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NORTHWEST ATLANTIC FISHERIES

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THE SELECTIVITY OF FISHING GEAR

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Contents

Preface

Following a proposal by the International Commission for the Northwest Atlantic Fisheries a joint scientific meeting of the Conseil Permanent International pour l'Exploration de la Mer, the Food and Agriculture Organization of the United Nations and the International Commission for the Northwest Atlantic Fisheries on "Fishing Effort, the Effect of Fishing on Resources and the Selectivity of Fishing Gear" was held in Lisbon at the invitation of the Portuguese Government from 27 May to 3rd June, 1957.

The meeting was chaired by Dr. Lionel A. Walford, Chairman of the ICNAF Standing Committee on Research and Statistics, with Mr. John R. Clark, USA, Mr. Sidney Holt, FAO and Dr. C. E. Lucas, UK as conveners for separate sections on gear selectivity, population dynamics and fishing effort, respectively.

The reports on the meetings have been published by FAO, Rome, 1960 under the title: "Proceedings of the joint Scientific Meeting of ICNAF, ICES and FAO on Fishing Effort, the Effect of Fishing on Resources and Selectivity of Fishing Gear. Vol. 1. Reports". The present publication, Vol. 2, comprises the papers on selectivity of gears submitted to the meeting. A few of these papers have since the meeting been published elsewhere, and only abstracts of them are given here. The papers have been edited by Mr. J. R. Clark, formerly of the US Fish and Wildlife Service, Woods Hole, Mass., in cooperation with Mr. Sidney Holt, FAO.

The ICNAF **Secretariat.**

Dartmouth, September 1963.

1.

The Influence of Behaviour on the Capture of Fish with Baits

by

K. RADWAY ALLEN [1]

By whatever method the fish are caught the size distribution of the catch has usually a single peak and the number of fish taken declines progressively above and below the peak size. When capture is by nets the effects causing the distribution are largely mechanical and the fish themselves play a relatively passive part. The decrease below the peak size is due to the increasing ease with which fish can escape through the net and the decrease above the peak arises largely from the size-composition of the population, although in gill nets it may be modified by mechanical factors. Data obtained from this part of catch curves are often used to indicate directly the structure of the population.

While the entire population of a species must show a continuous decrease in numbers with age and therefore normally with size, sometimes only a section of the population is present in the waters fished and in these cases the catch may fully reflect the structure of the local population. This is only likely to occur in large water systems and in the sea.

When fish are taken by baits, the main factors determining which fish are caught are no longer mechanical but arise from the behaviour of the fish. Thus the bait used may only attract fish within a certain size range. When long-finned eels (*Anguilla dieffenbachii*) are taken in a carrion-baited trap, which will retain eels of all sizes, the results show that the attraction of this species to such a bait does not commence until a size of 20 inches is reached and is not fully effective until at least 30 inches. The following example taken from the Wainui-o-mata, a small river with a complete population of eels, illustrates this (Burnet, 1952).

Length in inches	%
Under 23	5.5
24	5.9
26	11.0
28	19.0
30	22.6
32	19.6
34	8.0
36	4.8
Over 37	4.6

The increase up to 30 inches is due to increasing attraction and the decrease beyond this size probably reflects population structure.

When hooks with baits or lures are used the effects are more complex. My data are derived from freshwater sport fisheries for trout but it seems likely that similar effects may merit consideration in dealing with marine commercial line fisheries. In river fisheries where small artificial flies are used the usual peaked size distribution in the catch generally occurs but the peak size varies greatly from water to water. Where the maximum size is fairly small the catch may reflect fairly accurately the population structure as the following data from the Horokiwi, a fairly typical small stream, show: -

Length in inches	Percentage	
	Catch	Population
- 10	56.0	49.4
11 - 12	25.1	29.1
13 - 14	13.4	14.2
15 -	5.5	7.3

[1]) New Zealand Marine Department.

There is no significant difference between the series and it appears that under these conditions the method exercises little or no selection. In the population data the 0 age-group which is in its first summer is ignored; very few fish of this age-group are caught and these only at the extreme end of the season.

Population data are not available for waters in which the average size at capture is large, but many instances are known where this occurs in rivers where the entire population is present in the areas fished and where growth rate is fairly similar to that in the Horokiwi. The following example comes from the Motueka River:

Length in inches	Percentage
– 11	17.8
12 – 13	3.0
14 – 15	17.2
16 – 17	26.9
18 – 19	22.9
20 – 21	9.3
22 –	2.9

It is obvious that in such instances some form of selection of the large fish is occurring and the Horokiwi and similar data suggest that it is not due to any inherent inefficiency of the method for fish of less than about 14 inches. This leads to the conclusion that there is a tendency for angling, at least with small artificial flies, to select the largest fish commonly present in the particular water. Since there is little or no deliberate selection by the angler, this seems to imply that some aspect of fish behaviour is involved. Relevant aspects of behaviour could include competition among the fish for an apparently attractive mouthful, or competition for good feeding positions in which food organisms, or anglers' lures, which are also coming down with the current, are abundantly brought to the fish. It is commonly believed that in salmonids the largest fish are most successful in competition and occupy the best lies and this has recently been confirmed by critical studies.

If mechanisms of this sort are operating it seems logical that they should extend throughout the normal life of the fish and that fishing effectiveness should continue to increase indefinitely with size. This presents a definite contrast with the usual interpretation of net-fishing results where efficiency remains constant or decreases above the peak size. It must be realized that a peaked size distribution can be obtained even if fishing efficiency is continually increasing. The only condition for a peak to occur is that the rate at which the proportion due to fishing, out of the total deaths, is increasing should decrease more or less steadily during life. The peak will occur at the point at which the instantaneous rate of increase in the fraction of deaths due to angling equals the instantaneous total mortality rate.

A number of mathematical models complying with these conditions have been constructed and shown to produce curves not unlike those actually occurring. One such model is shown graphically in Fig. 1. This is based on the formula –

$$C = e^{-Zt} \; (1 - e^{-Zt}) \; t$$

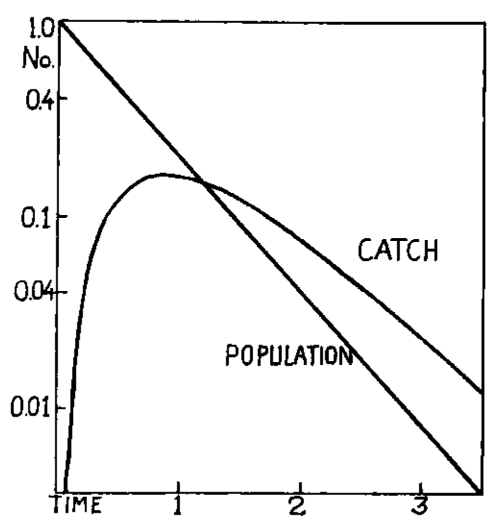

Fig. 1. For explanation see text.

where C is the number of fish caught at age t. This is based on the assumption that the success in competition of the fish (i.e., its chance of being caught) depends on the proportion of the population smaller than it in size and thus unlikely to succeed against it in competition $(1 - e^{-Zt})$, and on its size (t), which could affect its chance of encounter. It also assumes that the total mortality rate Z remains constant despite the changes in fishing mortality rate. This condition would be approached under very low fishing intensity, or, less probably, if there were compensating changes in the natural mortality rate. Where fishing removed an appreciable proportion of the fish the curve would be similar but the peak would move somewhat to the left and the right-hand limb would be steeper.

The purpose of this note is not to present any final theory or result but to point out that where fish are caught by means of baits the behaviour aspects must be considered and that it is unsafe to assume that the descending limb of the catch size distribution reflects accurately the structure of the population from which the fish are taken.

Reference

BURNET, 1952. Studies on the ecology of the N. Z. longfinned eel, *Anguilla dieffenbachii;* Gray. *Aust. J. Mar. F. W. Res.* 3, 32-63.

2.

The Selective Action of Nets Made of Manila, Hemp and Nylon

by

J. ANCELLIN AND P. DESBROSSES[1]

Abstract[2]

A brief review is given of the selection experiments carried out by France on European whiting, hake, sole, and langoustine. Highest escapement is shown for synthetic fibers, lowest escapement for manila, and intermediate escapement for hemp. The application of these findings to the program of the International Overfishing Convention (London, 1946) is discussed.

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[1]) Institut Scientifique et Technique des Pêches Maritimes, Paris, France.

[2]) The paper submitted at the Lisbon Meeting has later been published under the title: Ancellin, J.: Recherches sur la sélectivité des chaluts pour la pêche de la sole, du merlan et du merlu. Rev. d. Trav. de l'Inst. des Pêches Maritimes, 20, 3. Paris, 1956.

3.

Escape of Fish Through Different Parts of a Codend

by

R. J. H. BEVERTON [1]

Abstract

An experiment is described which shows that nearly all the fish which escape from a trawl codend fitted with a small - meshed cover do so from very near the end. This result was obtained for five kinds of fish, including both demersal and pelagic species. The bearing of this result on mesh measuring for selectivity tests is discussed.

Introduction

It is usual to find an appreciable variation in mesh size within a codend; often the size of mesh in a codend is largest near the end, where the weight of the "bag" of fish has stretched the meshes most. The "average" size of mesh in the codend, to be related to its observed selectivity, should therefore be weighted according to the frequency of escape from the various parts of the codend.

The impression gained from the underwater films of a seine net catching plaice is that most of these fish escape from the first few clear rows of meshes above the "bag". The experiments described here were designed to test this inference directly in the case of trawls.

Method

A trawl (*Lowestoft No. 1*) codend was fitted with a small-meshed nylon cover divided transversely into four equal compartments by vertical partitions made of the same material. Each compartment was provided with a laced-up aperture so that the fish caught in it could be extracted and kept separate. There was plenty of lateral slack in the cover after fitting, and trawl floats were attached along the centre line of the cover above each partition to keep the latter as nearly vertical as possible when the gear was being fished.

The cover was also considerably longer than the codend, and the first compartment (I) lay over the rear part of the top belly, where the mesh was about 84 mm (single sisal). The remaining three compartments (II, III, and IV) divided the top side of the codend (mesh about 70 mm double sisal) into three equal sections, each about 5 ft. (see Fig. 1).

Results

A total of 17 hauls was made, giving adequate catches of four different species in each compartment. These were whiting (*Gadus merlangus*), haddock (*Gadus aeglefinus*), dab (*Pleuronectes limanda*) and horse-mackerel (*Caranx trachurus*). In addition, a few mackerel (*Scomber scomber*) were caught. The codend catch was rather constant in bulk, and ranged between 1 and 3 baskets. It filled on the average about one-quarter of that part of the codend lying beneath compartment IV.

The following table gives the percentage of fish retained in each compartment, the actual number being shown in brackets. The results are also shown diagrammatically in Fig. 1.

Species	Cover Compartment I	II	III	IV	Total
Whiting	6.0 (484)	1.8 (144)	2.7 (222)	89.5 (7274)	100 (8124)
Haddock	6.9 (39)	1.8 (10)	1.4 (8)	90.0 (511)	100 (568)
Dab	1.2 (36)	1.1 (33)	2.0 (59)	95.7 (2822)	100 (2850)
Horse-mackerel	8.2 (136)	1.0 (16)	1 4 (24)	89.4 (1492)	100 (1668)
Mackerel	11.1 (4)	2.8 (1)	– –	86.1 (31)	100 (36)

[1]) Fisheries Laboratory, Lowestoft, England

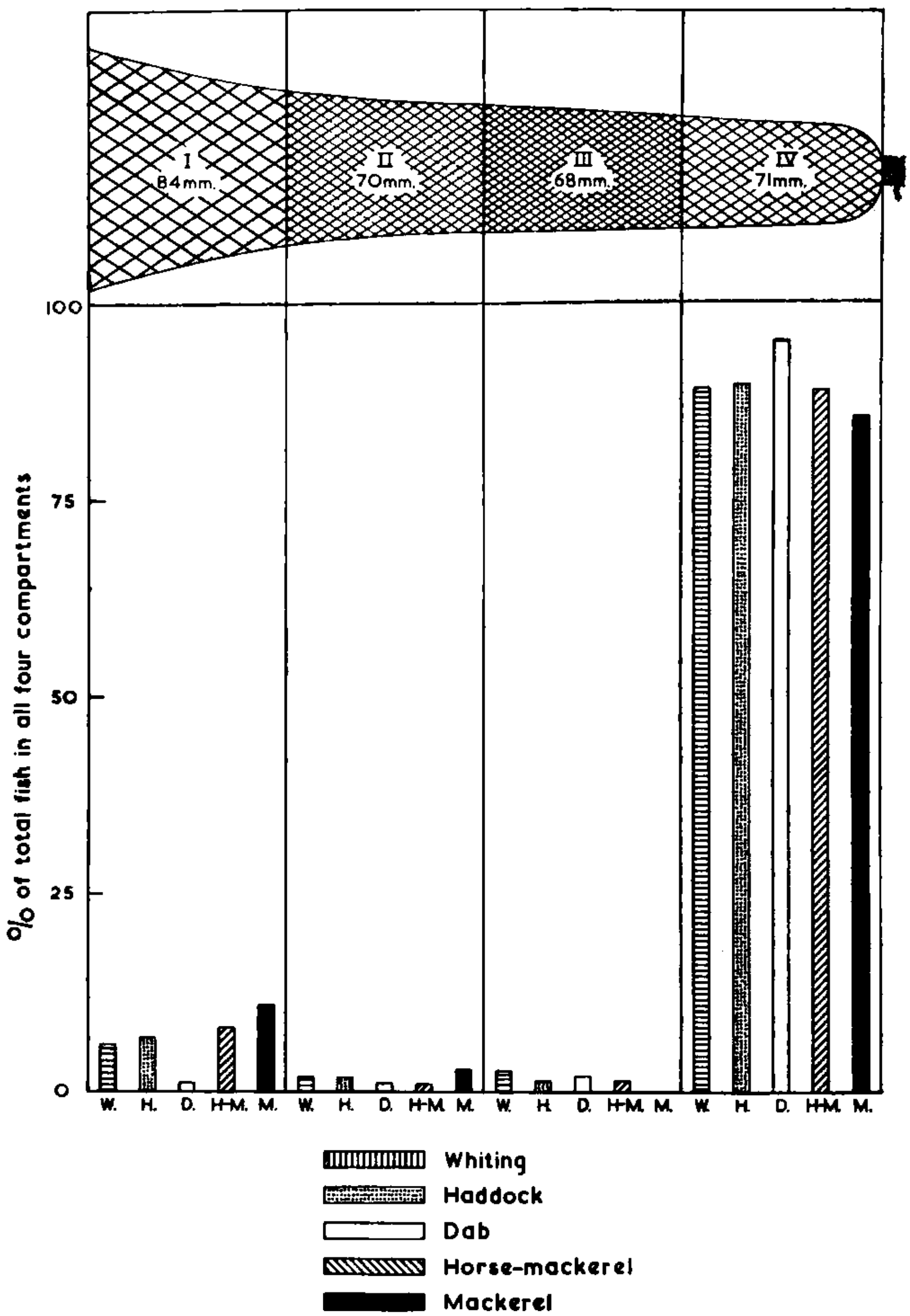

Fig. 1. Diagram showing relative numbers of 5 species of fish escaping through different parts of a codend.

The following conclusions can be drawn from these results: –

1. In all five species, roughly 95% of the fish escaping from the codend did so into the last of the cover compartments (IV).
2. About 2% escaped into each of the other two compartments covering the codend (III and II).
3. In all species except dab, a significantly greater percentage (6-10%) escaped into the first cover compartment (I) (over the rear top belly) than into compartments II and III (over the codend proper).
4. Much of the greater escape noted in (3) can be attributed to the larger area of net lying below compartment I and its greater mesh size. In the case of dab, this means that the true frequency of attempts at escape was probably less into compartment I than into compartments II and III.

Conclusions

Although each compartment covered about 5 ft. of codend, the fact that the percentages of escapes into compartments II and III were virtually identical and changed so abruptly in compartment IV suggests that nearly all the escapes must have been sharply restricted not merely to the lowest third of the codend but to the last few rows of "clear" meshes in front of the bag. This is perhaps what might have been expected with demersal fish such as dab, but it was rather surprising to find the same in pelagic and semi-pelagic species.

The possibility cannot, of course, be ruled out that despite all precautions the cover overlaid the codend and masked it to some degree, and that escapes from an uncovered codend would not be so rigidly confined to the extreme end. Be that as it may, as far as codend mesh measuring in covered net trials on the above species is concerned, the implication is that the "average" mesh size should be that computed from measurements of meshes from the cod - line (neglecting the first few bunched rows) up to a few rows in front of the limit of the bag. This is evidently the part of the codend through which most of the escapes will have occurred during the haul.

If there is large variation in bulk of codend catch from haul to haul it means that the effective region of escape also varies. If, in addition, there is an appreciable difference in size of mesh along the codend (I have recorded up to 10 mm), these two factors together may contribute significantly to the observed haul-to-haul variability of selection. The results presented here indicate that this component of variability can be minimised by relating the "average" mesh size to the limits of the bag in each haul.

4.

The Effect of Codend Mesh Size on Certain Working Characteristics of Trawls

by

R. J. H. BEVERTON AND A. R. MARGETTS[1]

Abstract

Simple flowmeters were placed in a codend towed with its mouth held open by a metal hoop. No appreciable differences were recorded between the flow at the mouth and that farther down the codend. There was more flow through a 71 mm single cotton codend than through a 74 mm double sisal codend.

Codends of different mesh size were towed at various speeds and their drags measured. The relationship of drag to speed was apparently approximately exponential. The drags at speed 3½ knots were 800 lb. for 53 mm double-braided sisal, 700 lb. for 69 mm double manila, and 150 lb. for 215 mm single sisal. The codend is estimated as contributing something less than 8% of the total drag of a trawl, and a change of codend mesh from 70 to 80 mm is estimated to affect total drag by less than 1%.

The speed of towing a trawl, fitted first with one and then with the other of two codends of extremely different mesh size, was measured by timing tows over a measured distance at constant engine revolutions. Codend mesh size apparently had no measurable effect on speed of towing.

Results of these experiments are believed to show that any increase in fishing power accompanying increase in mesh size is not due, at any rate largely, to the larger meshed net covering appreciably more ground per tow.

Introduction

A number of trawl mesh selection tests, notably those by Davis (1934), Graham, H. W. (1954), and Saetersdal (1955), in which codends or whole trawls of different mesh size have been fished alternately or in parallel, have indicated that the fishing power of the gear is increased by increasing the size of mesh. The evidence for this is that the catch by the larger mesh of fish beyond the selection range of either of the two meshes being compared more often than not exceeded that by the smaller mesh, but further analysis is limited by the high haul-to-haul variability which characterises trawl catches. Yet, in view of the introduction of mesh regulation in many fisheries in recent years, this effect of increased fishing power with increase in mesh size, if it is at all appreciable, is of more than academic interest.

The way in which mesh size affects fishing power is not at once clear, but it must presumably be connected in some way with the hydrodynamics of the gear, perhaps with increased flow of water through the larger mesh, and perhaps also with a reduced resistance to tow caused by the larger mesh permitting easier passage of water.

This report concerns some preliminary results which have been obtained from three kinds of tests aimed at measuring how certain of these physical properties, such as flow and drag, are influenced by the size of mesh in the codend. The tests, with codends of different material and mesh size, were: Measurement of water flow in the codend (by A. R. M.), measurement of the towing resistance of codends (by A. R. M.), and measurement of the effect of codend mesh size on the speed at which the gear is towed (by R. J. H. B.).

Measurement of Water Flow in the Codend

A codend was attached to a simple iron hoop 8′ 6″ in diameter towed by a single trawl warp, rather like a horizontal plankton tow-net, and the flow of water through the mouth of the codend and that down the centre of the codend near the

[1]) Fisheries Laboratory, Lowestoft, England.

tied up codline were measured simultaneously by two simple flowmeters; also the load on the warp was measured. All comparative trials were carried out under calm sea conditions and at standard towing engine revolutions giving M. V. *Platessa* a speed of about 4½ knots. By this means a 74 mm double-braided sisal codend and a 71 mm single seine net cotton codend were roughly compared. Results were somewhat variable and not very precise, but the following features emerged:

The flowmeter comparisons, after switching positions of the flowmeters and adjusting for flowmeter calibrations, showed that the rate of passage of water through the mouth of the cotton codend (flowmeter 5.3 revs. per sec.) was faster than that through the sisal codend (4.8 revs. per sec.). The measurements indicated that in each codend there was probably no substantial difference between the flow at the mouth and the flow farther down the codend; the errors in measurement were, however, quite large and the measured flow differences between positions quite small; *e.g.*, in the sisal codend the flow inside was 2% greater than at the mouth, while in the cotton codend that at the mouth of the codend was 3% - 6% greater than inside.

Measurement of the Towing Resistance of Codends

In the trials described above, while the flowmeter measurements were being made, the loadings on the towing warp at the ship were measured by two instruments, an hydraulic weighing machine and a dynamometer, both dial-reading. Even slight swell and ship's motion caused a marked surge in the loading, so a number of observations were made during each tow and the means calculated. After eliminating the load due to the warp and the frame, the towing load of the 74 mm double sisal codend at a speed estimated as 4½ knots was 926 lb, or 394 kg, according to the two different measuring instruments, and that of the 71 mm single cotton codend at the same speed was 779 lb , or 313 kg. Thus the measured difference was approximately 160 lb, the drag of the double sisal being some 20% greater than that of the single cotton.

When the single cotton codend was used fitted to the trawl, the load on one of the two towing warps was measured as approximately 1,150 kg (2,530 lb), compared with approximately 1,045 kg (2,300 lb) when a double sisal codend was fitted on the same trawl; this difference was probably due in part to tidal effects and perhaps also to inaccuracy of measurements.

A similar form of experiment involving the towing of codends on a hoop was subsequently conducted from the steam trawler *Sir Lancelot*. The codends being tested were attached to the metal hoop frame of a 2 m plankton ring net and towed on a single warp, the load on which was measured by an hydraulic weighing machine. Three codends were tested, each over a range of speeds, and the drag of just the towing warp and frame together was similarly measured. The speed range for each codend was limited by the top loading of the weighing machine or the surfacing of the frame and codend. The load and speed were measured after they had become settled at each of the various settings of engine revolutions. The three codends used were to the following specifications:

1 53 mm mesh, double - braided sisal twine 125 yd/lb, overall length 14′ 6″, meshes across 90/60/60;

2 69 mm mesh, double - braided manila twine 125 yd/lb, length 17′ 6″, meshes across 80/50/50;

3 215 mm mesh, single - braided sisal twine 112 yd/lb, length 15 ′ 6″, meshes across 28/22/22.

(The notation 90/60/60 indicates the number of meshes across one half of the codend; it starts at 90 meshes across, is bated every third row down to 60 meshes across, after which there is no reduction in width; the figures quoted are the effective meshes after take-up into the two laced-ridges) Each codend was closed by means of a codline knotted in the usual way.

The speed and load measurements are given in Table 1.

TABLE 1. Drag of codends at various speeds.

Towing	Engine Revs.	Speed Kn.	Observed Total Load lb	Net Load lb
Warp and frame alone	50	5	280	
	60	6	315	
	70	7	336	
	80	8–8¼	357	
	90	9	399	
53 mm double sisal codend	45	3–3½	840	610
	50	3½–3¾	1,218	978
	50	3½–4	1,183	939
	55	4–4¼	1,414	1,159
	60	4½–5⅝	1,680	1,413
	60	4½–4⅝	1,610	1,343
	65	5–5⅝	2,058	1,777
69 mm double manila codend	45	3–3½	854	624
	50	3½–3¾	1,022	782
	55	4	1,176	925
	60	4½	1,568	1,303
	65	5	1,820	1,541
215 mm single sisal codend	50	4–4¼	434	179
	55	4½–5	532	260
	60	5–5¼	6,602	319
	65	5½–6¼	714	410
	70	6¼–6¾	826	505
	75	6½–7¼	952	620
	80	7½	1,078	728

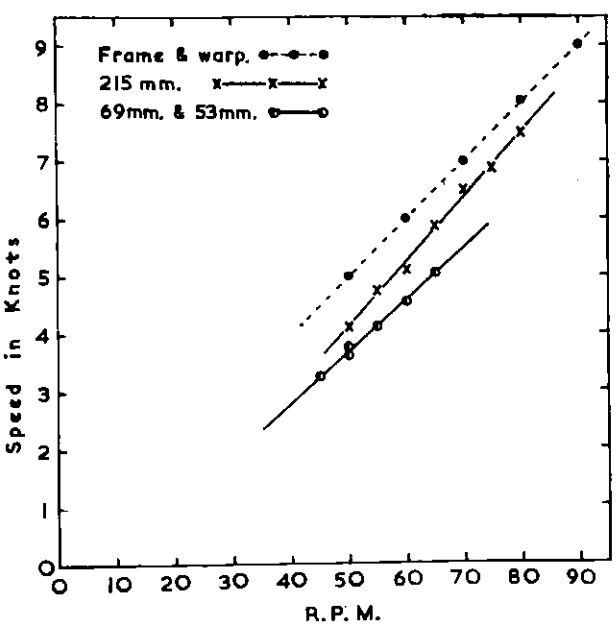

Fig. 1. Speed at engine revolutions of S.T. *Sir Lancelot* towing frame with and without a 215 mm single sisal, a 69 mm double manila, and a 53 mm double sisal codend.

The drag component of just the frame and warp at various speeds was plotted as a straight line through the points observed and extrapolated to cut the ordinate of speed (knots) at load 140 lb (indicating the weight of the apparatus). From this curve were derived the corrections to be applied to the measurements made with codends in order to show the drag components caused by the codends only.

The effect of codend drag on the speed of the ship is shown by plotting speed against engine revs. for each codend used (Fig. 1). At 60 revs. the effect of the drag of the 215 mm single - braided codend was to reduce the speed from about 6 to 5¼ knots, while the 69 mm double - braided and 53 mm double - braided codends (which had the same scale of effect) reduced the speed further to about 4½ knots. To maintain a speed of 5 knots the revs. would have to be increased from 50 when not towing a codend, to 56 when towing the 215 mm single - braided codend, and to 65 when towing the 53 mm or 69 mm double - braided codend.

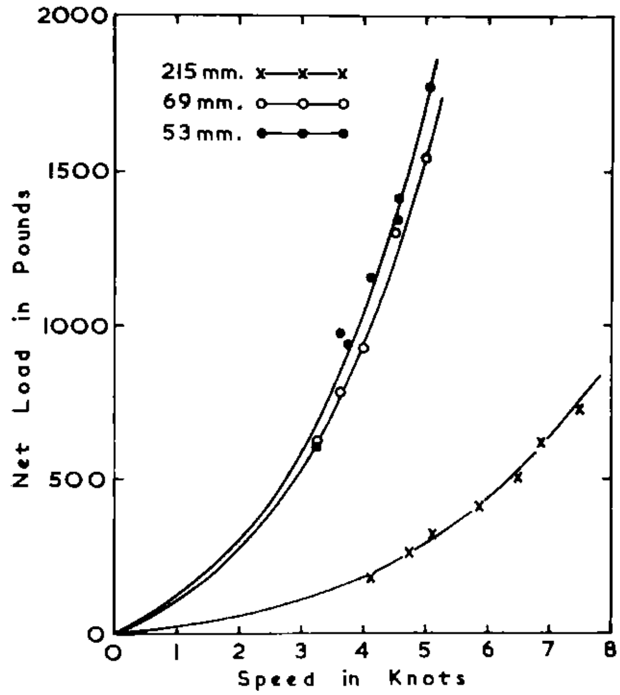

Fig. 2. Drag of 215 mm single sisal, 69 mm double manila, and 53 mm double sisal codends.

The curves of load plotted against speed for each of the three codends tested are shown in Fig. 2; these have been fitted by eye and drawn as smooth, thus not taking into consideration any possible change from laminar to turbulent flow. They show very great differences between the drag of the conventional type of codend and that of the huge - meshed single - braided net, but only relatively slight differences between the drag of the 53 mm and of the 69 mm conventional codends. At normal trawling speeds of 3-4 knots the 16 mm difference of mesh size between 53 mm and 69 mm caused a difference in drag of about 100 lb. This difference of 100 lb seems trivial in comparison with the total drag of a deep - sea trawl which may be from 3-7 tons.

It is interesting to note that, when moving from the lower speeds of demersal trawling to the higher speeds, such as are sometimes used for herring trawling on or off the sea-bed, the load caused by netting drag increases very greatly, *e.g.*, with a 69 mm double-braided codend the load increases from 530 lb at 3 knots to 1,550 lb at 5 knots. This illustrates both the need for adequate strength and good design in fast-towed trawls and also the advantages to be gained in fast trawling by keeping meshes large and netting fine.

Effect of Codend Mesh Size on Speed of Tow

If a change of mesh size in the codend of a trawl were to alter the drag of the gear sufficiently, the vessel towing at unchanged engine revolutions would tow the gear at a different speed; unless the difference was marked it is unlikely that it would be detected or compensated by altering the engine revolutions. Thus the average distance towed per haul would change correspondingly, and to this extent so also would the catch per unit fishing time. In addition, the fact that the gear was being towed at a different speed would be expected to alter its ability to catch the fish in its path, although this effect would depend partly on the behaviour of the fish in question and could not be predicted simply from a knowledge of the difference in speed of tow.

An experiment was therefore carried out to test the first of these possibilities, that is, whether a difference in the size of codend mesh would produce a detectable difference in the speed with which the gear is towed, all other conditions being equal. Two codends were used, with a difference in mesh size as contrasting as possible. The first was of 53 mm mesh double sisal, masked internally with shrimp netting of 25 mm mesh; the second was of 215 mm mesh single sisal. These were fitted alternately to a No. 1 Lowestoft trawl, which was towed by the M.V. *Platessa*, a 100 ft. (o.a.) motor trawler with an engine of 240 B.H.P. governed to 280 r.p.m. This trawl was a size smaller than that normally used by the *Platessa*, in order to magnify the difference in drag of the two codends. Pairs of timed runs were made with each codend in opposite directions along the main line of tidal flow. Each run covered about 2 miles, but in order to minimise the effect of tide, the distance travelled relative to the water was measured by the ship's log and used to compute the vessel's speed through the water. The depth of water was 14 fathoms throughout the tests.

Two sets of tests were made. In the first, six pairs of runs were made with each codend, the gear being towed on the bottom on 45 fathoms of warp. In the second, seven pairs of runs were made with the gear just off the bottom on 13 fathoms of warp, in order to eliminate the frictional resistance of the gear passing over the bottom. Each set of tests extended over about 40 hours. The direction of the wind was nearly constant throughout the tests, its strength varying between forces 3 and 6 (Beaufort).

The average speeds of tow (knots) relative to water for the two codends are summarised in Table 2, each entry being the average of a pair of runs, one in each direction.

TABLE 2. Towing speeds, in knots, of trawl fitted with large - and small - meshed codends.

Gear on bottom, 45 fm warp		Gear off bottom, 13 fm warp	
53 mm codend mesh	215 mm codend mesh	53 mm codend mesh	215 mm codend mesh
2.37	2.46	2.72	3.04
2.73	2.60	2.94	2.73
2.49	2.68	2.74	2.81
2.51	2.40	2.85	2.86
2.22	2.37	2.78	2.96
2.88	2.71	2.93	2.75
		2.90	2.85
Mean 2.53	Mean 2.54	Mean 2.84	Mean 2.86

From these data it would appear that the size of codend mesh has no measurable effect on the speed of tow, but that towing the gear off the bottom on shortened warps increased the speed of tow by about 13%. The variability of the above estimates of speed, more especially those with the gear on the bottom, is greater than can be accounted for by errors in the log distance, which were not greater than ± 5%, and it is probable that wind and tide effects have not been entirely eliminated by averaging speeds of a pair of runs in each direction. It would be worthwhile to repeat tests of this kind using a more accurate device for measuring speeds through water in the region of 2½ to 3 knots; but the conclusion from the above results is that the effect on speed of tow of the very large difference in mesh size of the two codends, if it existed at all, could hardly have been more than a few per cent. For the much smaller differences in mesh size that are likely to be involved in practice, the effect would seem to be negligible.

Conclusions

Comparing a 74 mm double sisal and a 71 mm single cotton codend, the drag of the former was 160 lb or 20% greater than that of the latter at 4½ knots. The water flow through the cotton codend was about 11% above that through the double sisal codend.

At trawling speeds of 3-4 knots the drag of a conventional 53 mm mesh codend was about 800 lb, of a conventional 69 mm mesh, 700 lb, and of a 215 mm single - braided codend, 150 lb. The drag of a widely opened 74 mm codend was measured as representing about 8% of the total drag of a rather small deep - sea trawl at 3 knots; because the codends tested were larger than those fitting the trawl and were held wide open, the true percentage would be considerably less than 8%. Assuming the figure to be 6%, then, from the curves in Figure 2, a change from a small - meshed double - braided codend to an extremely large-meshed single - braided codend might be expected to alter the total drag by about 4½%. Now a difference in drag of 4½% would cause less than a proportional change in ship's speed because of the drag of the ship itself and also because the engine of M.V. *Platessa* is governed. Thus the finding of no apparent trawling speed change accompanying a big change of codend mesh is confirmed by codend drag measurements. The relatively small change from 53 mm to 69 mm alters the drag of the whole trawl by a very trivial amount; a 10 mm change at the 70 mm level is estimated to affect the total drag of the trawl by less than 1%.

Throughout this study the assumption has been made that the drags of component parts of a trawl are simply additive. The very nature of a trawl net renders this not so, the integration of the effects of component parts of the trawl being complex. Differences in the shape or water flow of one part of a trawl affect the shape and flow in other parts to varying extents; for instance, altering the codend mesh affects the netting and its action in the belly of the trawl.

These investigations, though admittedly somewhat incomplete, do not indicate any obvious physical reason for the observed large changes in fishing power which sometimes apparently accompany changes in size of trawl codend and mesh. Differences in water flow through differently constructed codends have been recorded, but even drastic changes in the mesh size of codends did not produce the scale of effect on drag and speed of tow which might reasonably be expected to substantially alter the fishing power of the gear. Thus the reasons for any increase in fishing power with increase in mesh size still remain to be demonstrated.

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5.

Selectivity Data for Synthetic Fibres

by

A. v. BRANDT[1]

Abstract

To find data on the relations between net material and selection factor, tests with codends of manila, Perlon, and nylon were carried out for whiting, haddock, and cod in the Permanent Commission's 75 and 110 mm area. The results show that meshes 10-15% smaller in size are required for Perlon and nylon, in order to obtain the same selection as with equivalent manila 110 mm. It is proposed, through a study of different elongations, to find relations between twine properties and selectivity. This paper discusses the results of some experiments, but further tests are necessary with other net materials in order to prove a definite relationship between net material used and selectivity.

A number of investigations on the selection of trawled or dragged fishing gear have shown that the degree of selectivity depends on the material the fishing gear is made of. For example, it was found that codend meshes made of manila and sisal retained fishes which escaped through cotton meshes of the same size, measured by the same method.

It was proved that nets made of polyamide fibres (Perlon and nylon) also retained fewer fish as compared with meshes made of hard fibres (Ancellin 1956, v.Brandt 1956, Clark 1956 and 1956b, Desbrosses 1956, Margetts 1956). The difference amounts to 10-15%, *e.g.* meshes made of Perlon or nylon, which are 10 to 15% smaller, retain the same sizes of fish as the correspondingly wider meshes made of manila or sisal.

Testing of various materials should be made on the basis that only nets of equivalent strength can be expected to be comparable. Net materials are of equal value for fisheries use only if they are interchangeable. The interchangeability of the materials for trawls should not be based upon their textile characters, such as structure of material, diameter of twine, number of yarn, or runnage, but upon their tensile strength in wet condition. Exactly speaking, it should be based on the wet knot strength. On the other hand, no absolute conformity is required. With non-rotting synthetic net materials weaker twines may replace the initially stronger twines of natural fibres since the tensile strength of the latter would probably decrease because of rotting after a few fishing days. This would not be so with the synthetic fibres. The point of view that only interchangeable net twines can be expected to have comparable selection qualities is essential in so far as the properties of net twine, which might be decisive for the selection, change with their diameter. Figure 1 shows the load-elongation curves for twines of 210 den. nylon with different numbers of plies. The thicker the twine, the lower the extension at the same load. A thin twine will probably have quite a different selectivity from a thick one, even with the same type of fibre. Recently Cieglewicz and Stryzewski (1957) have demonstrated that a very coarse twine of cotton had a selection factor nearly as low as an equal sisal twine. From this it must be concluded that one cannot put forth a general assertion that a twine of a certain fibre material has a higher or lower selectivity without referring to its properties.

The pre-requisite for the experiments is not only equivalent material but also the use of a uniform method of measuring the meshes. All workers appear to agree that the proper method

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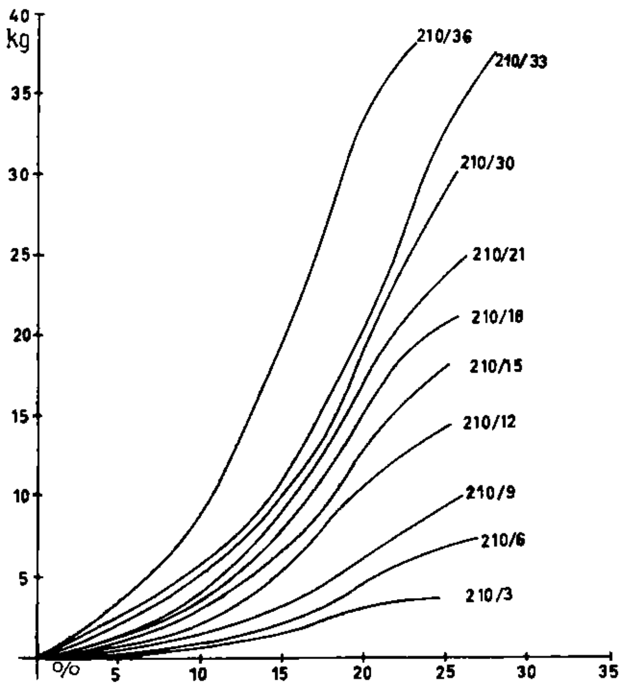

Fig. 1. Load - elongation curves for wet nylon twines, 210 den., of different numbers of plies. Ordinate - load in kg; abscisse - tension in %.

of carrying out mesh measurements is with a pressure gauge. The degree of pressure is suggested to be 3 to 5 kg (7 to 11 lb) and more (ICNAF 12 lb)[2]

There are two systems of pressure gauges: a gauge pushed vertically into the mesh, and a longitudinally operating gauge. The measuring gauge recommended for enforcement by ICNAF belongs to the first group; this gauge is also used by workers in many countries (*e.g.* Federal Republic of Germany, Denmark). The gauges proposed by Scottish and English, and quite recently also by Polish experts, belong to the longitudinal type.

The measurements of the mesh-sizes give varying results, always depending on the type of pressure gauge used. However, the differences are not such that the one type yields values which always exceed the other by a certain percentage since the difference depends also on the material. In other words; between the vertically operating gauge and the longitudinally operating one there will always be the same differences for a certain fibre material, but for another fibre material the differences may be totally divergent.

When measuring wet meshes of a double manila codend, the vertically operating pressure gauge may show meshes which are 7 to 10% longer on the average than those measured by the longitudinally operating gauge. The greater average size of meshes measured by the vertical gauge probably is due to the fact that the gauge may at first be pushed into the mesh with a force somewhat above 4 kg. The mesh consisting of hard fibre twine does not slide back when the pressure decreases to 4 kg, as happens with the longitudinal gauge.

In contrast to manila nets, the average difference in the result would be small when meshes made of continuous Perlon or nylon are measured by the two types of pressure gauge. The longitudinally operating gauge indicates here meshes which are longer by 2% on the average, than those measured by the vertical gauge. These values are so small that the differences are not essential for the sizes of mesh involved.

During selectivity experiments on board the *Albatross III* Cruise 74 (Clark 1956b) comparative measurements of nylon and Dacron nets with the two types of mesh gauges gave similar results: "No consistent difference between the two gauges was observed for nylon twines when the Scotch gauge was set for 10 to 12 pounds and the ICNAF gauge was used with 8 to 10 pounds pressure. The Scotch gauge did give rather smaller measurements for the Dacron cod end." Like Terylene, Dacron is a polyester fibre.

The differences between the two mentioned mesh-measuring methods are not so great as to have an important effect on the computed selection factor, as may be seen in the result set out below.

[2]) During the Annual Meeting of ICES 1961 the "Westhoff 1961 model" was recommended as a standard gauge for scientific purposes by the Comparative Fishing Committee. Furthermore it was recommended to use this gauge with a pressure of 4 kg. These recommendations were adopted by the Council.

For all that, if the mesh measurements are made by different methods, the selection factor must tend to change. A greater measuring pressure results in a larger mesh for the same 50% retention length of the fish, and the selection factor is smaller. On the other hand, when a light pressure is used, the resulting selection factor must be greater. These facts explain the differences of the selection factors computed below, which are smaller than those stated by the *ad hoc* Committee of the Permanent Commission or the Liaison Committee of ICES. With higher catches the length of the tow may be rather short. Shorter tows probably diminish the 50% retention length of the fish and thus the selection factor by not allowing the fish time to complete their escape.

For the purpose of comparing the various selectivities of equivalent net twines we made several experiments with codends of manila, Perlon and nylon. Manila was used in the remainder of the net. In order to catch the fishes escaping from the meshes, the covered codend method was used. Preliminary results were submitted as "Paper 71" to the meeting of the Comparative Fishing Committee of ICES. in the fall of 1956. The data for codends which had a mesh size of about 75 and 110 mm are given below. It appears from the publications by different experts that the selection factory may increase with the size of mesh for certain species. Therefore, only experiments made with meshes of nearly equal sizes can be directly compared.

A. Experiments with meshes of about 75 mm.

The following codends with meshes of about 75 mm in size were available for experiments in the North Sea.

No. of the net	Material, double knitted	Strength wet (kg)	Size of mesh (mm) vert. gauge	long. gauge
1	manila 3/500	140	74	74
4	Perlon	109	73	73

The data resulting from the vertically operating pressure gauge as well as those obtained from the horizontally operating gauge are given for each size of mesh.

The selection values obtained with these codends in the North Sea are given in Table 1. The selection factors coincide, whether or not the sizes of mesh are determined by the vertical gauge or by the longitudinally operating gauge. The selection factor is smaller for manila than for Perlon I. If one converts the sizes of mesh with equal selection factors to 75 mm manila, the following results are obtained:

Whiting, 20 cm in length	manila	75 mm
	Perlon	56 mm
Haddock, 20 cm in length	manila	75 mm
	Perlon	67 mm

TABLE 1. Selection values obtained for codends of about 75 mm mesh.

Whiting:

Codend Number	Mean Mesh-size (mm)	Number of hauls	Number of fish c.e.	cover	50% ret. length (cm)	Selection factor vert. gauge	long. gauge
1-manila	74	7	2,911	263	20	2.7	2 7
4-Perlon	73	2	1,940	1,566	26	3.6	3.6

Haddock:

Codend Number	Mean Mesh-size (mm)	Number of hauls	Number of fish c.e.	cover	50% ret. length (cm)	Selection factor vert. gauge	long. gauge
1-manila	74	7	1,827	3,633	19	2.6	2.6
4-Perlon	73	2	1,707	8,727	22	3.0	3.0

The selective effect of the codend thus varies greatly with the materials. As for whiting a codend of Perlon with about 25% smaller meshes had the same selective effect as a manila codend. For haddock the difference is about 10%.

B. Experiments with meshes of about 110 mm.

For experiments with a mesh size of about 110 mm. the following cod ends are available:

No. of net	Material, double knitted	Strength wet (kg)	Size of mesh (mm) vert. gauge	long. gauge
2a	manila 3/500	140	108	111
2b	manila 3/500	140	113	111
5a	Perlon braided	109	107	108
5b	Perlon braided	109	107	106
10	Nylon braided	112	104	106

Nets 2a and 5a were used during a cruise in the North Sea and nets 2b, 5b and 10 during a voyage to Spitsbergen. Selection factors obtained are given in Table 2.

If the values obtained for the selection factors are compared, it will be seen that the mesh measurements made with the vertical and logitudinal pressure gauge differ only by 0.1 mm at the maximum.

This experiment also confirms the previous statement that manila retains more fish than Perlon, whereas nylon retains the smallest quantity. The differences are more striking with cod than with haddock.

Referred to manila meshes 110 mm the following retain up to 50%:

Haddock	33 cm	in length	manila	110 mm	North Sea
	33 cm	,,	Perlon	100 mm	,,
	32 cm	,,	manila	110 mm	Spitsbergen
	32 cm	,,	Perlon	103 mm	,,
	32 cm	,,	nylon	94 mm	,,
Cod	37 cm	,,	manila	110 mm	,,
	37 cm	,,	Perlon	100 mm	,,
	37 cm	,,	nylon	95 mm	,,

This comparison shows also that 10-15% smaller meshes are required for Perlon and nylon, in order to attain the same selection as with manila of 110 mm.

TABLE 2. Selection factors for codends of about 110 mm. mesh.

