfisher* II and III. The mesh sizes for these experiments are rather definitely established, for consistent averages were obtained from several series of mesh measurements made at various times during these trips. However, the median value for *Kingfisher* I is the less reliable, for the length-frequency curve (fig. 12) shows that the number of fish for the lengths 40 to 50 centimeters averages less than 50; therefore, a rather small chance variation in the sample taken in the savings cod-end could shift the median size by several centimeters. On the other hand, the frequencies for the *Kingfisher* II and III curve run between 300 and 400 and the position of the median point is correspondingly more reliable. Consequently, the *Kingfisher* II and III median value is taken to be the more significant.

Turning now to the European experiments, we find our attempt to reconcile results somewhat difficult. The high median length for Todd's supported cod-end (fig. 15 *A*, no. 6) might be ascribed to the effect of the rigid hoop and single twine in raising the level of the selection curve. The points 1 to 4 in figure 15 *A* from the data given by Fulton, Todd, and Bowman, fall on an approximately straight line which if projected out from a point on the Y axis corresponding to the probable knot thickness would give us close to a 6-inch mesh for a median selection point of 40 to 42 centimeters. This is far above the actual mesh size found necessary in our experiments. Furthermore, the weight of twine used probably was considerably less than in our *Kingfisher* nets and would cause a smaller reduction in the opening of the mesh, clear of knots and twine. No information is given as to method of measuring the mesh or whether the netting was new or in use. The median from Davis' selection curve (point 5) falls but little above the line drawn from the points for our experiments to the Y axis, but the twine used by Davis was considerably lighter (3-ply, manila 100[6] untarred twine, double). It was measured "under working conditions" which apparently corresponds to our measurements of netting after use.

As the clear opening of the mesh inside of knots is the significant characteristic in determining the maximum size of fish that can escape, we have plotted, in figure 15 *B*, the length at which median selection occurs against the inside diameter of the mesh. For our experiments and for Russell and Edser, actual measurements have been

[6] Equivalent to 3-thread, 900-twine, American specifications.

used; for Davis' experiment the knot thickness for the weight of twine used has been subtracted from the mesh diameter given; for the Todd, Fulton, and Bowman data, the same correction was made as for Davis on the assumption that double twine of similar weight was used, except that for Todd's supported cod-end the correction for single twine was used.

The difference between the results for our trouser cod-end and alternate net experiments may be characteristic of the gear used, but to some extent at least, must be the result of the larger catches made with the *Kingfisher* net. Regardless, the value from the alternate net experiments must be accepted as most significant as it was obtained with a full-sized cod-end and from a much greater series of data. In figure 15 *B* results from European experiments, except for Todd's supported cod-end, fall above the line connecting the origin to the point for our experiments. At least part of the deviation may be accounted for by differences in method of measuring the mesh but the consistent disagreement apparently indicates that the length at which median selection occurs is not directly proportional to the size of the mesh or that the considerably larger catches normally made in our fishery hold the cod-end mesh more fully extended during the tows and permit proportionately larger haddock to escape.

We are prepared now to apply our selection data to a practical problem. From our *Kingfisher* II and III data we find that 5-inch cod-end mesh (diameter "in use" 4⅝ inches) of 4-thread, 750 to 1000 manila twine[7] double, compared to 3-inch mesh of 4-thread, 1100 manila twine, double, permits the escape of about 85 percent of the haddock between 0.2 and 1.5 pounds (escapement index), and that it releases about 25 percent of those between 1½ to 2½ pounds. However, if the selection curve could be moved downward until the median length was 3 centimeters less, i. e., 39.1 centimeters instead of 42.1 centimeters, meantime keeping the same C_s value, the proportion of haddock between 1½ to 2½ pounds which escaped would be reduced to 8 percent and practically all of these would be of the smallest scrod size, less than 2 pounds. At the same time the escapement of haddock below 1½ pounds would be reduced from 85 percent to 78 percent. From figure 15 we find that a 3-centimeter reduction in median selection length can be accomplished by decreasing the mesh diameter approximately one quarter inch. Applying this to the 5-inch mesh used on *Kingfisher* II and III we get a 4¾-inch mesh (4⅜ inches in use). This is the size which our results indicate will release about 78 percent of the haddock below the market size limit of 1.5 pounds with the loss of but 8 percent of the smallest scrod and practically no loss of larger fish. Similarly, the mesh size can be approximately determined to give any other position for the selection curve.

OTHER SPECIES

Although the primary task on all of our savings gear trips was to obtain complete data on the sizes of haddock caught and other relevant information, it was found possible at various times to obtain data on other species. About 14,000 such measurements were obtained but only a few series of hauls are available for which sufficient numbers of any one species were obtained to afford fair comparison.

[7] Corresponds to 4 thread 60 to 80 twine, English specifications.