Haddock: Codend Number	Mean Mesh-size (mm)	Number of hauls	Number of fish c.e.	cover	50% ret. length (cm)	Selection factor vert. gauge	long gauge
(a) North Sea							
2a-manila	108	3	1,587	3,111	32	3:0	2.9
5a-Perlon	107	14	2,061	12,977	35	3.3	3.2
(b) Spitsbergen							
2b-manila	113	22	3,610	727	33	2.9	3.0
5b-Perlon	107	5	359	175	33	3.1	3.1
10-nylon	104	11	710	1,145	35	3.4	3.3

Cod: Codend Number	Mean Mesh-size (mm)	Number of hauls	Number of fish c.e.	cover	50% ret. length (cm)	Selection factor vert. gauge	long. gauge
2b-manila	113	17	4,373	738	38	3.4	3.4
5b-Perlon	107	5	2,208	1,274	40	3.7	3.8
10-nylon	104	13	734	2,031	41	3.9	3.8

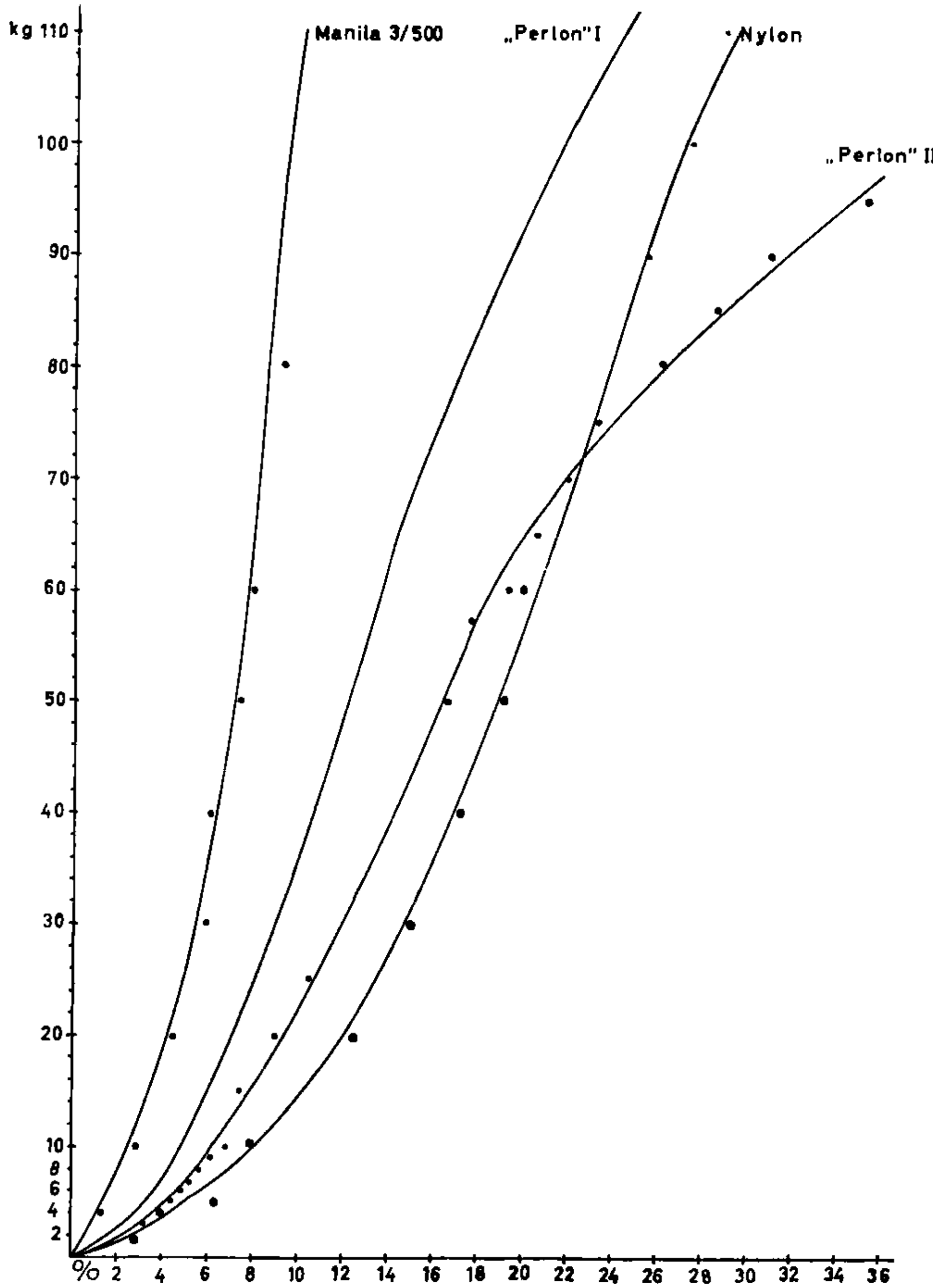

Fig. 2. Load - elongation curves for manila 3 /500, Perlon and nylon of equal value. Ordinate - load in kg; abscisse - tension in %.

It is interesting to speculate on causes for the difference in selection between the materials. The most striking factor distinguishing the materials used for the manufacturing of the experimental codends is their tension.

Figure 2 shows a so-called load-elongation curve for the materials used for the experimental codends. This gives the tension in percentage, occurring with the single net twines, twisted or braided, under varying loads. It can be seen from these figures that manila net twine, like all hard fibre materials, has only a small tension. Perlon, however, can be stretched substantially easier. The used nylon twine is even more stretchable, at least with medium loads. However, these load-elongation curves are not to be interpreted in such a way that they refer to all net twines of a material, but only for the concerned type of manufacture. Generally speaking, the tension decreases with the thickness at the same load, thus also changing the load-elongation curve (see Figure 1 showing such a change in nylon net twines of varying diameter).

The size of the selection factor appears to increase with the tension. The mentioned experiments indicate that the selection factors for whiting, haddock and cod increase in each case when codends made of the material mentioned above are compared at an increasing tension. These tests, however, are likely to be not fully sufficient. It appears that two factors restrict the importance of tension for selection:

(1) Like cotton codends, hemp codends are regarded as "light trawls." Hemp net twines, however, have a small tension, in which they resemble manila twines. From a survey on the selection of nets made of various materials, submitted by Beverton to the *ad hoc* Committee in London, 1955, it appears that the presumed equality of hemp and cotton was based on a conclusion resulting from the investigations of Boerema (made in 1954). Boerema, however, did not include cotton in his experiments, but only hemp and manila. Hemp differs here essentially from manila, but the comparisons were made between manila with a runnage of 250 m/kg and hemp with a runnage of 510 m/kg. The wet strength of that hemp might be only half the strength of manila used for the comparison and therefore, the materials are not quite comparable.

That hemp does not belong to the same selection group of the "light trawls" as cotton, appears clearly from the experiments made by Desbrosses and Ancillin on board the research ship "*Président Théodore Tissier*." Their selection factors for plaice, whiting and hake show little if any difference between nets made of manila and hemp, but a great difference as compared with those made of nylon. Therefore, it might be suggested that hemp used as **equivalent material** is not a "light trawl" material. This fact then does not speak against tension as the most important selectivity factor. The previously mentioned research results of Cieglewicz and Strzyzewski, however, do not support this. According to their results fine cotton twine is most selective, hemp slightly more selective, but nearer to fine cotton, and coarse cotton twine, sisal and manila least selective.

(2) Another fact to be considered is the following: Experiments were made with codends made of wire mesh (Clark, J. R., 1956b). This wire mesh has practically no tension, and escapement of haddock was substantially, although considerably lower than for a manila codend of equivalent mesh size. However, the experiment with the rigid wire mesh only comprised a limited number of fish, and should be repeated.

Therefore, more investigation would be necessary to find the reasons for the varying selections resulting from different materials used. Besides tension, elasticity, softness, thickness and roughness of net twines might be factors influencing the selection. But tension certainly appears most important.

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6.

Size Selection of Fish by Otter Trawls
Results of Recent Experiments in the Northwest Atlantic

by

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Contents

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A. INTRODUCTION TO SELECTION EXPERIMENTS

Introduction

Studies of optimum yields for Northwest Atlantic groundfish species have been greatly intensified by the United States since the establishment of the International Commission for the Northwest Atlantic Fisheries. Controlling the fishing mortality of the early ages of fish has come to be an accepted method of providing optimum yields for species taken by otter trawl. This control is accomplished by adjusting the size of mesh in the nets to permit escapement of fish below a chosen size.

An extensive series of experiments with various species of fish and types of nets was carried out during the years 1952 to 1956 by the Woods Hole Laboratory of the U. S. Fish and Wildlife Service to provide adequate bases for the regulation of mesh sizes (Table 1). The results of these experiments are presented in the following series of papers. It is the purpose of this report to describe methods and equipment used and to present other general background material.

TABLE 1. Summary of Mesh Selection Experiments, 1952-1956

Cruise	No.	Date	Primary Purpose	Other Purposes
Michigan	1	June 4-12 1952	Selection of haddock by manila codends	Validity of covered codend method
Michigan	2	June 15-22 1952	do.	do.
Wisconsin		Oct. 15-19 1952	do.	do.
Albatross III	49	May 15-20 1953	do.	Escapement through under side of codend. Effect of tow duration Escapement through top belly
Albatross III	51	June 8-17 1953	Validity of covered codend method for haddock	Selection of manila codends Escapement through various parts of codend. Escapement through top belly
Albatross III	52	July 20-29 1953	do.	Selection of manila codends Escapement through top belly
Priscilla V	1-5	Sept. 13-Nov. 2 1954	Selection of silver hake by manila, cotton, and nylon codends	Escapement through forward parts of net Validity of covered codend method
Priscilla V	6	Nov. 16-23 1954	Selection of redfish by manila codends	
Albatross III	59	Apr. 6-12 1955	Selection of haddock by manila codends	
Albatross III	64	Aug. 23-Sept. 2 1955	Selection of redfish by manila codends	Validity of covered codend method Meshing of redfish
Pairtows[1]	1	Oct. 12-28 1955	Selection of haddock by nylon and cotton codends	Fishing efficiency of large mesh nets Validity of paired tow method
Albatross III	74	May 2-10 1956	Selection of haddock by nylon and dacron codends	
Pairtows[1]	2	July 23-Aug. 4 1956	Escapement of haddock through forward parts of the trawl	Wire mesh codend escapement

[1]) Joint cruise of the *Albatross III* and *Delaware*

Fig. 1. Measuring haddock with aluminum "punch-strip."

Measurement of Fish

We used the total distance from tip of snout to median ray of caudal fin (fork length) in measuring all species. The resulting measurements were recorded to the "centimeter below"; *e.g.*, all fish from 29.0 to 29.9 are assigned to the 29 cm interval. Lengths which have been converted to the true mid-point of the cm interval (*i.e.*, 0.5 cm added) are marked with an asterisk (*) throughout the series.

The great quantities of fish bandled in these experiments required the use of a rapid measuring method. For this reason we used the "punch-strip" system; *i.e.*, the recording of each fish length by a mark on a thin aluminum strip (see Figure 1). The frequency distribution of 400 or more fish in a well distributed length group can be recorded on a single strip. The lengths are subsequently tabulated from the strips through use of a transparent overlay, graduated in one centimeter intervals.

Sampling Procedures

Since the experiments were generally carried out in a manner to approximate comercial fishing practice the catches were sometimes very large, and in such cases we were able to measure only a portion of the fish taken. Sampling by aliquot was avoided where possible, but was necessarily resorted to in the silver hake work. Where sampling was required, the catch was randomly distributed into lots of equal size through use of baskets varying from one to three bushel capacity. The number of lots depended on the size of the catch and work requirements, the latter usually permitting the measurement of at least 400 fish. One lot (an aliquot) was measured, the remainder discarded, and the length distribution for the catch increased by a factor representing the total number of lots.

For the purpose of determining the amount of error introduced by sampling, two catches of silver hake were divided into lots and the fish in each lot measured. The mean lengths and total numbers of fish for each of the two series of seven lots are given in Table 2. Also included for each series are the deviations of lot mean from series mean, from which it is possible to adjudge the validity of the sampling procedure.

TABLE 2. Results of Sampling Validity Study for Silver Hake.

Lot Number	1	2	3	4	5	6	7	Total
Series I:								
No. of Fish	126	117	105	111	117	105	129	810
Mean Length cm	31.0	31.2	32.0	31.2	31.8	31.8	30.6	31.3
Deviation of Lot mean from Series Mean	—0.3	—0.1	+0.7	—0.1	+0.5	+0.5	—0.7	
Series II:								
No. of Fish	115	108	108	108	98	113	97	747
Mean Length cm	33.3	32.7	31.7	32.5	32.5	32.5	33.2	32.6
Deviation of Lot mean from Series Mean	+0.7	+0.1	—0.9	—0.1	—0.1	—0.1	+0.6	

The average deviation of lot mean from series mean was 0.4 cm in both cases, with a maximum deviation of 0.9 cm (Series II, Lot 3) from which we concluded that the mean for the whole catch could be estimated within 1.0 cm by a single bushel sample. Nevertheless, we made it our practice to measure three or more bushels since every trawl tow constitutes an individual experiment in covered codend work. It was necessary to obtain reliability of data sufficient to guarantee valid results for individual tows, so that the differences between them could be reliably interpreted.

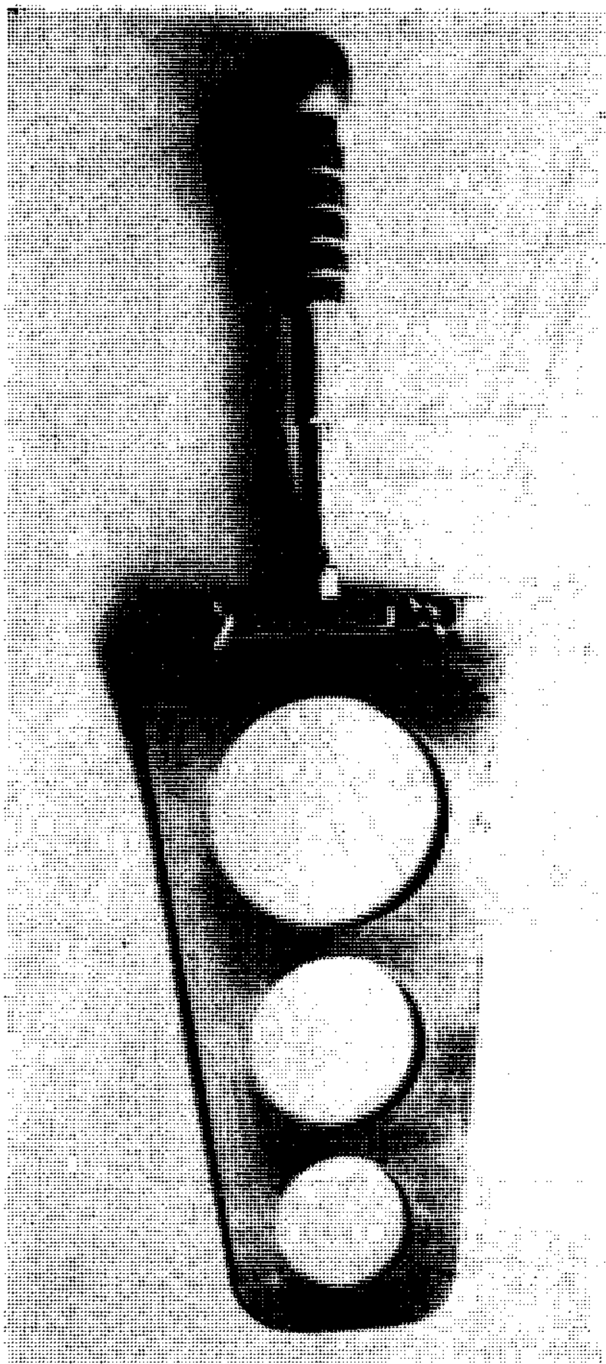


Fig. 2. Pressure-indicating mesh gauge of the type recommended by ICNAF.

Mesh Measurement

All meshes were measured with the gauge developed by the author and later recommended by ICNAF as the approved type for enforcement of regulations. This gauge, illustrated in Figure 2, is 2 mm thick and has a taper of 1 to 4. It was designed to provide for a minimum of variation in measuring through the use of a pressure indicating device. The model shown indicates the inner mesh length in eighths of an inch under any desired pressure up to 15 lb. We used the 12-15 lb. pressure recommended by ICNAF in our work. Mesh measurements were always taken soon after the net was hauled in order to most nearly approximate actual "working-size."

For codends, we measured one continuous series of meshes from one end of the codend to the other. In cases where the codends were over 75 meshes in length we measured alternate meshes of the series. We have converted our mesh measurements originally taken in inches, to millimeters for convenience of analysis and comparability with results of other workers.

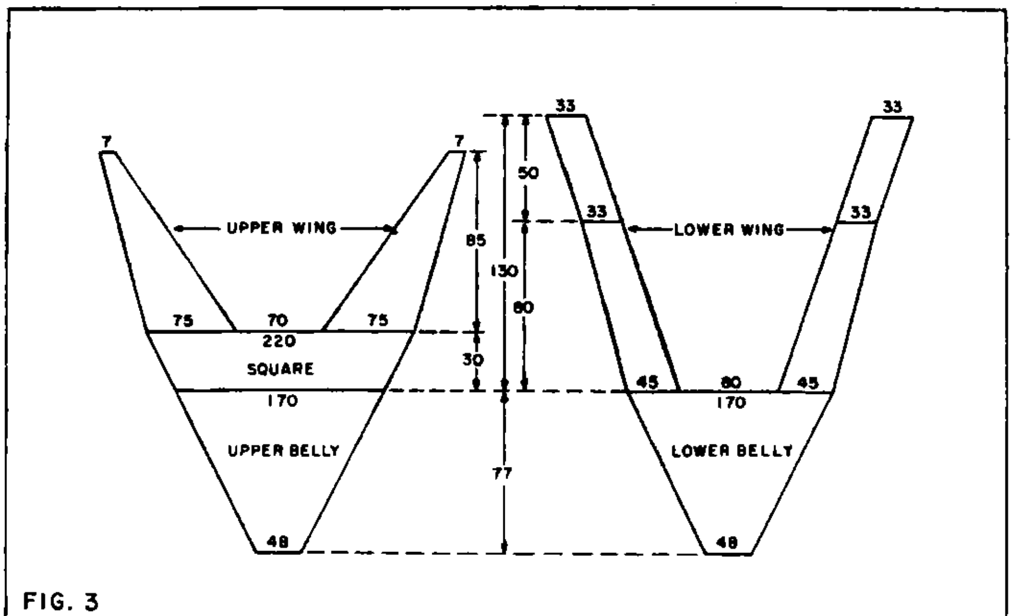
Description of Vessels Employed

Our experiments were conducted at various times aboard the five vessels listed below:

Vessel	Type	Length (ft.)	Horse-power	Gross Tonnage
Albatross III	Research Vessel	179	805	340
Delaware	Research Vessel	139	735	303
Priscilla V	Commercial Dragger	57	165	42
Michigan	Commercial Trawler	105	550	203
Wisconsin	Commercial Trawler	110	900	226

Description of Otter Trawls

The *Michigan, Wisconsin, Albatross III,*" and *Delaware* used the standard "Number 41 Yankee" manila trawl of 5 inch mesh (knot-center size). *Priscilla V* used a "Number 35" cotton trawl of 2½ inch mesh (knot-center size) modified for silver hake fishing through use of an oversize lower belly. These trawls are shown in Figures 3 and 4.



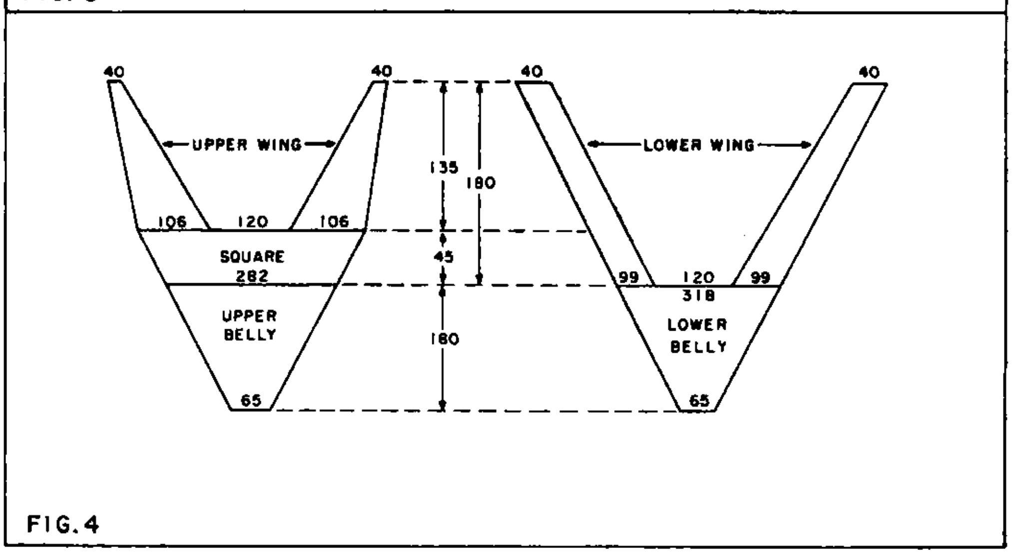


Fig. 3. Standard "Number 41 Yankee" trawl (manila). Dimensions in numbers of meshes of 5 inches (127 mm) between knot centers.

Fig. 4. Modified "Number 35" whiting trawl (cotton). Dimensions in numbers of meshes of 2½ inches (63 mm) between knot centers.

Description of Covers

The covers used on the codends varied somewhat in dimensions, material, and mesh size, but usually were of 38 mm ($1\frac{1}{2}$ inch) cotton mesh, rigged to allow about 20% slack transversely (relative to the codend) to allow the netting to stand well away from codend meshes. The lower side of the codend was covered by chafing gear of some sort, usually hides, for most of its length. The bag or "cod-end" of the cover was 8 to 12 feet long, and joined at its upper side to the cover and at its lower side to the upper side of the codend, a few meshes ahead of the lachets. This method of attachment provided for maximum ease of handling, in that the codend could be emptied independently of the cover bag. The typical codend cover rig is illustrated in Figure 5.

In some instances the top bellies were also covered wholly (Figure 5A) or partially (Figure 5B). The material and general methods of attachment were the same as for the codend covers.

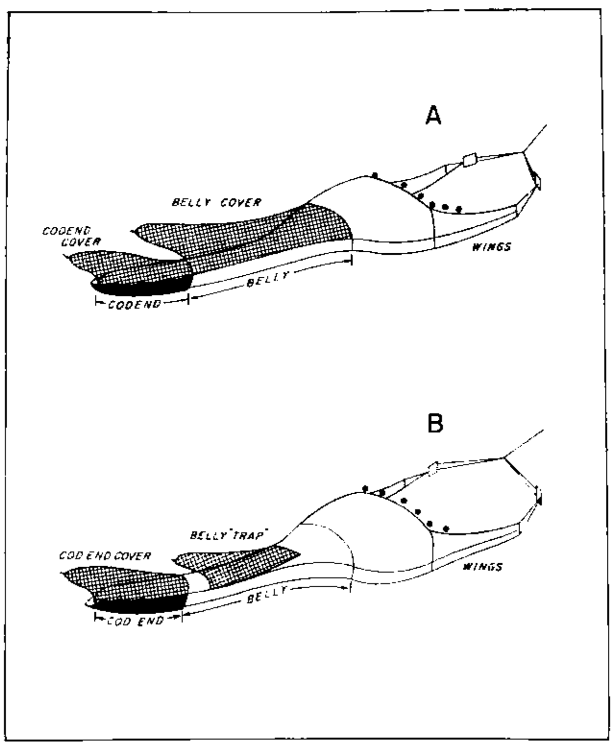


Fig. 5. Diagrammatic representation of codend cover, belly cover (A) and belly "strap" (B).

Area of Operation

The haddock work was all carried out in the Georges Bank area (Division 5Z) with the exception of *Albatross III* Cruise 59 which was carried out in the Browns Bank area (4X) and some incidental data collected in Massachusetts Bay (5Y) during the *Priscilla V* silver hake cruises.

The redfish work was carried out in various parts of the central Gulf of Maine by the *Priscilla V* and in "the Gully" near Sable Island (4W), in the vicinity of Browns and LaHave Banks (4X), and in the vicinity of Cashes Ledge (5Y).

The silver hake work was carried out in Massachusetts Bay and vicinity with the exception of some incidental results obtained from *Albatross III* cruises to Georges Bank.

Definition of Terms

A somewhat specialized vocabulary has been built up around the subject of gear selection. In the following list we have attempted to provide definitions for the terms of long standing as well as those to be introduced for the first time in this series.

Alternate tows. A variation of *Replicate tows.*

Bar. The component of a mesh which includes one knot and the twine extending to, but not including, the next knot; four bars make up a complete mesh. Thus the expression "bar measurement" (or "on the square") which is half the knot-center measurement.

Chafing gear. Any material, such as netting, hides, canvas, etc., attached to the trawl to prevent abrasion of the netting; usually used in reference to the codend.

Codend. The terminal portion of an otter trawl in which the catch is retained and lifted aboard, consisting of a long tube of netting of comparatively small cross section, attached to the after end of the belly, which may be opened at its terminus for removal of the catch.

Covered net method. The method of determining the escapement of fish from otter trawls by capturing tbe escapees in a second layer of netting of smaller mesh applied over the primary netting of the trawl. The covering netting is fitted loosely to allow the fish to escape unhampered from the primary netting and usually terminates in a collecting pocket similar to a codend. This method is most often used on the codend, although covers have been used on certain forward parts of the netting also.

Double codend. (*See* Multiple codend.)

Double twine. A method of fabricating netting in which the meshes are made from two individual pieces of twine knotted together (*cf.* single twine).

Escape factor. The factor relating tbe length of fish escaping to the size of mesh from which they escape:

$$\text{E.F.} = \frac{\textit{Length in mm}}{\text{Internal mesh size in mm}}$$

Escapement curve. A variation of *Selection curve.*

Fifty percent point (also *fifty percent escapement* or *retention length*).
The length of fish at which 50% are retained by a particular fishing gear and 50% escape. Otber points are similarly used but must specify "escapement" or "retention"; *ergo* 25% *escapement* length or 70% *retention* length.

Girth factor. The factor expressing the relation of length to maximum girth:

$$\text{G.F.} = \frac{\text{length}}{\text{maximum girth}}$$

Internal mesh size. The distance between, not including, opposite knots of a fully elongated mesh.

Knot-Center size. (*See* Knot-to-Knot size.)

Knot-to-Knot size. The distance between any two equivalent points of the knots at opposite ends of a fully elongated mesh. Often expressed as "knot-center" size, although the measurement may be taken between any other equivalent points of the two knots.

Longitudinal mesh measurement. Measurement of internal mesh size through use of an instrument which elongates the mesh by applying force to each end of the mesh (knot) parallel to the face of the mesh (*cf.* vertical mesh measurement).

Masking effect. The obstruction, or partial obstruction, of the meshes of a trawl by a cover used for determining escapement, such that fish are to some degree prevented from escaping. Generally, any effect of a cover in reducing escapement.

Mesh gauge. Any device used to measure the dimensions (usually internal) of a mesh. Present styles are classified as longitudinal mesh measurement gauges or vertical mesh measurement gauges.

Mesh index. The index expressing the relation between mesh shape and fish cross-sectional shape: $1.0 > \text{M.I.} = A/B$ or B/A, where $A =$ fisb breadth/fish depth, and $B =$ mesh length/mesh width.

Meshing. The ensnaring of fish by meshes resulting from their becoming ensnarled by and lodged within the meshes.

Multiple codend (also *e.g.*, double codend). A codend constructed of multiple layers of netting, usually of two layers (double codend), although instances of three layered (triple) codends have been reported.

Paired tows. A variation of *Replicate tows.*

Ply. (*See* Strand.)

Potential escape index. The index determined from girth factor and mesh index which expresses maximum possible escapement for a species from meshes of given shape:
$\text{P.E.I.} = \text{G.F.} \times \text{M.I.}$

Replicate tows. Tows of trawls in series of two each, the design being such that the two members of each pair approximate each other in space and time as nearly as possible, in order to equalize all factors except a particular difference in the construction or operation of two nets with the object of isolating and measuring the difference. Two variations are: *Paired tows*, in which the two gears are towed at the same time, often by two different boats; and *Alternate tows*, in which one boat fishes first with one gear variant and then with the other.

Retention curve. A variation of *Selection curve.*

Runnage. The specification of twine determined by its length per unit weight; *e.g.* 50 yd/lb or 450 ft/lb. It may be expressed by length for a known standard weight; *e.g.* "50-yard twine." The numeral alone may be used preceding the virgule (/) in abbreviated forms expressing runnage and number of strands; *e.g.* 50/4 twine.

Selection. In reference to fishing gear, the mechanism by which fishes with certain characteristics are captured and others escape; usually in reference to the selection of certain sizes of particular species.

Selection curve. A curve, often sigmoid, fitted to points representing the percentage of fish either retained by the gear or escaping from it at each size interval; more specifically, *Retention curve* if retained percentages are used, *Escapement curve* if escape percentages are used.

Selection factor. An index, related to *Escapement factor*, expressing the relation between the 50 percent point and the size of the mesh involved:

$$\text{S.F.} = \frac{\text{50 percent point}}{\text{internal mesh size}}$$

Usually used for codends of trawls; mesh size most often average for whole codend.

Selection range. The range in fish lengths over which a fishing gear exercises selection.

Selection span. A term expressing the range between 25 and 75 percent retention lengths, analogous to the interquartile range of a normal curve.

Selectivity. The selection properties of fishing gear; usually referring to the sizes of fish selected by the gear from the available population.

Single twine. A method of fabricating netting in which the meshes are made from a single piece of twine (*cf.* double twine).

Strand. (also *Ply, Thread, Twist.*) The smallest continuous component of which a twine is made, composed of comparatively short fibers if of natural material. Two or more strands are usually twisted (or braided) together to make a twine – thus *3-strand twine.* In abbreviations of twine characteristics the number following the virgule (/) indicates the number of strands.

Thread. (*See* Strand.)

Twine. Cordage used in fabricating netting, which is made by braiding or twisting together several strands.

Twist. (*See* Strand.)

Vertical mesh measurement. Measurement of internal mesh size by inserting into it a measuring instrument, usually in the form of a flat, tapered blade, graduated in appropriate size intervals. The vertical force applied elongates the mesh and is often controlled through use of a spring and the instrument therefore termed "pressure gauge."

B. ESCAPEMENT OF FISH THROUGH VARIOUS PARTS OF THE TRAWL

Abstract

Haddock are shown to escape primarily through the upper part of the after portion of the codend of otter trawls. Of the small numbers that escape through forward parts of the trawl, an estimated 10% do so through the top belly, 30% through the lower belly, 60% through the lower wings, and none through the square and top wings.

Silver hake escape through forward meshes to a greater extent than haddock. Silver hake also differ in that they are shown to escape through the lower side of the codend to a greater extent than haddock.

Introduction

The codend is usually considered to be the important escape area of the trawl and most available selection data concern codend escapement. Just what part of the codend is most used by the fish in escaping through meshes has not been known. An increasing collection of experimental data shows that fish of many species also escape through forward parts of the net. Material is presented in this paper which bears upon the problem of escapement of silver hake and haddock through various parts of the trawl.

Escapement Through the Codend

Various methods are available for the purpose of determining the effective escape area of the codend. A codend cover may be used over individual parts of the codend and catches compared with those with a cover over the whole codend. In another method the codend may be covered with a series of individual "pockets" covering sections of the codend, each retaining the portion of fish escaping through the section covered. Another approach to the problem is to use different mesh sizes in various parts of the codend and rearrange these to determine the effect upon escapement.

Michigan 2: The meshes in the after ends of codends beyond the splitting strap tend to enlarge with use. This causes a disparity in size between the meshes at each end of the codend.

We have noticed that if such a codend is reversed, putting the smaller meshes at the after end, the escapement of fish decreases. We are therefore led to believe that fish are escaping in greatest numbers through the after meshes.

When a double manila codend of 105 mm mesh was reversed during the *Michigan 2* experiments the selection factor for haddock first dropped from 3.1 to 2.8 and then returned to the original value as the after meshes (previously forward) increased in size. The results are briefly summarized below:

	Before Reversal, Average of 14 tows	After Reversal			
		Tow 1	Tow 2	Tow 3	Tow 4
Average mesh size for whole codend (mm)	105	106	110	111	113
Mesh size for the last one-quarter of codend only (mm)	111	98	105	106	114
50% point (cm)	32.3*	29.2*	32.7*	34.1*	35.2*
Selection factor	3.1	2.8	3.0	3.1	3.1

The difference of 3 cm in 50% point between the first series of tows and the first two with reversed codend is certainly due to the smaller meshes being positioned at the after end of the codend.

Albatross Cruise No. 74: When a single braided nylon codend of 122 mm mesh size was reversed during Cruise No. 74 of the *Albatross III*, the selection factor for haddock increased from 3.1 to 3.5 (p. 74). This codend had been used previously, and the meshes had enlarged at the after end. We did not fully realize the importance of the difference in mesh size between the two ends of the codend (119 and 113 mm) while rigging the gear, and the larger mesh end was attached to the belly.

With the codend in this abnormal position, the low selection factor was obtained (3.1), and the reversing was done to put the large meshes at the after end, which is more in line with normal commercial practice. Catches were small and mesh size did not change significantly during the experiments.

We were again led to the conclusion that haddock tend to escape through tbe after end of the codend.

Pairtows II: In the course of what we refer to as the Pairtows II experiments (the 2nd joint cruise of the *Albatross III* and the *Delaware*), we made a series of tows from the *Albatross III* in which various portions of the upper side of a double manila 45/4 codend were covered. In each case the cover extended from side lacing to side lacing. The lower side was covered with hides. The codend was 44 meshes in length and the mesh size averaged 123 mm. The following series were carried out:

Series	I	(9 tows)	all 44 meshes covered (whole codend)
Series	II	(4 tows)	last 22 meshes covered (1/2 of the length of codend)
Series	III	(3 tows)	last 16½ meshes covered (3/8 of the length of codend)
Series	IV	(2 tows)	last 11 meshes covered (1/4 of the length of codend)

The data for individual tows are given in Tables F-1 and F-2). Retention curves for each series are shown in Figure 6. We see from the figure that reducing the cover to 22 meshes reduced the 50% point by about 1.5 cm. The reduction to 11 meshes reduced the 50% point by anotber 1.0 cm. The 16½ mesh cover, however, has a 50% point even higher than the full cover. A reason for this and for the entirely different shape of the curve cannot be provided. If we exclude the 16½ mesh cover anomaly it appears that the decrease in 50% point (indicating lower escapement) has been caused by fish escaping through parts of the codend which are not covered.

We can gain some information on the importance of various parts of the codend by comparing the percentage of fish of various sizes whicb entered the 11, 22, and 44 mesh covers. The percentages in Table 3 have been read from Figure 6.

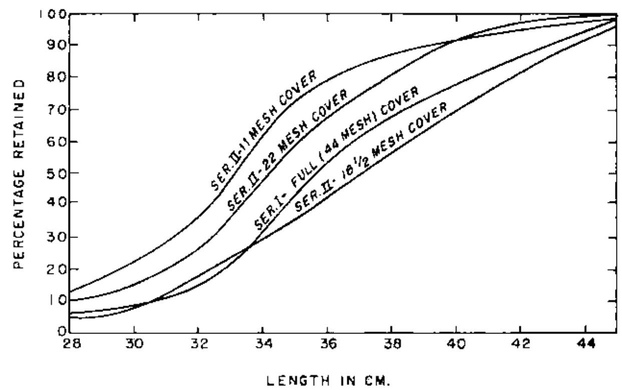


Fig. 6. Selection curves for 44 mesh (full) cover and 22, 16½, and 11 mesh covers.

TABLE 3. Percentage of Total Catch in Cover for Series I, II, and III.

Fish Size (cm)	Percentage of total catch in: Ser. I-44 Mesh Cover	Ser. II-22 Mesh Cover	Ser. III-11 Mesh Cover
<29	95	90	88
29	93	88	83
30	92	84	78
31	89	80	71
32	85	73	63
33	79	63	52
34	68	52	38
35	57	42	28
36	47	32	20
37	38	25	15
38	32	13	12
39	26	14	10
40	21	8	8
41	17	4	7
42	13	2	5
43	9	1	4
Mean	54	42	36
% of 44 Mesh Cover	—	78	67

From the 44 mesh cover figures we see that for every 100 fish of 29 cm entering the codend, for instance, 93 entered the cover. Only 88 out of every 100 fish taken were in the 22 mesh cover. The 11 mesh cover in like fashion caught only 83. We may assume that the difference between these figures represents the number of fish escaping through the uncovered parts of the codend. Thus out of 100 fish of 29 cm which entered the codend, 83 escaped through the 4th (terminal)

[1]) Tables marked F are not printed in the paper but filed in the ICNAF Secretariat for reference.

quarter of the codend meshes, 5 escaped through the 3rd quarter of meshes, and 5 escaped through the 2nd and 1st quarters. We may conclude, therefore, that approximately 90% (83 out of 93) of the escapement takes place in the terminal one quarter of the codend. If we apply this reasoning to fish of 36 cm for example, we discover that 20 escape through the 4th, 12 through the 3rd, and 15 through the 2nd and 1st quarters. We then conclude that about 43% (20 out of 47) of those which escaped did so through the terminal quarter. We may estimate, in like manner, that 38% of the escapement by 42 cm fish takes place through the terminal quarter. We can also make a combined estimate for all the size groups represented by using the means for each cover. Thus out of 100 fish of 43 cm and lower entering the codend an estimated 54 escape. Of these 54 which escape, 67% do so through the 4th, 11% through the 3rd, and 22% through the 2nd and 1st quarters combined.

No good reason offers itself to explain why a higher proportion of smaller than of larger fish which escape should do so through the terminal part of the codend. It may be owing to greater swimming power for large fish or to some differential behaviour in the net; or perhaps it is an artifact of the escape calculations made above.

It may be argued, however, that even if all the escapement took place in the after part of the codend, we could still obtain reduced numbers in the cover by just moving it rearwards. This could come about by the shortened cover not having length enough from its place of forward attachment to permit it to rise up clear of the codend, even at its terminal quarter. This source of experimental error presumably could in itself cause masking and thus reduce the cover catches. Our other data and our observations of covered rigs underwater with television, however, suggest that this is not a significant source of error.

Albatross cruise No. 51: A series of tows with a full cover (Series I) and a half-cover (Series II) [1] was conducted during Cruise No. 51 of the *Albatross III* in June 1953. The codend was of 45/4 double manila mesh which averaged 75 mm in size. The data for each of the 4 tows with the half-cover are given in Table F-3 along with a summary of 14 tows with a full cover. The selection curves are plotted for each series in Figure 7. We see from the figure that the half-cover results indicate ***higher*** apparent escapement than the full cover results. If many fish were escaping through the forward half of the codend we would expect the half-cover to show *lower* escapement. Why it should show the opposite is not easily explained. Nevertheless, we can find no evidence in these results to suggest that the forward half of the codend is of importance in the release of haddock.

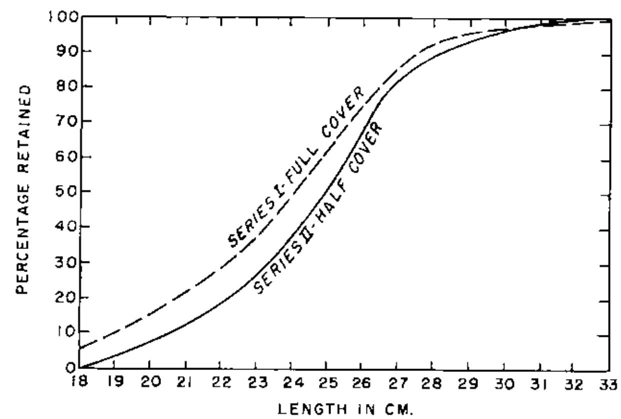


Fig. 7. Selection curves for full cover (Ser. I) and half-cover (Ser. II) with 75 mm mesh codend of 75/4 double manila.

Albatross cruise No. 49: During Cruise No. 49 of the *Albatross III* in May 1953, we carried out an investigation of the escapement through the lower side of the codend. The experiment consisted of two series of tows one with and one without bull hide chafing gear on the lower side of the codend.

During both series we were also varying the length of tow for another purpose (*see* p. 55). As the number of tows of each length were about equally represented we feel that no important effect upon these results was caused.

In Series I we made 14 tows with hides and 10 tows without hides. The 50/4 double manila codend used had a mesh size of 123 mm during the "with hides" tows and 124 mm during the

1) In this series the cover extended over exactly half the length of the codend (the terminal 12 ft.).

"without hides" tows. The individual tow results are given in Table F-26. A summary of "without hides" and "with hides" results is provided in Table F-4.

We see from Figure 8, wherein the two selection curves are plotted, that the proportions of fish in cover and codend in the "with hides" and "without hides" tows do not differ greatly. If large numbers of fish were able to escape through the lower side with hides removed, fewer fish would enter the cover and the percentage "retained" would appear much higher. This took place to a limited extent throughout the 30 to 60% range, and as a result the 50% point (39.6 cm*) and selection factor (3.2) appear slightly lower for "without hides" tows. Although the 50% point is at a lower size, higher escapement is indicated at each end of the "without hides" curve. We cannot conclude from this study, therefore, that the underside of the codend is of much importance in the escapement of haddock.

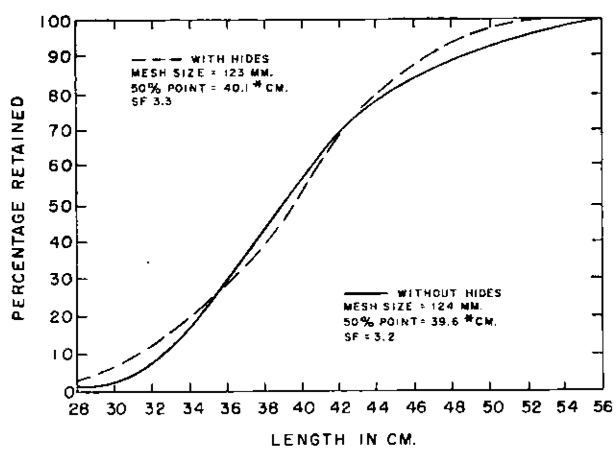


Fig. 8. Selection curves for "with hides" and "without hides" tows, Series I.

In Series II the study was continued with a double manila codend of smaller mesh size in a series of 8 "with hides" and 5 "without hides" tows. The mesh size was increasing throughout the experiment and averaged about 71 mm during the "with hides" tows and 75 mm for "without hides" tows. The individual tow results are given in Table F-27. A summary of "without hides" and "with hides" results is given in Table F-5. The selection curves are

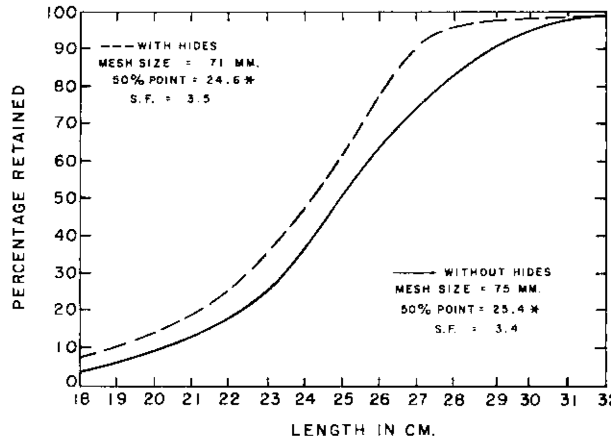


Fig. 9. Selection curves for "with hides" and "without hides" tows, Series II.

plotted in Figure 9. We see that greater proportions of fish of all sizes occurred in the cover during the "without hides" tows, but the mesh size had increased 4 mm over the "with hides" tows. The selection factor corrects for this and shows the "with hides" tows (3.3) to have more fish in the cover than the "without hides" tows (3.2). The selection factor is dependent only upon the 50% point, however, and the two curves have different shapes, as in Series I, so the same effect does not hold over the range of lengths. An escape factor calculated for the 85% retention point, for instance, is actually the same for both (3.8). We cannot, therefore, conclude from these data either that important quantities of haddock escape through the underside of the codend.

Priscilla V: In the *Priscilla V* experiments we were primarily concerned with the escapement of silver hake. Because the escapement of this species was much lower than expected, we attempted many modifications to the gear. One of these modifications provided data relating to the escapement through the lower side of the codend.

The codends tested during the *Priscilla V* work normally had covers only on the upper side. The after 12 feet of the lower side was partially covered with discarded codend netting as chafing gear. In order to test whether low selection factors obtained might be owing to large numbers escaping through the incompletely blocked lower side meshes, we applied additional fine mesh netting over these meshes. The primary purpose of this modification was to prevent passage of fish through the lower side, but we discovered that the additional covering meshes were functioning as a regular cover, even though very little slack was provided, and considerable numbers were thus taken in this "lower cover." The codend used was made of single, twisted, 125/3 nylon of 103 mm mesh size.

The catches of silver hake for 3 tows with both upper and lower covers are given in F-6. The data show that about one-fifth of the 4,428 silver hake that escaped did so through the lower side. We have shown elsewhere (p. 34) that little effect upon the selection curves results from using covers only on the upper side.

The lower cover was constricted at its median point by the attached chafing gear and catches of escapees from the forward and rearward parts did not mix. Although we did not separate catches in the separate parts of the lower cover, we observed that catches were about equally divided between the two. Thus, lower side escapement of silver hake appeared to take place equally in forward and after parts of the codend.

Remarks: These studies indicate that for haddock the important escape area of the codend is the after part of its upper side. Thus, no major error is likely to be caused by determining escapement from covers applied only to the upper side even if parts of the lower side of the codend are not covered with chafing gear.

Although haddock do not appear, from indirect reasoning, to utilize the lower side of the codend for escapement, more direct evidence available indicates that about one-fifth of the silver hake escapement takes place there. It is possible that some haddock, yet not enough to affect the selection curves, may in fact escape through the underside of the codend. This is not of great practical importance, however, as in haddock fishing the whole underside is usually obstructed with bull hide chafing gear. Silver hake codends are more frequently protected with discarded pieces of codend netting which would permit escapement to take place.

Underwater television observations have shown that haddock which escape usually do so while the net is under tow. Silver hake on the other hand appear to escape in large quantities in hauling back after the way is off the net, but considerably before it reaches the surface. Thus we have come to believe that there are important differences in the escapement behaviour patterns of the two species.

We have shown elsewhere (p. 68) that escapement may be diminished when catches are heavy. This may be due in part to blocking of the normally larger after meshes which would force the fish to escape through smaller meshes. We have also shown that more consistent results are obtained in some instances by relating escapement to mesh size in the after part only of the codend.

Escapement in Forward Parts of the Trawl as Shown by Covers

Gear and Methods: The application of covering mesh over the forward parts of otter trawls is made difficult by the very expanse of the meshes involved; *e.g.*, the upper belly has about 20 times as many meshes as the upper side of the codend. Differences in configuration of the forward sections of the trawl also militate against the use of covers. We were, however, able to apply covers successfully to the upper belly in several instances.

In experiments board the *Albatross III* (Cruises 49 and 51) we used a full cover over the belly of the starboard trawl and a partial cover ("belly trap") over the belly of the port trawl. The codend was covered in both cases. (*see* p. 29 for descriptions of covers.) The cover was made of 35 mm mesh, 15 thread cotton. The 130 mm mesh belly was of 125/4 manila (single) at its forward end and 75/4 manila (single) at its after end.

During several cruises of the *Priscilla V* we employed a cover over the whole square and top belly. The covering mesh was 15 thread cotton of 35 mm mesh size. The belly was of 57 mm. mesh, 24 thread cotton throughout. The cod ends were of 85 mm, 400/3 nylon and 73 mm 72 thread cotton.

Covers applied to the upper wings at various times failed to produce catches. This we believe may be owing in part to the configuration of the trawl and design of the cover but primarily to lack of escapement in this part of the trawl.

Results, Albatross III Experiments: Two series of tows are available for the full belly cover used on the *Albatross III*. We completed 28 tows successfully in Series I, and 11 in Series II. These results are given in Table F-7.

Escapement of haddock from the top belly was found to be much lower than through a cod-end of the same mesh size. For example, 3% of 32 cm haddock escaped from the belly in Series I and 1% in Series II, while about 90% of 32 cm fish will escape from a codend of the same mesh size.

Catches in the belly cover represented only 8% and 9% of the numbers taken in the codend cover. As there are only 1/20 as many meshes in the upper belly as in the upper side of the cod-end we see how ineffective the belly meshes are in releasing haddock.

The smaller cover or "belly trap" caught very few haddock. A total of 35 fish, of 21-37 cm length, were taken in it in 24 tows. The combined catch of codend and its cover for these tows was 10,716 fish within the 21 to 37 cm range. As the belly trap covered only 11% of the belly area, the escapement of 35 fish would, of course, be an underestimate. The total escapement from the belly can be estimated from direct proportion of belly area covered to total belly area. This would give an estimate of 318 escaping or about 3% of the total catch of 10,716 fish of 21 to 37 cm. In Series I and II the full cover took 8% and 9% of the numbers of those sizes caught. The belly trap is then either operating at a lower efficiency or else escapement of haddock through the portion covered by the trap is proportionately less than through other parts of the belly. The full belly cover results are considered the more reliable.

Priscilla V Experiments: The results for the series of tows carried out with a cover over the whole square and belly of the cotton trawl are given in Table F-8. Escapement of silver hake from the top belly and square is much less than escapement from a codend of equivalent mesh size. For instance, only 18% of the 14 cm fish escaped from the top belly and square while about 70% of 14 cm fish would escape from a cotton codend of the same mesh size. The smallest fish are apparently escaping in large numbers. However, all fish of less than 10 cm are being taken in the belly cover. We have shown elsewhere (p. 82) that fish up to 12 cm are escaping through the 35 mm covering mesh. Our records of the catches of the smallest fish are thus underestimated.

Escapement through Forward Parts of the Trawl as Shown by Replicate Tows

Covers can be used with some success for determining escapement through the top belly and square but cannot be expected to work well on wings and lower belly. We have, therefore, used the replicate tow method to extend our studies to these parts.

Methods: A series of paired tows was carried out during Operation Pairtows, a joint cruise of the *Albatross III* and *Delaware*. The two vessels, of similar fishing ability, attempted always to fish their nets simultaneously. They usually succeeded in this, setting and hauling back within a few minutes of each other. The two nets were towed for equal periods of time and as closely together as safety would permit.

Care was taken to assure that the No. 41 nets used by each were rigged in identical manner. We used on each net the same size and weight of "doors", number of floats, and length of headline and footline. Netting components and other attachments were of the same specifications; the only difference was in mesh size. Four series of tows were carried out:

Series I The *Albatross III* and *Delaware*, towed nets of identical mesh size (120 mm.) to determine the fishing power of the two units for various sizes of fish. Both codends were of 63 mm mesh size. (The *Delaware* continued towing the 120 mm trawl through Series II to IV.)

Series II The *Albatross III* had 55 mm mesh in the square and top wings in place of the 120 mm mesh of the *Delaware*.

Series III: The *Albatross III* used 55 mm mesh in all parts except the lower wings.

Series IV The *Albatross III* used 55 mm mesh in all parts of her trawl.

In Series V the *Albatross III* made alternate tows of her own port and starboard nets with 120 mm and 55 mm mesh respectively throughout the forward parts. Double manila codends of 63 mm were used in both trawls.

In addition to the above experiments a series of alternate tows was conducted by the *Priscilla V* for silver hake. A trawl of 57 mm mesh was fished from the port side and one of 84 mm mesh from the starboard side of the vessel. The codends were both of 40 mm mesh.

Results, Pairtows Series I: We intended, by reducing the amount of known variables, to eliminate bias caused by different catching rates of the *Albatross III* and the *Delaware.* To ascertain whether, in fact, the two vessels were normally catching proportionately equal numbers

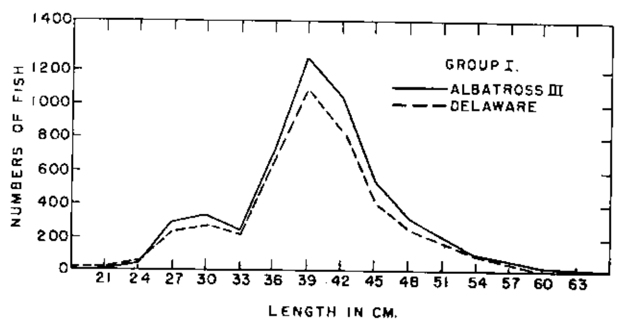


Fig. 10. Numbers of haddock of each length taken by the *Albatross III* (5122 ind.) and *Delaware* (4364 ind.) in standardization tows, Series I.

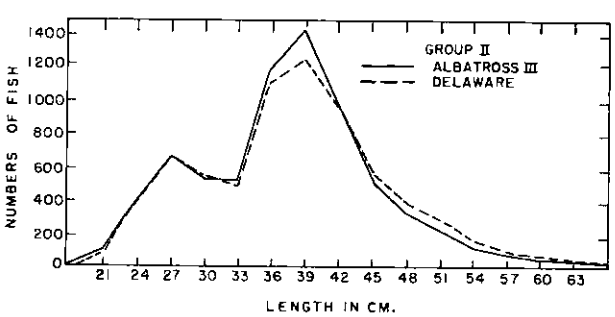


Fig. 11. Numbers of haddock of each length taken by the *Albatross III* (7103 ind.) and *Delaware* (7073 ind.) standardization tows, Series II.

of all sizes we conducted a series of standardization tows. Thus, two groups of paired tows were made with identical manila trawls. The results from the two groups are given in Tables F-9 and F-10. The length compositions for the two series are shown in Figures 10 and 11.

We see from the figures that the proportions of various lengths taken by the two vessels are nearly identical, although the *Albatross III* caught greater total quantities of fish. On the basis of the similarity of the length distributions we proceeded to test the escapement through various parts of the trawl although we realized that some biasing effect might be caused by the differences in the total catches.

Pairtows Series II: With 55 mm mesh inserted in the top wings and square only, of the *Albatross III* trawl, we conducted a series of four pairs of tows. The results are given in Table F-11 and may be summarized as follows:

Length in cm	Number of Fish *Alb.*	Number of Fish *Dela.*	% "Retained" (*Dela./Alb.*)
17-22	39	40	103
23-25	218	324	149
26-28	1205	1403	117
29-31	1355	1941	143
32-34	477	628	132
35-37	926	748	81
38-40	1193	1109	93
41-43	803	859	107
44-46	229	336	147
47-49	95	94	99
50-66	92	61	66
TOTALS	6632	7543	

If the fish of the smaller sizes were passing through the top wings and square of the 120 mm mesh trawl (*Delaware*) and were prevented from doing so in the *Albatross III* trawl by the 55 mm mesh, then greater quantities of smaller size fish should have been taken by the *Albatross III* trawl. The results show that this is not so, and we may thus assume that escapement through the top wings and square is negligible. Why the *Delaware* actually caught more, rather than less, fish cannot be determined; her catching power was shown in the previous section to be lower than that of the *Albatross III*.

Pairtows Series III: With 55 mm mesh in the top wings, square, and top and bottom bellies of the *Albatross III* trawl we completed four pairs of tows. The results are given in Table F-12, and can be summarized as follows:

Length cm	Number of Fish *Alb.*	*Dela.*	% "Retained" (*Dela./Alb.*)	% Escaping
<24	26	9	35	65
23-25	370	227	61	39
26-28	1733	1508	87	13
29-31	1736	1798	104	—
32-34	508	548	108	—
35-37	459	563	123	—
38-40	563	832	148	—
41-43	311	505	162	—
44-46	104	206	198	—
47-49	21	31	148	—
50-52	24	15	62	—
>52	14	15	107	—
Total	5869	6257		

Greater numbers of the smaller sizes were taken by the *Albatross III*. The figures in the column headed % "Retained" *Delaware* of *Albatross* can be thought of as the percentage retention of the larger mesh. The converse figures to these, given in the next column, indicate percentage escapement. The only difference in gear between this series, where escapement is apparent, and the last series, where no escapement could be shown, is that 55 mm mesh was used in the bellies. The escapement shown must therefore be through the bellies and may be estimated for each length by the percentage "escaping" figures.

Pairtows, Series IV: We inserted 55 mm mesh into the lower wings for this series so that the whole trawl was of 55 mm mesh. Seven pairs of tows were completed. The results are given in Table F-13, and may be summarized as follows:

Length in cm	Number of Fish *Alb.*	*Dela.*	% "Retained" (*Dela./Alb.*)	% Escaping
17-22	68	8	12	88
23-25	951	318	33	67
26-28	3541	1705	48	52
29-31	3041	1861	61	39
32-34	780	519	67	33
35-37	734	576	78	22
38-40	972	1069	110	—
41-43	515	770	150	—
44-46	141	241	171	—
47-49	27	52	193	—
50-66	20	66	330	—
Totals	10790	7185		

That considerably greater numbers of the smaller sizes were taken by the *Albatross III*, indicates a high escapement through the 120 mm mesh. The only difference in gear from Series III was the insertion of 55 mm mesh in the lower wings. The difference between the percentages in the two series is thus a measure of the percentage escaping through the lower wings only. Calculating this difference we obtain the following estimate of escapement through the lower wings:

Length in cm	% "Escaping"
17-22	23
23 25	28
26-28	39
29-31	39
32-34	33
35-37	22
38-67	—

We see from the results of Series III and IV that much greater numbers of fish beyond the selection range are caught by the 120 mm mesh. This disparity is shown to increase as larger mesh is used. Thus the larger mesh appears to be operating more efficiently. This cannot be owing to a greater speed of tow as the two vessels were fishing side by side throughout.

A most interesting aspect of the results is the progressive increase in numbers taken by the larger mesh trawl, with increase in fish size, relative to the small mesh trawl. It thus appears that a single efficiency adjustment cannot be applied to the catches of all sizes as has been done in so many replicate tow codend selection experiments.

Although the efficiency difference certainly affects the validity of the results, we must conclude that substantial numbers of small haddock escape through the lower wings and bellies of the 120 mm trawl. Adjusting the *Albatross III* catches upward on the basis of relative numbers beyond the selection range would result in ***higher*** apparent escapement than that already calculated.

Pairtows, Series V: A total of six pairs of alternate tows with 120 mm. (port) and 55 mm (starboard) nets was made by the *Albatross III.* The results are given in Table F-14, and may be summarized as follows:

Lengths in cm	Number of Fish 55 mm trawl	120 mm trawl	% "Retained" 120mm/55mm	% Escaping
17-22	89	69	78	22
23-25	220	215	98	2
26-28	424	360	85	15
29-31	350	464	132	—
32-34	453	391	86	14
35-37	791	777	93	7
38-40	777	825	106	—
41-43	479	565	118	—
44-46	302	400	132	—
47-49	232	225	97	3
50-75	372	393	106	—
Totals	4489	4684		

Contrary to the pair tows results, little escapement through forward parts of the net is demonstrated. We must consider the results of the paired tows of the two vessels as being the more reliable. It is probable, therefore, that the difference in results is owing to experimental error in the *Albatross III* alternate tow results. A major source of error could be the difference in speed of the two nets, the smaller offering more resistance and therefore slowing the speed of tow, which could cause the escapement to be underestimated. This did not occur in the paired tow work when the speed of towing of the two nets could be equalized with the *Albatross III* and *Delaware* towing side by side.

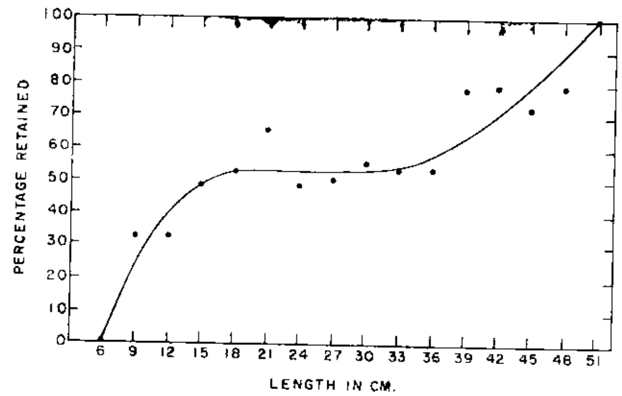


Fig. 12. Percentage "retained" by an 84 mm cotton trawl, silver hake.

Priscilla V.: A series of four pairs of alternate tows were carried out with 84 mm and 57 mm trawls to investigate the escapement of silver hake. The results are given in Table F-15. The data shows that the number of fish taken by the 84 mm net increases relative to the 57 mm net with increasing fish size. The results when plotted as a selection curve (in Figure 12) show that the 84 mm mesh allowed many silver hake to escape. The curve, however, does not take the form typical to codend escapement. Increasing retention is indicated from 6 to 15 cm and from 33 to 51 cm, but throughout the middle part of the range no selective effect is demonstrated. Fish of 18 cm, for example, appear no more likely to escape than fish of 36 cm.

The escapement is shown to be higher for sizes over 32 cm than for a codend of equal mesh size. Silver hake of over 40 cm have a girth larger (girth factor = 2.4) than the average mesh circumference (168 mm). Thus many of those shown to escape may be doing so only with considerable effort, or perhaps they are choosing the larger individual meshes for escape.

Summary and Discussion

We have seen through the course of this discussion that the most important escape area for haddock and silver hake is the upperside of the codend which contains only about one percent of the total number of meshes of the trawl. Haddock do not appear even to utilize all the meshes of the codend but rather restrict their escape efforts to its after one-quarter. In terms of managing fisheries this means that control of the codend alone may be necessary, as the escapement within the selection range is, in fact, higher for the codend than for the total remaining area of the trawl. Fish prevented from escaping through the forward parts of the net would still be able to escape from the codend in all probability.

Haddock of lengths up to 37 cm are shown by replicate tow results to escape through forward parts of the 120 mm mesh trawl. The escapement determined for the whole trawl from replicate tows is much higher than that for the top belly determined from covers. In comparing the results from both, we can estimate that approximately 10% of the haddock which escape through the forward parts do so through the top belly. The alternate tow data show that about 40% of the forward escapement takes place in the bellies. Thus an estimated 30% escape from the lower belly. The remaining 60% are indicated to escape from the lower wings and none escape from the square and top wings.

The covered top belly (120 mm mesh) results show escapement of sizes of haddock up to 47 cm. The replicate tow results for both upper and lower bellies indicate escapement up to 28 cm only. This apparent discrepancy has probably arisen because of lower numbers of all sizes caught by the inefficient small mesh trawl as previously pointed out. Adjusting the small mesh curve to a catch equivalent to that of the large mesh would increase the apparente scapement and the discrepancy would be eliminated.

We discovered that the small mesh trawl offered much more resistance than the larger mesh trawl. In making paired tows with the two large mesh trawls, the *Albatross III* used 215-220 r.p.m. engine speed and the *Delaware* used 200-205. The *Albatross III* was required to reduce her speed by 10 r.p.m. (to 210) while towing the small mesh net to prevent overheating, and the *Delaware* was required to reduce her engine speed by 15 r.p.m.'s (to 190) in order for the *Albatross III* to stay abreast of her. In the *Albatross III* alternate tow experiment the same r.p.m.'s were used for each net. This explains partially at least, why the alternate tow results showed so much less escapement than the paired tow results.

Silver hake were shown to escape in great numbers through the forward parts of the net. The selection as shown by the cover results appears to be sharp through the 57 mm belly and square where relatively small fish were escaping. Selection as shown by the alternate tows appeared sharp for the small sizes through the whole 84 mm trawl and very dull for the intermediate sizes. Some fish with girth larger than mesh circumference were also shown to escape. Our other silver hake experiments (pp. 61 and 81) have shown the escapement of this species to be typified by unique characteristics. Certain of the differences are explainable only on the basis of psychological factors. In this study where fish of 16 cm were not escaping in greater numbers than fish of 36 cm, a certain indifference to capture is shown.

C. VALIDITY OF THE COVERED CODEND METHOD

Abstract

Eleven series of replicate tow experiments with covered and uncovered codends were carried out to determine the validity of the covered codend method.

For many experiments no effect of the cover was indicated; for others a definite reduction in escapement was shown and for some the reverse seemed true. In one instance modification of the gear appeared to eliminate the "masking" effect.

The conclusion drawn from the study is that properly controlled covered net experiments will give valid results.

Introduction

The "covered codend method" has proven to be the simplest experimental technique for determining the escapement of fish through codend meshes. This technique consists of applying covering netting of small size mesh around the codend, either covering it entirely or only the parts from which fish are likely to escape (see p. 29). A covering of netting over the codend can be expected to reduce the escapement of fish if it is not properly rigged. Many investigators, questioning the validity of the covered codend technique, have employed more complicated methods for measuring escapement. Two such methods are the alternate tow method and the double codend (or "trouser trawl") method.

The alternate tow method requires the alternate towing of two nets which are identical except that one net is rigged with the codend to be tested and the other with a smaller mesh codend. The difference in the catches of the two nets represents the escapement from the larger mesh codend. The double codend method, which is based on the same principle, requires that two codends of different mesh size be attached to the same net. The difference in catches of the two codends represents the escapement.

Other less direct methods may be employed but all involve comparison of catches made with codends of different mesh sizes. The validity of techniques other than the covered codend method has been questioned chiefly because of the difficulties in insuring that equal numbers of fish of each size have actually entered the two codends to be compared. The data usually must be adjusted by some method to remove the effect of inequalities in total numbers entering the two codends. The adjustment is usually made by choosing an arbitrary 100% retention length and multiplying the length frequency of the catches of one codend or the other by a factor which will equalize the numbers above the 100% size. In using such an adjustment one must assume that the proportions of fish of each size entering the two codends are equal. The adjustments and assumptions employed in these experiments admit rather serious sources of error to the results.

Results obtained by different workers have varied considerably. Figure 13 (from Graham, 1952) demonstrates the extent of differences obtained from experiments on the escapement of haddock. This graph shows as complete a summary of 50% points as was available in 1952. The mesh sizes shown represent the best estimate of the internal size of the mesh and were converted from whatever dimensions the authors had given. Errors in estimating the mesh size alone could not have accounted for such great differences in results as are shown for the larger

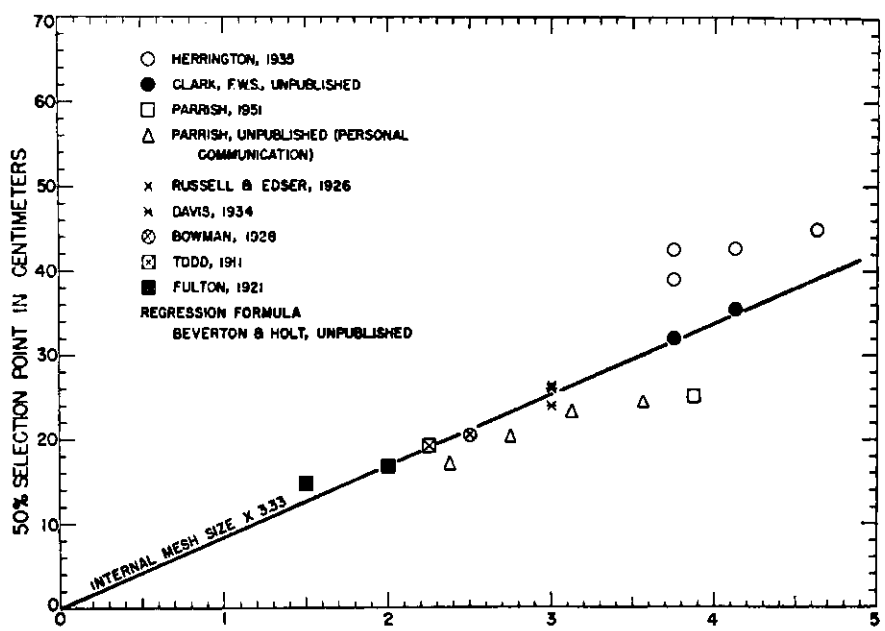


Fig. 13. Relation of size of mesh to size of haddock retained.

mesh sizes, however. At a mesh size of approximately 3.75 inches, Parrish's results indicate a 50% point at about 25 cm (Selection Factor = 2.6), Clark's results at about 32 cm (S.F. = 3.4), and Herrington's at about 43 cm (S.F. = 4.5). Clark used a cover over the upper side of the codend only, the under side being covered by hides. Parrish's method was essentially the same. Herrington's results were obtained by making alternate tows with large and small mesh codends and by using two codends of different mesh size on the same trawl (double codend method). Parrish worked in the Eastern Atlantic, Clark and Herrington in the Western Atlantic.

Because of the seriousness of these differences much of the time available to us for gear selection work since 1952 has been devoted to establishing the validity of techniques. It is the purpose of this paper to present the results obtained which bear on the validity of the covered codend method.

Methods and Gear

The validity of covered net results can be determined in many ways. The most widely used method has been that of replicate tows with codends of the same mesh size, with and without covers (Davis 1934, Parrish 1950, and others). To use this method without adjustments we must assume that random tow-to-tow differences in numbers of fish of all sizes entering the two codends have been equalized by a sufficient number of tows. It is possible, however, to adjust the data in the manner described previously for replicate tows with different codend mesh sizes, but this cannot correct for unequal proportions of various sizes entering the two codends. The catches in the covered and uncovered cod ends are subjected to analysis to determine if the numbers of fish of various sizes in the two catches are equal. If the cover is inhibiting the escapement of fish this will be shown by a greater number of fish of escape sizes in the covered codend catches.

The methods we used were generally as described above. Eleven series of experiments were carried out with codends of various mesh sizes and types. A summary of these experiments is given in Table 4. The vessels and their otter trawls are described elsewhere (p. 27).

TABLE 4. Summary of Experiments on the Validity of the Covered Codend Method.

Experiment	Species	Type	Mesh size (mm) cov. c.e.	uncov. c.e.	No. of Pairs of Tows
Michigan No. 1	Haddock	50/4 manila, dbl.	92	93	7
Michigan No. 2	Haddock	50/4 manila, dbl.	105	104	5
Albatross III Series I – No. 51	Haddock	75/4 manila, dbl.	76	75	5
Albatross III Series II – No. 51	Haddock	75/4 manila, dbl.	76	75	9
Albatross III – 52	Haddock	45/4 manila, dbl.	113	114	10
Pairtows I Series I	Haddock	120th. cotton, single	138	144	5
Pairtows I Series II	Haddock	Braid, nylon, 43 yds./lb. single	135	128	3
Priscilla V Series I	Silver hake	96th cotton, single	73	72	4
Priscilla V Series II	Silver hake	400/3 twisted nylon, single	85	84	4
Priscilla V Series III	Silver hake	400/3 twisted nylon, single	82	82	9
Albatross III No. 64	Redfish	45/4 manila, dbl.	109	110	6

We have discovered, as have others, that it is not always possible to conduct this kind of experiment at sea according to a predetermined design. A certain amount of latitude must be allowed the experimenter in deciding which tows to accept and which to reject. It is obvious that if a net is badly damaged and the catch partially lost, the tow should be rejected. But more arbitrary judgments must be made ou occasions of improper condition of gear, differences in location of gear, differences in location of tow due to tide, wind, course error, etc., and diurnal changes in abundance of fish. It is often not possible to make sufficient tows to compensate for differences in catch resulting from these factors and some tows must be rejected.

Results

Michigan, No. 1 - Haddock: Seven pairs of alternate tows were completed on the first cruise of the *Michigan*[1] in June 1952 with results as follows:

Codend	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	No. of fish in: c.e.	cov.	50% Point (cm)
Covered	8 – 26	92	50/4 manila dbl.	5992	378	29.0*
Uncovered	8 – 45	93		6167	–	–

The numbers of fish of each length caught by the two codends are given in Table F-16. Length frequencies of the catches are plotted in Figure 14. We see from the figure that the characteristics of the catches from the two codends are quite similar. The catches are almost identical in magnitude, the differences being only about 3%. The mean lengths of fish caught in the two codends were identical (40.7 cm).

As any masking effect of the cover could only operate on the sizes within the selection range, the most pertinent comparison is probably of catches within the effective selection range (*i.e.*, smaller than 38 cm) only. The numbers of fish smaller than 38 cm were 1,939 and 1,979 for the covered and uncovered codends, respectively (difference of 2%). The mean sizes within the selection range were nearly the same, being 35.0 cm for the covered codend and 34.8 for the uncovered codend.

Only a small proportion of fish escaped into the cover because of the low abundance of the smaller escape sizes. No very pronounced effect upon the catches can be expected, therefore, and the results are of somewhat limited value. We can only say that these results give no evidence to support the theory that the cover restricts the escape of haddock through codend meshes.

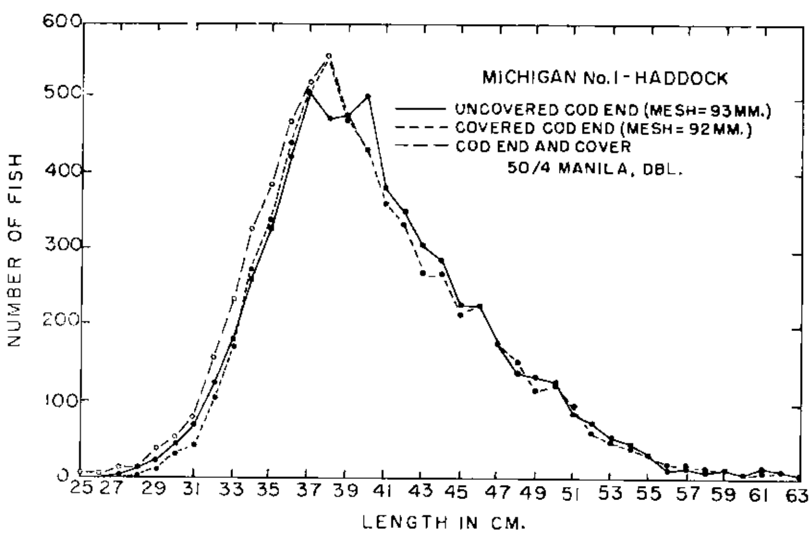


Fig. 14. *Michigan 1* catches with covered and uncovered codends (7 tows, 12,157 ind.).

1) Preliminary results of the *Michigan* cruises were published by Clark (1952).

Michigan, No. 2 - Haddock: Five pairs of alternate tows were completed on the second *Michigan* cruise in June 1952 with results as follows:

Codend	Towing Time Hrs. – Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 – 35	105	50/4 manila	2861	519	32.3*
Uncovered	5 – 35	104	double	3026	–	–

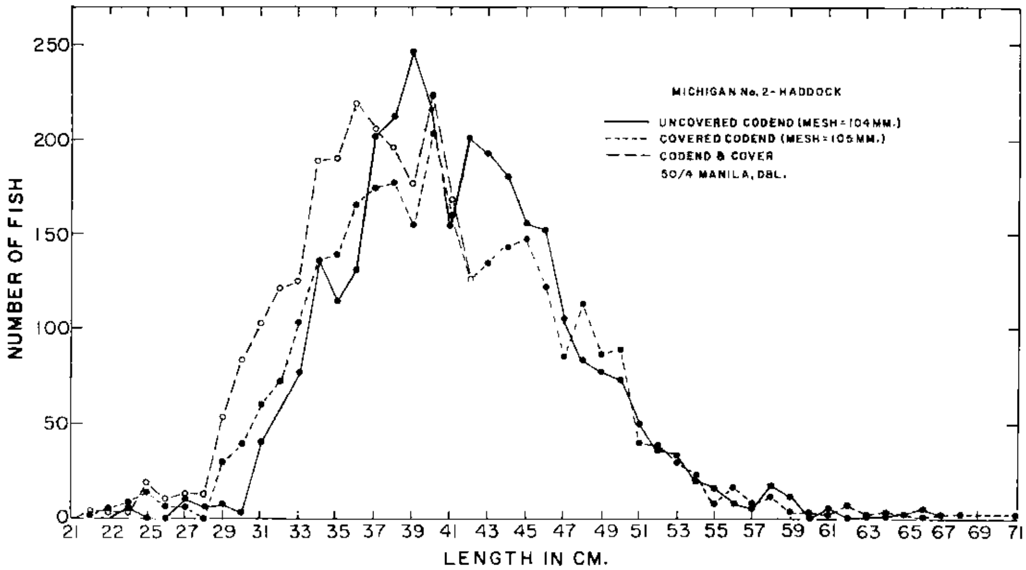


Fig. 15. *Michigan II* catches with covered and uncovered codends.

The numbers of fish of each length caught by the two codends are given in Table F-17. Length frequencies of the catches are plotted in Figure 15. The length frequency curves are less regular than in the *Michigan* No. 1 series, because just half as many fish were caught. Again, nearly the same numbers of fish were caught by the two codends. The mean length was slightly lower in the covered codend (41.0 cm) than in the uncovered codend (41.6 cm). Within the effective selection range (*i.e.*, less than 41 cm) the covered codend caught slightly more fish (1,450) than the uncovered codend (1,430). The mean sizes of fish within the selection ranges were 35.9 cm for the covered codend and 36.7 cm for the uncovered codend.

Thus our analysis demonstrates that somewhat more fish of a smaller average size were taken within the selection range by the covered codend. The slight difference of 1 mm in the mesh size could not be expected to cause this. The differences could very well have come about through random variation in catches. If we assume, however, that the difference is real and the catches in the uncovered codend best represent the retained portion of the catch, a recomputed 50% point for this series of tows can be calculated which is approximately 3.5 cm higher (from 29.5* to 32.5 cm*).

This adjusted 50% point agrees well with that of 32.3 cm* obtained for the whole series of tows with the covered codend (14 tows - see p. 67). We may conclude from this that escapement from the covered net for the 5 tows which were paired was artificially low. This effect must not have extended to the whole series of covered tows made on this cruise because the final 50% point determined from the series of 14 tows and the adjusted 50% point for the 5 replicate tows show good agreement.

The small number of fish caught in the lower part of the selection range of the codends again restricts the applicability of results.

Albatross III No. 51 - Haddock: Two series of replicate tows, one of 5 and one of 9 pairs, were completed on Cruise No. 51 of the *Albatross III* in June of 1953, with the following results:

Series I

Codend	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 - -	76	75/4 manila	7121	2733	24.5*
Uncovered	5 - -	75	double	8982	-	-

Series II

Codend	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	9 - -	76	75/4 manila	8248	4337	24.5*
Uncovered	9 - -	75	double	10906	-	-

The same covered codend was used throughout, but different uncovered codends were used for Series I and Series II. The mean mesh sizes for the two uncovered codends were identical, however. The data for the two series are given in Table F-18; the results of the two series are quite similar. Because of this, and the fact that the mesh sizes of the two uncovered codends are the same, we have combined the results and will consider both series together. The results are plotted in Figure 16.

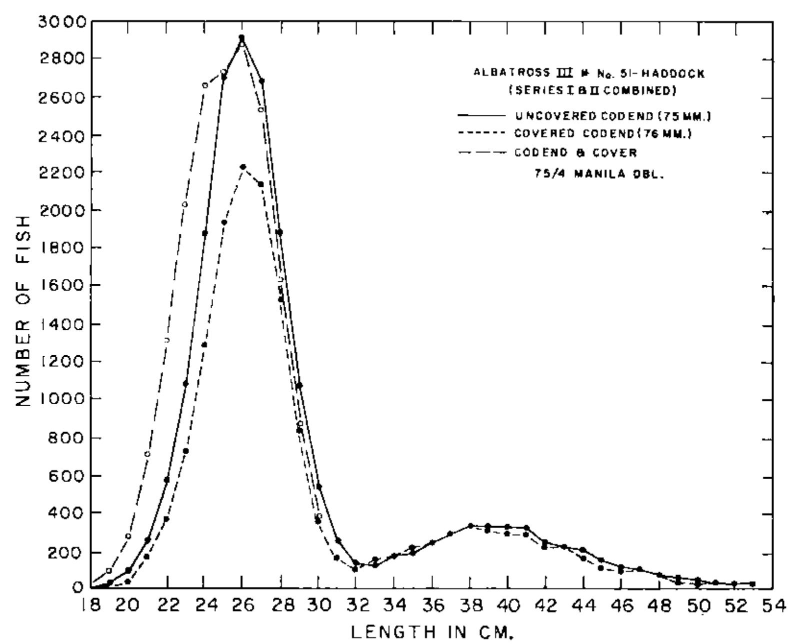


Fig. 16. *Albatross III* No. 51 catches with covered and uncovered codends.

Upon examining the length frequencies we see that more, rather than less, of the fish within the effective selection range (*i.e.*, less than 31 cm) have been caught by the uncovered codend. We observe also that there are more fish above the selection range in the uncovered codend and may propose that the net without the cover is operating more efficiently for *all* sizes than the covered uet. We can test this hypothesis by comparing the total number of fish of 31 cm and over in the two nets. The catches in this category are 3,769 for the covered codend and 4,212 for the uncovered codend, a difference of 443 fish representing 12% of the covered codend catch. But below 31 cm the uncovered codend caught 35% more fish than the covered codend. If we adjust the uncovered codend catch of sizes less than 31 cm by the 12% it still remains 23% above the covered codend catch. We therefore cannot conclude tbat the higher catches by the uncovered codend of fish in the selection range were due to greater overall efficiency.

Another possibility is that the uncovered net actually operated with about 23% greater efficiency for fish within the selection range only. A possible explanation of this is offered by results obtained in another set of experimeuts (p.00) which indicated that a high proportion (ca. 50%) of haddock between 20 and 30 cm escaped through the forward parts (mesh of about 120 mm) of the trawl used on the *Albatross III*. All fish of over 47 cm were shown to be retained by the forward parts of the trawl. If the effect of the cover were such as to enable these fish to escape more easily through the forward parts of the trawl we could expect to catch fewer in the covered codend.

This hypothesis, however, does not assist us in detemining if the cover has a masking effect. We can, however, propose that if a masking effect were operating, the excess of the uncovered codend catch over the covered codend catch at each size would be related to the proporton of fish of that size which escape. Thus, as the escapement increases, per size interval, the excess of the uncovered over the covered codend should decrease. The approximate percentages of fish which escape at each size and the percentage excess of the uncovered over the covered codend catches are shown below for the sizes between 21 and 30 cm:

Length (cm)	21	22	23	24	25	26	27	28	29	30
% Escapement	79	72	62	50	38	25	15	7	5	4
% Excess	52	54	47	45	40	31	26	23	29	49

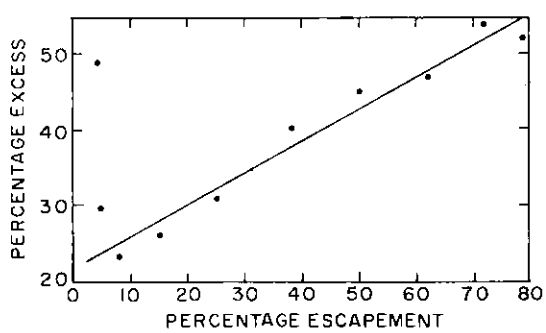


Fig. 17. Percentage escapement and percentage excess of uncovered over covered codend in *Albatross III* No. 51 results.

The relationship, which is plotted in Figure 17, shows that our hypothesis is not supported, and no masking effect can be demonstrated. Thus, the cover has not been shown to reduce escapement and in fact, if anything, has seemed to improve it.

Albatross III No. 52 - Haddock: Ten pairs of alternate tows were completed on Cruise No. 52 in July 1953, with results as follows:

Codends	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	12 - 50	113	45/4 manila	2977	2455	36.8*
Uncovered	11 - 50	114	double	3555	–	–

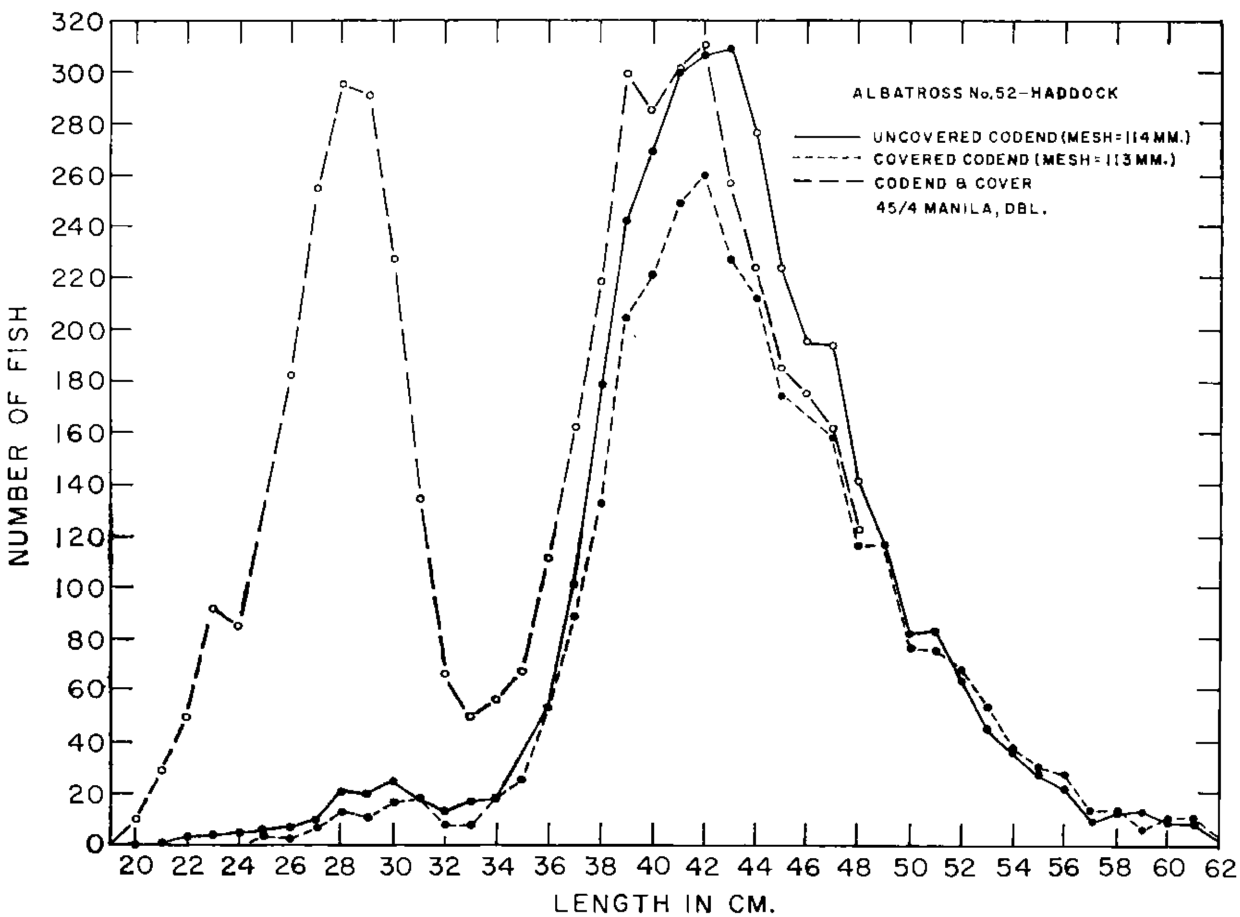


Fig. 18. *Albatross III* No. 52 catches with covered and uncovered codends.

The numbers of fish of each length caught by the two codends are given in Table F-19. Length frequencies of the catches plotted in Figure 18 show the great amount of escapement of small sizes of haddock in this experiment. The small number of 20-33 cm fish remaining in the covered codend do not exceed the number of these sizes remaining in the uncovered codend. Although this condition is particularly well demonstrated at the smaller sizes it exists generally throughout the selection range of the codend. The numbers of fish caught by the two codends are nearly identical from 49 cm on, being 561 for the uncovered codend and 570 for the covered codend.

This experiment yields results similar to those of the *Albatross III* No. 51 experiments in respect to the excess of the uncovered codend catch over the covered codend catch within the escape sizes. The difference in towing time (about 8%) could partially account for this difference, but we would then have to accept a lowered relative efficiency for sizes over 49 cm by the uncovered codend.

The percentage escapement from the codend and the percentage excess of the covered over the uncovered codend within the selection range are shown below:

Length (cm)	25	26	27	28	29	30	31	32	33	34	35	36
% Escapement	98	97	97	96	95	93	89	85	80	71	62	52
% Excess	25	133	43	61	82	47	6	62	113	—	40	4

Length (cm)	38	39	40	41	42	43	44	45	46	47	48
% Escapement	38	30	24	19	15	11	8	6	4	3	1
% Excess	35	18	22	20	18	37	30	28	16	22	21

These data are plotted in Figure 19.

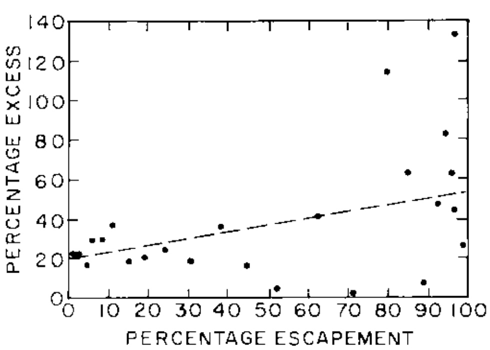


Fig. 19. Percentage escapement and percentage excess of uncovered over covered codend for *Albatross III* No. 52.

Again we see no sign of decrease in excess of uncovered over covered codend catch, even with the increase in escapement. We may conclude, therefore, that the cover did not reduce the escapement of haddock from the codend in this series of tows.

Pairtows I - Haddock: Operation Pairtows I was a joint operation of the *Albatross III* and the *Delaware* in October 1955. The vessels were rigged with identical nets. Initial tests showed that they caught nearly equal proportions of sizes of fish within the effective selection ranges of the codends to be tested (*see* p. 38). We then made two series of paired tows with covered codends on one vessel's net and uncovered codends on the other's, the vessels fishing as near to each other as possible and setting and hauling back at nearly the same time. Series I consisted of 5 pairs of tows with cotton codends. Results were as follows:

Codends	Towing Time Hrs. - Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	5 - 50	138	120th cotton	305	2299	49.6*
Uncovered	5 - 57	144	single	73	-	-

The data are given in Table F-20 The length frequencies are plotted in Figure 20. Any analysis of the catches of the two codends would show them to be greatly dissimilar, with the covered codend having many more fish of a smaller size than the uncovered codend, and we must conclude that the cover is indeed exerting a masking effect. We see from the great escapement of fish, however, that this effect is of little consequence for the smaller sizes of fish. The apparent masking has a much more important effect upon the larger sizes (*i.e.*, 43 cm and above) where considerably fewer fish are escaping. Why the larger sizes of fish should be more affected by the cover than the smaller sizes of fish is difficult to explain. One possibility is the larger mesh size of the uncovered codend. The effect, of course, could be owing to chance variation.

A singular demonstration of the effectiveness of the cover was provided by an "unpaired" tow which followed immediately the conclusion of the above series. In this tow, 1,087 haddock were caught in the cover and none in the codend; all had escaped. The sizes ranged from 20 to 46 cm (Pairtows, Tow No. 42 of *Delaware*). The gear was apparently operating properly and conditions were, as nearly as can be determined, much the same as on the previous 5 tows of this net reported above.

Pairtows I, Series II, consists of 3 pairs of replicate tows with braided nylon cargo netting (43 yards/pound). Results are as follows:

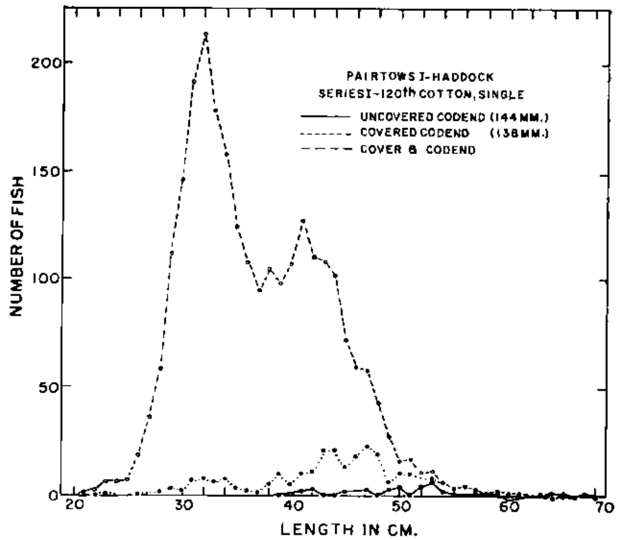


Fig. 20. Pairtows I, Series I. Catches with covered and uncovered codends.

Codend	Towing Time Hrs.	Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	3	0	135	Braided nylon	215	1167	44.6*
Uncovered	3	8	128	43 yds/lb single	50	—	—

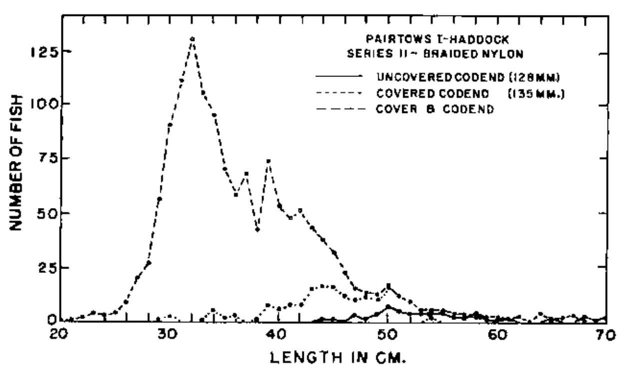


Fig. 21. Pairtows I, Series II. Catches with covered and uncovered codends.

The data are given in Table F-21. The length frequencies are plotted in Figure 21. The results are similar to those obtained in Series I. The smaller catches of the uncovered codend cannot be explained on the basis of mesh size in this instance as the uncovered codend mesh was 7 mm smaller than the covered codend mesh.

We should draw conclusions from these two experiments with caution because of the few tows involved. The case is strengthened by the similarity of results of the two series, however, particularly since the *Delaware's* codend was covered in one series, the *Albatross III's* in the other, thus eliminating the possibility of bias caused by differential selection characteristics of different nets.

Considering the results of Series I and II, we can draw certain inferences: with codends of the sizes tested, masking caused by the cover is unimportant for lengths of 40 cm and smaller. Beyond that size more serious consequences can result, particularly because the 50% point, which is of great usefulness, could be estimated several cm too low.

Priscilla V - Silver Hake: Three series of replicate tow experiments were carried out aboard the *Priscilla V*. The *Priscilla V* is a wooden otter trawler of the size that normally fishes for silver hake. Her net was a cotton trawl rigged to conform as nearly as possible to average characteristics of the diverse types used in the fishery (*see* p. 28 for specifications).