The data for the various species are shown in table 10, compared to those for haddock. The value for cod appears rather high but as this fish has a square tail it measures somewhat longer than a haddock of the same weight. The median lengths given for the various species lie at or below the lower limit of their marketable size. Without further confirmation these data can be considered only for determining the approximate effect of these large-meshed cod-ends on the escapement of the various species.

TABLE 10.—*Selection data for all species measured on "Exeter" trips. Due to limited data the values for species other than haddock can be considered only as fair approximations*

Species	*Exeter* trips							
	I		II		III		IV	
	Mdn	C_s	*Mdn*	C_s	*Mdn*	C_s	*Mdn*	C_s
	Centimeters		*Centimeters*		*Centimeters*		*Centimeters*	
Haddock	38	85	43	82	42	88	-------	-------
Cod	-------	-------	-------	-------	50	87	-------	-------
Hake	42	-------	-------	-------	47	-------	46	86
Whiting	51	-------	55	-------	53	-------	-------	-------
Flatfish	28	-------	27	-------	28	-------	-------	-------

CONCLUSIONS

Toward the solution of the five questions enumerated on page 14, we now can offer the following contributions:

1. No final proof can be cited that the young haddock which escape through the meshes of the net, while still on the bottom, successfully survive the experience; but no cause has been offered which reasonably might be expected to prevent the great majority from so doing (p. 41).
2. An increase in the size of diamond mesh in the cod-end to a diameter of 4 to 5 inches will produce an increase in the size and percentage of young haddock which escape (p. 42).
3. A cod-end made of 4¾-inch diamond mesh (about 4⅛ inches after use) using 4-thread, 750 twine, double, will capture about 22 percent as many haddock between 0.2 and 1.5 pounds, about 92 percent as many between 1.5 and 2 pounds, and at least as many above 2 pounds, as a cod-end of 3-inch mesh.
4. No savings cod-end yet described has given materially sharper selection for haddock than that obtained from cod-ends of diamond mesh. One cod-end has been described which gives sharper selection for flatfish than ordinary diamond mesh but it suffers practical disadvantages. The cod-ends with stringers described in this paper gave somewhat better selection than the same cod-ends without stringers, but the difference has not been sufficiently demonstrated.
5. This paper offers no data on the value of the forward part of the net for the escape of small fish, except that provided by European experiments. However, if the cod-end mesh is increased to 4¾ to 5 inches, there is no good reason for not increasing the mesh in the forward part of the net to at least this size. Therefore, if the forward

part is an important escapement area, such an increase in mesh size will increase still further the saving of small fish.

RECOMMENDATIONS

In view of the definite evidence that:

1. The nets now used in the otter-trawl fishery cause the destruction each year of great numbers of small haddock and other food fish.
2. The relatively poor yield of the haddock fishery over the past 5 years demonstrates the importance of curtailing all unnecessary strain on the supply.
3. The results of this investigation demonstrate that the use of the correct cod-end mesh will reduce the destruction of small haddock to approximately one-fifth the present amount without losing more than a very small fraction of the smallest scrod.
4. The saving of small fish involves no sacrifice on the part of the owners or crews either in respect to cost of the gear or loss of time in its handling.

It is recommended:

That the industry adopt a minimum mesh size of not less than 4¾ inches (between knot centers, stretched mesh, new netting, the measurement to be the average of at least 10 consecutive meshes) to be used in any part of the otter trawl except the belly and after-end of the cod-end.[8] This increase in mesh size, of course, should be accompanied with an adequate increase in size of twine to give the net the required strength and wearing qualities.

It must be remembered that the use of 4¾-inch mesh will not eliminate the capture of all haddock below commercial size. Small haddock still will be taken, at times in large numbers, and predominantly of the sizes between 1 to 1½ pounds. A further increase in mesh size to 5 to 5¼ inches probably would prove beneficial for it would release a large part of these fish and lose but a moderate fraction of the smaller scrod.

Furthermore, it cannot be assumed that the saving of undersized haddock will restore the fishery to its 1926 to 1928 level; in fact, no one can guarantee that the fishery will be maintained at its present level. But we can be sure that if the destruction of small fish is prevented, the fishery will be maintained at a higher level than would otherwise be possible.

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[8] The attitude of certain trawler operators toward the use of nets of larger mesh should be recognized. Capts. William Westerbeke and John H. Westerbeke pioneered the use of large-meshed nets in the dragger fishery in 1931; and John Graham of the Portland Trawling Co., A. L. Parker, and others have furnished invaluable cooperation in the present work. More recently, there has been a general trend by many of the operators toward the use of nets with larger mesh; and in February 1934, members of the "Federated Fishing Boats of New England and New York" went on record in favor of increasing the size of mesh in the otter trawls to a minimum of 4¾ to 5 inches.

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