Four pairs of replicate tows with cotton codends were completed in Series I with the following results:

Codend	Towing Time Hrs.	Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	3	35	73	96th cotton	4515	1433	19.9*
Uncovered	3	50	72	single	3341	—	—

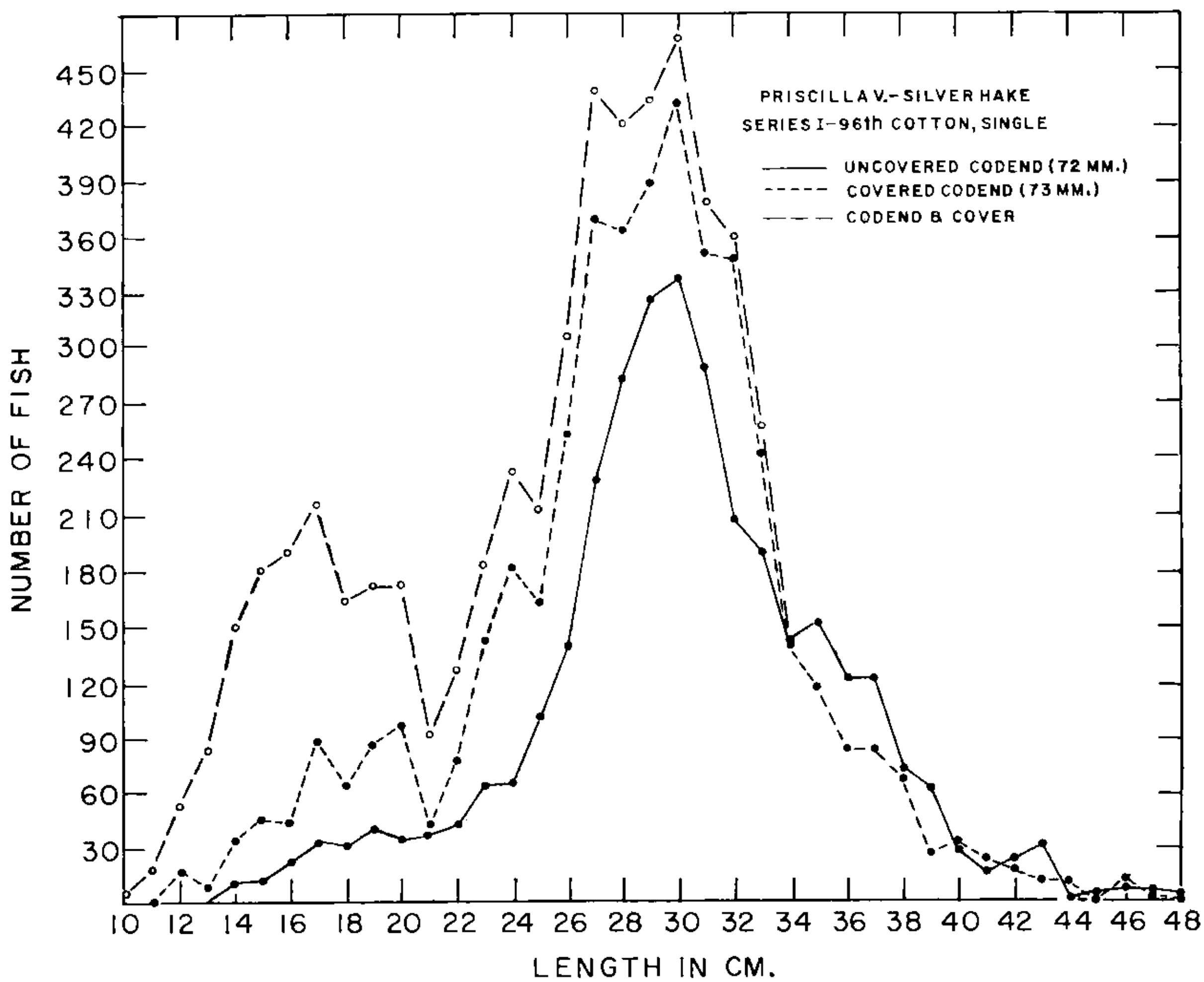


Fig. 22. *Priscilla V* catches with covered and uncovered codends, Series I.

The data are given in Table F-22 and plotted in Figure 22. The greater "retention" of the escape sizes of silver hake indicates that the cover is exerting a serious masking effect.

We commenced to make various adjustments to the gear in order to eliminate the observed masking effect. Divers, who examined the rig while towing slowly in shallow water, reported that the cover was constricted by the splitting strap and appeared to have too little slack. The splitting strap was adjusted and the cover enlarged before Series I tows were begun. Additional observation by divers during the Series showed that the adjustments had improved the action of the cover somewhat, but the cover was still not flowing clear of the codend. We then added floats to the upper side of the cover and its operation was further improved. However, the covered codend was still retaining more of the escape sizes, and work with it was discontinued.

Upon completion of Series I tows, the cotton codends were exchanged for nylon codends and the study continued with Series II. Four pairs of tows were completed in Series II with the following results.

Codend	Towing Time Hrs.	Towing Time Min.	Mesh Specifications Size (mm)	Mesh Specifications Type	Number of fish in: c.e.	Number of fish in: cov.	50% Point (cm)
Covered	4	55	85	400/3, nylon	2896	2626	29.8*
Uncovered	4	55	84	twisted, single	1898	—	—

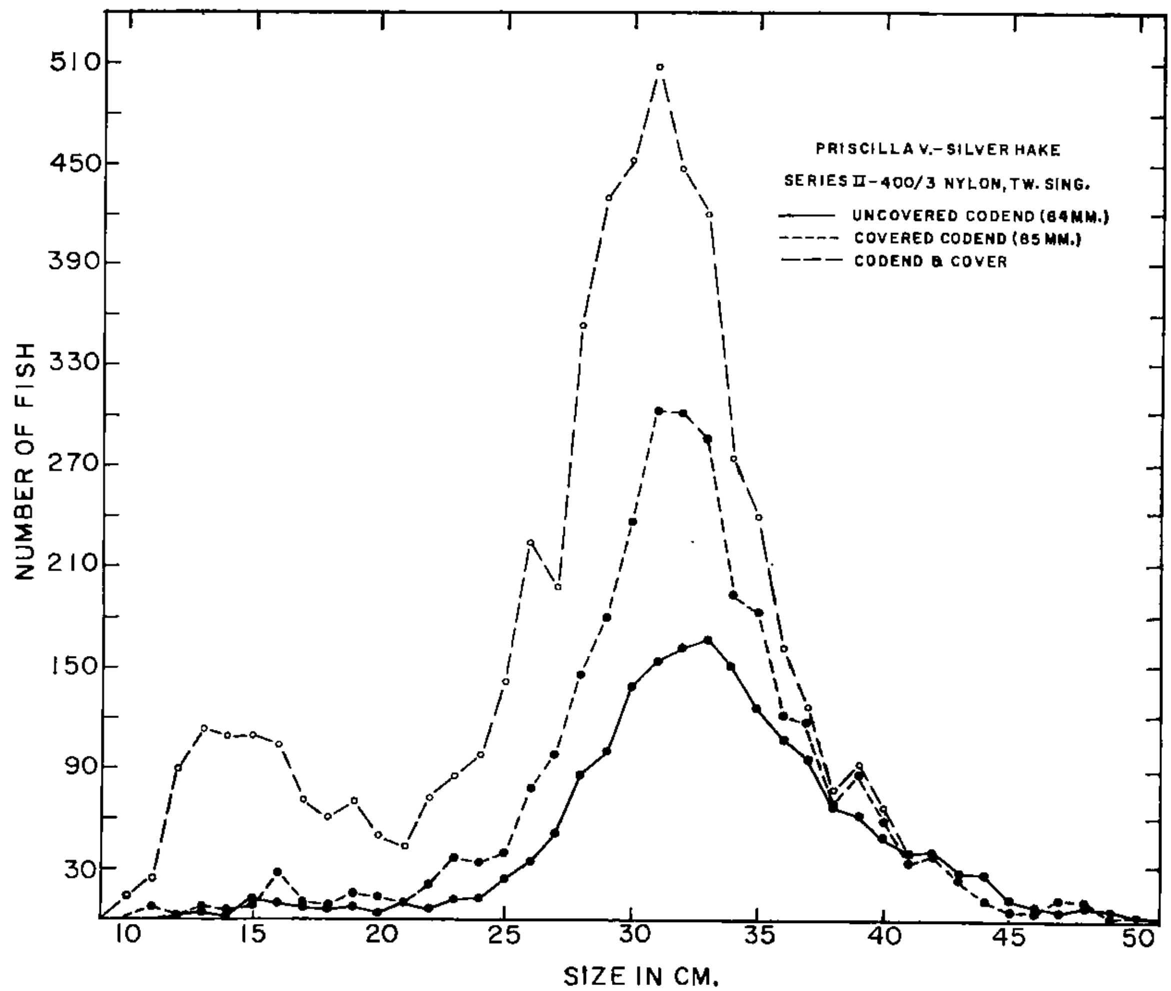


Fig. 23. *Priscilla V* catches with covered and uncovered codends, Series II.

The data are given in Table F-23 and plotted in Figure 23. A masking effect of the cover is again evident. At this point in the operations the nets were completely overhauled for various reasons. One major change involved rehanging the nets to the foot ropes and headlines, the lengths of which were altered. Another major change was the removal of a cover which had extended over the whole area of the upper belly. We then commenced Series III with the same codends and 9 pairs of tows were completed with the following results:

Codend	Towing Time Hrs.	Min.	Mesh Specifications Size (mm)	Type	Number of fish in: c.e.	cov.	50% Point (cm)
Covered	8	50	82	400/3, nylon	3570	1214	27.7*
Uncovered	8	45	82	twisted, single	3700	—	—

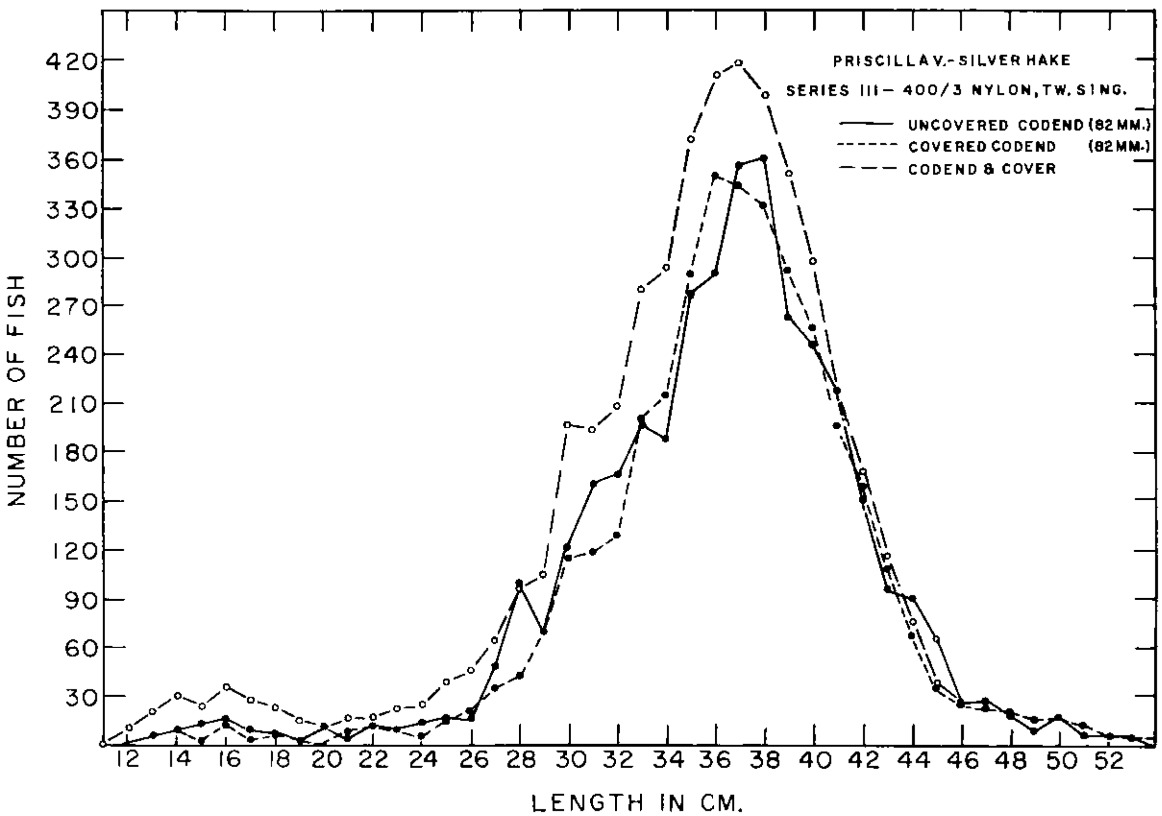


Fig. 24. *Priscilla V* catches with covered and uncovered codends, Series III.

The data are given in Table F-24 and plotted in Figure 24. Although the escape sizes of silver hake were scarce in this series, a sufficient number were taken to show that the masking effect was no longer pronounced. The rehanging and removal of the belly cover had apparently in some inexplicable way improved the operation of the gear.

We are, however, not able to explain easily why the 50% point should be lower in Series III than in II. This is partially explained by the shrinkage of the covered codend from 85 to 82 mm but the selection factor remained higher for Series II (3.5) than for III (3.4). Throughout much of the *Priscilla V* work, escapement of silver hake was much lower than would be expected from comparison with other species and from European results with *Merluccius*. The operation of many unknown factors could increase the escapement considerably, just as fear stimulated by a shark in the codend did on one occasion (*see* p. 61). During Series III we operated at a different time, in somewhat deeper water (23 rather than 19 fm.), and on different grounds within the same general area. Catches were lower and a greatly different size composition was encountered. Also the modification to the gear could have somehow lowered the escapement even while lessening the masking effect of the cover.

We may conclude, nevertheless, that the covered codend results obtained for Series III and subsequent operations were not seriously affected by masking of the cover, and, albeit somewhat less safely, that the modifications to the gear somehow improved the operation of the cover.

We may propose that the uncovered codends in Series I and II give a better representation of the "actual" retention than the covered codends. If the percentages retained are recalculated on the basis of the uncovered codend catches, the 50% points will be about 3 cm higher. The apparent masking effect has thus reduced the 50% point by 3 cm for both series. Selection factors are similarly reduced by about 0.4. These differences point up the necessity of conducting tests on the operation of covers before proceeding with selection experiments.

Albatross No. 64 - Redfish: The final series of covered and nncovered codend tows to be presented is that of Cruise No. 64 of the *Albatross III* in August 1953. The first part of this redfish selection cruise was devoted to studying the effect of the cover. We experienced great difficulty in obtaining a good series of replicate tows with and without covers because of the sporadic changes in abundance of fish and because the steep contours of the grounds worked caused difficulty in controlling the depth of tow. Nevertheless, a series of 6 pairs of tows was completed which can be examined with the reservations mentioned. The results are as follows:

Codend	Towing Time Hrs.	Towing Time Min.	Mesh Specifications Size (mm)	Mesh Specifications Type	Number of fish in: c.e.	Number of fish in: cov.	50% Point (cm)
Covered	5	45	109	45/4, manila	3417	1916	23.6*
Uncovered	5	37	110	double	3287	—	—

The data are given in Table F-25 and plotted in Figure 25. The figure shows that the covered codend retained no more redfish throughout the important part of the selection range than the uncovered codend. The reverse is shown to be true in the vicinity of the 50% point. No explanation can be given for this except that it may be owing to random variability caused by difficulties in controlling the paired tows. At all events, we can see no evidence in these results that the cover exerted a masking effect.

Discussion

No single conclusion can be supported by all these studies as to whether the covered codend technique is valid. In many instances no effect of the cover can be demonstrated. In some instances definite reduction in escapement is shown, while in others the reverse seems true. In one instance, modification of the gear appeared to eliminate the masking effect. We are led to conclude from our study, however, that properly controlled covered net experiments will give valid results.

The final proof, of course, is in the application of the experimental results to the management of a fishery. We have shown elsewhere (p. 88) that the selection of haddock in the Georges Bank fishery by ICNAF recommended $4\frac{1}{2}$ inch codends agrees almost exactly with our covered codend experimental results. This fact provides the most significant confirmation of our haddock selection results.

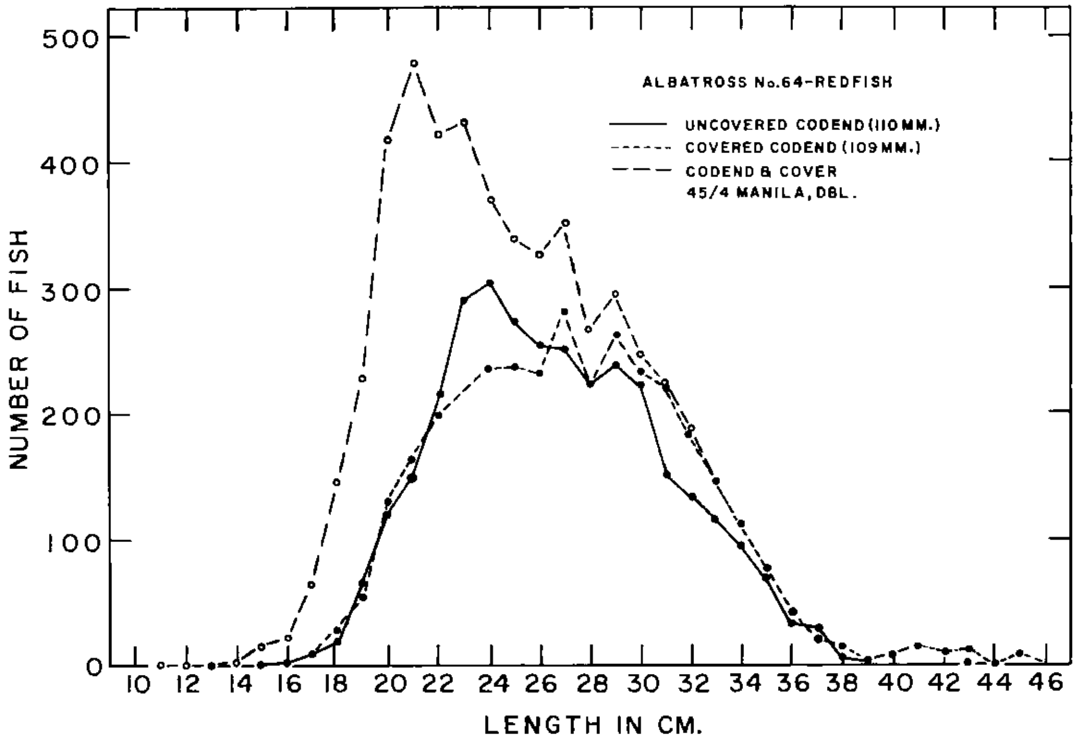


Fig. 25. *Albatross III.* No. 64 catches with covered and uncovered codends.

D. EFFECT OF DURATION OF TOW ON CODEND ESCAPEMENT

Abstract

The results of three series of tows of varying duration are analyzed. It is shown that the selection factor is closely related to tow duration, with longer tows yielding substantially higher escapement.

Methods

Variation in tow length is one of the factors which many workers consider important in determining codend escapement. Previous experimental evidence has not been conclusive. Gulland (1956), for example, found insufficient evidence in a study of tows of 1/2 hour to 3 hours to show that the duration of tow had an effect upon the amount of escapement. The three lowest 50% points obtained, however, were all for tows of shortest duration.

Investigating the effect of duration of tow was the primary objective of Cruise No. 49 of the *Albatross III.* The standard net and cover rig (p. 29) were employed throughout the experiment. Three series of tows of varying duration (20, 40, 60, and 80 minutes) were conducted in alternating sequence.

Results

Series I consisted of 3 tows each of 20, 40, 60, and 80 minutes duration. The codend was double manila 50/4 of 113 mm mesh size. The data (length measurements of haddock) are given in Table F-26 and selection curves for each tow duration are shown in Figure 26. The 50% point advanced regularly with increasing length of tow (33.8*, 35.2*, 37.3*, and 38.6* cm). The selection factor increased from 3.0 for 20 minute

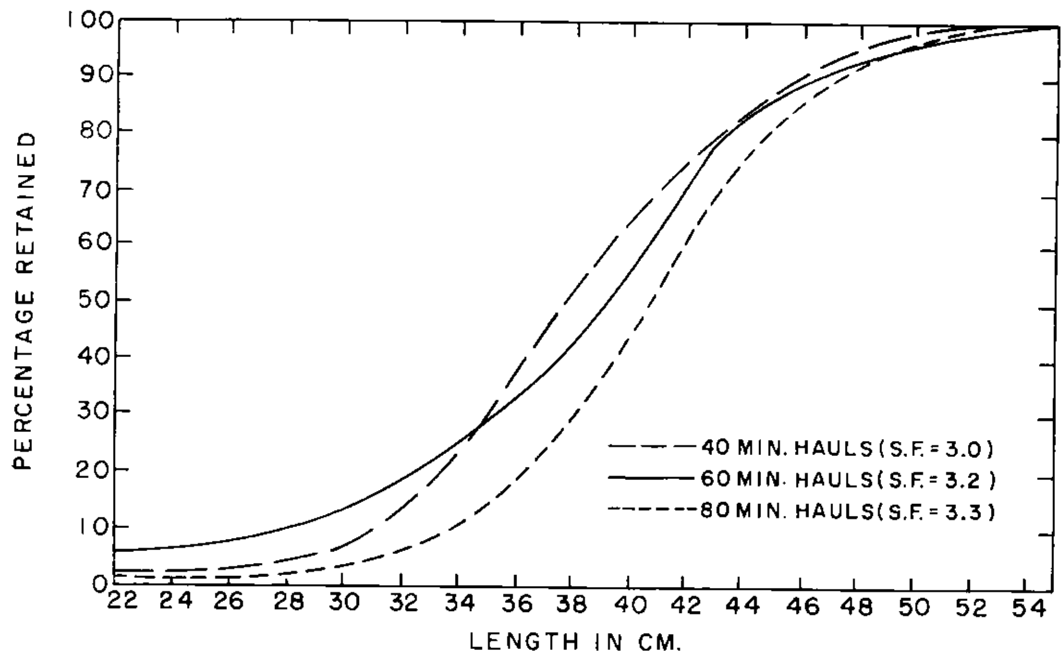


Fig. 26. Selection curves for 20, 40, 60. and 80 minute tows with a 113 mm mesh codend of 50/4 manila, double.

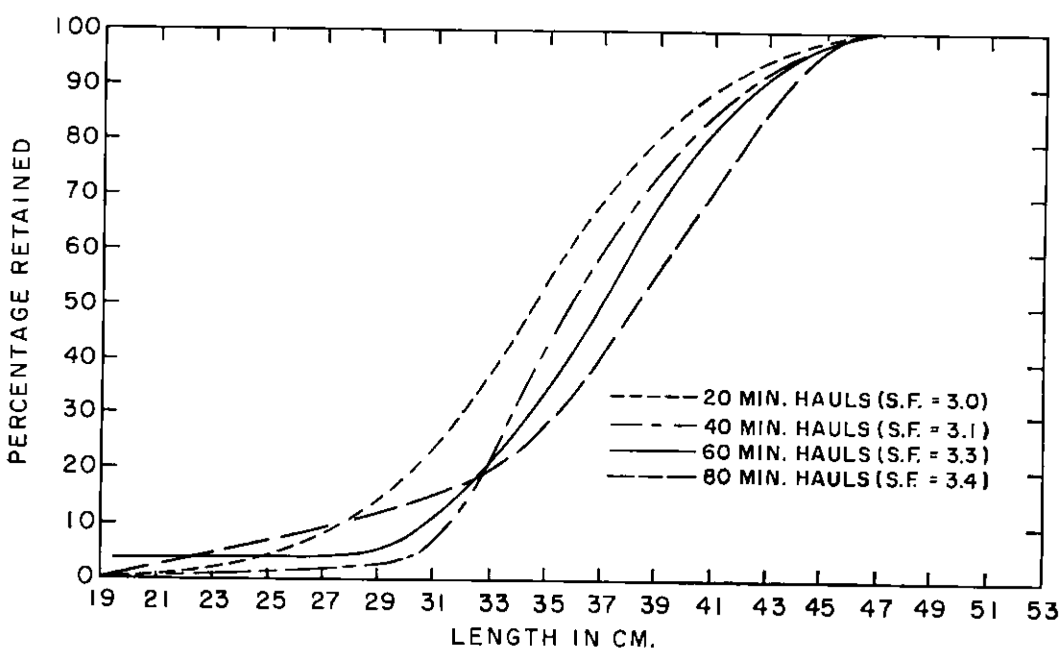


Fig. 27. Selection curves for 40, 60, and 80 minute tows with a 123 mm mesh codend of 45/4 manila, double.

tows to 3.4 for 80 minute tows. Slight anomalies appear at the lower ends of the curves; these are not important enough to affect the general conclusions.

Series II consisted of 8 tows each of 40 and 80 minute duration and 7 tows of 60 minute duration. The codend was double manila 45/4 of 123 mm mesh size. The data are given in Table F-27, and the selection curves for each tow duration are shown in Figure 27. The 50% points advanced regularly with increasing length of tow (36.8*, 39.7*, 41.2* cm). The selection factor increased from 3.0 for 40 minute tows to 3.3 for 80 minute tows. The 60 minute group shows a lower escapement below the 30% escapement point, however, than the 40 minute group.

Series III consisted of 4 tows each of 40 and 60 minutes duration and 5 tows of 80 minutes duration. The codend was double manila 75/4 of 73 mm mesh. The data are given in Table 3, F-28, and the selection curves for each tow duration are shown in Figure 28. The 50% point is shown to advance from 24.8* for the 40 minute tows to 25.2* for 60 minute tows but then decreases to 24.8* cm for 80 minute tows. The shapes of the curves are shown to differ somewhat among the three towing durations. The escapement for 80 minute tows is shown to be higher than for the other two durations up to about the 35% point and from the 70% nearly to the 100% point. Although the dampened escapement in the middle of the selection range has reduced the selection factor for the 80 minute tows, the general result is not greatly different from that of Series I or II.

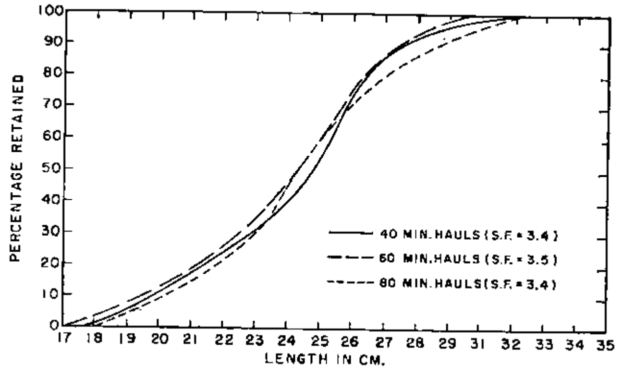


Fig. 28. Selection curves for 40, 60, and 80 minute tows with a 73 mm mesh codend of 75/4 manila, double.

Tows made without hides on the lower side of the codend were incorporated into Series II and III. We have shown previously that no demonstrable effect was produced upon escapement by removing hides (p. 35). We are assured, therefore, that this study was not influenced by combining the tows with and without hides.

We may thus conclude that, within the range of towing times studied, greater escapement is effected by lengthening the duration of tow.

Discussion

It may be argued that the increase in selection factor could have come about simply through associated increase in catch size and is not actually related to tow duration. We have, therefore, summarized below the average numbers of haddock in the codend and the selection factors for all series:

Tow Duration	Series I Numbers of Fish	Series I S.F.	Series II Numbers of Fish	Series II S.F.	Series III Numbers of Fish	Series III S.F.
20	96	3.0	—	—	—	—
40	150	3.1	475	3.0	134	3.4
60	161	3.3	492	3.2	199	3.5
80	128	3.4	880	3.3	175	3.4

As one might expect, the longer tows (which yielded the higher selection factors) generally produced the greater catches. Closer examination of the results for each series, however, indicates that the correlation between selection factor and number of fish caught is quite imperfect. Our analysis of the catch size - selection factor relation for tows of equal duration (p. 71) suggests that increased catches should lower the selection factor. Thus we are led to the conclusion that the increasing catches should have a contrary effect; *i.e.*, to actually dampen the effect of increasing tow duration on selection factor.

The effect of duration of tow was greatest for the 123 mm and least for the 73 mm codend. As shown also by our studies of other variables, the greatest consistency in results is found among the smaller mesh sizes. As the influence of variables, such as duration of tow, is greatest with large mesh sizes, we must be most critical of the results obtained from trials with larger meshes.

The 80-minute duration approximates most nearly the length of tow by our Georges Bank fleet of large (150 tons and over) otter trawlers. Our medium otter trawlers (50-149 tons), however, usually tow for two hours during the day and for three hours at night. Tows of one hour or less are not usual to any of our trawlers. Since the effect of tow length in applying selection results can be important, the range of towing times in experimental work should be extended to the maximum expected for important segments of the fishery when possible.

E. ESCAPEMENT OF HADDOCK AND SILVER HAKE THROUGH WIRE MESHES

Abstract

The effect of variation in mesh size upon selection was investigated through use of a codend made partially of wire meshes. The selection of the experimental wire mesh codend did not prove to be sharper than manila. Total escapement through the wire mesh codend was shown to be lower for haddock than through a manila mesh codend of equivalent size. The data for silver hake are indicative of the same results but do not appear reliable enough to permit definite conclusions.

Introduction

It has been suggested by McCracken (this publication no. 12) and others that the relative sharpness of selective action may be determined, at least in part, by the uniformity of mesh size. It seems logical that a lack of uniformity would tend to dull the selective action of a codend. The size of meshes of codends, particularly those of hand-braided manila, may vary as much as 30% of the mean size. Since the selection range of any particular mesh size is normally about 30% of the 50% retention length, there is a suggestion that variation in mesh size may be significant in determining the selection range.

To investigate the importance of uniformity of mesh size and shape in escapement, we substituted a piece of heavy wire mesh into the escapement area of a standard codend. It was hypothesized that the uniformity of mesh size in the wire panel would have the affect of sharpening the selective action of the codend, providing that lack of flexibility and the unvarying mesh "shape" (mesh angle of 90°) among other inherent characteristics of this gear, were not important factors in the escapement of fish.

Methods and Gear

Because a codend made entirely of wire mesh would be diffieult if not impossible to handle we used only a partial section of wire mesh in place of the manila twine in the upper, rear part of the codend through which the most of the escapement takes place (p. 31). The wire mesh section, which was 8 feet long, extended from the center rearward to within 4 feet of the end of the codend and extended transversely from laceage to laceage as shown in Figure 29.

A cover was rigged in the standard manner (*see* p. 29) over the whole upper side of the codend, covering both manila and wire mesh. A number of standard round floats were attached to provide the buoyancy needed to offset the weight of the wire. A diagrammatic sketch of the completed rig is shown in Figure 30. A close-up view of the wire mesh, the normal twine mesh of the codend, the cover mesh, and the method of attachment is shown in Figure 31. The manila sections were made of small mesh (57 mm) to prevent fish from escaping through

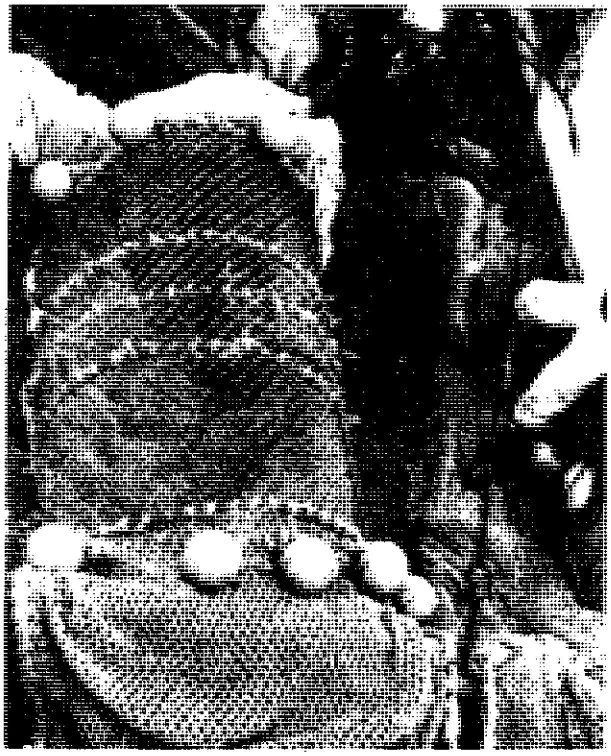


Fig. 29. Top view of the wire mesh codend before attachment of cover.

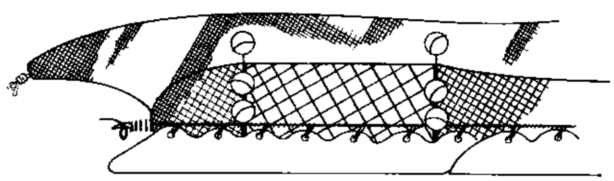


Fig. 30. The completed wire mesh codend.

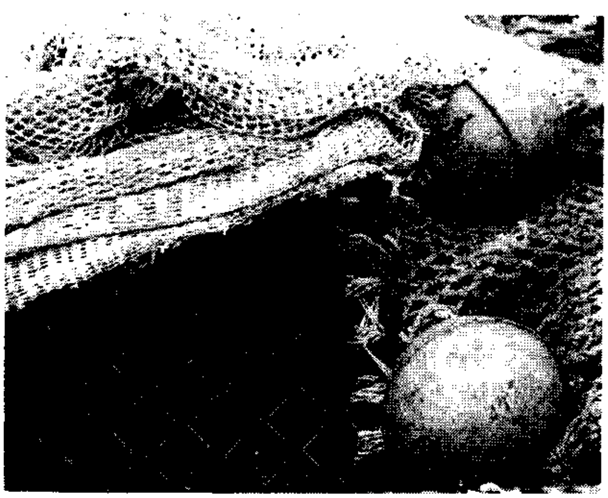


Fig. 31. Detail of wire mesh codend construction.

them rather than the wire mesh. Because of their rigidity, the wire meshes cannot be extended and measured directly as can twine meshes. A dimension of the wire mesh equivalent to that of twine mesh can be estimated by doubling the average dimension of the bar measurement, however. A twine mesh equivalent size of 100 mm thus may be estimated from the bar measurement of 50 mm.

Results

Two tows of one hour duration were made with the wire mesh codend yielding a total catch of 817 haddock and 2,358 silver hake. The numbers caught by cover and codend and the calculated percentages retained are given in Tables F-29 and F-30. The selection curves for the two species are plotted as the solid lines in Figures 32 and 33.

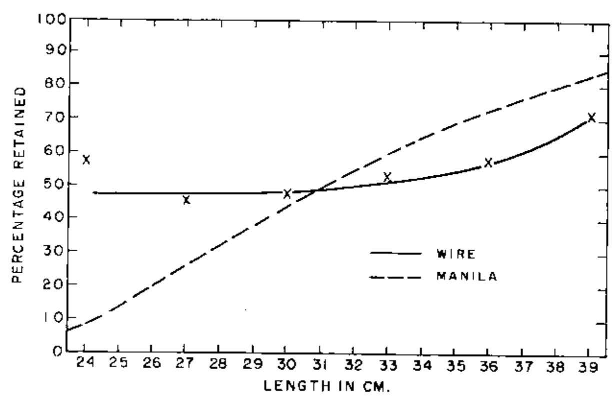


Fig. 32. Silver hake selection curve for wire mesh and manila mesh codends.

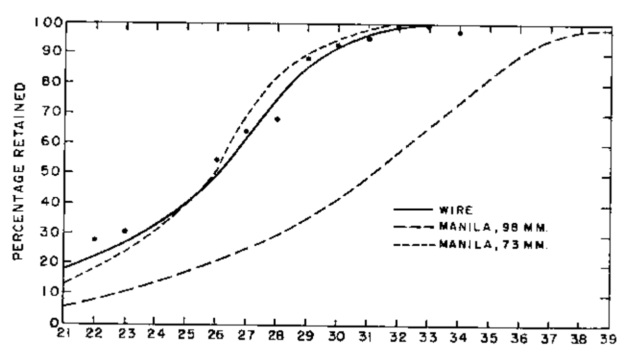


Fig. 33. Haddock selection curve for wire mesh and manila mesh codends.

The silver hake data suggest that the gear exercised little selective action, but this was not surprising in view of our results from other experiments. Silver hake do not appear to have a strong escape reaction to a codend and also seem to be significantly affected by the degree of flexibility of the twines (*see* pp. 63 and 83). The dashed line in Figure 4 represents the selection curve for a 100 mm manila mesh estimated from results of previous experiments (p. 82). The wire mesh selection curve is certainly duller, with only a hint of selective action towards the large sizes of fish and escapement appeared to be almost entirely random with respect to length.

The haddock selection curve for a manila codend of a mesh size (98 mm) comparable to the wire mesh is also plotted in Figure 5 from *Michigan*, Ser. II, p. 67.

The 50% point for the wire mesh is shown to be much lower, but its selective action appears to be sharper since the curve is steeper. Since the steepness of a codend selection curve is a function of the length of fish at 50% escapement, it is necessary, for proper comparison, to use the selection curve for a manila codend having the same 50% point as the wire mesh. Such a curve is available for a 73 mm double manila codend (from *Albatross III*, Cruise 49, Ser. III, 60 min. tows - see p. 69), and has been entered as the dotted line in Figure 5. Comparison of this curve with the wire mesh curve shows the manila to have the sharper selection.

The conclusion must be drawn from these comparisons that wire mesh yields selection no sharper than manila mesh, and if anything, yields duller selection.

Discussion

The results of this study do not confirm that sharpness of selection is correlated primarily with range in mesh size, as the wire netting, of a constant size throughout, yielded selection that was duller than manila. The special gear developed for this study, however, differs from the normal codend in many ways.

The fact that escapement of haddock appears to be generally lower for wire meshes than for equivalent size manila meshes can possibly be explained by the fact that the wire mesh only covered an area of 8 feet of the top of the codend and terminated 4 feet from its terminus. The manila meshes - of which the remainder of the upper side was constructed - were of a size so small (57 mm) as to prevent the escapement of haddock larger than about 20 cm. All the fish which are larger than this size must have escaped through the wire mesh. As the effective escape area of the codend is near the end of the upper side, we can conclude that the fish which were prevented from escaping by the small manila meshes have been so prevented primarily in the last 4 feet of the codend, rather than in the parts forward of the wire mesh.

We are concerned primarily with the sharpness of selection rather than the total amount, and therefore with the shape of the curve rather than the position. We can assume that fish which were prevented from escaping were of an average distribution of sizes and any effect would apply equally to all sizes. The shape of the selection curve, therefore, might not be altered by the fact that only a part of the upper side of the codend was made of wire mesh.

Our experimental results also relate to another factor of importance: that of the effect of the "extensibility coefficient" of the material used in codends. This matter has been investigated by von Brandt (p. 18) who discovered a relationship between the factor expressing elasticity of the fiber and the amount of escapement from the meshes. We may thus expect the wire mesh, which has no extensibility, to yield a much lower escapement than the manila mesh. This is confirmed by the haddock results but not by the silver hake results. The poor selectivity for silver hake cannot be easily explained and may be due to some flaw in the experimental method. We must, therefore, draw conclusions from the silver hake data with caution.

The rigidity of the wire itself may affect the selection as well as indeterminate factors in its rigging which might have caused abnormalities in escapement. We must, however, conclude that there are factors other than range in mesh size which may affect the sharpness of selection of codends.

F. ESCAPE RESPONSE IN MESH SELECTION

Abstract

The effect of escape response motivation on escapement through meshes is considered with particular reference to silver hake. An index, escape-response index, is developed to relate potential and actual escape for various species. An example is given of the effect of increased escape response due to the presence of a shark in the codend.

Introduction

Many workers have investigated physical and mechanical factors in attempting to explain certain features of mesh selection results. Relationships have been developed between such factors as girth of fish, opening of mesh, flexibility and tension of twine, and angles of approach incidence of fish to netting. These studies have not, however, considered psychological factors. So little is known about behavioral patterns of marine fish that it is not surprising that escapement through the meshes of a net is regarded as a more or less random, undirected process. It is the purpose of this paper to demonstrate the importance of response to stimulii in escapement, and to show how it varies with species and conditions of capture and how it may be measured.

Relation of Selection Factor to Girth Factor

It has been proposed by many workers that the selection factor of a species should be related to, and even predictable from, the girth. In general, this has been shown to be true although some anomalies may be found. Figure 34 shows the relation between selection factor and girth expressed in terms of the *girth factor* (G.F. = girth/length) for four representative species for which we have experimental results: yellowtail flounder (*Limanda ferruginea*), redfish (*Sebastes marinus*), silver hake (*Merluccius bilinearis*), and haddock (*Melanogrammus aeglefinus*). The selection factors shown represent average escapement from various kinds of nets under various conditions. We have fitted a line to the data for yellowtail, redfish, and haddock to permit comparison with silver hake. The selection factor

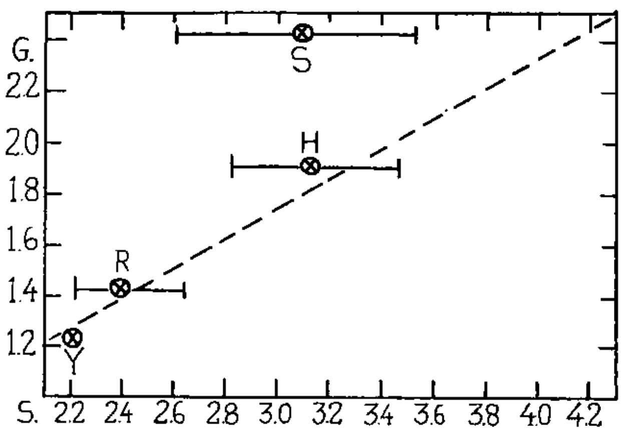


Fig. 34. The relation of selection factors (S) to girth factor (G). Range of selection factors indicated by line, average factor by encircled "X". S = silver hake, H = haddock, R = redfish, Y = yellowtail.

for hake appears to be very much lower than its girth factor would indicate.

A summary of selection factors for the European species of *Merluccius* (Gulland 1956) indicates an average of 4.1, which is in good agreement with the derived line of Figure 1 and much higher than our data indicate.

The poor fit of the silver hake data to the line indicates that these fish were not fully utilizing their escape potential during our experiments. The poor escapement could, perhaps, be due to lack of an escape response to whatever stimulus is provided by the imminence of the trawl meshes.

Derivation of Potential Escape Index

The possibility of escape is limited to fish whose maximum girth is not larger than the circumference of the mesh. With girth less than mesh circumference, the more nearly the cross sectional shape of a fish approximates the shape taken by the mesh of the net under tow, the better should be its chances of escaping. The situation is illustrated in Figure 35. For a mesh having the shape indicated, a fish of oval cross section, such as a silver hake, has the optimum shape for escapement. In theory, a more elongated mesh

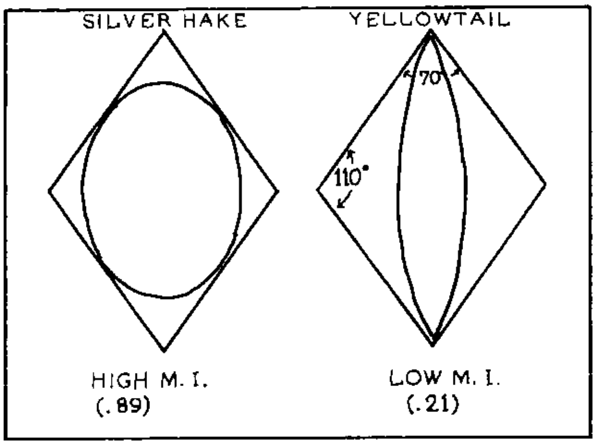


Fig. 35. Diagrammatic representation of the relation of fish shape to mesh shape.

would favor escapement of a deep fish such as yellowtail flounder, but the orientation of long axis of fish to long axis of mesh will be more important, and the angle of approach becomes critical.

The relation between fish dimension and mesh dimension which we have termed the *mesh index* (M.I.) may be defined as follows:

$$1.0 > \text{M.I.} = A/B \text{ or } B/A$$

where A = fish breadth/fish depth
B = mesh length/mesh width.

The mesh index may be used to adjust the girth factor for the relation of fish shape to mesh shape. The adjusted girth factor provides a measure of the maximum possible escapement size for a particular species and mesh shape. This we have termed the *potential escape index* (P.E.I.) which is defined as the square root of the product of girth factor times mesh index:

$$\text{P.E.I.} = \sqrt{\text{G.F. x M.I.}}$$

In order to relate the actual escapement under various conditions to potential escapement, we have developed the *escape response index* (E.R.I.) which is the selection factor (S.F.) divided by potential escape index:

$$\text{E.R.I.} = \text{S.F./P.E.I.}$$

The escape response index measures bow well a fish utilizes its physical potential for escape based upon the relation of its cross-sectional shape to the shape of the mesh.

Application of Escape Response Index

As an example of the use of the escape response index in helping to shed light on complex selection problems, its application to the curious problem of the low selection factor for our silver hake is illustrated below.

The relation between breadth and depth (A) of silver hake is 0.79. For a mesh having angles of 70° and 110° (*see* Figure 35), the relation between its length and width (B) is 0.7. The mesh index is, then, 0.79/0.7 or 0.89. Now the girth factor is 2.4 and the selection factor is 3.1. The escape response index becomes:

$$\text{E.R.I.} = 3.1\sqrt{2.4 \text{ x } .89}$$
$$= 2.1$$

This is much lower than the E.R.I. for any other species shown in Figure 34:

Yellowtail flounder	= 4.4
Haddock	= 3.4
Redfish	= 2.6

We are thus led to believe that the low selection factors for silver hake have resulted from a low level of escape response under average conditions.

Verification of this result occurred when a blue shark (*Prionace glauca*) was caught in the codend during one tow of the silver hake escapement experiments. This stimulus resulted in an increased escape response caused, apparently, by fright. The incident occurred during the second of four successive tows with the same codend made on the same day in the same locality.

The detailed data for the three normal tows and for the shark tow are given in Table F-31. The three normal tows averaged 411 fish in the cover and 526 in the codend. The shark tow yielded 699 fish in the cover and only 222 in the codend.

The selection factor was 3.4 for the normal tows and 4.1 for the shark tow; the 50% point advanced from 33.0* to 39.9* cm. The selection curves in Figure 36 show the pronounced effect upon escapement produced by the stimulus (shark).

The escape response index calculated on the basis of this tow is:

$$\text{E.R.I.} = 4.1\sqrt{2.4 \text{ x } .89} = 2.8$$

and is thus higher than the E.R.I. for redfish.

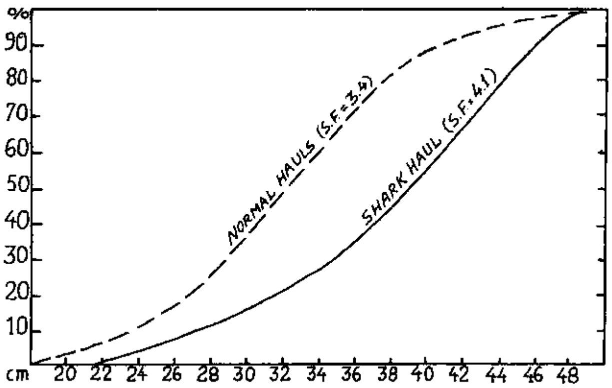


Fig. 36. Selection curves for silver hake for normal tows and shark tow. Ordinate - % retained; abscisse - length of fish, cm.

The possibility exists that the mesh index was altered by distortion of the meshes owing to the struggles of the shark in the net, thus providing more favorable escape conditions. Another possibility is that the shark in his struggling actually forced greater quantities of silver hake through the meshes than would normally be the case. These two possibilities are remote, however, and we favor the conclusion that a greater escape response motivation, owing to the stimulus afforded by the shark, was the causative factor.

It will be noted that the selection factor of 4.1 for the shark tow agrees with that which would be predicted for silver hake by the line in Figure 1. It also agrees with results for the European species. Why the escape response should have been so low in the normal course of our experiments is a question which cannot be answered at present. It may be inherent to the psychological make-up of the species.

G. ESCAPEMENT OF HADDOCK THROUGH CODEND MESHES

Abstract

Replicate tow and covered codend methods were used to determine the selectivity of codends of cotton, manila, and synthetic twines ranging in mesh size from 73 to 167 mm. Selection factors representing 40 experiments are presented. Codends of 45/4 to 75/4 double manila twine yielded selection factors of 3.0 to 3.5 Codends of single nylon twine yielded selection factors of 3.1 to 3.8. One Dacron codend tested yielded a selection factor of 3.1.

Variations in selection factor were shown to be associated with number of fish caught per tow, increasing catches yielding decreasing selection factors, and, for synthetics, with the size of meshes in the after part of the codend relative to the average size for the whole codend.

Introduction

The results of many experiments on factors affecting escapement of haddock through codends have been given in the preceding chapters. The remaining data and a summary of all escapement results for the species are presented herein.

Methods

We have determined escapement from codend meshes with the covered codend method and the replicate tow method. A brief description of these methods is given below.

The covered codend method consists of applying covering netting of small size mesh around the codend, either covering it entirely or covering only the parts from which fish are likely to escape. This method is explained in detail in the introductory chapter.

The covers used varied somewhat in dimensions, material and mesh size but usually were of 38 mm. (1½ inch) cotton mesh rigged to allow about 20% slack transversely (relative to the codend) to allow the netting to stand well away from the codend meshes. The lower side of the codend was covered by chafing gear of some sort, usually hides, for most of its length. The bag (*i.e.* codend) attached to the end of the cover was 8 to 12 feet long and joined at its upper side to the cover and at its lower side to the upper side of the codend, a few meshes ahead of the lachets.

This method of attachment provided for maximum ease of handling in that the codend could be emptied independently of the cover bag.

We have shown in a previous chapter that the covered codend method, if properly controlled, gives valid results for haddock.

The replicate tow method requires the towing of two nets which are identical except that one net is rigged with the codend to be tested and the other with a smaller mesh (control) codend. The difference in the catches of the two provides an estimate of the escapement from the larger mesh codend.

The validity of this method has been questioned chiefly because of the difficulty in insuring that equal numbers of fish of each size have actually entered the two codends to be compared. The data from replicate tow experiments are often adjusted by some method to remove the effect of such inequalities as are shown to arise.

The adjustment is usually made by choosing an arbitrary 100% retention size and multiplying the numbers at each length in the catch of either codend by a factor which will equalize the numbers above the 100% size. In using such an adjustment one must assume that the proportions of fish of each size entering the two codends are equal. The adjustments and assumptions employed in these experiments admit rather serious sources of error to the results. We have attached (as App. B) the results of an experiment carried out by the *Albatross III* in 1949 as an example of the results obtained with alternate tows. This experiment yielded a selection factor of 3.8 to 4.0 which is much higher than any obtained from other methods. The results were not accepted because of their anomalous nature, and we employed other methods in subsequent tests of codend selection.

Most of our selectivity experiments were done by the covered codend method described above. We did, however, engage in a modification of the replicate tow method which eliminates many sources of variation. This modification, which requires the use of two vessels, we term "paired tows." The two vessels employed in experiments were the *Albatross III* and the *Delaware*[1] which are of about equal fishing ability.

Great care was taken to assure that the No. 41 nets used by each were rigged in identical manner. We used on each net the same size and weight of "doors," number of floats, and length of headline and footline. Netting components and other attachments were of the same size and specifications. The only difference was in the mesh size of the codends. One vessel used the codend to be tested; the other used a similar codend but of a smaller mesh size. The catches of each size of fish in the two codends were compared in the manner usual to replicate tow experiments.

We attempted to have the boats fish simultaneously, and they usually succeeded in setting and hauling back within a few minutes of each other. The two nets were towed for equal periods of time and as closely together as safety would permit. The vessels usually set their nets well apart from each other, then converged while towing, separating again about 5 minutes before haulback time. In spite of the precautions taken, many of the pairs were unacceptable for our analysis and the results from them not used.

Results from Paired Tows

All of our paired tow results have come from operation Pairtows I, carried out on Georges Bank by the *Albatross III* and *Delaware*, October and November 1955. The experiments to be discussed herein were carried out in the following five phases:

Phase I – Standardization
Phase II – Selectivity of 119 mm manila
Phase III – Selectivity of 144 mm cotton
Phase IV – Selectivity of 106 mm cotton (58 mm control codend)
Phase V – Selectivity of 111 mm cotton (86 mm control codend)

Phase I - Standardization. We intended, through reduction of variables in gear construction and methods of operation, to eliminate sources of bias and the necessity for adjusting the data. To ascertain whether we had eliminated bias caused by different catching rates of the two

[1]) Characteristics of these vessels and gear are described elsewhere (see page 27).

nets for various sizes of haddock, we conducted a series of "standardization" tows, in which the identical nets had codends of nearly equal mesh size (*Albatross III*, 59 mm; *Delaware*, 56 mm) The difference of 3 mm has little bearing on the results because insignificant numbers were taken within the selection range of these mesh sizes. The results from the 12 paired tows conducted in this phase are given in Table F-32. The two different areas fished were typified by size compositions having modes of 51 cm in one instance and 40-41 cm in the other. We thus had the advantage of testing the nets with two entirely different length compositions and density levels.

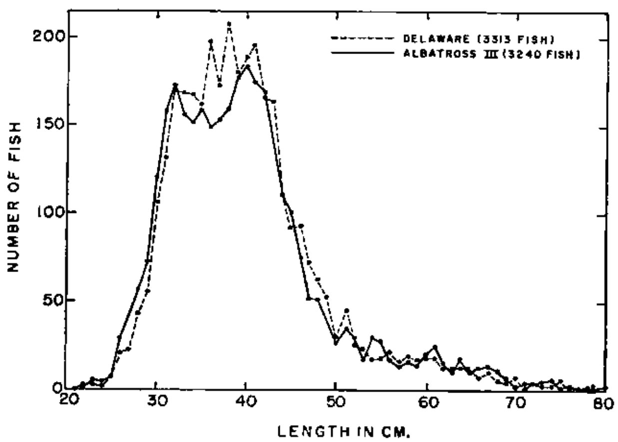


Fig. 37. Pairtows I, Phase I. Catches by *Delaware* and *Albatross III* with manila codends of 56 and 59 mm mesh.

The total numbers of each size of haddock taken by the two nets are plotted in Figure 37. We see from the graph that the two size distributions are quite similar. A discrepancy occurs at 36, 37 and 38 cm where the *Albatross III* catches were only 80% of the *Delaware's*. The *Delaware* caught only 85% as many fish of 26 to 32 cm as the *Albatross III*, however. Other lesser differences are evident. The catch of the *Delaware* of haddock of all lengths exceeded that of the *Albatross III* by about 4%. As tbe differences are not consistent, we may assume that they are owing to random causes and in any event not indicative of an overall difference in efficiency.

Another series of paired tows with identical nets which was carried out on operation Pairtows II for standardization purposes is reported in a previous paper in this series. The gear was essentially the same as that used in the above experiment. These results also showed that the nets of the two vessels caught equal numbers of fish of various sizes (*see* p. 38).

Phase II - Manila. This experiment was conducted to determine the selectivity of a 45/4 double manila codend of 119 mm mesh size. It directly followed Phase I, and we simply replaced the *Delaware's* 56 mm codend with the larger mesh codend and continued making pairs of tows against the *Albatross III's* 59 mm codend. A total of 11 successful tow pairs was completed.

No difference in relative speeds of the two vessels could be detected when the larger mesh was used on the *Delaware*. The vessels operated so close to each other that any measurable difference in speed would have been easily detected. This observation is of importance because many investigators have thought that the increase in efficiency caused by increases in codend mesh size was owing to an increase in speed of towing.

The data are given in Table F-33. An estimate of the selectivity of the 119 mm codend is obtained by calculating the percentage that the *Delaware* catch is of the *Albatross III* catch for each size interval. These percentages are shown in the table and plotted as a selection curve in Figure 38. The 50% point of 39.6* cm estimated from the selection curve, yields a selection factor of 3.3.

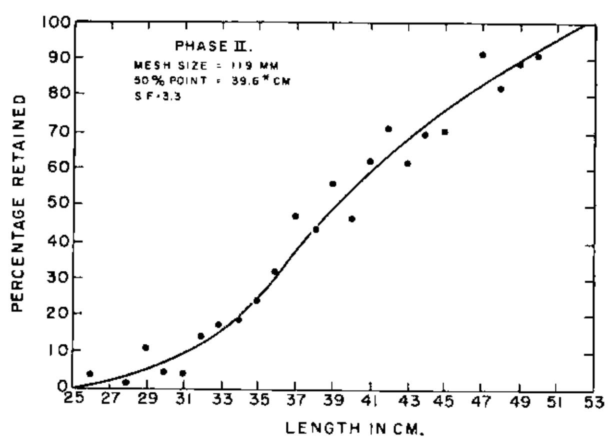


Fig. 38. Pairtows I, Phase II. Retention of sizes of haddock by a 119 mm mesh manila codend.

Phase III - Cotton. A series of 4 pairs of tows was completed with a single 120 thread cotton codend of 144 mm. mesh (*Albatross III*) and one of 84 thread, 57 mm mesh (*Delaware*). The data are given in Table F-34 and plotted as a selection curve in Figure 39. The usefulness of the data is severely restricted by a scarcity of fish within the upper end of the selection range. A 50% point of 52.4* cm may be estimated, however, providing a selection factor of 3.6 "Retention" of 100% is not attained.

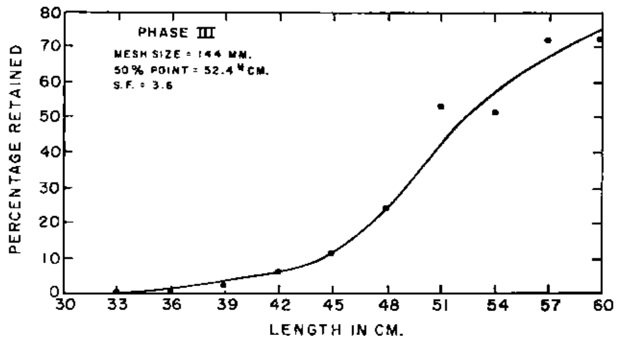


Fig. 39. Pairtows I, Phase III. Retention of sizes of haddock with a 144 mm single 120 thread cotton codend.

Phases IV and V - Cotton. A codend of single 120th cotton twine (*Delaware*) was tested against two different 84 thread control codends (*Albatross III*). The operations may be summarized as follows:

	Phase IV		Phase V	
	Mesh size (mm)	No. of pairs	Mesh size (mm)	No. of pairs
Test codend	106	8	111	12
Control codend	58		86	

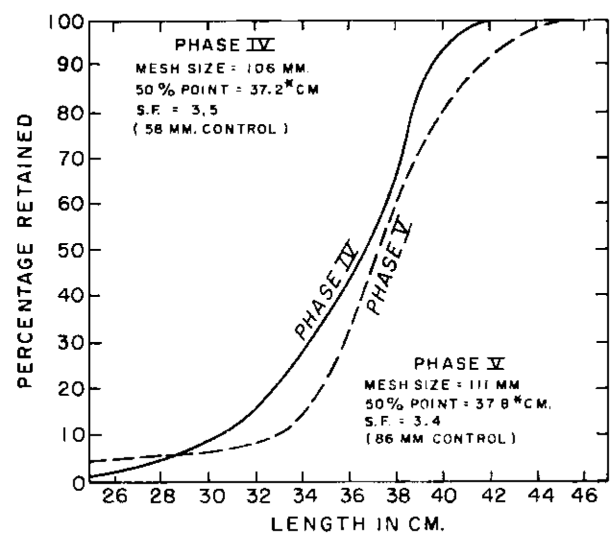


Fig. 40. Pairtows I, Phases IV and V. Retention of sizes of haddock with a single cotton codend of 106 and 111 mm. using controls of 58 and 86 mm. mesh size.

The data are given in Tables F-35 and F-36. Selection curves have been drawn for both phases in Figure 40. The curves for the two phases have somewhat different shapes owing to relatively higher retention in the middle of the selection range for the Phase V codend. The 50% points of 37.2* and 37.8* cm yield selection factors of 3.5 and 3.4 for Phase IV and V respectively. The increase in 50% point from Phase IV to Phase V is owing partially to the increase in average mesh size from 106 to 111 mm. That the escapement did not increase proportionately is shown by the decreasing selection factor. No explanation can be given for this decrease. The lower limb of the Phase V curve has undoubtedly been affected by escapement from the 86 mm. control codend, thus increasing the apparent retention.

Results with Covered Codends

We have carried out covered codend experiments for haddock with manila, cotton, and synthetic twines of various sizes. Most of the results are for double manila codends as other twines are used very infrequently in our haddock fishery. The various experiments with manila codends are considered below in the order of their occurrence.

Michigan **1 and 2.** Double manila 50/4 codends of three mesh sizes were tested during

June 1952, on two cruises of the *Michigan*. A preliminary account of these results has been published previously (Clark 1952).

In these experiments the *Michigan*, a commercial Boston trawler, modified her usual operations only to include handling of the cover catch. This catch did not exceed 1,600 pounds during the two cruises and was only rarely over 500 pounds. The four biologists aboard usually found it possible to measure the fish as fast as the six fishermen could handle them by using the "punch strip" method of measuring (*see* p. 26). In rare cases, such as the 1,600 pound catch of small fish in the cover, we were able to measure only a sample of the cover catch. Large catches in the codend (up to 5,500 pounds) prevented us from measuring any fish of the "large" category in a few instances.[2] As large haddock (about 48 cm and larger) are out of the selection range of the mesh sizes tested, the results were not affected.

In Series I we completed 11 successful tows with a codend of 92 mm mesh size (average for the 11 tows). The data for the series are given in Table F-37. Separate selection curves are plotted in Figure 41 for all 11 tows and for the last 6 tows only.

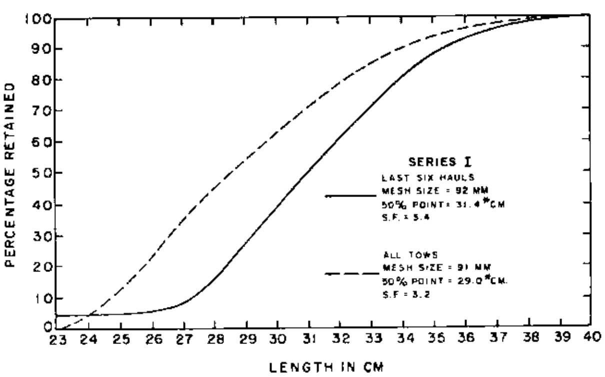


Fig. 41. *Michigan* Series I. Selection curves for a double manila 50/4 codend at 91 and 92 mm mesh size.

The curve for all tows shows the effect of poor escapement for the first five tows. The escapement in the last six tows, with mesh size only 1 mm larger than the average for all, is shown to be much greater. Conditions were the same for all tows, as far as can be determined, except that slightly different areas were fished. The selection factors of 3.2 and 3.4 obtained from these experiments agree well enough with the factor obtained from the paired tow experiment (3.3) with manila.

On this, our first such selection experiment, we did not realize the importance of changes in mesh size from tow to tow when catching large quantities of fish. Therefore, we did not measure the meshes until after tow No. 34 which was the twelfth tow with this codend. Another measurement was taken after the twentieth tow (No. 45). We have data for only 11 of the 20 tows because the *Michigan* fished continuously while we only measured fish daytimes. Our average mesh sizes for the Series I codend are based solely on the two measurements above, and our extrapolated estimates, particularly for the first several tows, may be somewhat unreliable.

In Series II we completed 5 successful tows with a codend of 98 mm. The data are given in Table F-38. The selection curve is plotted in Figure 42. A 50% of 31.4* cm was obtained, yielding a selection factor of 3.2 which is identical to that for all tows in Series I.

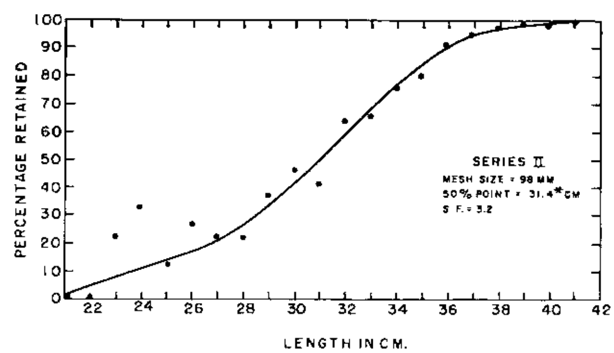


Fig. 42. *Michigan* Series II. Selection curve for a double manila 50/4 codend of 98 mm mesh.

In Series III we completed 14 successful tows with a codend which remained at 105 mm throughout the experiment (it had been used previously and was well set). The data for the series are given in Table F-39. The selection

[2]) Haddock fishermen separate their catches at sea into the following categories: *scrod* haddock, weighing less than 2.5 lb and *large* haddock weighing 2.5 lb and more.

curve is plotted in Figure 43. A 50% point of 32.3* cm was obtained, yielding a rather low selection factor of 3.1 The low selection factor appears to result from the influence of two large tows (Nos. 47 and 48) with 50% points of 30.7* cm and 30.6* cm. To determine if the size of the catch was related to escapement, we have plotted 50% points against both the weight and number of haddock taken on each tow in Figure 44. The 50% points appear to be more closely

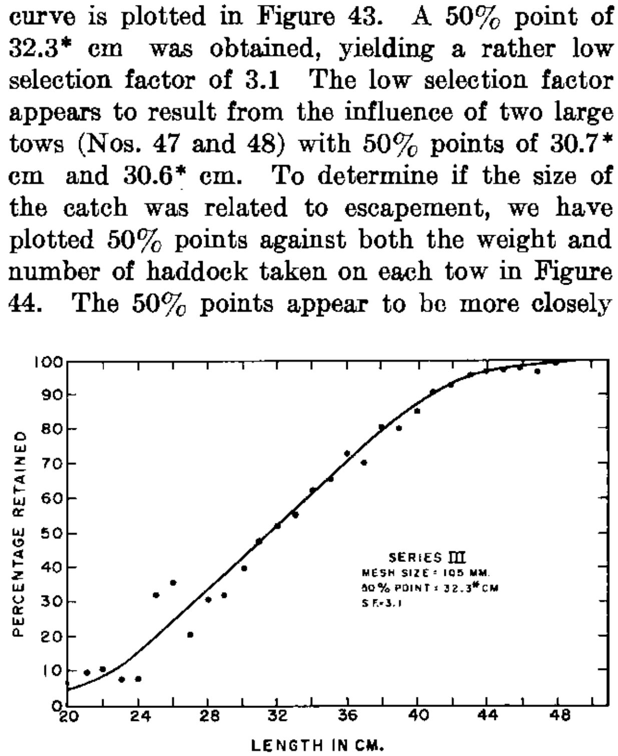


Fig. 43. *Michigan* Series III. Selection curve for a double manila 50/4 codend of 105 mm mesh.

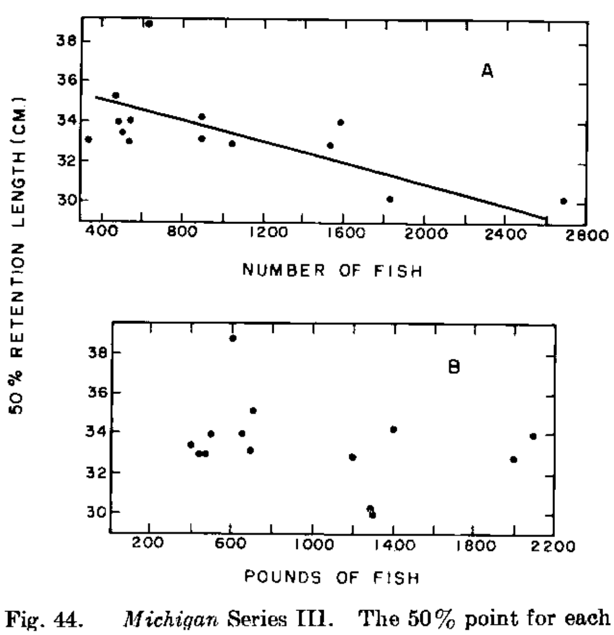


Fig. 44. *Michigan* Series III. The 50% point for each tow plotted against weight (B) and numbers (A) taken.

related to numbers than to weight. Although tows 47 and 48 exceeded all others in respect to numbers caught, they were equalled or exceeded in weights of catch by tows 2, 12, 13 and 14 which had high 50% points, ranging from 33.3* to 34.8* cm. We may then infer that the lowered escapement was perhaps owing not to greater weight but to greater numbers of fish in the codend. The reason for this is not clear since it would appear that the bulk of fish blocking the meshes would be the more important inhibiting factor.[3] Perhaps it is caused by an active competition among the fish for the larger individual meshes of the codend.

Wisconsin. Two double manila 50/4 codends were tested on a cruise of the *Wisconsin* in October 1952, using the same procedure as that described for the *Michigan* experiments.

In Series I we completed 17 successful tows for a codend with a mesh size which increased from 109 to 114 mm and averaged 112 mm. The data are given in Table F-40. A 50% point of 36.1*cm was determined from all 17 hauls, yielding a selection factor of 3.2. To study the effect of increasing mesh size upon the escapement, we divided the tows into groups on the basis of significant changes in mesh size. This division put 5 tows in Group I, 9 in Group II, and 3 in Group III. Selection curves for the three groups thus established are presented in Figure 45. We see that Group II and Group III curves

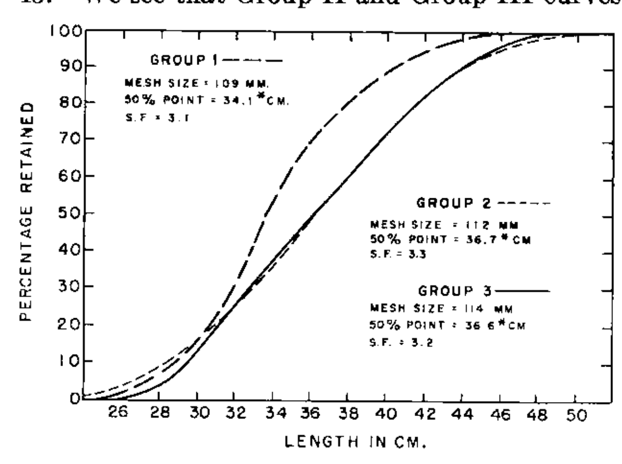


Fig. 45. *Wisconsin* Series I. Selection curves at three mesh sizes for a double manila 50/4 codend.

[3]) Upon completion of Series III the codend was reversed, replacing the larger meshes at the after end with the smaller meshes normal to the forward end. This reversal, reported on p. 32 resulted in a great reduction in escapement.

are nearly identical from 31 cm on. That the selection factor for Group II is higher may be owing to error in measurement or subsequent interpolation of mesh sizes. The curve for Group I, however, shows distinctly lower escapement. This may be due to the small catches taken in the initial tows which did not allow the meshes to become well "set." We have observed that the heavy twine of such codends remains rather gnarled until a good tow or two is made. The meshes will yield to the gauge and probably indicate a relatively larger mesh than is actually the case while being towed.

The relation between numbers caught per tow and 50% point is shown in Figure 46. A negative relation, similar to that of *Michigan* Series III data, holds generally for all groups combined. Within individual groups the relationship is consistent only for Group II, however, catch size appearing to have no significant effect for the other two groups.

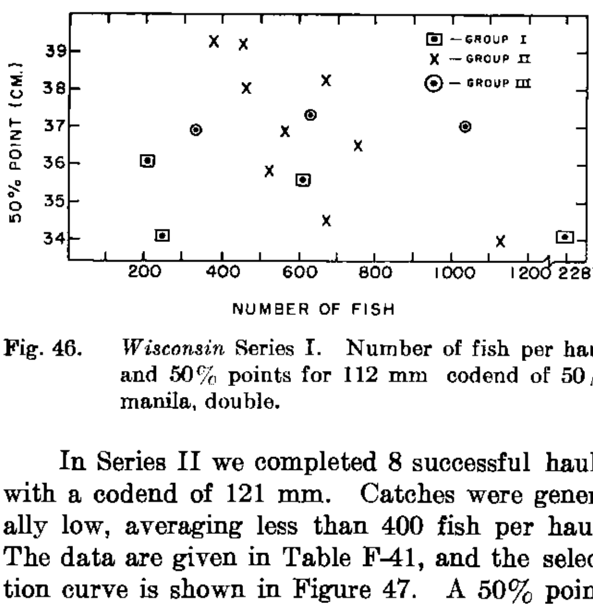


Fig. 46. *Wisconsin* Series I. Number of fish per haul and 50% points for 112 mm codend of 50/4 manila, double.

In Series II we completed 8 successful hauls with a codend of 121 mm. Catches were generally low, averaging less than 400 fish per haul. The data are given in Table F-41, and the selection curve is shown in Figure 47. A 50% point of 39.9* cm was obtained, yielding a selection factor of 3.3.

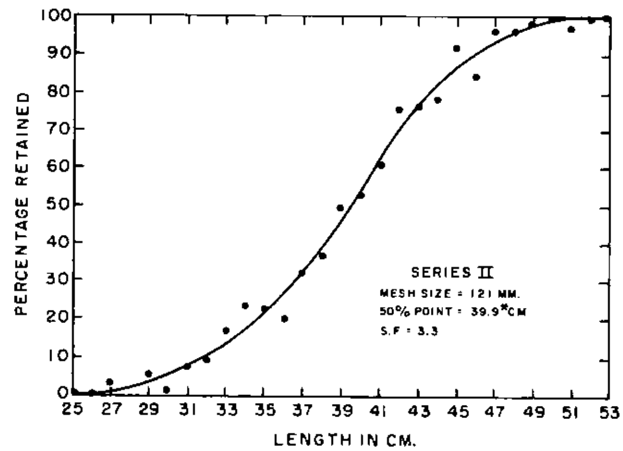


Fig. 47. *Wisconsin* Series II. Selection curve for a double manila 50/4 codend of 121 mm mesh.

High escapement on certain tows in this series appeared to be associated with the presence of mackerel in the cover. We cannot do more than note this occurrence because our records of incidental species are limited to general notes rather than quantitative estimates. We did, for instance, record that 1,500 pounds of mackerel were taken in the cover on tow 28 which was characterized by high escapement and yielded a selection factor of about 3.5.

Albatross III - **No. 49.** Experiments with double manila codends of three mesh sizes were conducted on Cruise No. 49. The primary purpose was to investigate the effect of length of tow on escapement. We also made tows, with and without hides under the codend, to investigate escapement through the lower side of the codend. These results, discussed in other papers in this series, show that the removal of hides had little effect upon catches in the cover relative to catches in the codend. Increasing the length of tow increased the escapement. The results for the three codends may be summarized as follows:

Series	Mesh Size (mm)	Type	Selection factor for tows of 20 min.	40 min.	60 min.	80 min.
I	113	50/4	3.0	3.1	3.3	3.4
II	123	45/4	---	3.0	3.2	3.3
III	73	75/4	---	3.4	3.5	3.4

The summary shows that the heavy 45/4 twine yielded the lowest escapement. The light 75/4 twine, in general, yielded the highest escapement, and the 50/4 twine gave intermediate results. (The results for 60 and 80 minute tows are the mose useful because large U.S. haddock trawlers normally make tows of 70-80 minute duration.)

Albatross III - **No. 51.** Two series of tows with double manila codends were conducted on Cruise No. 51 in June 1953.

In Series I we completed 8 successful hauls with a 45/4 codend of 107 mm mesh size. The data are given in Table F-42, and the selection curve is plotted in Figure 48. A 50% point of 31.8* cm. was obtained, yielding a selection factor of 3.0. The low escapement from this cod end is owing in part to the fact that catches were too light to set the meshes, and the heavy 45/4 twine remained gnarled throughout the series. The one-hour tows made should have given a selection factor of 3.2 on the basis of the results obtained in the *Albatross III* No. 49 experiments. The *Albatross III* codend (123 mm internal size) was ordered to be the same size new, but had been stretched out better as shown by the difference of 16 mm in mesh size.

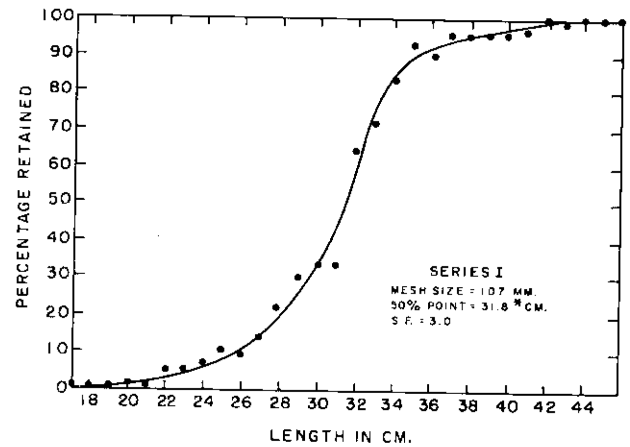


Fig. 48. *Albatross III* No. 51, Series I. Selection curve for a double manila 45/4 codend of 107 mm mesh.

In Series II we obtained additional results for the 73 mm. *Albatross III* No. 49, 75/4 codend.[4] We have plotted from these data the selection curve in Figure 49. The average mesh size of 75 mm obtaining during these tows was 2 mm

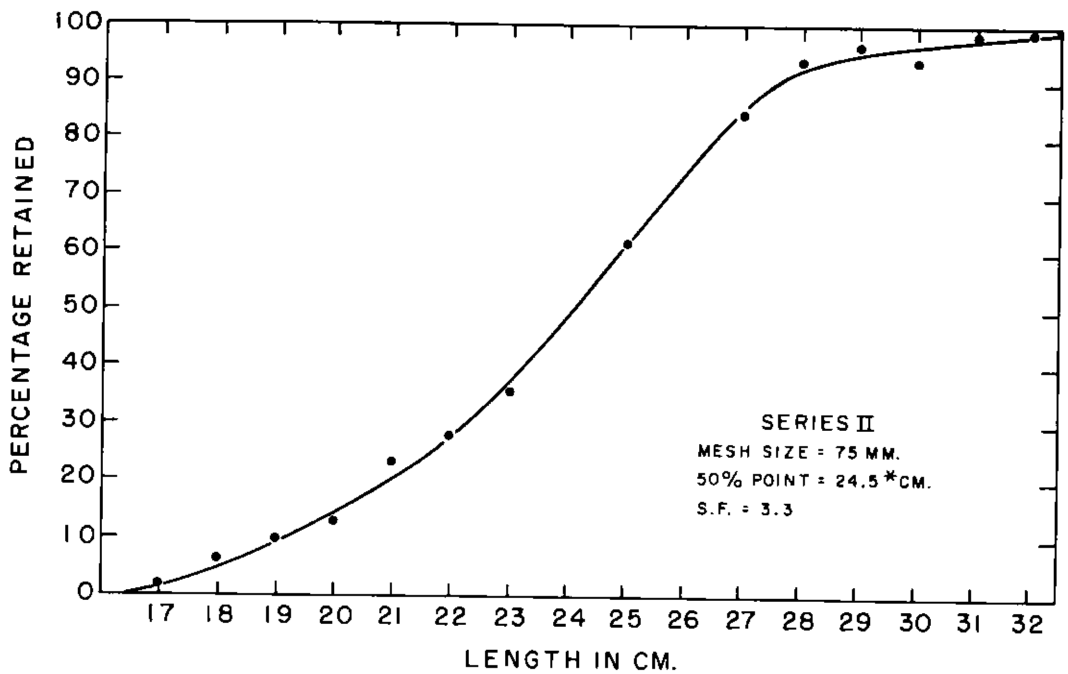


Fig. 49. *Albatross III* No. 51, Series II. Selection curve for a double manila 75/4 codend of 75 mm mesh.

[4]) The primary purpose of these tows was investigation of the validity of the effect of duration of tow. The results of this investigation and the data obtained are given in another paper in this series.

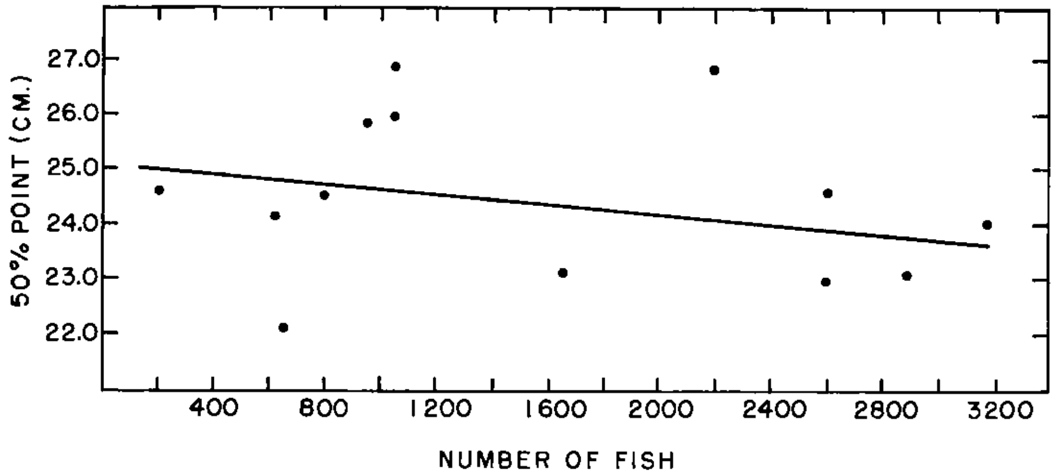


Fig. 50. *Albatross III* No. 51, Series II. Numbers caught and 50% points for a 75/4 double manila codend of 75 mm mesh.

higher than during the *Albatross III* No. 49 experiments. The 50% point of 24.5* cm yields a selection factor of 3.3 which is lower than 3.5 obtained from tows of the same length (60 min.) during the earlier experiments. Catches were three times as large, which we know now could very well have reduced the escapement. The relation between numbers caught and 50% point for each tow is shown in Figure 50. The relationship is weak, but an average of tows of less than 1,100 fish yields a selection factor of 3.4 while the large tows yield a selection factor of 3.3

Albatross III - **No. 52.** A series of 12 tows is available from a cover validity study conducted on Cruise No. 52 in July 1953. (The validity results are discussed in another paper in this series). The codend employed was of 45/4 double manila and averaged 113 mm for all tows. Although catches were only moderate, the mesh size increased from about 110 to 115 mm over the course of the experiments. (The data are considered in the paper mentioned above.) The selection curve is plotted in Figure 51. A 50% point of 36.8* cm was obtained, yielding a selection factor of 3.3 These results agree well with *Albatross III* No. 49 results for the same tow length (60 min.); the selection factors differ by only 0.03.

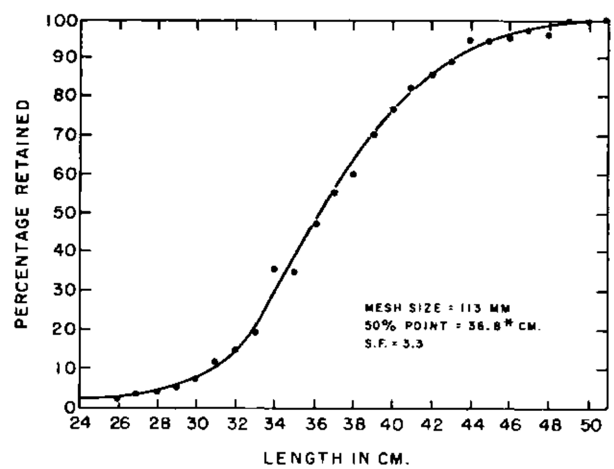


Fig. 51. *Albatross III* No. 52. Selection curve for a double manila 45/4 codend of 113 mm mesh.

Albatross III - **No. 59.** We tested three very large mesh double manila 45/4 codends on Cruise No. 59. An abundance of the large sizes required for these codends was located south of LaHave Bank (Subarea 4). Our previous studies had all been conducted on Georges Bank (Subarea 5). All tows were made within a restricted part of these grounds over a period of six days. No significant change in mesh size was observed for any codend during the course of the experiments. We thus were able to eliminate many

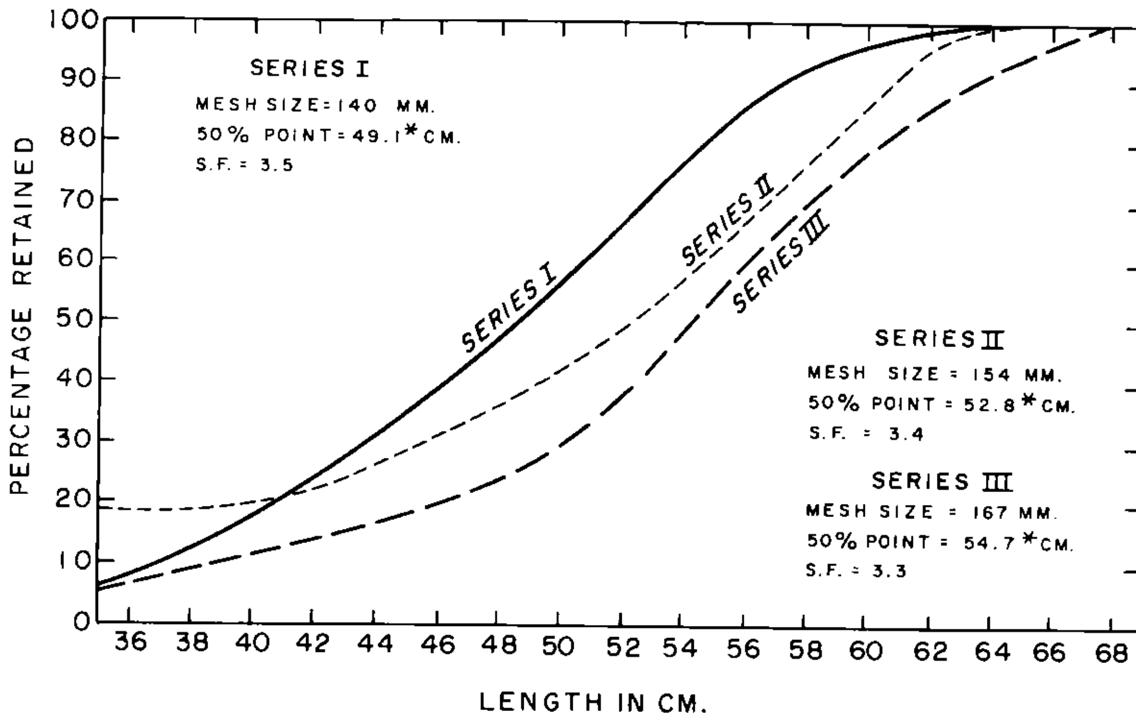


Fig. 52. *Albatross III* No. 59. Selection curves for double manila codends of 140, 154, and 167 mm mesh.

causes of variation which are troublesome in the comparison of results for various experiments. Ten successful tows were completed for each series. The data are given in Tables F-43, F-44 and F-45. Selection curves for each series are plotted in Figure 52. The results of the three series are summarized as follows:

	Series I	Series II	Series III
Selection factor	3.5	3.4	3.3
Mesh size (mm)	140	154	167
50% point (cm)	49.1*	52.8*	54.7*
Range of 50% points for individual tows (cm)	45-53	48-55	53-58
Average number of fish per tow	550	454	345
Range of numbers of fish per tow	342-785	326-630	276-500
Average tow duration (min.)	56	54	60

The selection factors are shown to decrease with increased mesh size. The average number of fish per tow also decreases, suggesting a positive correlation between number caught and escapement. This matter is elucidated in Figure 53 where we have plotted 50% points and numbers per tow for each series. The figure shows that the reverse is actually true; *i.e.*, a negative relation between catch size and 50% point is indicated. We must, therefore, assume that the differences in selection factor among the three series were owing to some cause other than numbers caught.

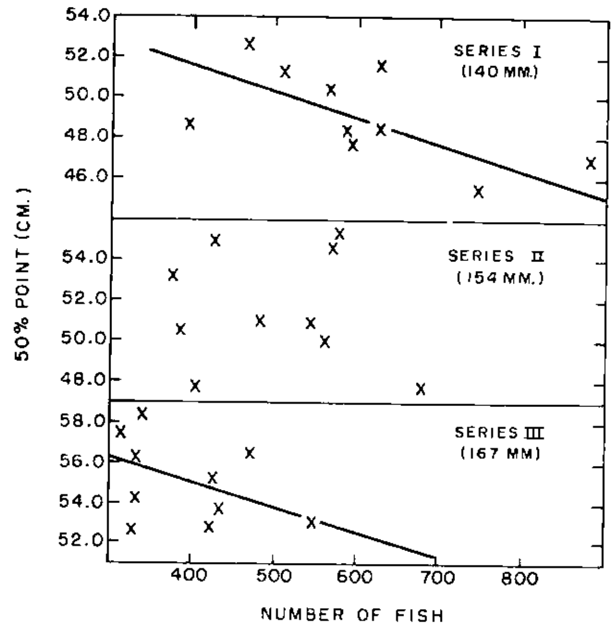


Fig. 53. *Albatross III* No. 59. Numbers of fish per tow and 50% points for three double manila 45/4 codends.

Cotton - Pairtows I and ***Priscilla V*****.** Three series of tows with single cotton codends of different mesh size and twine weights were carried out during the Pairtows I experiments. Some of the results are from studies on the validity of the covered codend method (*see* p. 41). Some haddock were also taken by a covered cotton codend during the *Priscilla V* silver hake experiments. These experiments have produced only limited results which may be summarized briefly as follows:

Experiment	Twine weight	Mesh size (mm)	50% point	Selection factor	No. of tows	No. of fish in cov.	No. of fish in c.e.
Pairtows I	120 th	138	49.6*	3.6	5	2289	305
Pairtows I	120 th	114	42.4*	3.7	8	355	501
Pairtows I	84 th	86	25.8*	3.0	6	85	2202
Priscilla V	72 th	73	20.8*	2.8	6	2157	192

Selection factors for the 138 and 114 mm codends agree well with the 3.4 to 3.6 for cotton from our paired tow results and the 3.5 and 3.6 for cotton reported by McCracken (p. 131) and by Margetts (p. 157). Selection factors for the two smaller codends of 3.0 and 2.8 appear to be underestimated. The low selection factor of 2.8 obtained from the *Priscilla V* experiments may be explained by slower towing speed and the different trawl used. Silver hake escapement also was very much lower than expected in these experiments (results appear in another paper in this series - *see* p. 81).

The occurrence of the low selection factor of 3.0 for the 86 mm codend cannot be easily rationalized. The experiment was conducted in exactly the same manner as the experiments with the two larger mesh sizes.

Nylon and Dacron - *Albatross III* **No. 74.** Covered codend experiments with various sizes of nylon and Dacron codends were conducted on Cruise No. 74 in May 1956.

The nylon used was a loosely braided twine developed for making cargo nets. It runs approximately 43 yards per pound and has a tensile strength of 1,000 pounds. While it has not won popularity with the larger trawlers, this twine has come into use in the "dragger" fleet (30-150 gross tons) in recent years.

The Dacron twine, manufactured especially for codends, was tightly braided and yet flexible,

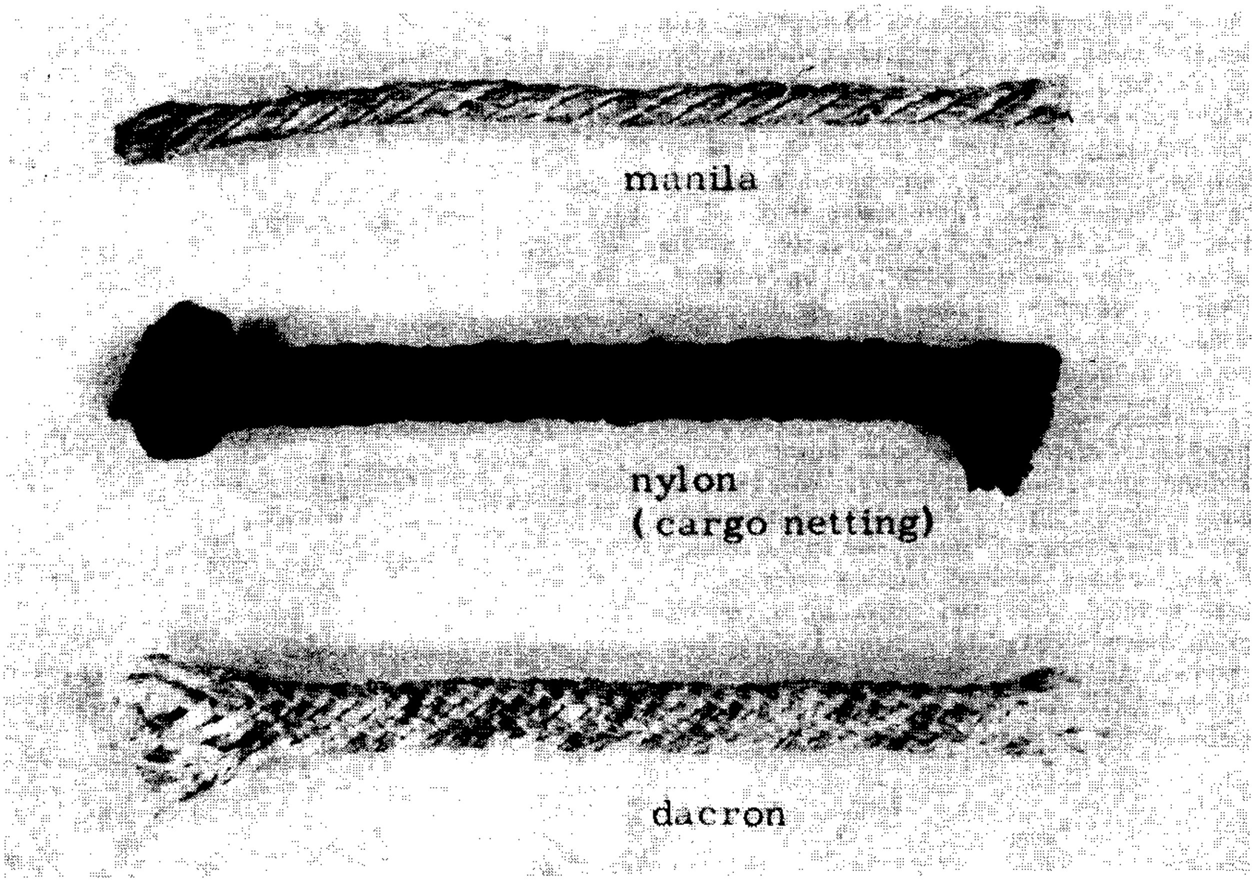


Fig. 54. Nylon (cargo netting type), Dacron, and 50/4 manila twine used in the selection experiments, Actual size.

although not as much so as the nylon. The two types of twine are illustrated in Figure 54 in comparison with manila.

None of the codends used increased in mesh size significantly during the experiments. The Dacron and nylon experiments may be summarized as follows:

Series	Material	Mesh size: Whole codend (mm)	Mesh size: Last 10 meshes (mm)	No. of tows	No. of fish in cov.	No. of fish in c.e.	50% point (cm)	Selection factor	Refer to Table No.
I	Dacron	127	124	15	2106	4619	39.8*	3.1	F-46
II	Nylon	105	113	11	2831	2378	40.2*	3.8	F-47
III	Nylon	134	134	14	2113	3075	46.1*	3.4	F-48
IVa	Nylon	122	119	10	931	2460	37.4*	3.1	F-49
IVb	Nylon	124	133	12	3259	2143	44.4*	3.5	F-50

From the selection curve for dacron plotted in Figure 55 we obtained a low selection factor of 3.1. The results, based on large numbers of fish and many tows, must be considered valid for this codend.

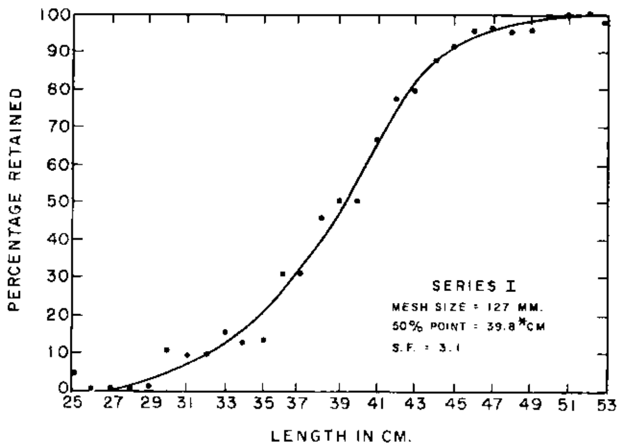


Fig. 55. *Albatross III* No. 74, Series I. Selection curve for a single dacron codend of 127 mm mesh.

From the selection curves for the Series II and III nylon codends of 105 and 134 mm plotted in Figures 56 and 57, we obtained selection factors of 3.4 and 3.8, indicating high escapement. The difference of 0.4 between the two selection factors must be assumed to be substantive because of the extensive series of tows involved and the large numbers of fish caught (5,209 and 5,188).

Series IVa and IVb results are for one nylon codend. The codend had been used previously, and the meshes were enlarged at the after end. For our experiments the codend was initially installed with these larger meshes forward. This arrangement resulted in very poor escapement, yielding a selection factor of 3.1. We were troubled by the low selection factor and reversed the codend, putting the larger meshes aft in an attempt to improve the escapement. The selection factor increased to 3.5 after the reversal. The selection curves for both series are shown in Figure 58. The increase in escapement effected through the reversal is consistent with studies reported in a previous paper in this series in which we demonstrated that most escapement takes place in the after end of the codend (*see* p. 36).

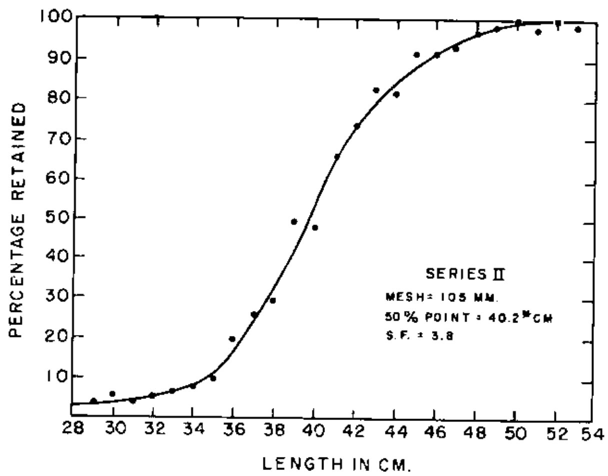


Fig. 56. *Albatross III* No. 74, Series II. Selection curve for a single nylon codend of 105 mm mesh.

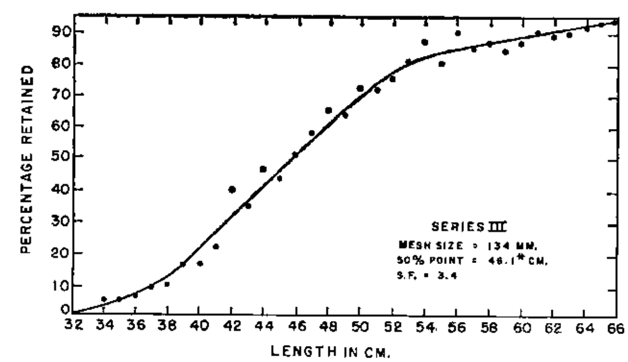


Fig. 57. *Albatross III* No. 74, Series III. Selection curve for a single nylon codend of 134 mm mesh.

Series I results with dacron provided a selection factor of 3.1 which is the same as for the Series IVa results. We also see (from summary table above) that the dacron codend had relatively small meshes at the after end. The average mesh size for the after 10 rows of meshes was 3 mm less than that for the whole codend in both cases. Both the over-all and the after section averages were the same (134 mm) for the Series III codend which yielded moderately good escapement. High escapement obtained for Series II and IVb where the average sizes for the after meshes were 8 and 9 mm larger than those of the whole codend.

For Series I, III, IVa, and IVb a negative relation between 50% point and numbers of haddock per tow may be seen. Numbers per

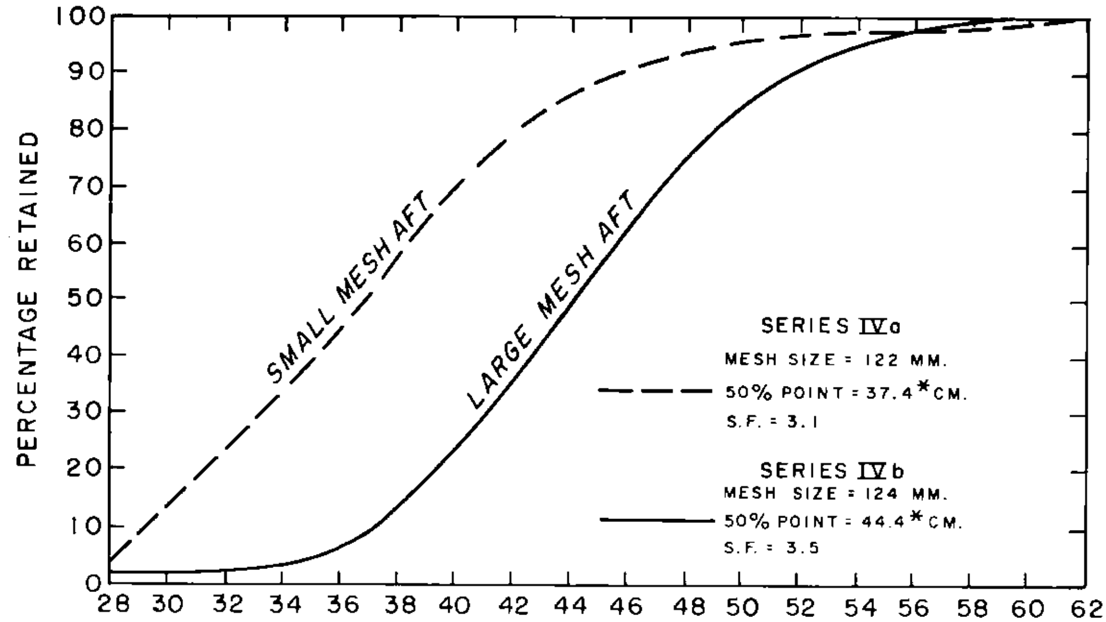


Fig. 58. *Albatross III* No. 74, Series IVa and IVb. Selection curve for a single nylon codend before and after reversal.

tow and 50% points are plotted for each series in Figures 59 to 63. Similar reductions in escapement associated with increasing size of catch have been demonstrated many times previously in this paper. The relations, as always, contain much variation but appear consistent enough to confirm previous results and to assist us in understanding the large differences we find in escapement from tow to tow and experiment to experiment.

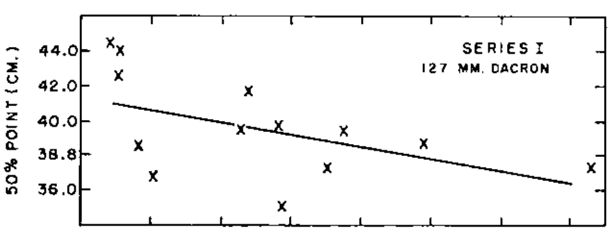


Fig. 59. *Albatross III*, No. 74, Series I. Numbers per tow and 50% points.

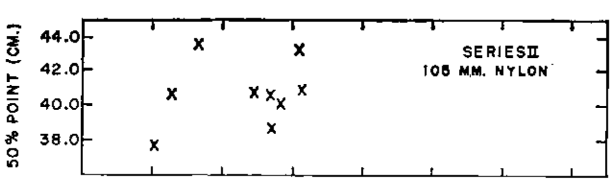


Fig. 60. *Albatross III* No. 74, Series II. Numbers per tow and 50% points.

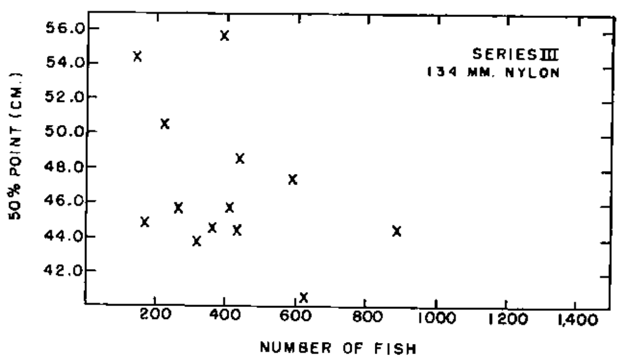


Fig. 61. *Albatross III* No. 74, Series III. Numbers per tow and 50% points.

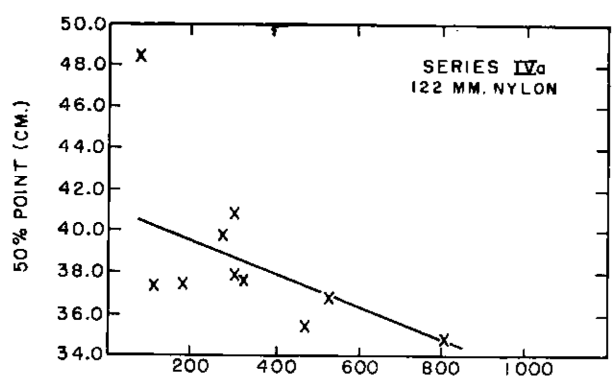


Fig. 62. *Albatross III* No. 74, Series IVa. Numbers per tow and 50% points.

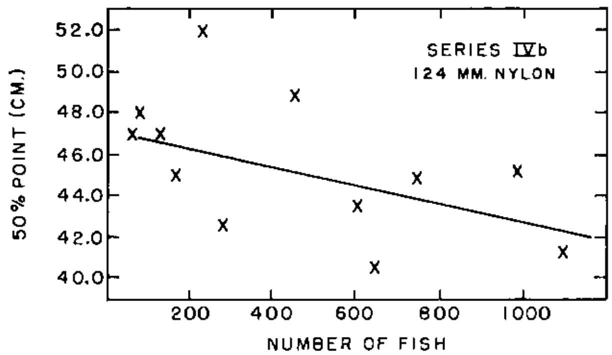


Fig. 63. *Albatross III* No. 74, Series IVb. Numbers per tow and 50% points.

Pairtows I and *Priscilla V*. Three series of tows with braided nylon (cargo netting) codends were carried out during the Pairtows I experiments. Some of the results have come from studies on the validity of the covered codend method, reported in another chapter in this series. Some haddock were also taken by a covered nylon codend on the *Priscilla V* silver hake experiments. The *Priscilla V* codend was made of a very light (400/3) twisted nylon twine.

These experiments have produced only limited results which may be summarized as follows:

Experiment	Twine spec's.	Mesh size: Whole codend (mm)	Mesh size: After quarter (mm)	No. of tows	No. of fish in cov.	No. of fish in c.e.	50% point (cm)	Selecton factor
Pairtows I	Braided 43 yd	135	130	3	1167	215	44.6*	3.3
Pairtows I	Braided 43 yd	107	113	7	285	854	44.3*	4.1
Pairtows I	Braided 43 yd	146	144	2	161	528	46.5*	3.2
Priscilla V	Twisted 400/3	84	85	4	169	203	(26) *	3.1

We see from the Pairtows I results that the highest selection factor (4.1) was obtained from the codend in which the after quarter of the codend had a higher average mesh size than the whole codend. The poorer selection factors were for the codends which had a smaller average size for the after quarter than for the whole codend These results thus confirm our *Albatross III* No. 74 findings in respect to the poor escapement from the codends with relatively small meshes aft.

The selection factor for the 400/3 nylon codend was low, as we might expect from the results of our other *Priscilla V* experiments. Escapement was even poorer than the relation between after quarter size and the whole codend size would suggest.

Discussion

A most interesting comparison of experimental results with selection applied in fisheries management is afforded through data from the regulated Georges Bank haddock fishery. In another paper in this series the lengths of haddock caught by trawlers fishing with the regulation mesh (average mesh size 116 mm) is compared with the lengths caught by trawlers fishing with the pre-regulation mesh (73 mm). These comparisons, extending over a three year period, yield an average selection factor of 3.3 which is exactly that predictable from our experiments for the type of fishing conducted on Georges Bank. This is perhaps the most substantial confirmation of our experimental results. (*see* p. 88).

It was not the purpose of this study to interrelate all the experiments and exhaustively analyze all factors affecting codend mesh selection but rather to present the large quantity of data available in summary form with the requisite descriptive material. The effect of certain factors, such as numbers caught and relative mesh size at after end of codend, were introduced only where necessary to explain the variation encountered among results of the many experiments. It was thus possible to prepare our data for presentation to experienced workers in the mesh selection field in the most concentrated form. A more exhaustive treatment of the subject is planned at a later date which will benefit from the results of the deliberations of the Lisbon conference.

Summary

Replicate tow and covered codend methods were used to determine the selectivity of codends of cotton, manila, and synthetic twines ranging in mesh size from 73 to 167 mm. Selection factors from 40 experiments are presented. Codends of 45/4 to 75/4 double manila twine yielded selection factors of 3.0 to 3.5. The variations in selection factor were shown to be associated with the number of fish caught per tow, increasing catches yielding decreasing selection factors.

Codends of single nylon twine yielded selection factors of 3.1 to 3.8. The one dacron codend tested yielded a selection factor of 3.1. The variations in selection factor were shown to be associated with numbers caught (as above) and with the size of meshes in the after part of the codend relative to the average size for the whole codend.

A summary of all experimental results for haddock is given Table 5.

TABLE 5. Summary of Haddock Escapement Experiments.

Twine type	Experimental method	Experiment	Twine weight	Mesh size mm	50% point cm	Selection factor
Double manila	Paired tows	Pairtows I	45/4	119	39.6	3.3
,, ,,	Cover	*Michigan*	50/4	91	29.0	3.2
,, ,,	,,	,,	50/4	98	31.4	3.2
,, ,,	,,	,,	50/4	105	32.3	3.1
,, ,,	,,	*Wisconsin*	50/4	109	34.1	3.1
,, ,,	,,	,,		112	36.7	3.3
,, ,,	,,	,,		114	36.6	3.2
,, ,,	,,	,,		121	39.9	3.3
,, ,,	,, 20 min. tows	*Alb.* No. 49	50/4	113	33.8	3.0
,, ,,	,, 40 ,, ,,	,, ,, ,,			35.2	3.3
,, ,,	,, 60 ,, ,,	,, ,, ,,			37.3	3.3
,, ,,	,, 80 ,, ,,	,, ,, ,,			38.6	3.4
,, ,,	,, 40 ,, ,,	,, ,, ,,	45/4	123	36.8	3.0
,, ,,	,, 60 ,, ,,	,, ,, ,,			39.7	3.2
,, ,,	,, 80 ,, ,,	,, ,, ,,			41.2	3.3
,, ,,	,, 40 ,, ,,	,, ,, ,,	75/4	73	24.8	3.4
,, ,,	,, 60 ,, ,,	,, ,, ,,			25.2	3.5
,, ,,	,, 80 ,, ,,	,, ,, ,,			24.8	3.4
,, ,,	,,	*Alb.* No. 51	45/4	107	31.8	3.0
,, ,,	,,	,, ,, ,,	75/4	75	24.5	3.3
,, ,,	,,	*Alb.* No. 52	45/4	113	36.8	3.3
,, ,,	,,	*Alb.* No. 59	45/4	140	49.1	3.5
,, ,,	,,	,, ,, ,,	45/4	154	52.8	3.4
,, ,,	,,	,, ,, ,,	45/4	167	54.7	3.3
Single cotton	Paired tows	Pairtows I	120th	144	52.4	3.6
,, ,,	,, ,,	,,	120th	106	37.2	3.5
,, ,,	,, ,,	,,	120th	111	37.8	3.4
,, ,,	Cover	,,	120th	138	49.6	3.6
,, ,,	,,	,,	120th	114	42.4	3.7
,, ,,	,,	,,	84th	86	25.8	3.0
,, ,,	,,	*Priscilla V*	72th	73	20.8	2.8
Single dacron (Br.)	Cover	*Alb.* No. 74		127	39.8	2.1

TABLE 5. Summary of Haddock Escapement Experiments (cont.)

Twine type	Experimental method	Experiment	Twine weight	Mesh size	50% point cm	Selection factor
Single nylon (Br.)	Cover	*Alb.* No. 74	*1000	105	40.2	3.8
,, ,, ,,	,,	,, ,, ,,	,,	134	46.1	3.4
,, ,, ,,	,,	,, ,, ,,	,,	122	37.4	3.1
,, ,, ,,	,,	,, ,, ,,	,,	124	44.4	3.5
,, ,, ,,	,,	Pairtows I	,,	146	46.5	3.2
,, ,, ,,	,,	,,	,,	135	44.6	3.3
,, ,, ,,	,,	,,	,,	107	44.3	4.1
Single nylon (twist)	,,	*Priscilla V*	400/3	84	26	3.1

Appendix

Albatross III Cruise 24 Alternate Tow Experiment

An alternate tow experiment was carried out on Georges Bank in 1949 to determine the selectivity of a codend of 75/4 (double) manila twine. The nets used were the standard 1-1/2 "Iceland" type fitted with codends of 127 and 95 mm.[1]

The results from this experiment have not been published heretofore because we were uncertain of their validity. The very fact that these results do not agree with covered net experiments, however, makes them appropriate to the study of methodology of gear selection experiments.

Haddock was the only species caught in sufficient quantity to provide meaningful results in this experiment. A series of 18 pairs of tows was completed.

The results from the original unpublished report (by Louis D. Stringer and the present author) are summarized in Table 6. The actual catch made by the 95 mm codend is shown in Column A. Because the 95 mm codend was itself selecting sizes of fish, an adjustment was employed to estimate the numbers of each size which entered it. This adjustment was based upon the percentages of each size retained in a 95 mm codend (Column B) determined by replicate tow experiments as reported by Herrington (1935)[2] The calculated total number of fish entering the 95 mm codend is shown in Column C. The actual catch made by the 127 mm codend is shown in Column D. The percentages that the 127 mm codend catch (Column D) were of the 95 mm codend adjusted catch (Column C) are shown in Column E.

These figures represent our best estimate of the selectivity of the 127 mm codend. The percentages for Column E are plotted in Figure 64, and smoothed percentages read from the graph are shown in Column F of the table.

The 50% point of 48.5* cm estimated in Figure 28 yields a selection factor of 4.8 which is much higher than those determined from covered codend experiments. If the catches of the two codends had been directly compared (*i.e.*, without adjusting for escape through the 95 mm codend), the 50% point would have been decreased only a few mm. The 25% point, however would have been decreased by about 2 cm and the 10% point by about the same amount.

1) Converted to standard measurement (pressure gauge, internal) from original measurements.

2) Herrington, W. C., 1935. Modifications in gear to curtail the destruction of undersized fish in otter trawling. *U.S. Dept. Comm. Bur. Fish.*, Inv. Report 24(1): 48 pp.

TABLE 6. Catches in 95 mm and 127 mm codends and calculated percentage retention of the 127 mm codend.

	A	B	C	D	E	F
Fish length	Numbers of fish retained by the 95 mm codend	Percentage retention of a 95 mm codend $\frac{100}{B} \times A$	Total numbers of fish which entered the 95 mm codend	Numbers of fish retained by the 127 mm codend	Unsmoothed retention of the 5-inch net (%) D/Cx100	Smoothed retention of the 5-inch net (%)
7	1	0	?	0	–	–
9	17	0	?	0	–	–
11	17	0	?	0	–	–
13	1	0	?	0	–	–
15	0	0	?	0	–	–
17	3	0	?	0	–	–
19	59	0	?	0	–	–
21	217	2	10,850	2	–	–
23	395	3	13,167	0	–	–
25	404	3	13,467	6	–	–
27	225	5	4,500	6	0.1	–
29	105	7	1,500	6	0.4	–
31	43	9	478	1	0.2	0.2
33	37	12	308	6	1.9	0.3
35	92	15	613	2	0.3	0.6
37	105	23	457	7	1.5	1.5
39	117	39	300	12	4.0	5.5
41	121	60	202	29	14.4	12.5
43	122	75	163	34	20.9	20.9
45	145	86	169	53	31.4	31.4
47	137	93	147	62	42.2	42.2
49	103	97	106	62	58.5	58.5
51	59	99	60	58	96.7	80.5
53	62	100	62	50	80.6	95.0
55	46	100	46	47	100.0+	99.5
57	22	100	22	44	100.0+	100.0
59	17	100	17	23	100.0+	100.0
61	10	100	10	20	100.0+	100.0
63	7	100	7	12	100.0+	100.0
65	12	100	12	12	100.0+	100.0
67	9	100	9	12	100.0+	100.0
69	4	100	4	4	100.0+	100.0
71	0	100	0	6	100.0+	100.0
73	3	100	3	2	67.7	100.0
75	1	100	1	2	100.0+	100.0
77	1	100	1	0	–	100.0
79	0	100	0	1	100.0+	100.0
TOTALS	2719		46,681	581		

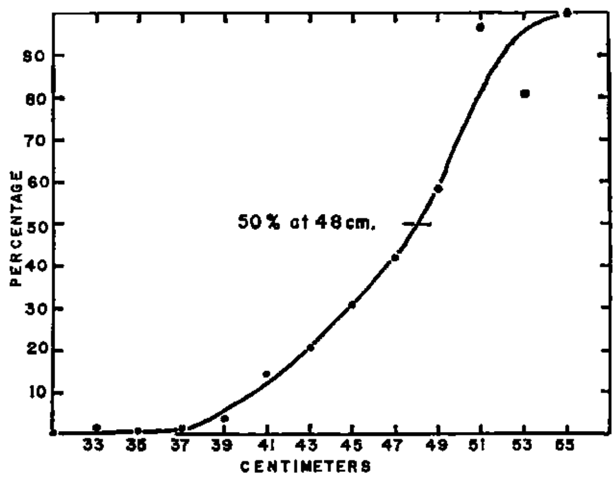


Fig. 64. The percentage of sizes of haddock retained by a double manila codend of 127 mm mesh.

Greater catches of the larger sizes of haddock were taken by the larger mesh. The 127 mm codend caught 185 fish of over 50 cm, and the 95 mm codend caught 132 of these. This phenomenon has been demonstrated by a good many other replicate tow experiments. It is customary to adjust the whole catches on the basis of the proportions of fish which are definitely past the 100% point in the two codends. The numbers of fish in the 95 mm codend would, by this method, be increased by the ratio 185/132. The results of such an adjustment would raise the 50% point to 51.5* cm, providing a selection factor of 4.1.

H. ESCAPEMENT OF SILVER HAKE THROUGH CODEND MESHES

Abstract

Covered codend experiments on the escapement of silver hake yielded selection factors of 2.6 to 3.4 for manila, 2.5 to 3.4 for cotton, and 3.2 to 3.8 for nylon. The selection factors for each type of material are shown to be linearly related to mesh size. It is suggested that the variation in selection factors results from differences in flexibility of the twines.

Introduction

A fishery for silver hake (*Merluccius bilinearis*) has been carried out for many years along the New England shores by a fleet of small draggers. Approximately 50,000 metric tons have been taken each year. Only in recent years has a fishery developed for the abundant stocks of silver hake offshore on Georges Bank. Haddock fishermen had frequently discarded great quantities of silver hake here before the Subarea 5 mesh regulation became effective. An extensive series of experiments was carred out in the autumn of 1954 to provide the mesh selection information needed to consider regulatory measures for the intensive inshore fishery and to determine the effect of diminished fishing mortality on the Georges Bank stock through use of large mesh by the haddock fleet.

Methods

The experiments were carried out aboard the *Priscilla V*, a small wooden dragger of the type that usually fishes for silver hake. Her towing speed approximates 2-1/2 knots. The characteristies of the vessel are given on p. 27.

The net employed for most of the work was a modified No. 35 cotton trawl rigged to conform as nearly as possible to average characteristics of the diverse types used in the fishery. The results for one codend (Series II) were obtained while conducting redfish selection experiments with a No. 35 manila trawl. Most tows were of one hour duration.

The experiments were restricted to the waters surrounding Cape Cod at depths of 20-40 fathoms. Some data collected incidentally while doing haddock selectivity experiments on Georges Bank with a standard No. 41 manila trawl are also reported. The trawls used in our experiments are described on p. 28. Codend escapement was measured with covers used in the manner described on p. 29.

The first three series of tows were made to study the validity of the covered codend technique. Although the cover was attached to the upper side only, most of the lower side was usually covered by chafing gear made from worn codends. We have shown that valid selection results were obtained by covering the upper side only, basing our conclusion upon experiments with 103 mm nylon codend in which tows with upper and lower side covers were compared with tows with an upper cover only. The results of this study (*see* p. 51) describe, in addition, how an initial masking effect was eliminated through various modifications of the net and cover.

During the first two series of tows the top belly was completely covered to investigate escapement through this part of the net. In addition, a series of replicate tows was made with 2½ and 3½ inch mesh (knot centers, new) trawls to investigate escapement in all forward parts of the 3½ inch net. These results are reported in another paper of this series (p. 40).

Our experiments involved ten codends of different mesh sizes made of manila, cotton, and nylon twines. All were of single construction, with the exception of one of double manila. In addition, we determined the escapement from the 35 mm mesh cotton codend bag of the cover by applying over it a secondary cover of 16 mm mesh.

Results

The quantity of length data (60,000 fish) collected during these experiments does not permit us to list the results for individual tows. Accordingly, we have simplified our presentation by giving only a summary of the length data for each codend. The original data are available in the Woods Hole files. The basic data are presented in tables F-51 to F-64, and in an Appendix of 13 figures, also filed in the Secretariat in the form of selection curves. The results for silver hake obtained incidentally in haddock selection experiments on the *Albatross III* are also given in the above mentioned Tables F-51 to F-64.

A summary account of all the *Priscilla V* results and the codend specifications are presented in Table 7. The results show that the selection factors varied greatly – from 2.5 to 3.8. Much of the variation is of a systematic nature, however, with the selection factors being related in general to the type of twine. For a given mesh size, nylon allows the highest escapement, manila the lowest, and cotton an intermediate amount. This suggests a relationship between flexibility and escapement because the most flexible material (nylon) affords the greatest escapement and the least flexible (manila) the least escapement.

TABLE 7. Summary of *Priscilla V*. Codend escapement results.

Series	Codend Type: Material	Codend Type: Size	Number of Tows	Mesh Size: Makers Size in.	Mesh Size: Makers Size mm	Mesh Size: Gauge Size, after use mm	50% point cm	Selection Factor	Number of fish in: cov.	Number of fish in: c.e.
1	Manila	750/4[1]	6	4	102	94	28.4*	3.0	7427	6410
2	Manila	750/4	5	3	76	64	16.7*	2.6	544	3218
3a	Nylon	400/3	6	4¼	108	103	39.1*	3.8	2539	1374
3b	Nylon	400/3	3			103	38.6*	3.7	4428	1453
4a	Nylon	400/3	7	3½	89	85	29.8*	3.5	2626	2896
4b			10			82	27.7*	3.4	3284	3400
5	Nylon	400/3	4	2½	63	54	17.5*	3.2	216	2115
6	Cotton	72 thread	4	4½	114	96	32.4*	3.4	3324	2892
7	Cotton	72 thread	6	3½	89	73	19.9*	2.7	1514	5126
8	Cotton	72 thread	3	2¾	70	60	19.4*	3.2	631	3480
9	Cotton	72 thread	2	2	51	40	9.8*	2.5	37	221
10	Cotton	(cov) 21 thread	3	1½	38	35	9.3*	2.7	21	45
11	Manila	(dbl) 650/4	4	6	152	115	38.7*	3.4	704	119

1) Signifies twine made of four strands, each of 750 per pound runnage.

The relation between the 50% point and mesh size is not linear, as is the case with haddock and many other species, and in fact the selection factor increases with increasing mesh size (Fig. 65). The relationship of mesh size and selection factor is consistent for the manila and nylon codends, but the points for cotton vary considerably. The low selection factor for the 73 mm codend may be explained by the masking effect of the cover which was later eliminated by altering the gear, as previously mentioned. No explanation can be provided at present for the high selection factor for the 60 mm codend.

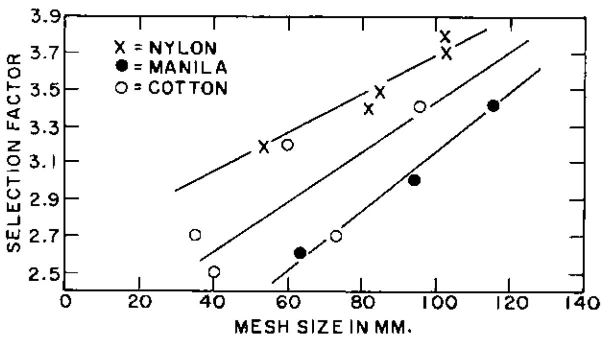


Fig. 65. Selection factor and mesh size for each codend tested.

The lines fitted to all the data for the three net materials tend to converge toward the higher mesh sizes. A theoretical point of equivalent escapement for all three materials is reached where the three lines would, if extrapolated on a straight line basis, intersect at a mesh size of about 180 mm and selection factor of 4.6. The maximum escape factor (girth factor times two) for silver hake is 4.8.

Flexibility differences may be involved in the increase in selection factor with increase in mesh size. The flexibility of the whole mesh, apart from that of the twine itself, can be assumed to increase with increase in mesh size; the longer the scope between knots the more flexible the mesh unit will tend to be. Thus the increasing selection factor for each type of twine may be owing to increasing flexibility of the mesh as a whole.

In addition to the flexibility of the twines there are differences in their frictional characteristics which one would expect to have some effect. The smooth nylon twine, for instance, should offer the least frictional resistance to the passage of fish.

Discussion

If our assumptions about twine flexibility are to be valid, then fish of the critical escape sizes must actually contact the netting in their escapement; otherwise the flexibility (or frictional) effects would not be important. We can further speculate that if our assumptions about flexibility of the whole mesh are valid, the fish must have been forcing their way through meshes. Meshes of the greatest flexibility would, of course, yield most easily to their efforts, and escapement would be greater.

This effect would be most pronounced in meshes which were of a shape not optimal for the escapement of silver hake. The relationship between fish shape and mesh shape has been developed in another paper of this series (pp. 61 to 62) for several species through means of the mesh index which relates body cross-section of the fish to the shape of the mesh. Where the two correspond most closely in shape the mesh index is highest. Partially closed meshes would give a low mesh index for silver hake because of their roundish bodies.

The small net and slow towing speed of the *Priscilla V* would both lend to a low passage of water through the codend mesh, and we might expect the meshes to be more closed than in a larger net being towed faster. This would result in reduced escapement. The limited results of the *Albatross III* with a larger net and faster towing speed (circa 4 knots) do, in fact, suggest that this was the case.

The silver hake taken by the *Albatross III* were too small to permit determination of a firm 50% point, although the data suggest a selection factor of at least 3.8 for the 123 mm double mesh used. A selection factor estimated from the *Priscilla V* results for manila mesh of the same size would be only 3.5. Something more definite could be determined, however, if we knew the exact mesh shape of the codends under tow.

We do have some limited observations of mesh shape in codends under tow. Underwater camera shots of the *Priscilla V* Series 7 cotton codends indicate mesh angles of 25°-30° at a speed of less than 1 knot. The angle would certainly be larger at the normal towing speed of about $2\frac{1}{2}$ knots. Underwater television studies conducted with a double manila codend under tow by the *Albatross III* at $2\frac{1}{2}$ to 3 knots indicate an average mesh angle of 62° at $2\frac{1}{2}$ to 3 knots and 75° at 4 knots.

An assumed mesh angle of 70° gives a mesh index for silver hake of .89. Adjusting the escape factor with these figures gives a figure of 4.3 which is a measure of the maximum escapement which could occur without distortion of fish or mesh. A mesh angle of 47° would provide the lowest selection factor; i.e., the 2.5 found for the 40 mm cotton codend. A mesh of this twine thickness and small size has a minimum flexibility and probably does not permit much distortion by the escaping fish, and escape would be most closely related to the mesh shape under tow for this codend. We might, therefore, assume that the mesh angle of the *Priscilla V* codends at the normal towing speed of $2\frac{1}{2}$ knots would be about 47° or perhaps only slightly less. The various mesh angles mentioned are demonstrated in Figure 66.

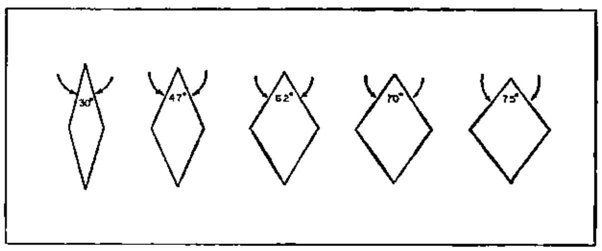


Fig. 66. The shape of meshes having various angles.

If the angle of the *Priscilla V* codend mesh was normally about 47° at normal towing speed (it was 25° to 30° at 1 knot), a selection factor of only 2.5 could be obtained without distortion. For factors as high as 3.8, observed for nylon, a considerable distortion of the mesh would be required. The more flexible twines would, of course, yield more easily and permit a higher escapement. This distortion would also be more easily achieved in the larger meshes. This would, as previously mentioned, explain the relation of selection factor to both twine type and mesh size. The convergence of the lines of Figure 1 at mesh size of 180 mm suggests that at this size maximum distortion is permitted for all of the materials tested and twine flexibility, *per se*, is no longer important.

Another factor that would cause the effect we have noticed is that the mesh might open wider of itself in the lighter twines and in the bigger meshes of any twine. This is only a matter for conjecture, but it does seem possible that such an effect could take place. This might come about through tbe lessened resistance of the netting to the water with the lighter, smoother twines and witb the larger meshes of a given twine.

Some further results of interest concerning the effect of twine flexibility are gained from a special experiment with a wire mesh codend (pp. 58 to 60). The stiffness of the wire held the mesh to nearly optimal shape for escapement of silver hake (mesh index = .99). We would thus expect to find maximum escapement for this mesh which would neither require nor permit distortion for easy passage. The escapement, compared with that of manila, was actually much reduced at the sizes below the 50% point but much increased beyond it, giving a dull selection curve. Although no explanation could be given for the low escapement below the 50% point, the higher escapement beyond it may very well be due to the optimal shape of the wire meshes.

I. ESCAPEMENT OF REDFISH THROUGH CODEND MESHES

Abstract

Experiments with covered codends of double manila twine were carried out with two types of trawls (large and small) to investigate their selectivity for sizes of redfish. The resulting selection factors of 2.2 to 2.6 did not differ with size of net.

The relation of catch size to escapement was investigated without conclusive results.

Meshing of redfish occurred, but not to the extent of hampering the fishing operation. The meshing records indicated that most redfish escape from the last one-third of the codend.

Investigations of the escapement of redfish through meshes of codends were carried out aboard the commercial dragger *Priscilla V* in November 1954 and the research vessel *Albatross III* in May 1956 (Cruise No. 64).

Gear and Methods

All codends used were of double manila twine. The trawl used by the *Priscilla V* was the standard No. 35 manila groundfish trawl. The trawl used by the *Albatross III* was the standard No. 41 Yankee manila trawl. The standard covered codend method was used in all cases. The results of replicate tow experiments, also carried out on this cruise (*see* p. 54), indicated that reliable results could be obtained for redfish selection with covered codends. Records of fish caught by the meshes ("meshed") were kept for all tows in order to investigate the objection that excessive amounts of meshing would occur when using large mesh.

Escapement Results, *Priscilla V*

In three series of tows with double manila codends very few fish were taken, and the results are therefore of limited usefulness. The operations may be summarized as follows:

Series	Mesh Size mm	50% Points cm	Selection Factor	No. of Hauls	Number of fish in c.e.	Number of fish in cov.
I	115	28.2*	2.5	8	396	507
II	99	24.0*	2.4	3	162	923
III	69	15.8*	2.3	4	147	124

A summary of numbers of fish of each length caught in the codend and cover for each series is given in Table F-65. The selection curves are shown in Fig. 67.

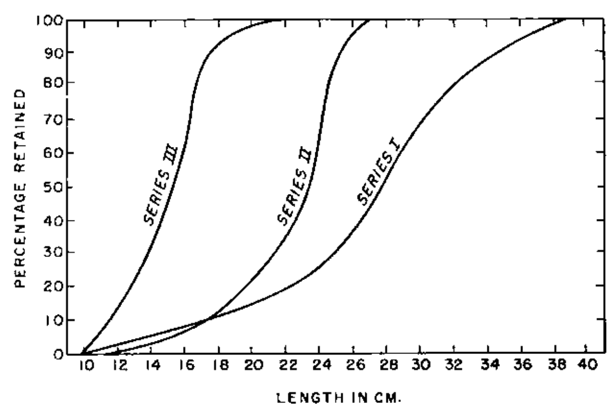


Fig. 67. Selection curves for *Priscilla V*; double manila codends of Series I (115 mm), Series II (99 mm), and Series III (69 mm).

"Albatross III" **Cruise No. 64.**

Three series of tows with double manila codends were carried out with the catches varying from small to very large. The numbers of fish of each length taken in the codend and cover are given in Tables F-66, 67 and 68. The operations may be summarized as follows:

Series	Mesh Size mm	50% Point cm	Selection Factor	No. of Hauls	Number of fish in c.e.	cov.
I	132	31.6*	2.4	2	360	1625
II	109	23.6*	2.2	8	7455	7620
IIIa	80	17.7*	2.2	4	4713	370
IIIb	82	21.3*	2.6	3	567	643

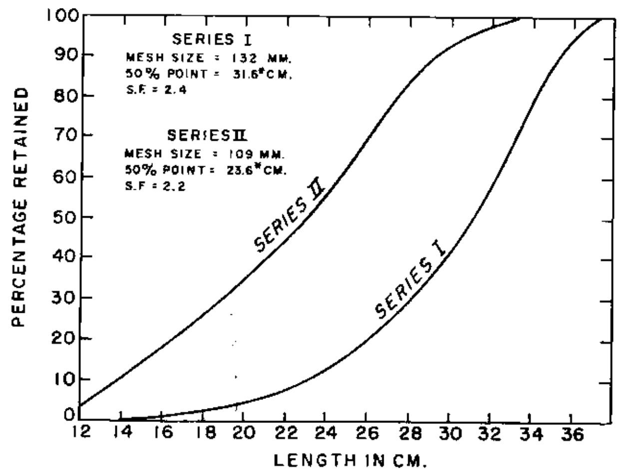


Fig. 68. Selection curves for *Albatross III* No. 64; double manila codends of Series I (132 mm), and Series II (109 mm).

The selection curves for Series I and Series II, plotted in Figure 68, yield selection factors of 2.4 and 2.2, respectively. These low selection factors may be expected of such deep-bodied and spiny fish.

The results of Series III have been divided into two sections; IIIa, Western Nova Scotian Banks, and IIIb, Gulf of Maine. The results for the two areas differed, although the codend was the same in both cases, the only difference being an increase of 2 mm in mesh size. The selection curves for the two series, shown in Figure 69, indicate a greater increase in escapement than the 2 mm difference in mesh size would lead us to anticipate. This difference is associated with a change in location, length composition, and size of catch. Which, if any, of these factors were causative cannot be inferred.

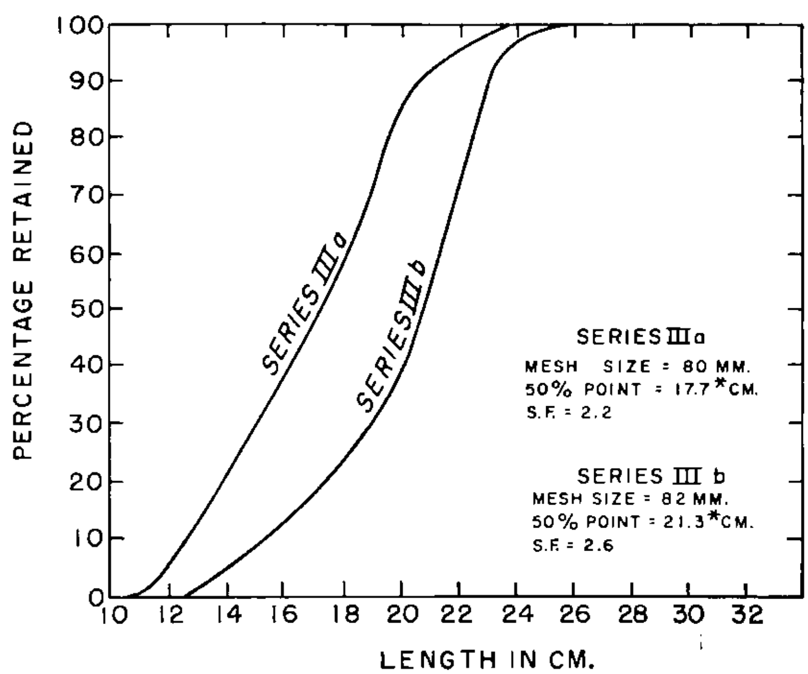


Fig. 69. Selection curves for *Albatross III* No. 64; double manila codends of Series IIIa (80 mm) and Series IIIb (82 mm).

Selection experiments with other species (*e.g.* haddock) have shown that catch size is inversely related to escapement. Therefore, we have plotted, in Figure 70, the 50% points against the numbers of redfish caught on individual tows in Series IIIa and IIIb. Escapement appears to be related to the size of the catches to some extent.

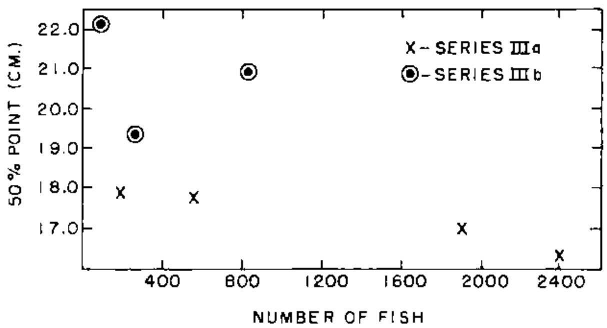


Fig. 70. Number of redfish per tow and 50% points for Series IIIa and IIIb.

The numbers per tow and 50% points for Series II, plotted in similar manner in Figure 71, show no relationship. The large tows of 1,243 and 9,811 fish have the same amount of escapement as the smaller tows of 262 and 449 fish.

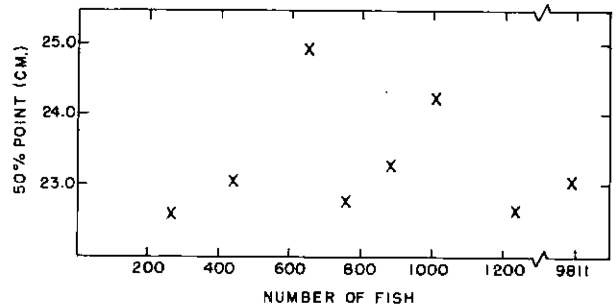


Fig. 71. Number of redfish per tow and 50% points for Series II.

The two tows of Series I of 1,405 and 580 fish gave similar 50% points, indicating no effect of catch size.

Meshing Results, *Priscilla V*

In Series I, 38 fish were meshed in the 115 mm codend. This is less than 7% of those which escaped into the cover. Very few were meshed in the other series.

Meshing Results, *Albatross No. 64*

Meshing was slight in all series: none were meshed in Series I; 43 in Series II; 90 in IIIa; and 17 IIIb. The greatest amount of meshing thus occurred in Series IIIa where it amounted to less than 25% of the total number in the cover.

TABLE 8. Numbers of fish gilled in Series IIIa.

Length cm	Number of Fish meshed in Codend by Zone 1	2	3	4	5	6	7-9	All Zones	Total in c.e.	Total in cov.	Total fish taken	Percentage in cover	Percentage Meshed
18		3						3	24	32	59	54.2	5.1
19		2	1					3	43	42	88	47.7	3.4
20	1	4	2					7	75	26	108	24.1	6.5
21	1	4	2	3	1	1		12	92	20	124	16.1	9.7
22	3	9	3	3	1			19	180	12	211	5.7	9.0
23	7	10	3	2	1			23	227	7	257	2.7	8.9
24	5	4	1	2		1		13	232	3	248	1.2	5.2
25	1	4	2	1				8	216	1	225	0.4	3.6
26			1					1	153	3	157	1.9	0.6
27		1						1	135		136	0.0	0.7
TOTAL	18	41	15	11	3	2	–	90					
Accum. Percent	20	66	82	94	98	100	100						

The codend in Series IIIa was divided into 9 lateral zones of 8 rows of meshes each, numbered 1 to 9 from the after end forward. In Table 8 we have listed the number of fish of each length meshed in the various zones of the codend, and for comparison the numbers of each length taken in the codend and cover over the range of sizes of fish that were meshed. Table 1 shows that the percentage of redfish of various lengths meshed in the codend reaches a peak of 9.7% at 21 cm where only 16.1% were escaping into the cover. Fewer fish are meshed at the lower lengths where more fish escape and also at the higher lengths where fewer fish escape.

In the three after zones, 82% were meshed, 18% in the three central zones, and none in the forward zones. We have shown in another section (p. 37) that over 80% of haddock which escaped did so through the after quarter of the codend. These meshing results suggest that redfish also escape mostly through the after end of the codend.

Summary and Discussion

The selection factors of 2.3 to 2.5 obtained from the *Priscilla V* experiments were confirmed by the selection factors of 2.2 to 2.6 obtained from the *Albatross III* experiments. The two entirely different fishing units and gear types thus produced similar results. We may tentatively conclude, although the data are sparse, that net type, overall size of the codend, speed of tow, and other related factors have limited effect, and that the most important factor influencing redfish escapement is mesh size.

Our results agree with the selection factor of 2.3 found by McCracken (p. 149) for the Gulf of St. Lawrence. Templeman (p. 204), working on Newfoundland Banks, obtained selection factors ranging from 2.1 to 2.7 which do not disagree with ours but merely extend the range. Our meshing results also agree with Templeman's in that the quantities involved were, in general, slight and meshing did not create any operational difficulties.

It would appear from the *Priscilla V* results that mesh size and 50% point are not linearly related, since the selection factor increases with increasing mesh size; *i.e.*, from 2.3 for 69 mm mesh to 2.5 for 115 mm mesh. This is probably an artifact, however, as it is not borne out by the more extensive *Albatross III* results. Nor do Templeman's results show a relationship between selection factor and mesh size. This matter would, nonetheless, bear further investigation.

J. EFFECT OF THE GEORGES BANK MESH REGULATION: SELECTIVITY AND FISHING POWER OF LARGE MESH OTTER TRAWLS

Abstract

A comparison is made of the catches of Georges Bank haddock trawlers with the $4\frac{1}{2}$ inch regulation mesh and the $2\frac{7}{8}$ inch pre-regulation mesh for the period 1954-1956. The regulation mesh caught 8% more large haddock and 19% less scrod haddock than the preregulation mesh. A selection factor of 3.3, calculated from the length compositions of the catches, agrees with that predicted from experimental results.

Introduction

The first management recommendation made by the International Commission for the Northwest Atlantic Fisheries following its inception was for a minimum mesh size of $4\frac{1}{2}$ inches (114 mm.) for otter trawls used in the Subarea 5 haddock fishery (Graham 1952). The recommendation was subsequently approved by all member nations and became effective as a regulation in June 1953.

Only the United States fishes extensively in Subarea 5 and *within this subarea* takes about 90% of its haddock catches on Georges Bank (5Z). A control plan was established for the Georges Bank fishery to permit assessment of the effectiveness of the regulation. Under this plan a group of large trawlers from Boston, varying in number from four to eight, was licensed to fish with the pre-regulation small mesh. Comparison of the records of this control group with those of the regulated vessels was expected to demonstrate the effectiveness of the regulation.

The change-over to the regulation mesh for the Georges Bank trawlers took place over a period of several months. Our information indicates that the conversion was completed and all regulated vessels were using large mesh by the end of 1953. The Georges Bank fishery is carried out for the most part by a fleet of about 47 large otter trawlers of 150-300 gross tons (OTL's) (*see* Fig. 72). The vessels all use the standard "No. 41 Yankee" trawl and generally fish the various parts of Georges Bank in company with one another in such a manner as to distribute their effort similarly with respect to gear, time, and area.

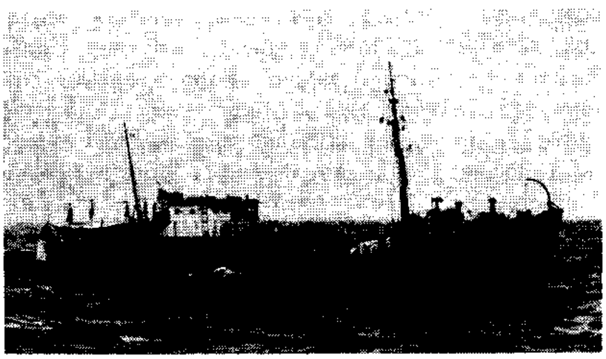


Fig. 72. A typical Georges Bank large otter trawler.

Comparisons of catches per day and lengths of haddock taken with regulation size and pre-regulation size ($2\frac{7}{8}$ inches, 74 mm) meshes have been published previously by Graham (1954) Graham and Premetz (1955) and Clark (1955). These studies indicated that the $4\frac{1}{2}$ inch mesh was releasing many of the smaller sizes, and that it was probably operating at a higher efficiency for sizes above the selection range. However, the methods of analysis were not sufficiently refined to express these differences in quantitative terms.

It is the purpose of this study to determine, from differences in catch per unit effort of pre- and post- regulation mesh sizes for various sizes of haddock, the selectivity and the relative fishing power of the $4\frac{1}{2}$ inch mesh. To make these determinations required the use of analytical methods which differ from those of the earlier studies mentioned above. The basic difference is in the derivation of comparable effort statistics.

Data Sources and Methods

The data were provided by routine interview and catch sampling activities at New England landing ports, primarily Boston where each vessel captain is interviewed upon arrival to obtain information upon area fished and effort expended. This information together with landings records provided us with the information required to determine catch per unit of effort for each vessel. The period of study is calendar years 1954, 1955, and 1956.

The routine sampling program at New England ports yields an extensive collection of length measurements of Georges Bank haddock (30,000 fish per year). These data were used to determine the length compositions of landed haddock for each mesh size category. A concurrent sampling program aboard the trawlers provided estimates of the length composition of haddock discarded at sea.

Codends of the Georges Bank trawlers were measured regularly at Boston through the period of study. The mesh sizes used represent the average for the whole upper side of the codend (usually 44-50 meshes in length). The Georges Bank OTL's invariably use bull hide protectors on the undersides of their codends. The codends are normally made of a single layer of netting with no protective material on the upper side. The twine used for the large mesh codends during the period of study was invariably 50/4 manila, double. Tow duration is normally 80 minutes.

To provide for direct comparisons between small- and large-mesh fleets, it is necessary to express the records in terms of catches per unit of effort. We did this in terms of the average catch per day's fishing.

The catch per day for each fleet was determined for each quarter by averaging the quarterly catches per day of the individual vessels after adjusting each to a standard fishing power. This adjustment was made by multiplying each vessel's catch per day by the reciprocal of its "efficiency factor", as listed in Table 9. Differences in fishing power of the vessels are thus compensated by adjustment to a theoretical standard fishing power. The necessity for such an adjustment is shown by the variation in efficiency factors from a low of 0.74 to a high of 1.55. The inclusion of either of these extremes in the small group of four to eight small mesh vessels would, of course, greatly influence its fishing power and average catch per day.

The catch per day values computed in the above manner are in terms of landed weight of gutted fish in the market categories of "large" and "scrod."[3] The weights were converted to numbers of fish of each length caught per day (from the length data derived from the sampling mentioned previously) by the small and large mesh fleets. The average numbers of each length discarded per day (from sampling at sea) were added to those landed to obtain the final estimates for each quarter.

Results

The catch per day (landings only) averages for the small and large mesh fleets for each quarter over the three-year period are given in Table 10. The small mesh vessels landed more scrod per day than large mesh vessels in every quarter except January-March 1954, when catches per day were generally poor and the two fleets landed equal amounts. A reverse, although less consistent, situation is shown for large haddock: large mesh outfished small mesh in the majority of quarters (7 out of 12, one equal). Large haddock are mostly over 48 cm and thus beyond the effective selection range of the large mesh.

The average catches per day of large haddock for the full three-year period (5,300 pounds for large mesh, 4,900 pounds for small mesh) show the large mesh to have an average of about 8% greater fishing power for large haddock. The average catch per day of scrod haddock for the three years (7,600 pounds for large mesh, 9,400 pounds for small mesh) shows the large mesh to have 19% lesser fishing power for scrod haddock.

The increased catches of large haddock by the large mesh fleet may reflect an increased efficiency of the large mesh gear. This could come about through improved hydrodynamic properties of the trawl, resulting perhaps from better straining action or greater distance towed because of the lowered resistance of the net. The former appears the more likely as we have observed (*see* p. 65) that in trawls of given specifications those modified only to the extent of having large mesh in the codend do not tow measurably faster than those with small mesh codends. We have observed on another occasion (*see* p. 41) that a trawl constructed wholly of very small mesh offers much more resistance than one of large mesh and consequently tows more slowly. The regulation required only a change in the codend and a small section of the after belly of our Georges Bank otter trawlers, other parts of the trawls have always been made of large mesh. This small alteration does not appear to be sufficient to alter the towing speed of the net significantly. We are thus led to believe that the increased catches come about from improved hydrodynamic properties of the net or other, indeterminant, factors rather than from increases in towing speed.

There is another entirely different factor which could cause the same effect; *viz*., the large mesh vessels making lower catches of scrod than small mesh vessels would direct their efforts toward concentrations of larger fish. This might mean shifting only a few fathoms in depth or a few hundred yards in distance. It is not possible to isolate this factor from present data. Nor have our attempts to measure its influence by studying fleet distributional patterns met with success.

However, other experiments, involving vessels with large and small mesh fishing side by side, have shown evidences of greater fishing power for large mesh. Davis (1934), for example, demonstrated an approximate 17% increase in catches of haddock beyond the selection range with large mesh in a well controlled experiment involving two vessels fishing for several months in close proximity. Our Pairtows I studies (p. 41), with two large trawlers fishing within a few hundred feet of each other, also show large mesh to operate at a higher efficiency than small mesh.

3) Haddock fishermen separate their catches at sea into official market categories of large (over 2½ pounds) and scrod (1½ to 2½ pounds). Fish smaller than 1½ pounds are often landed and included in the scrod.

TABLE 9. Efficiency factors for vessels by year and the average for all years.

Vessel	1954	1955	1956	Average
0275	1.25	1.28	1.40	1.31
0300	1.10	.94	.89	.98
0385	1.13	.79	.92	.94
0480	1.21	1.22	1.02	1.15
0490	.92	.71	.84	.82
0495	1.08	.89	.90	.96
0500	1.20	.96	.93	1.03
0525	1.10	1.15	1.06	1.10
0560	1.06	1.31	1.25	1.21
0790	.85	.62	.80	.76
1270	1.56	1.55	1.55	1.55
1590	.94	.97	.98	.96
2165	1.11	.84	1.42	1.12
2480	1.13	1.00	1.05	1.06
2760	.62	.86	.73	.74
2845	1.34	1.05	1.03	1.14
2880	.99	.95	1.08	1.01
2910	.77	.75	.74	.75
3045	1.36	1.37	1.37	1.37
3145	.72	.76	.92	.80
3020	.94	.89	.95	.93
3150	.68	.79	.89	.78
3195	.88	.72	.90	.83
3710	.94	.85	.79	.86
3740	.75	.76	.78	.76
3785	.89	.81	.75	.82
4005	.93	.90	1.02	.95
4065	.95	1.00	.88	.94
4075	1.15	1.08	1.01	1.08
4090	.99	1.22	1.09	1.10

TABLE 10. Catch per day for Georges Bank large otter trawlers in thousands of pounds landed.

	Large Haddock				Scrod Haddock			
	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.
1954:								
Large mesh	7.6	5.1	2.9	3.1	2.8	9.8	15.6	8.6
Small mesh	5.4	3.9	2.5	3.6	2.8	14.1	19.3	10.1
1955:								
Large mesh	7.1	6.1	4.3	4.7	4.0	8.3	11.8	4.6
Small mesh	7.3	6.3	4.3	3.9	6.2	9.8	16.0	5.2
1956:								
Large mesh	8.2	7.2	3.7	3.8	5.3	6.0	9.0	5.7
Small mesh	8.4	6.3	2.9	3.1	6.1	7.1	9.8	6.6
Quarterly Averages:								
Large mesh	7.6	6.1	3.6	3.9	4.0	8.0	12.1	6.3
Small mesh	7.0	5.5	3.2	3.5	5.0	10.3	15.0	7.3
3-year Average								
Large mesh		5.3				7.6		
Small mesh		4.9				9.4		
Percentage difference		+8.2%				−19.1%		

The lower catches of scrod for large mesh, on the other hand, may be easily explained by escapement through the meshes. To determine the size of fish passing through the meshes we compared the catches per day of each length by the small and large mesh trawlers. For simplicity of presentation the length data have been summarized by quarter for all three years and presented as the average numbers of each size caught (both landed and discarded) per day fished. These data are given in Table F-69 and plotted as length frequency polygons in Figures 73-77.

Examination of the polygons shows (from the greater catches of the small mesh) that selection was operating for large mesh below about 50 cm. Greater numbers of fish beyond the selection range (*i.e.* greater than 50 cm) were taken by the large mesh in all quarters (from 103-114% of small mesh catches). The average value of 108% for all quarters confirms our previous estimate of an 8.2% increased efficiency for large mesh based on landings in pounds of the market category "large."

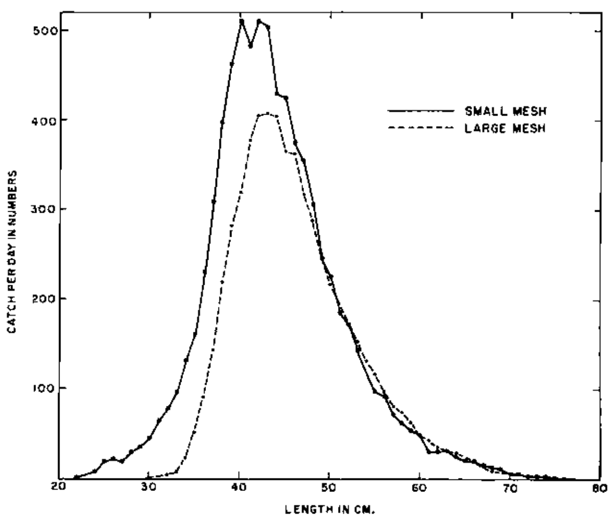


Fig. 73. Length composition of small and large mesh catches, average for all quarters.

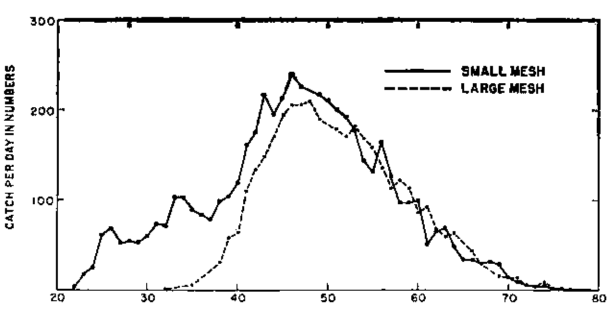


Fig. 74. Length composition of small and large mesh catches, January - March.

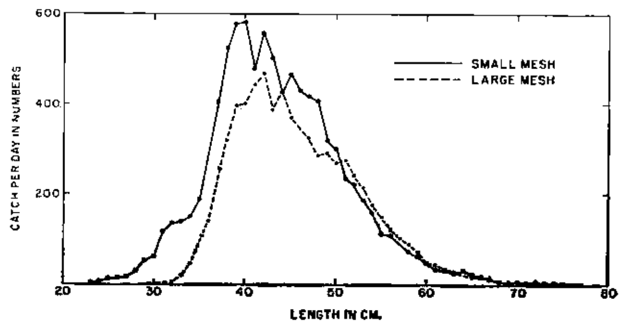


Fig. 75. Length composition of small and large mesh catches, April - June.

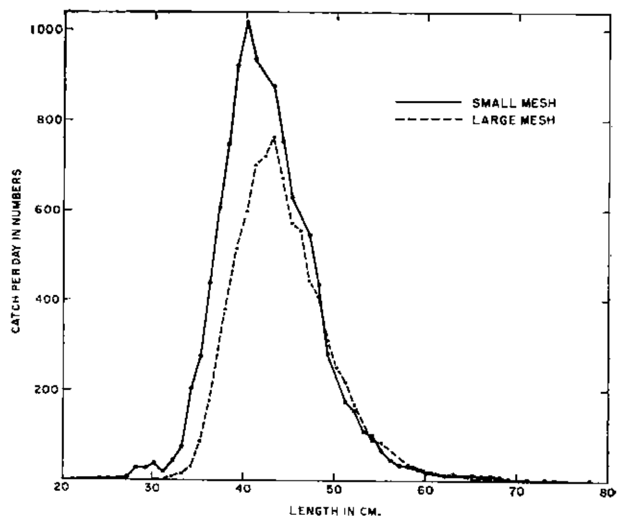


Fig. 76. Length composition of small and large mesh catches, July - September.

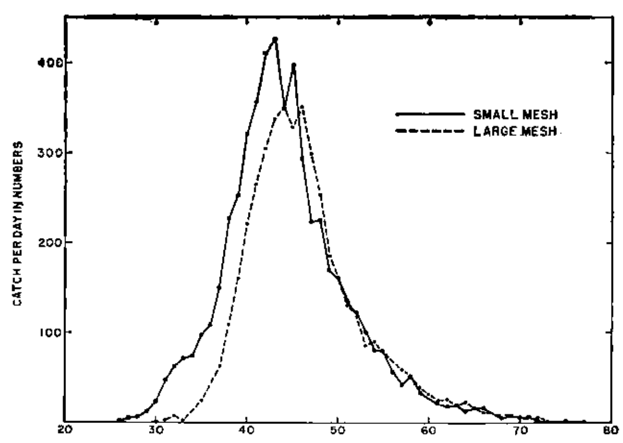


Fig. 77. Length composition of small and large mesh catches, October - December.

These data on numbers caught per day can also be expressed as selection curves in the manner of a replicate tow experiment. We have plotted, from the percentages given in Table F-69, selection curves for each quarter and for the full three-year period. These are presented in Figures 78-82. The curves are of the sigmoid type usual to mesh selection studies and, although considerable variation is evident, reliable 50% retention points may be estimated. These vary from 36.5* to 39.6* cm with an average for all quarters of 37.9* cm.

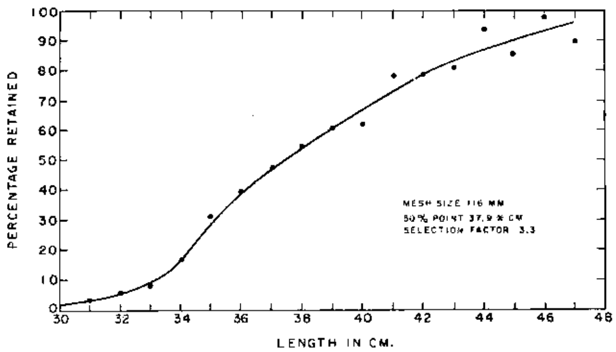


Fig. 78. Selection curve for all quarters. Mesh size 116 mm, 50% point 37.9 cm, Sel. F. 3.3.

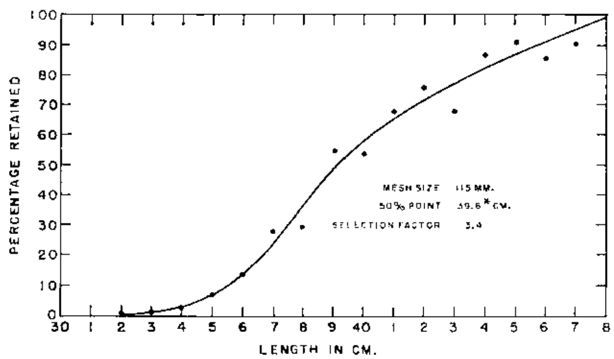


Fig 79. Selection curve for January - March quarter. Mesh size 115 mm, 50% point 39.6 cm, Sel. F. 3.4.

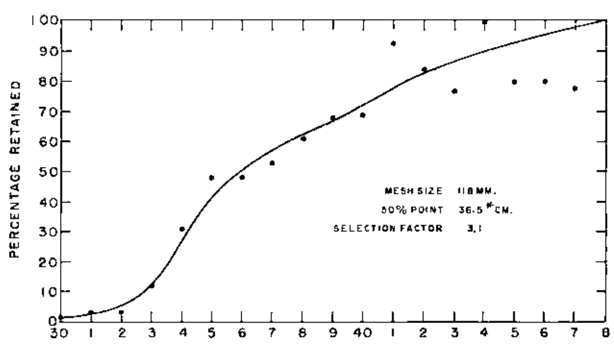


Fig. 80. Selection curve for April - June quarter. Mesh size 118 mm, 50% point 36.5 cm, Sel. F. 3.1.

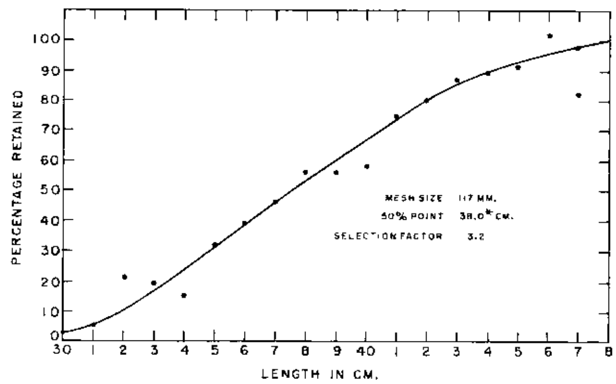


Fig. 81. Selection curve for July - September quarter. Mesh size 117 mm 50% point 38.0 cm, Sel. F. 3-2.

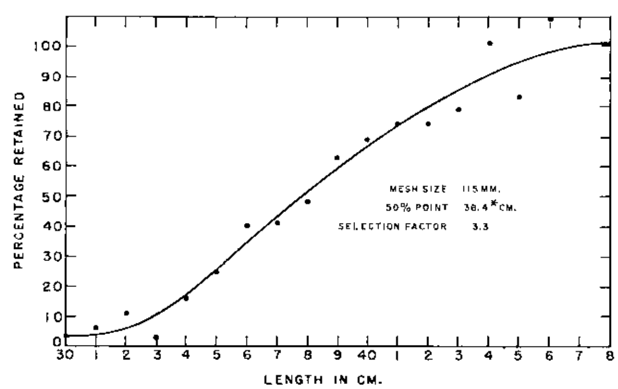


Fig. 82. Selection curve for October - December quarter. Mesh size 115 mm, 50% point 38.4 cm, Sel. F. 3.3

We had predicted a 50% point of 37.5 cm for the regulation, 114 mm, mesh on the basis of a selection factor of 3.3 (Graham 1952). The regulation mesh in actual practice, however, varied from 115 to 118 mm for the various quarters, as may be seen from the following tabulation of average mesh sizes:

	January to March		April to June		July to September		October to December	
	in	mm	in	mm	in	mm	in	mm
1954	4.56*	116	4.50	114	4.44	113	4.35	110
1955	4.55*	116	4.75	121	4.68	119	4.65	118
1956	4.49	114	4.70	119	4.65	118	4.64	118
Average	4.53	115	4.65	118	4.59	117	4.54	115

*partially estimated

We would then expect a 50% point somewhat higher than that predicted on the basis of a 114 mm mesh.

The selection factors varied from 3.1-3.4 and averaged 3.3 (the predicted selection factor) for the whole period.

Summary

Otter trawlers using the regulation size mesh on Georges Bank landed about 8% more large haddock and 19% less scrod haddock than small mesh control vessels.[4] Their codends averaged 116 mm in mesh size, about 2 mm larger than required by the regulation (114 mm).

The increase in large haddock catches is probably owing to an increased efficiency of larger mesh gear. The decrease in scrod haddock catches came about through escapement of small haddock.

Selectivity curves were computed which yielded an average 50% point of 37.9* cm. That this is slightly higher than the 37.5* cm predicted is shown to be associated with a slightly higher than required average mesh size. The calculated average selection factor of 3.3 agrees with that predicted for the regulated fishery.

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List of Tables Including Basic Data

The tables F-1 to F-69, listed below, give detailed data on length measurement of fish from the experiments referred to in the above paper. These Tables – not printed in the paper – are filed with the ICNAF Secretariat, from where they can be requested for reference.

[4])The escapement of 19% of the scrod—or 13% of the total catch—produces the beneficial effect of the mesh regulation. Even after natural mortality a gain of 8% might be expected.

F - 7. *Albatross III*. Total catches of haddock and belly cover (full) catches, series I – 21,454 spec., series II – 19,221 spec.

F - 8. *Priscilla V*. Total catches and belly cover catches of silver hake, 11,925 spec.

F - 9. Numbers of haddock of each length taken by the *Albatross III* (5,122 spec.) and *Delaware* (4,364 spec.) in standardization tows, group I.

F - 10. Numbers of haddock of each length taken by the *Albatross III* (7,103 spec.) and *Delaware* (7,073) spec.) in standardization tows, group II.

F - 11. Numbers of haddock of each length taken by the *Albatross III* (6,632 spec.) and *Delaware* (7,543 spec.) in paired tows, series II.

F - 12. Numbers of haddock of each length taken by the *Albatross III* (5,869 spec.) and *Delaware* (6,257 spec.) in paired tows, series III.

F - 13. Numbers of haddock of each length taken by the *Albatross III* (10,790 spec.) and *Delaware* (7,185 spec.) in paired tows, series IV.

F - 14. Numbers of haddock of each length taken by the *Albatross III* with 120 mm (port) (4,648 spec.) and 55 mm (starboard) (4,489 spec.) trawls.

F - 15. Comparison of sizes of silver hake caught by 57 mm (4,749 spec.) and 84 mm (2,643 spec.) mesh cotton nets.

F - 16. *Michigan*, No. 1, catches of haddock with covered (5,990 spec.) and uncovered (6,167 spec.) codends.

F - 17. *Michigan*, No. 2, catches of haddock with covered (2,861 spec.) and uncovered (3,026 spec.) codends.

F - 18. *Albatross III*, No. 51, catches of haddock with covered (15,369 spec.) and uncovered (19,888 spec.) codends. Series I and II.

F - 19. *Albatross III*, No. 52, catches of haddock with covered (2,977 spec.) and uncovered (3,557 spec.) codends.

F - 20. Catches of haddock with covered (305 spec.) and uncovered (73 spec.) codends, pairtows I, series I.

F - 21. Catches of haddock with covered (215 spec.) and uncovered (50 spec.) codends, pairtows I, series II.

F - 22. *Priscilla V*, catches of silver hake with covered (4,515 spec.) and uncovered (3,341 spec.) codends, series I.

F - 23. *Priscilla V*, catches of silver hake with covered (2,896 spec.) and uncovered (1,898 spec.) codends, series II.

F - 24. *Priscilla V*, catches of silver hake with covered (3,570 spec.) and uncovered (3,700 spec.) codends, series III.

F - 25. *Albatross III*, No. 64, catches of redfish with covered (3,416 spec.) and uncovered (3,287 spec.) codends.

F - 26. Series I, catches of haddock in a 113 mm double manila codend and cover for various tow intervals (all tows with hides); (4,419 spec.)

F - 27. Series II, catches of haddock in a 123 mm double manila codend and cover for various tow intervals (tows 6-32 with hides, tows 41-50 without hides); 15,626 spec.

F - 28. Series III, catches of haddock in a 73 mm double manila codend and cover for various tow intervals (tows 18-34 with hides, tows 35-40 without hides); 14,302 spec.

F - 29. Haddock caught in wire mesh codend (632 spec.) and cover (185 spec.).

F - 30. Silver hake caught in wire mesh codend (1,188 spec.) and cover (1,170 spec.).

F - 31. Number of silver hake of each size in codend and cover of normal tows and shark tow; 3,733 spec.

F - 32. Catches of haddock in paired tows of *Delaware* and *Albatross III* with manila codends of 56 mm and 59 mm mesh (phase I); 6,613 spec.

F - 33. Catches of haddock in paired tows of *Albatross III* and *Delaware* with double manila codends of 59 and 119 mm mesh (phase II); 8,194 spec.

F - 34. Catches of haddock in paired tows of the *Delaware* and *Albatross III* with single cotton codends of 57 and 144 mm mesh (phase III); 2,167 spec.

F - 35. Catches of haddock in paired tows of *Albatross III* and *Delaware* with single cotton codends of 106 and 58 mm mesh (phase IV); 8,557 spec.

F - 36. Catches of haddock in paired tows of *Albatross III* and *Delaware* with single cotton codends of 111 and 86 mm mesh (phase V); 6,048 spec.

F - 37. *Michigan* series I, catches of haddock in cover (405 spec.) and codend (10,465 spec.) with 92 mm mesh of 50/4 double manila.

F - 38. *Michigan*, series II, catches of haddock in cover (955 spec.) and codend (4,103 spec.) with 98 mm mesh of 50/4 double manila.

F - 39. *Michigan*, series III, catches of haddock in cover (3,684 spec.) and codend (10,285 spec.) with 105 mm mesh of 50/4 double manila.

F - 40. *Wisconsin*, series I, catches of haddock in cover (3,069 spec.) and codend (8,179 spec.) with 109-114 mm mesh of 50/4 double manila.

F - 41. *Wisconsin*, series II, catches of haddock in cover (1,470 spec.) and codend (1,640 spec.) with 121 mm mesh of 50/4 double manila.

F - 42. *Albatross III*, No. 51, series I, catches of haddock in cover (2,004 spec.) and codend (1,643 spec.) with 107 mm mesh of 45/4 double manila.

F - 43. *Albatross III*, No. 59, series I, catches of haddock in cover (3,065 spec.) and codend (2,435 spec.) with 140 mm mesh of 45/4 double manila.

F - 44. *Albatross III*, No. 59, series II, catches of haddock in cover (2,564 spec.) and codend (1,961 spec.) with 154 mm mesh of 45/4 double manila.

F - 45. *Albatross III*, No. 59, series III, catches of haddock in cover (2,294 spec.) and codend (1,153 spec.) with 167 mm mesh of 45/4 double manila.

F - 46. *Albatross III*, No. 74, series I, catches of haddock in cover (2,106 spec.) and codend (4,619 spec.) with 127 mm mesh of Dacron.

F - 47. *Albatross III*, No. 74, series II, catches of haddock in cover (2,831 spec.) and codend (2,378 spec.) with 105 mm mesh of nylon (cargo netting).

F - 48. *Albatross III*, No. 74, series III, catches of haddock in cover (2,113 spec.) and codend (3,075 spec.) with 134 mm mesh of nylon (cargo netting).

F - 49. *Albatross III*, No. 74, series IVa, catches of haddock in cover (931 spec.) and codend (2,460 spec.) with 122 mm mesh of nylon (cargo netting).

F - 50. *Albatross III*, No. 74, series IVb, catches of haddock in cover (3,259 spec.) and codend (2,143 spec.) with 124 mm mesh of nylon (cargo netting).

F - 51. Numbers of silver hake caught and percentages retained in a 94 mm manila codend; 13,837 spec.

F - 52. Numbers of silver hake caught and percentages retained in a 64 mm manila codend; 3,762 spec.

F - 53. Numbers of silver hake caught and percentages retained in a 103 mm nylon codend; 3,913 spec.

F - 54. Numbers of silver hake caught and percentages retained in a 103 mm nylon codend; 5,881 spec.

F - 55. Numbers of silver hake caught and percentages retained in an 85 mm nylon codend; 6,684 spec.

F - 56. Numbers of silver hake caught and percentages retained in an 82 mm nylon codend; 4,824 spec.

F - 57. Numbers of silver hake caught and percentages retained in a 54 mm nylon codend; 2,331 spec.

F - 58. Numbers of silver hake caught and percentages retained in a 96 mm cotton codend; 6,216 spec.

F - 59. Numbers of silver hake caught and percentages retained in a 73 mm cotton codend; 6,640 spec.

F - 60. Numbers of silver hake caught and percentages retained in a 60 mm cotton codend; 4,111 spec.

F - 61. Numbers of silver hake caught and percentages retained in a 40 mm cotton codend; 258 spec.

F - 62. Numbers of silver hake caught and percentages retained in the 35 mm cotton cover; 66 spec.

F - 63. Numbers of silver hake caught and percentages retained in a 115 mm double manila codend; 725 spec.

F - 64. *Albatross III*, catches of silver hake in a double manila codend of 123 mm mesh size; 1,416 spec.

F - 65. Catches of redfish in *Priscilla V* double manila codends of series 1-115 mm (903 spec.), series II - 99 mm (1,085 spec.) and series III - 69 mm (271 spec.).

F - 66. Catches of redfish in *Albatross III* double manila codend of 132 mm mesh size (series I); 1,985 spec.

F - 67. Catches of redfish in *Albatross III* double manila codend of 109 mm mesh size (series II); 15,075 spec.

F - 68. Catches of redfish in *Albatross III* double manila codend of 80 mm (series III a) and 82 mm (series IIIb) mesh sizes; 6,293 spec.

F - 69. Haddock, average catch per day in numbers of each length for large and small mesh by quarters; 68,656 spec.

7.

Experiments to Investigate the Escape of Fish Through the Meshes of Different Parts of the Trawl

by

ROBERT W. ELLIS [1]

Abstract

The escape of fish through the meshes of different parts of trawls was studied by means of pockets of small mesh netting attached at different positions on the trawl during routine sampling hauls. Few fish escaped through the meshes of the wings. Considerable numbers of active swimming fish such as *Gadus esmarki*, whiting, herring, sprats and *Ammodytes* were captured after escaping from the square and the batings. Other species, including the haddock and common and long rough dabs, escaped from the square and batings in smaller numbers.

Introduction

The use of mesh regulations as a management technique has resulted in many experiments upon the escape of fish through trawl codend meshes. Little comparable work has been done to determine the escape of fish through the meshes of other parts of the trawl. Knowledge of the escape from all parts of the trawl is important not only in the formulation of mesh size laws but also in increasing understanding of trawl efficiency.

The experiments described below were done to obtain preliminary data on the escape of different species of fish through the wings, square and bating (upper belly) of trawls and to compare the escape from these parts with the escape through the codend meshes.

Procedures and Results

Fish escaping through the trawl meshes were caught in pockets of 3/4″ mesh cotton netting. The pocket was bagshaped with a tied-up opening and is shown in Figure 1.

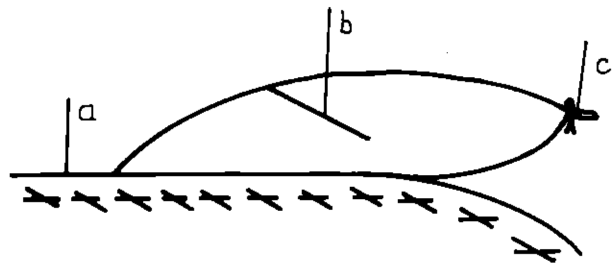

Fig. 1. Diagrammatic side view of pocket; a - dorsal surface of trawl, b - floppa, c - tied-up opening.

Particulars of the sizes and positions of the pockets are given below for each experiment separately. A codend cover of the same netting was used for all experiments.

The data were obtained during routine sampling cruises of the research vessels *Explorer* and *Kathleen* of the Marine Laboratory, Aberdeen, Scotland. During the first two experiments, a 46-foot otter trawl was used on the *Explorer*. (The 46-foot dimension used in designating otter trawls applies to the length of the section of the groundrope between the wing tip and the point of attachment of the bosom rope.) A 26-foot otter trawl was used on the *Kathleen* during the third experiment.

The mean mesh size of the wings of the 46-foot trawl was about 110 mm., the square 80 mm, the batings 70 mm, and the codend 50 mm.

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Experiment 1

During this experiment, the small mesh netting pocket was attached over part of the square and the batings. It was ten feet square at its attachment to the trawl, and covered the lower five feet of the square and the upper five feet of the batings (Figure 2). Between 1/3 and 1/6 of the total area of the square and 1/6 and 1/8 of the batings were covered by the pocket.

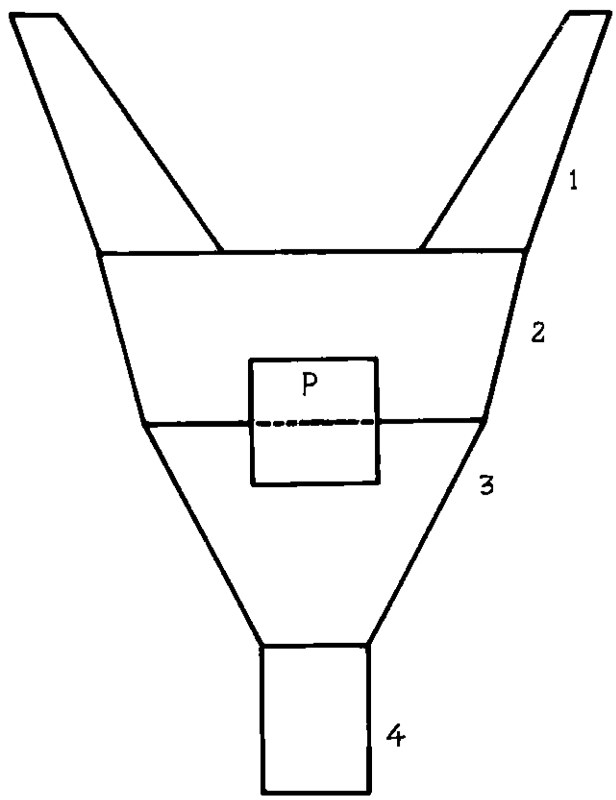

Fig. 2. Diagrammatic top view of trawl showing position of single pocket. 1 - upper wings, 2 - square, 3 - batings (upper belly), 4 - codend, P - small mesh pocket.

The principal species caught were herring, sprat, whiting, *Gadus esmarkii* and long rough dab. The distribution of these species in the different net components during thirteen hauls is shown in Table 1.

The escape of small specimens from the covered parts of the codend, square and batings is shown to be appreciable. The escapes from the pocket, expressed as a percentage of the escapes from the codend for all hauls, were: herring and sprats 9.4%; whiting 3.3%; and *Gadus esmarkii* 15.2%. No long rough dab were taken in the pocket. If it be (rashly) assumed that escape from all parts of the square and batings is equally likely, the total escape from these net parts would be estimated by multiplying the catch in the pocket by a factor of 5 or 6, representing the approximate proportion of the total area of the square and batings covered by the small mesh netting. The percentage releases from the square and batings relative to those from the codend would thus be about 50% for herring and sprat, 17% for whiting and 80% for *Gadus esmarkii.*

In view of the likely inequality of the relative escapes from different parts of the square and batings, it is probable that these percentages considerably overestimate the true value.

TABLE 1. The numbers and sizes of fish caught in one pocket (10′ x 10′) on the square and batings and in the codend small mesh.

Pooled Results of 13 Hauls

Species	Codend	Codend Cover	Pocket	
Gadus	–	368	56	Number
esmarki	-	9-13	9-14	Size range in cm
Whiting	285	5283	176	Number
	11-53	7-22	10-19	Size range in cm
Long rough	187	507	–	Number
dab	4-32	6-22	–	Size range in cm
Herring &	14	9845	928	Number
sprats	14-29	5-26	5-16	Size range in cm

Experiment 2

Nine pockets, each four feet square at their attachment to the trawl, were used during three cruises for a total of 35 hauls. The positions of these pockets are shown in Figure 3.

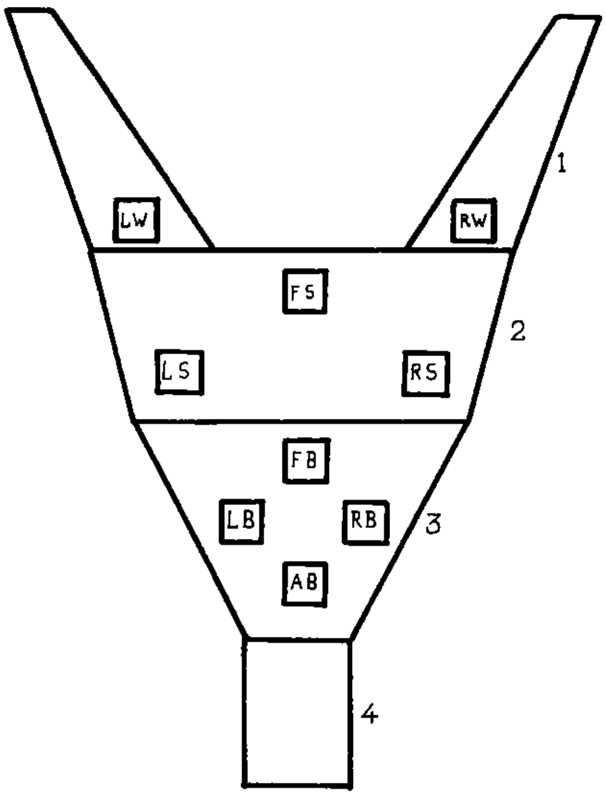

Fig. 3. Diagrammatic top view of trawl showing positions of nine pockets.
1 - upper wings, 2 - square, 3 - batings (upper belly), 4 - codend.
LW - left wing RW - right wing FS - fore square
LS - left square RS - right square FB - fore batings
LB - left batings RB - right batings AB - after batings.

Table 2 (A, B and C) shows the grouped results for all hauls. The results for each of three cruises are tabulated separately. During the first cruise, 39 hauls were made and 21 of these yielded fish in one or more of the pockets. Eight hauls out of 16 in the second cruise and four out of 19 in the third cruise yielded fish in the small mesh pockets.

Seven species were taken in the pockets. *Gadus esmarki* and *Ammodytes* were taken in quite large numbers in one or more of the pockets. Haddock, whiting, herring, long rough dabs and *Gadus poutassou* occurred in smaller numbers.

During the first cruise, more *Ammodytes* were taken in the square and batings pockets than in the codend cover. *Gadus esmarki* and *Ammodytes* were the only species taken in the wing pockets. As in the previous experiment, *Gadus esmarki* were well represented in the square and batings pockets.

The size ranges of each species caught in the pockets were similar to those in the codend cover of the same haul, except in the case of *Gadus poutassou* (Table IIA). The specimens of this species taken in the pockets on the square were larger than those in the codend cover.

Experiment 3

A pocket, covering an area four feet square, was attached in different positions on the dorsal surface of the 28-foot trawl. During the first trip, the pocket was attached to the left wing of the trawl close to the point of attachment of the square. Common dab, sprat and one cod were taken in the pocket.

During the second trip, the pocket was attached across the midline of the dorsal surface of the square; herring, sprat and common dab were taken in it.

The pocket was attached as shown in Figure 2 in the third experiment; herring, sprat, *Gadus esmarki* and one goby were caught in it.

Discussion

Pocket experiments, designed to test modified trawls, were carried out by Bowman in 1923 and 1928. The results are unpublished. Common and long rough dab, whiting, *Gadus esmarki*, haddock, *Agonus*, *Callionymus* and *Motella* were taken in these experiments.

Although the numbers of species and individuals taken in the pockets are considered too small for detailed analyses the following general conclusions appear justified.

These experiments and those done by Bowman show that several species of fish escape through the meshes of the wings, square and batings, as well as the codend of the otter trawl.

The escape from the wings was shown to be small and only two species, *Ammodytes* and *Gadus*

TABLE 2. The numbers and sizes of fish caught in various small meshed pockets (4′ x 4′) on the 46 foot otter trawl during three successive cruises.

A. Data from 21 Hauls in Faroese Waters

Species	Left Wing	Right Wing	Fore Square	Left Square	Right Square	Fore Bat-ings	Left Bat-ings	Right Bat-ings	After Bat-ings	Codend Cover	Codend	
Gadus	3	–	86	34	16	32	18	16	7	1210	48	Number
esmarki	12-15	–	10-18	10-17	10-17	10-18	11-19	13-18	10-12	5-21	11-20	Size range in cm
Haddock	–	–	2	1	–	1	1	–	–	169	888*	Number
	—	—	16-24	-19-	—	-7-	-18-	—	—	6-22	15-23	Size range in cm
Ammodytes	22	5	150	71	106	143	114	59	30	28	—	Number
	13-18	15-16	13-20	13-19	14-18	13-19	13-19	14-19	13-18	14-19	—	Size range in cm
Long rough	—	—	—	—	—	—	—	1	—	205	33	Number
dab	—	—	—	—	—	—	—	-17-	—	3-17	20-40	Size range in cm
Gadus	—	—	1	1	3	—	—	—	—	43	35	Number
poutassou	—	—	-21-	-21-	19-20	—	—	—	—	5-13	22-34	Size range in cm

*Haddock of 23 cms and less included only.

B. Data from 8 Hauls in the North Sea

Species	Left Wing	Right Wing	Fore Square	Left Square	Right Square	Fore Bat-ings	Left Bat-ings	Right Bat-ings	After Bat-ings	Codend Cover	Codend	
Gadus	—	—	24	9	2	11	19	3	196	4933	118	Number
esmarki	—	—	12-18	12-17	12-15	10-18	11-17	12-14	11-20	9-20	11-18	Size range in cm
Haddock	—	—	1	—	1	—	1	—	2	448	419	Number
	—	—	-17-	—	-20-	—	-18-	—	19-24	15-23	15-22	Size range in cm
Whiting	—	—	—	—	—	1	1	2	7	148	525	Number
	—	—	—	—	—	-26-	-24-	17-26	17-31	13-27	21-49	Size range in cm
Herring	—	—	—	—	—	1	—	—	—	—	—	Number
	—	—	—	—	—	-27-	—	—	—	—	—	Size range in cm

C. Data from 4 Hauls in the North Sea

Species	Left Wing	Right Wing	Fore Square	Left Square	Right Square	Fore Bat-ings	Left Bat-ings	Right Bat-ings	After Bat-ings	Codend Cover	Codend	
Gadus	—	—	—	13	11	—	3	2	8	924	134	Number
esmarki	—	—	—	15-19	14-19	—	16-17	-16-	15-18	6-20	15-21	Size range in cm
Whiting	—	—	—	—	—	—	—	—	1	10	262	Number
	—	—	—	—	—	—	—	—	-24-	9-25	21-18	Size range in cm
Ammodytes	—	—	—	—	—	—	—	—	1	—	1	Number
	—	—	—	—	—	—	—	—	-18-	—	-17-	Size range in cm

esmarki were taken in the wing pockets. (Table 2A).

About the same number of fish escape from the square as from the batings per unit area and these numbers are usually considerably less than the escape from the codend.

The lengths of the fish escaping from the wings, square and batings are usually similar to the lengths of the same species escaping from the codend. The only exception was in the case of *Gadus poutassou* for which larger specimens were retained in the square pocket than in the codend cover.

The species of fish which occurred most frequently in the pockets were those considered to be active swimmers. These species include herring, sprat, *Ammodytes*, and *Gadus esmarki*. Species considered less active swimmers, such as common dab and long rough dab, occurred less frequently and less abundantly in the pockets. Few *Gadus esmarki* were caught during *Kathleen's* (inshore) trawling surveys, hence the almost complete absence of this species in the pockets of the 28-foot otter trawl.

It is possible that the presence of the pockets affects the normal behaviour of the trawl, and that the catches of fish in them are not an exact measure of the escape from different parts of the net when used operationally. If the pockets exerted a masking effect, the escapes recorded in this study might be expected to be an under-estimate of the true values.

The above results lend support to the view, demonstrated by other means, that the meshes of the net remain open during the fishing operations.

8.

Approximations to the Selection Ogive, and their Effect on the Predicted Yield

by

J. A. GULLAND[1]

Abstract

Yields were calculated using "knife-edge" selection and other closer approximations for a range of fishing mortalities and mesh sizes. The results showed that differences between yields estimated from the simple approximation (knife-edge) and the closer ones were nearly always sufficiently small to be ignored. The differences were appreciable when the fishing mortality was very high and the mesh size was such that the fish were caught at a size only just less than the maximum attainable. In this case, the error in using the simple approximation was toward underestimating the yield from largest meshes.

Introduction

When the results of a mesh experiment with a trawl, and in general any net, are expressed as the percentage of each size or age of fish retained by the gear (*i.e.*, the percentage of the full fishing mortality sustained by that size of fish), they generally fit a curve of the form of the line DOD′ in Figure 1.

That is, there is a considerable range of size (or age) of fish which do not sustain the full fishing mortality, but do sustain an increasing fraction of the total. As described by Beverton in another paper presented at this meeting, it is often convenient to approximate to this curve by a knife-edge selection, at some properly chosen mean selection age, (or length) t_c. This supposes that the effective fishing mortality is zero for ages less than t_c, but is constant, equal to the full fishing mortality, for ages greater than t_c; this selection is represented in Figure 1 by the line AOA′. This paper presents an interim report on certain investigations into some of the situations where such an approximation may not be appropriate.

Methods

The calculation of the yield from a selection curve such as DOD′ presents major difficulties, so that for the present purposes two approximations, closer than the knife-edge AOA′, were used: first, the linear selection, for example, the lines BOB′ and COC′ in Figure 1; second, the step, or discontinuous approximation, which may be considered as a set of knife-edge approximations to successive sections of the selection curve. Two such steps were used in this paper (see below) but Beverton and Holt have used many more. Obviously, by taking a sufficient number of steps the latter approximation can be made as close as desired. The linear approximation can also be very close. From Figure 1 it seems clear that the results from the true selection curve DOD′ must lie between those of the lines BOB′ and COC′, and that some intermediate line must fit very closely.

The yields per recruit were calculated for a wide range of fishing mortalities and mesh size, using the various approximations. These yields were examined, firstly to note any absolute differences, and secondly, and perhaps more important, to see whether such differences as did exist would affect the estimates of the change in yield per recruit from one amount of fishing to another, or from one mesh size to another. The presence or absence of marked effects has implications not only on the method of calculating the yield, but also on the amount of information required from selection experiments. If the knife-edge

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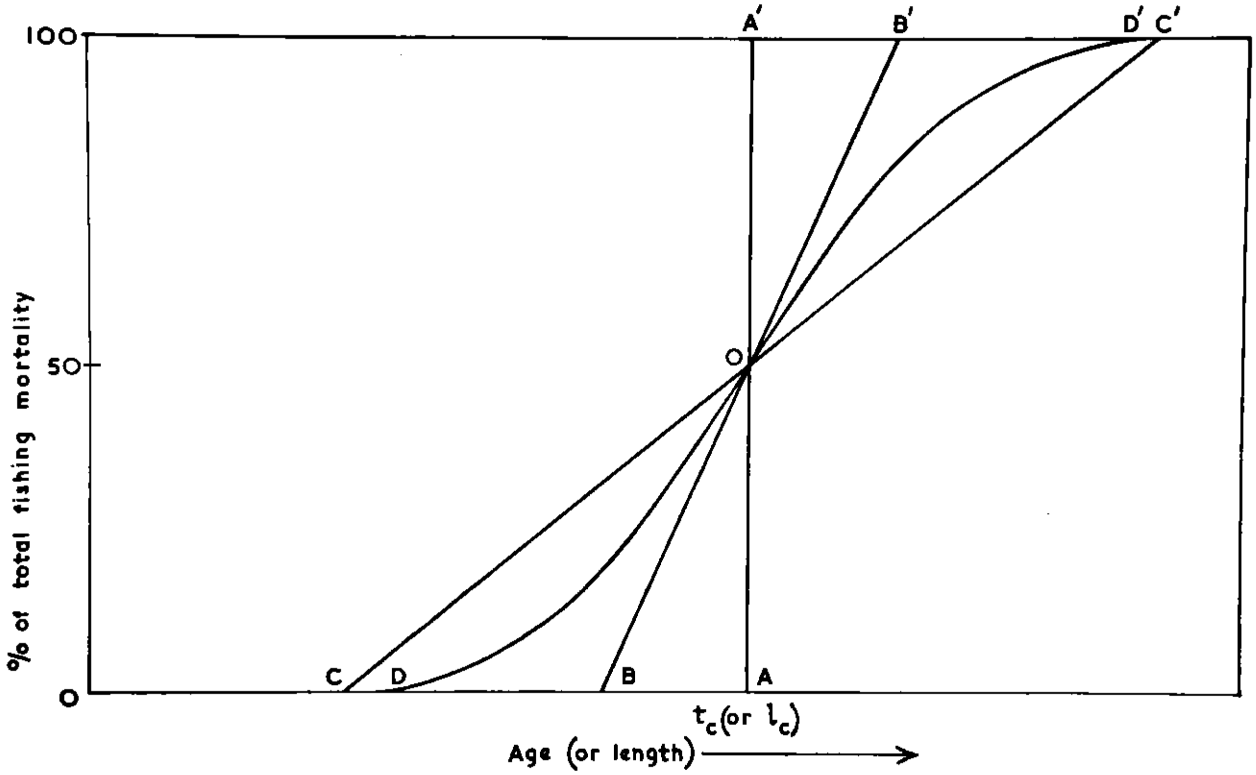

Fig. 1. Types of selection ogives, showing the percentage of fish of each size or age retained by the fishing gear.

gives an adequate representation, the only data required are on the mean selection age; alternatively, it may be found necessary to obtain detailed information on the shape, and particularly the slope, of the selection curve.

Symmetrical Age Ogive

For a symmetrical age ogive, *e.g.*, DOD' of Figure 1, the mean selection age will be at the 50% point, and the main differences between the true selection curve and any approximation will be in their slopes, the true value being within the range of increasing slopes given by COC', BOB' and AOA'. By symmetry the "triangular" areas AOD and A'OD' are equal as are other pairs. Therefore, the total mortality occurring at ages less than C', the highest age within any selection range, will be the same for all the approximations. Hence the number of fish reaching age C', and the yield from all older fish, will be the same, *i.e.*, any differences in yield will occur within the selection range. For instance, the difference between the true yield and the knife-edge yield is the difference between the fish represented by the areas AOD, and A'OD'. The former set of fish, included in the true selection, but not in the knife-edge, will be smaller, but more numerous (because of the intervening mortality) than the latter set, included in the knife-edge, but not in the true selection. Thus the use of the knife-edge selection will tend to under-estimate the number caught, but probably over-estimate the weight caught. This difference has been determined by Beverton and Holt (1957) for certain mesh sizes and fishing efforts on the plaice. It was highest at high fishing rates, but even at a value of F (the fishing mortality coefficient) of 1.5, the knife-edge yield in weight was only 8% less than the true value. This difference, being fairly consistent over a range of fishing rates and mesh sizes, is not large enough to invalidate conclusions based on the knife-edge selection.

In order to see whether this result, based on plaice, could be applied more generally, further calculations were made on whiting. This species was expected to show well any differences, both because the actual spread of the selection curve against length is wider than for the plaice (the range from 25% to 75% selection being 2.4 cm for plaice (trawl), and 4.4 cm and 7.0 cm for whiting (trawl and seine, respectively), and also because the bulk of the catch comes from a restricted size range, much of which is contained within the selection range of present mesh sizes. However, over the range of mesh sizes and fishing intensities used no very marked differences were found between "knife-edge" selection and a linear selection even spread over as much as 3 years. At a fishing mortality coefficient of 1.0 the linear selection gave a yield about 10% higher in numbers and 5% lower in weight than the knife-edge, and these differences varied only slightly with change in slope of the selection ogive, or in fishing mortality. These results suggest that the knife-edge approximation gives a perfectly adequate approximation to a symmetrical selection curve, at least for calculating changes in yield resulting from moderate changes in mesh or amount of fishing, and when only a small part of the yield comes from within the selection curve (*e.g.*, cod), the approximation may be satisfactory for virtually all work.

Asymmetrical Age Ogive

The observed selection curve, plotted against length, is usually nearly symmetrical, and so long as the rate of growth in length is nearly constant, so will be the age selection ogive. When the fish has nearly reached its maximum length, the growth in length will be far from constant, and if the length-selection ogive is symmetrical, the age-selection ogive will be distorted; the time taken in growing from say 5% to 50% retention size will be less, and possibly considerably less, than that from 50% to 95% retention size. To estimate the effect of this, the whiting was taken as an example. The growth was assumed to fit the Bertalanffy curve, with a maximum length of 44 cm, and the selection factor (50% length divided by mesh size) was taken as 4.1, which corresponds to the selection for seines. The length-selection curve was for convenience taken as linear, with the interval between 25% and 50% points being 3.5 cm. Thus 100% retention with a 90 mm mesh is only just achieved at an age of over 10 years and is never reached with 100 mm, the maximum retention being about 70%.

The yields for a range of fishing mortalities and mesh sizes were calculated; first for a knife-edge selection at the 50% point (equal to the mean selection length, but rather less than the mean selection age); secondly for a double knife-edge, at the 25% and 75% points, the fishing mortality being zero up to the 25% point, half the full fishing from 25% to 75%, and thereafter equal to the full fishing mortality. Though the latter will not give exactly the true yield, it will be nearer than the single knife-edge, and the difference between the true yield and the double knife-edge will probably be less, and certainly not very much greater, than the difference between the single and double knife-edge. Thus the differences, if any, between the two latter will give a good guide to the differences between either of them, and particularly the single knife-edge, and the true yield. Except for a mesh of 100 mm, the yield from the single knife-edge was greater than that from a double knife-edge, which was in turn presumably greater than the true yield. The differences increased with increasing mesh size or fishing effort, but (for fishing mortality coefficients less than 3.0) were less than 10%.

The curves of yields given by the two approximations plotted against mesh size for two values of fishing effort (F = 0.2 and 2.0) are given in Figure 2, the curve for the double knife-edge being broken, and the single knife-edge being a full line. For the low fishing mortality the differences are trival and the single knife-edge may be taken as giving a perfectly adequate approximation to the true yield. For the higher fishing mortality (which is probably higher than any occurring in practice), the two curves follow a similar pattern up to the highest mesh size

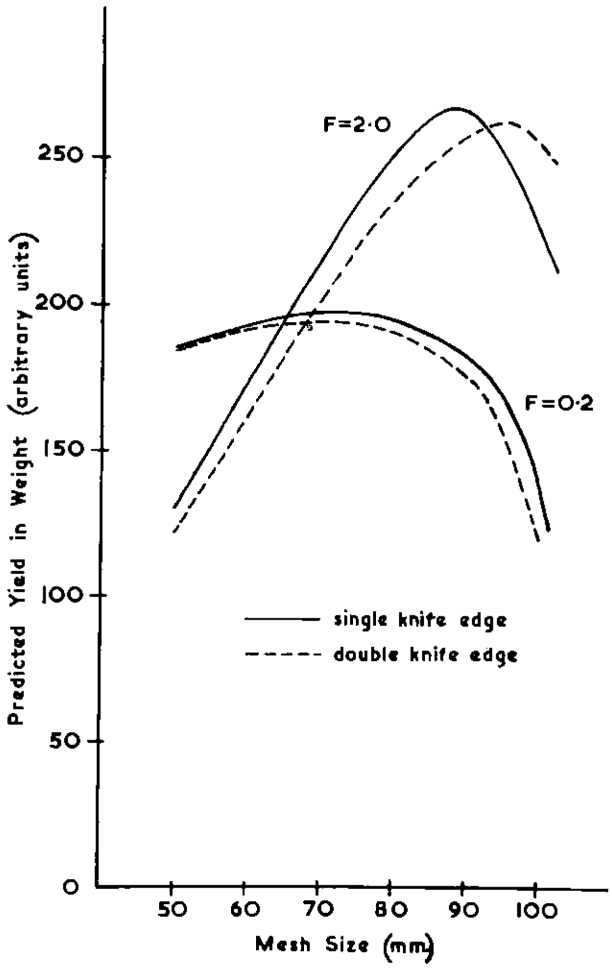

Fig. 2. The predicted yield in weight of whiting for two fishing mortalities, showing the difference between two forms of selection ogive.

(100 cm), when the yield predicted by the single knife-edge drops off much more sharply than the other. The reason for this is that while fish are in fact subjected to an appreciable part of the total fishing mortality from 4 years old upwards, the single knife-edge assumes that none are caught until nearly $6\frac{1}{2}$ years old, by which time natural mortality has taken a large toll. The effect of this is to shift the maximum in the yield-mesh curve from about 95 mm in the double knife-edge (and probably really about 100 mm) to about 90 mm. However, this is a fault in the right direction, as the use of the (supposed) best mesh of 90 mm will at least give a yield higher than that for any smaller mesh. Again, if it is necessary for fishing some other more important species to use a very high mesh, say 100 mm, it is probably better to underestimate the yield of whiting.

The calculations can be easily adapted to show the effect on the yield of using a knife-edge not at the mean selection length, which is the same as the 50% length for the symmetrical ogive, but at the mean selection age. Because of the spread of the upper part of the age selection ogive, this mean selection age will be greater than the age at the 50% point. The yield would therefore be the same as that calculated for the mean selection length of a slightly larger mesh. Figure 2 shows that over much of the range of F and mesh size this will give a yield above that estimated for the mean selection length, but that this itself is greater than the true yield, i.e. the use of the mean selection age will be less accurate than the mean selection length.

Summary

The commonest and simplest approximation to the selection curve is the knife-edge, such that the fishing mortality is zero below a certain age or size, and is constant, equal to the full fishing mortality, above that age or size. The yields using this and certain other closer approximations were calculated for a range of fishing mortalities and mesh size. The results showed that the differences between the yields estimated from the simple approximation and the closer ones were nearly always sufficiently small to be ignored. The differences were appreciable when the fishing mortality was very high, and the mesh size was such that the fish were caught at a size only just less than the maximum attainable. In this case the error in using the simple approximation was towards underestimating the yield at largest meshes.

Reference

BEVERTON, R. J. H., and S. J. HOLT, 1957. The Dynamics of Exploited Fish Populations. *Fish. Invest. Lond. Ser. II, 19.*

9.

A Method for Determining Gear Selectivity and its Application

by

S. J. HOLT[1]

Abstract

A brief review of the problem of studying the selectivity of fishing gears other than bag-nets is followed by a theory of gill-net selection. The theory is applied to data for the Fraser River sockeye salmon and it is shown that the gill-net mesh selection curve is approximately normal. The parameters of the selection curve can all be determined from comparative fishing experiments in which only gill-nets are used; the mean of the length selection curve is proportional to the size of the mesh, and the girth of a fish of the mean selection length is approximately equal to the perimeter of the mesh-lumen. The applications of the method to other kinds of gear, and to general problems of stock-assessment and choice of mesh size, are mentioned.

Introduction

Analysis of the selectivity of bag-nets such as trawls and seines by conducting comparative fishing experiments is a relatively straightforward matter. Since it has been demonstrated that the greater part of selection for size of fish occurs in the cod-end it is only necessary to fish alternately with the test cod-end and one having a much smaller mesh attached to the gear, or to arrange some other device, such as a cover, that will retain small fish and give a catch having a size composition more or less the same as that of the population being fished. With other kinds of gears it may not be possible to determine the composition of the population on the ground in this way, though it is known that gears such as hook and line, traps and gill-nets are selective and that the selectivity may be altered by changing the dimensions of parts of the gear such as the size of the hook or the mesh of the gill-net.

From general inspection of the size-frequency distribution in catches taken by gill-nets of different mesh-sizes, it has long been believed that the typical selection curve is similar to the normal distribution. The fraction of the number of fish of a certain length which encounter the net and are retained by it is thus highest at a certain central length, and decreases symmetrically to zero both above and below that length.

This supposition can be tested in those rare situations where gears that are unselective over a certain range of size are being used to fish a stock in the same area as gill-nets. Such a case has been described by Rollefsen (1953) who has given the length distributions of cod taken by purse seines, lines and gill-nets at Lofoten. If we divide the % frequency at each size in the gill-net catches by the corresponding pereentage in the purse-seine catches - which are unselective over the range of lengths considered - we obtain a symmetrical distribution (Table 1) which approximates very closely to a normal curve.

In fisheries where no information concerning the composition of the fished population can be obtained from the catches of non-selective gear, attempts have been made to resolve the difficulty by fishing experimentally with a series of gill-nets having a range of mesh-sizes, and combining the catches to give a total size-frequency distribution. Kesteven (1950) has shown, however, by back-calculating from hypothetical examples, that such a procedure is not valid, the combined catch frequency curve having a shape quite different from that of the population. Yet it is necessary to determine the population composition in some way in order to be able to estimate mortality coefficients and hence make yield assessments for the stock.

It has been shown (Beverton and Holt, 1957) that catches of two trawls having only very slightly different cod-end mesh sizes can be used

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to determine the selection curves for both trawls by a simple ratio-method, provided that certain assumptions can be made concerning the general shape of the selection ogives of trawls. Such assumptions are justified by information obtained from many experiments in which trawls of widely differing mesh-sizes have been operated comparatively and the true selection ogive obtained. I shall show in this paper that a similar procedure is possible for gill-nets.

The general equation

If the length-selection curve of a gill-net unit can be represented by a normal curve, we may write

$$C_l = n.P_l.p_m.V.\ \exp.\left[-\ (l - l_m)^2/2\sigma^2\right]$$

where

- C_l is the catch in numbers of fish of length l
- n is the number of operations (or fishing time)
- P_l is the number of fish of length l which is liable to capture by the gear
- V is the vulnerability of the species
- p_m is the fishing power of the fishing unit, referred to a length l_m which is the mean length of the normal selection curve of standard deviation σ, and is therefore the length for which that particular net is most efficient.

Now suppose we operate comparatively two gill-net units, A and B, the meshes of which differ slightly, and we will assume that $\sigma_A = \sigma_B$ and that the fish behave in the same way towards the two units and are therefore equally vulnerable to them. Then the natural logarithm of the ratio of the catches at each length by the two units is given by

$$\log {}_BC_l/{}_AC_l = l\ ({}_Bl_m - {}_Al_m)\ /\sigma^2$$
$$+\ ({}_Al^2_m - {}_Bl^2_m)\ /2\sigma^2 + \log {}_Bp_m/{}_Ap_m$$

(Notice that the index of abundance, P, has cancelled out.)

This equation is linear in l; that is, we may write it as:

$$y = a + b.\ l$$

where

$$y = \log {}_BC_l\ /\ {}_AC_l \quad ,$$

the y-intercept

$$a = ({}_Al^2_m - {}_Bl^2_m)\ /\ 2\sigma^2 + \log {}_Bp_m/{}_Ap_m$$

and the slope

$$b = ({}_Bl_m - {}_Al_m)\ /\sigma^2$$

Now if the fishing power of a net depends on its mesh-size it is nevertheless unlikely to differ much between nets that differ only slightly in mesh size, and we may to a first approximation neglect the term $\log {}_Bp_m/{}_Ap_m$. We then find that

$$-\ 2a/b = {}_Al_m + {}_Bl_m\ .$$

It is not possible to determine ${}_Al_m$, ${}_Bl_m$ and σ separately unless there is some further information. Thus if the mean selection length l_m were proportional to the mesh size, θ, or to some other directly measurable quantity, then we could write

$${}_Al_m = k_A\theta \quad ,$$
$${}_Bl_m = k_B\theta \quad ,$$

hence

$${}_Al_m + {}_Bl_m = k\ ({}_A\theta + {}_B\theta) = -\ 2a/b.$$

This gives a solution for k and hence for ${}_Al_m$ and ${}_Bl_m$ and finally, from a or b, for σ. The search for a measurable characteristic which is proportional to l_m can be accomplished by operating several units A, B, C . . . etc. comparatively. This gives a series of values, $({}_Al_m + {}_Bl_m)$, $({}_Bl_m + {}_Cl_m)$ etc., which may be plotted against quantities chosen for examination.

Application to data

Peterson (1954) gives extensive data for the length distribution of sockeye salmon caught in the Fraser River by gill-nets of various mesh-sizes operated experimentally in 1947 and 1948. The data for the eight meshes that caught a sufficient number of fish to make analysis worthwhile are summarised in Table 2. Columns A to H give the total number in each 2 cm size group caught in the two years by each mesh-size. All these nets fished equal lengths of time, so no adjustment to catch-per-unit is necessary. The nets shrank in use, and the mean mesh sizes are the average sizes attained after the initial shrinkage (three week-ends of fishing).

The right-hand columns of Table 2 are the natural logarithms of the ratios of the catches in each length group for pairs of nets A and B, B and C etc. The ratios were only calculated in the cases where the total number of fish of the size caught by both nets exceeded fifty - a number chosen arbitrarily to exclude small samples, for which the estimated ratio would be extremely variable.

The logarithms in the right-hand columns all gave, when plotted against length, clear linear regressions. Straight lines were fitted by the method of least squares and the parameters a and b thus determined for each pair of meshes. These are given at the bottom of Table 2, and the quantities - 2a/b are tabulated in Column II of Table 3. For each pair of meshes - 2a/b was then plotted against the sum of the mesh-sizes (Table 3, Column III) and it was found that the two quantities were very closely proportional, so the mean selection length is proportional to the mesh size. The best straight line passing through the origin was then fitted by least squares, and found to have a slope of $k = 4.1$. This value of k was then multiplied by each mesh-size to give the mean selection lengths tabulated in Column IV of Table 3.

The differences between the squares of successive mean selection lengths were divided by the corresponding value of a to give an estimate of σ^2, the variance of the normal selection curve, and hence of its standard deviation. The values obtained are given in Table 3, Column V. They have no apparent trend with size of mesh (or mean selection length) and it seems therefore that the initial assumption that the standard deviation did not vary with mesh size was justified.

Data given by Hodgson (1933) for herring in the North Sea also show very clearly the predicted linear relation between the length of the fish and the logarithm of the ratios of the catch at each size by pairs of gill-nets. Hodgson's data are expressed throughout as **percentage** length compositions, but it appears that all fish in eatch experimental net section were measured so that the percentage values can be treated as catches per unit effort. (It should be noted that if only percentage compositions are available - perhaps in the absence of effort statistics - we may determine from the slope b and the difference between pairs of meshes values for the ratio k/σ^2, but not either k or σ^2 separately.) The results for two experiments are summarized in Table 4. The two experiments gave remarkably consistent results as may be seen from Columns III, IV and V, but the slopes of the regressions for the two pairs of meshes were very different, resulting in the estimate of spread (σ) for the larger pair being less than half that for the smaller, although the mean selection lengths have about the expected values. The explanation might lie in a change in the mechanism of selection over the experimental range of meshes, and a means of investigating this when detailed data are available is discussed in the next section. The mesh measurements given correspond to internal mesh-sizes of about 5.0, 5.4 and 5.7 cm, so that the selection factor (ratio mid-selection length/mesh size) is about 4.8. This is of the same order as, but rather greater than, the ratio length/half maximum girth in the herring (Farran, 1929, and I. D. Richardson, in correspondence).

Discussion

The above analysis has shown that it is possible to determine the parameters of a gill-net selection curve from the results of comparative fishing experiments using only gill-nets, provided the general form of the selection curve is known. The significance of this result seems to me to be that it demonstrates how advantage may be taken of the special conditions pertaining in some fisheries to solve problems of others. If we can in this way build up a body of knowledge about the shapes of selection curves for particular types of gear, then the potential information that can come from comparative fishing and other experiments is enormously increased.

Having estimated the parameters of the selection curve we may proceed to examine further their relation to measurable characteristics of the gear and of the fish. Peterson gives measurements of greatest depth and thickness of the fish in his samples. The ratios of these dimensions to the fork length did not apparently vary significantly with size of fish, or between years. For the whole sample we find

Mean length = 61.2 cm
Mean greatest depth = 13.5 cm
Mean greatest thickness = 6.8 cm

If we assume that the fish is approximately elliptical in cross-section at the point of greatest depth and thickness we can calculate the average maximum girth, and we find

ratio length/girth = 1.9

From this we find the ration of the girth at the mean selection length to the perimeter of the mesh-lumen is

4.1/2 x 1.9 = 1.08.

No significance can be attached to the difference of this value from unity.

Table 1. Size-selection of Lofoten cod by gill-nets (data from Rollefsen, 1953)

I Length (5 cm groups)	II Ratio gill-net/purse seine	III Fitted normal curve	IV Theoretical selection curve
63-67	0.21	0.26	0.18
68-72	0.67	0.52	0.35
73-77	0.74	0.79	0.52
78-82	1.14	1.12	0.75
83-87	1.59	1.39	0.93
88-92	1.72	1.50	1.00
93-97	1.19	1.39	0.93
98-102	0.82	1.12	0.75
103-107	0.56	0.79	0.52
108-112	0.35	0.52	0.35
113-117	0.32	0.26	0.18
118-122	0.30	0.11	0.08
123-127	0.21	0.04	0.03
Mean	90 cm		
Standard deviation	14 cm		
SD/Mean	0.16		

Notes

Column I— Fish in the samples actually ranged in length from 52 to 139 cm, but the very large and very small fish were too few in number to justify inclusion in the calculation.

Column II—Mr. Rollefsen has been kind enough to send me a table of data for the year 1952 giving the length distribution as the number of fish per centimeter group, adjusted to a total of 10,000 fish for each of the different gears. I give here the ratios of these °/₀₀₀ frequencies.

Column III—Gives for each 5 cm group the fraction of the area of a normal curve having the same mean, standard-deviation and total area as the curve obtained by plotting the figures of Column II against the mid-points of the corresponding size groups of Column I.

Column IV—Gives the ordinates of a normal curve having the same mean and standard deviation as those of Column III, adjusted so that the modal ordinate is unity. These curves therefore express the fishing power of a gill-net for a fish of a given size relative to the fishing power for fish of the size at which the net is most efficient, i.e. the mean, 90 cm.

Peterson does not give data for the variability of mesh measurements or of the length/girth ratio in a form that permits analysis of the contribution that these variabilities make to the spread of the mesh-selection curve. It may be worth pointing out, however, that the standard deviations we have obtained for the gill-net selection curves are of the same order of magnitude as, but tending to be greater than, those which have been found for the selection ogives of trawls. Table 5 illustrates this, drawing upon data presented in another paper submitted to this meeting (Holt and Akyuz, 1957).

Now mesh experiments carried out so far with trawls show that the variation of mesh-size within the cod-end and the variation in length-girth

TABLE 2. Analysis of gill-net selection data for Fraser River Sockeye Salmon (from Peterson, 1954) - see text for explanation

Mesh size cm	A 13.5	B 14.0	C 14.8	D 15.4	E 15.9	F 16.6	G 17.8	H 19.0	log B/A	log C/B	log D/C	log E/D	log F/E	log G/F	log H/G
Length cm															
52.5	52	11	1	1	0	0	0	0	−1.55						
54.5	102	91	16	4	4	2	0	3	−0.11	−1.74					
56.5	295	232	131	61	17	13	3	1	−0.24	−0.57	−0.76	−1.28			
58.5	309	318	362	243	95	26	4	3	+0.03	+0.13	−0.40	−0.94	−1.30	−2.30	
50.5	118	173	326	342	199	100	10	11	+0.38	+0.63	+0.05	−0.54	−0.69	−1.64	−0.9
62.5	79	87	191	239	202	201	39	15	+0.10	+0.79	+0.23	−0.17	−0.01	−0.94	−1.0
64.5	27	48	111	143	133	185	72	25	+0.58	+0.84	+0.25	−0.07	+0.33	−0.50	−0.5
66.5	14	17	44	51	52	122	74	41		+0.95	+0.15	+0.02	+0.85	+0.10	+0.1
68.5	8	6	14	23	25	59	65	76				+0.08	+0.86	+0.75	+0.0
70.5	7	3	8	14	15	16	34	33				+0.07			
72.5	—	3	1	2	5	4	6	15							
								a	−7.14	−12.56	−6.23	−6.70	−13.96	−20.41	−10.4
								b	0.12	0.21	0.10	0.10	0.22	0.30	0.1

TABLE 3. Analysis of data for selection of Fraser River Sockeye Salmon by gill-nets (continued)

I Meshes	II Sum of mean selection lengths cm	III Sum of mesh sizes cm	IV Calculated mean selection length	V Standard deviation of selection curves cm
A			54.8	
A and B	119.0	27.5		5.8
B			56.8	
B and C	119.6	28.7		5.6
C			60.1	
C and D	124.6	30.1		6.9
D			62.5	
D and E	134.0	31.3		6.5
E			64.6	
E and F	127.0	32.6		5.1
F			67.4	
F and G	136.0	34.4		5.7
G			72.3	
G and H	139.6	36.8		8.0
H			77.1	
			Mean =	6.2

TABLE 4. Analysis of gill-net selection data for North Sea herring (from Hodgson, 1933)

I Experiment	II Meshes rows/yard	III -2a/b	IV k	V x cm	VI Calculated mean selection lengths
	35				24.3
25-27/10/32	35 and 33	51.3	4.93	4.93	
16-19/11/32	35 and 33	51.8	4.98	4.7	
	33				25.9
25-27/10/32	33 and 31	52.4	4.73	2.2	
16-19/11/32	33 and 31	51.8	4.68	2.2	
	31				27.6
		Mean	4.83		

Note $k = \frac{\text{mean selection length } l_m}{\text{mesh size in cm}}$ where mesh size is calculated as

$$2 \times \left(\frac{914.4}{\text{rows per yard}} - 0.09\right)$$

Table 5. The spread of selection curves

	S.D. of girth-selection curve cm
Gill-net	
Cod	7.0
Sockeye	3.3
Herring	2.2 - 4.0
Trawl	
Hake	2.4
Red-mullet	2.4
Plaice	1.9
Haddock	1.8

ratio between fish account for only a small part of the spread of the length selection ogive; although the same is probably true for mesh variation in gill-nets the data given by Farran for the variation of condition factor, and hence of length-girth ratio, in herring show on the other hand that it is large enough to account for the greater part - though not all - of the spread of the drift-net length selection curve. Attention has been drawn to this point in the belief that comparisons of the characteristics of selection curves for different kinds of gear may help to elucidate the processes of size selection by those gears.

The results we have obtained do not depend greatly on the exactness of the assumption that gill-net length-selection curves are normal. It may well be that gill-net curves are more nearly log-normal, since one might expect that the chance of a fish escaping depends not on the absolute amount, but on the proportion, by which its size differs from that size for which the net is most efficient. In such a case the standard deviation of the selection curve should increase with its mean. I have repeated the analysis, working throughout with logarithms of lengths, and have found that for the range of mesh size used in the Fraser River experiments the results are virtually the same as those obtained assuming normal distributions and constancy of standard deviation. For the analysis of experimental data for gears having widely differing meshes it would, however, be useful if it could be determined whether gill-net selection curves are usually almost symmetrical and whether their standard deviations are more or less constant or tend to increase with the mean. In another paper submitted to this meeting (Holt and Thomas, 1957) it is shown that length selection curves for hook and line gear may be log-normal and the above method would then be applicable to analysis of hook catch.

I have been informed by Mr. I. D. Richardson, of the Lowestoft Fisheries Laboratory, that recent comparisons of herring catches taken in the North Sea by drift nets with ring-net catches show that the drift-net selection curve is not normal, but may be skew, rather flat-topped and even bi-modal. This is caused at least partly by the fact that the herring are enmeshed in drift-nets in at least three positions - at the maxillae, the operculum and the point of maximum girth. The observed selection curve may in such cases be regarded as the algebraic sum of two or three normal selection curves (see appendix) thus:

$$C \propto \exp.\left[-(l-l_m)^2/2\sigma^2\right] + \exp.\left[-(l-l'_m)^2/2\sigma'^2\right] + \exp.\left[-(l-l''_m)\ /2\sigma''^2\right]$$

where l_m, l'_m, etc. define the modes of the several component curves and refer to the length -equivalent of the dimensions of the fish at the various capture points. The parameters of this expression can be estimated as before by treating maxillae-, operculum-, and girth-caught fish separately.

An alternative procedure is to fit an empirical curve of convenient mathematical form which can represent with the fewest parameters the essential features of the expected selection curve. Such an expression is the general cubic exponential:

$$C_l \propto \exp.\left[-u\,(l-l_m)^3 - v\,(l-l_m)^2\right]$$

This gives a curve skewed either way and sharply peaked or flat-topped according to the relative magnitudes of u and v. It results in a parabolic instead of a linear relation between fish length and the log-ratios of catches, and might be used to analyse the results of experiments with trammel nets (see Broadhead, 1953) and also with trawls in which there is evidence of escape of large fish other than through the cod-end meshes.

Some mention should be made of the uses to which knowledge of the absolute selection curve might be put. In his work Peterson had the problem of computing mesh-sizes to give maximum efficiency of capture, and also of determining the optimum distribution of mesh-sizes among the fleet. Now, as we have shown, the absolute selectivities of two gill-nets can in theory be determined by operating them both comparatively. Thereafter the catches by gill-nets of a given size, say those used commercially, can be used to determine the size frequency distribution of the population. Let us express this as a percentage length distribution, the percentage of fish at size l being denoted by N_l. Then the rate of catch in weight is given by

$$Y \propto \sum_{l} W_l N_l \exp.\left[-(l-l_m)^2/2\sigma^2\right]$$

where W_l is the weight (or value) of a fish of size l.

The value of l_m and hence the size of mesh which maximises the righthand side of the above equation can readily be computed. The method can be extended directly to cover problems arising from the change in the population size distribution during a season (either by growth or migration of fish), to examine the possible advantage of using a variety of meshes, and ultimately to derive equations permitting the computation of steady-state catches as functions of the number of nets, the time they operate, and their mesh sizes.

Now we should mention here that in order to predict both the short- and long-term effects on the catch of changing the selectivity of the gear in use, it is not essential to know the absolute selection curve of the old or the new gears. This may be demonstrated as follows:

Let the ordinate of a resultant selection curve for fish of length l be ${}_lS$

then

$${}_lS = {}_lS_r.{}_lS_g$$

where S_r are ordinates of the recruitment-selection curve for that fishery and S_g are ordinates of the selection curve for the particular gear in use.

The resultant selection curve is obtained directly from the size composition of the commercial catches. For computation in simple population models we need an estimate of the mean resultant length at first capture, l_c, given by

$$l_c = \sum_{l=0}^{l_{m-1}} ({}_{l+1}S - {}_lS)\,(l+0.5) \Big/ \sum ({}_{l+1}S - {}_lS)$$

(see for example Permanent Commission, Report of Ad Hoc Committee, 1956). For trawls $l_m \rightarrow L_\infty$ because the selection curve is asymptotic. For an approximation to gill-net selection we should need to calculate a mean resultant length at **last** capture, l_L, given by the same expression but with the lower and upper limits of the summation as $l = l_m$ and $l = l_\infty$ respectively. Suppose now it is proposed to use a new gear having a selection curve represented by ordinates S'_g so that

$$S' = S_r.S'_g$$
$$= S.S'_g/S_g$$

and

$$l'_o = \sum_{l=0}^{l_{m-1}}\left[{}_{l+1}(S.S'_g/S_g) - ({}_lS.S'_g/S_g)\right]\left[l + 0.5\right] \Big/ \sum\left[{}_{l+1}(S.S'_g/S_g) - {}_l(S.S'_g/S_g)\right]$$

A comparative fishing experiment will give directly the set of values

$$\frac{{}_lC'}{{}_lC} = \frac{{}_lS'_g}{{}_lS_g} \quad \text{for each length of fish.}$$

Then to compute the new mean resultant selection length it is necessary to know neither the recruitment selection curve nor the absolute gear selection curve, but only the initial resultant selection curve and the **ratio** of the new to the old gear selection curves. It is worth noting also that if there is a difference in the fishing power of the old and new gears, so that

$$\frac{{}_lC'}{{}_lC} = \frac{p'_m.}{p_m}\frac{{}_lS'_g}{{}_lS_g}$$

the estimates of the new mean lengths at first and last capture will be unbiased because the ratio p'_m/p_m appears in both the numerators and the denominators of the expressions for these quantities, and cancels out in each case.

The above argument can readily be extended to the situation where several gears having different selectivities are simultaneously fishing a given stock, and where it is desired to predict the effects of changes in the proportions of the different gears. Consider for simplicity two gears, identified by indices ′ and ″ and let the initial and changed situations be identified by suffices, $_1$ and $_2$, then we have

$${}_lS_1 = i_1.{}_lS' + j_1.{}_lS''$$

and

$${}_lS_2 = i_2.{}_lS' + j_2.{}_lS''$$

where i is the proportion of the total effort exerted by the gear having a **resultant** selectivity denoted by ${}_lS'$ and j is the proportion exerted by the other gear having resultant selectivity ${}_lS''$, so that $i + j = l$. The initial resultant selection ${}_lS_1$ is obtained from the composition of the total catch by both gears, and the ratio of the catches by each of the two gears gives

$${}_lC'_1/{}_lC''_1 = {}_lS'/{}_lS''$$

Substituting for ${}_lS''$ in the above equation we find

$${}_lS_2 = {}_lS_1 . \frac{i_1 + j_1 . {}_lC_1''/{}_lC_1'}{l_2 + j_2 . {}_lC_1''/{}_lC_1'}$$

If therefore the total efforts are known and we have data for the size-composition of the catches by each gear we can calculate the resultant selection curve for any hypothetical relative redistribution of effort between the several gears, provided of course that there is no relative change in the spatial distribution of their operations or other change which will alter the effective recruitment selection functions for each gear.

The analysis given above indicates that calculations of the expected effects of a change in gear selectivity, for which there are data from comparative fishing trials, do not necessarily depend critically on any knowledge or theories about absolute gear selection curves. In practice, however, estimation of the absolute selection is most desirable, firstly because measurable characteristics of the gear are related directly to it, thus making possible prediction of the effects of changing one or other of these characteristics, which may be tested experimentally. Secondly, to estimate the resultant selection curve from the composition of the catch requires knowledge of the relative magnitudes of the fishing and natural mortality coefficients, and information concerning the absolute gear selection curves, for situations where gear selection is occurring well above the recruitment selection range, can itself be used to separate the fishing and natural components of the total mortality rate (see Beverton and Holt, 1956).

APPENDIX I

Let ${}_xp_l$ be the probability that a fish of length l will encounter a gill-net and be retained by it at position x on its body, and the number of retaining positions be a finite number, n. Then the probability of capture for a fish of that length is

$$p_l = 1 - \prod_{x=1}^{x=n} (1 - {}_xp_l)$$

If all ${}_xp_l$'s are rather small we have, approximately,

$$p_l = \sum_{x=1}^{x=n} {}_xp_l$$

When

n = 3, and ${}_xp_l = {}_xp_m \cdot \exp\left[-(l - {}_xl_m)^2/2\sigma^2\right]$

we have the equation given in the text.

APPENDIX II. Some illustrations of the method.

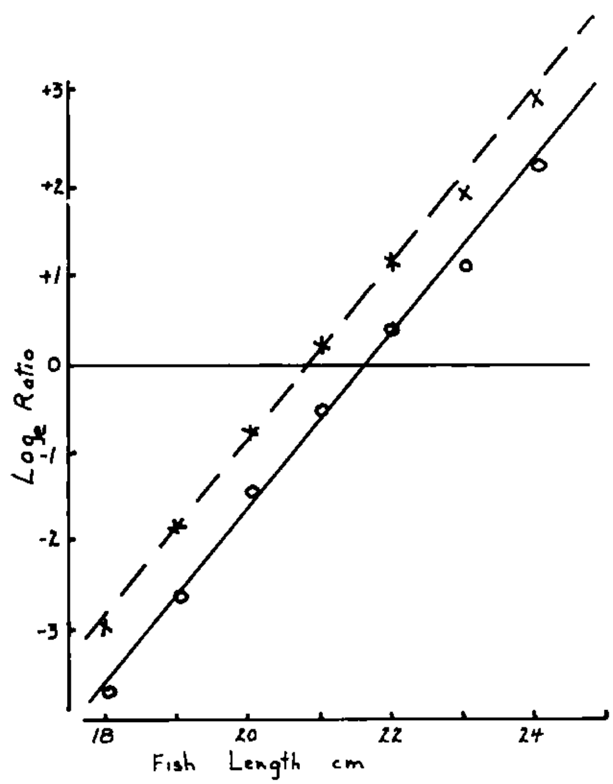

Fig. 1. Hodgson's data for herring, North Shields experiment, 12-20 July 1932. Mesh sizes — 36 rows per yd (4.90 cm) and 39 rows per yd (4.50 cm); k = 21.6/4.70 = 4.60; σ = 1.9 cm; x- - -x uncorrected % ratios, 0———0 corrected to catch per unit effort; ordinate — $\log_e$ ratio, abscissa — length of fish.

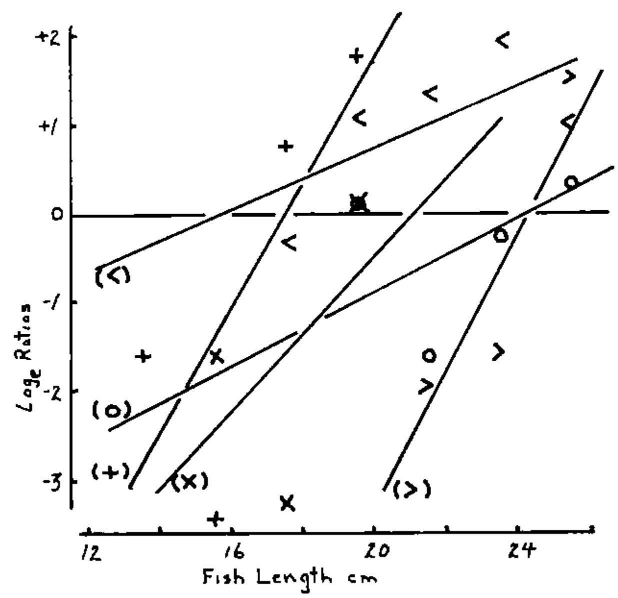

Fig. 2a. Thomson's data for yellow-eye mullet, *Aldrichetta forsteri* (C. et V.) caught by set nets. + = 1.5/1.25 meshes; x = 2/2.5; < = 2.25/2; 0 = 2.5/2.25; > = 3.25/2.5. Data grouped by 2 – cm groups, regressions fitted by least squares. Ordinate — $\log_e$ ratio, abscissa — length of fish.

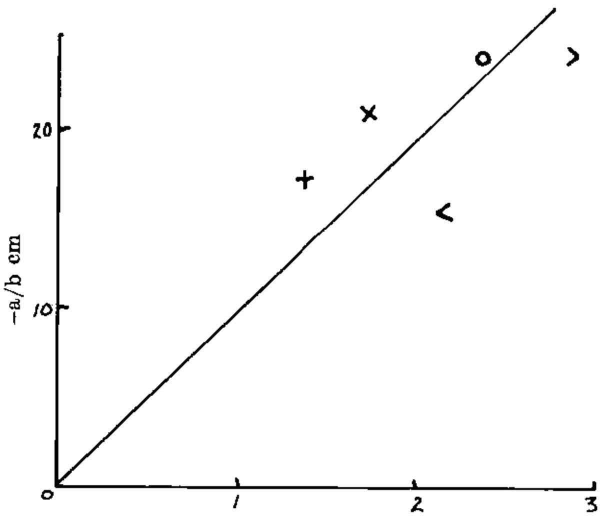

Fig. 2b. Thomson's data for yellow-eye mullet, continued. Ordinate — $-a/b$ cm; abscissa — mean mesh size (in). Slope of regression = 9.8; converting both scales to cm gives k = 9.8/2.54 = 3.9

The total number of fish caught in all tests was less than 1000. Only those ratios have been plotted which were based on catches of more than five fish taken by both nets. This example (Figs. 2a and b) illustrates the use that can be made of this method when there are rather few data. The regressions for each pair of nets are not very clear, but reasonable value for k is nevertheless obtained.

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10.

Some Theoretical Observations on the Escape of Haddock from a Codend

by

R. JONES[1]

Abstract

In this report an attempt has been made to consider quantitatively the effects of different factors on the mechanism of escape. This was done with a view to obtaining a theory that could

(a) explain the observed form of a selection ogive

(b) account for the observed ogive slope at the 50% release length

(c) explain why these slopes tend to de-decrease as the mesh size increases

(d) account for the observed difference in the girth/length relationship of haddock taken from the codend and cover.

As a first approximation, a theoretical ogive was predicted and its maximum slope determined as a function of the slope of the girth/length relationship, a coefficient related to mesh shape variation in mesh size, and variations in girth of fish of the same length.

The slope of this ogive at the 50% point was too great, however, and it was found that the girth/length ratios of haddock from the cover and codend should have differed more than they actually did.

The effect of haul duration and repeated attempts to escape were first considered and it was shown that doubling the duration would probably increase the 50% point by not more than 4 mm and have little effect on the ogive slope.

The possibility that large haddock were better able to force their way through meshes, or were able to make more attempts at escaping than small ones was then considered, but it was concluded that even if this occurred it was insufficient to explain the observed ogive slopes for all mesh sizes.

Finally, the possibility was considered that the shape of the meshes might vary throughout the codend. Considerations of the probable shape of a codend in motion suggested that this was quite probable and theoretical considerations indicated that if this were so, it would be possible to explain (a) why the observed ogive slopes were so low, (b) why they tended to decrease with increasing mesh size, and (c) why the girth/length ratios of haddock from codend and cover did not differ as much as might otherwise have been expected. These considerations are important in that they suggest that, apart from the nature of the codend twine, and the actual mesh size, perhaps the most important single factor affecting selection will be the range of shapes of the codend meshes. These will depend on the weight of the codend material and the flow of water through the codend which in turn will depend on various factors, including the shape of the trawl where the codend is attached and probably the whole rig of the net. It seems quite reasonable therefore to suppose that a codend could have different selective characteristics dependent on the type of net to which it was attached.

The Probable Shape of an Ogive

Many determinations of mesh selection have been made during the past fifty years, and these have shown that the escapement curve of fish from a trawl codend is not knife-edged, but tends rather to be sigmoid. Now, if all the fish of a given length had the same girth, and if all the meshes in the codend had the same shape, one might expect near knife-edge selection, since for any fish with a particular girth, its chances of escape would be 0 or 1, according to whether it could slip through the meshes or not. In practice, the meshes will vary in size and shape, so

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that the chances of a fish with a particular girth escaping will no longer be 0 or 1, but will depend on its chance of encountering, or finding, a mesh that it can get through.

If the distribution of mesh size is normal, then for any one shape of mesh the chances of escape of a fish of particular girth can easily be determined from the known properties of the normal curve. Since it has been more customary to relate escapement to the length of the fish rather than to its girth, it is also possible to take into account the distribution of girths among fish of a given length. This is done in the theoretical section where it is found (6) that the probability of escape of a fish of length L from a codend of mean mesh size M, is given by

$$P(L, M) = \frac{1}{\sqrt{2\pi(\mu^2\sigma_a^2 + \sigma_G^2)}} \int_X^{\infty} \exp - \frac{1}{2(\mu^2\sigma_a^2 + \sigma_G^2)} (X - \mu M)^2 \, dX \quad .. (6)$$

where σ_a^2 is the variance of the mesh size about the mean M, σ_G^2 is the variance of the girths of fish of the same length and μ is a constant dependent on the shape of the mesh and defined as the ratio of any girth so that mesh size that just "fits it". X is the mean girth of a fish of length L, and can generally be written as $X = \alpha + \beta L$ where α and β are constants and L is the length of the fish.

For haddock, $\alpha = 4.2$ and $\beta = 4.45$ when L is in cm and the girth (X) is in mm.

This formula was reached by supposing that each fish made only one attempt to escape. The effect of repeated attempts will be considered later.

Estimating the Parameters of the Theoretical Selection Curve

1. σ_G^2 is the variance of the girths of individual haddock of the same length. This can be determined by first plotting a regression of girth on length so as to determine the parameters of the relationship $X = \alpha + \beta L$, and then estimating σ_G^2 as the residual variance of girths about this line. Several sets of data have been analysed in this way, using maximum head girths rather than the more yielding body girths. These are tabulated below. All head girths were measured in mm and lengths in cm.

	σ_G^2(mm²)	β	α (mm)	Source
	39	4.39	10.2	J. A. Pope
	21	4.41	5.6	(Lucas *et al*).
	42	4.60	—3.2	Present author
Mean	34	4.45	4.2	

Margetts (1954) using body girths rather than head girths obtained slightly higher values of β (ca 5.0 for constricted body girths).

2. σa^2. This is the variance of the codend meshes when fishing. It is not practical to measure this directly, but as a first approximation the variance in mesh size when measured aboard ship can be used. Many estimates of variance have been obtained during Scottish gear testing experiments and the range in mesh size variance was from 5.4 mm² to 12.6 mm².

3. μ. This defines the relationship between mesh size and girth when the girth is such that a fish can only just slip through the mesh concerned. This constant takes account, therefore, of variations in the shape of the meshes, and of the tension on the twine. If the meshes were quite slack, and a fish could push its way through until it completely filled the lumen of the mesh, the internal perimeter of the mesh would be equal to its girth. Also, as a first approximation the internal measurement of the mesh when stretched diagonally would equal half its internal perimeter and therefore be equal to half the fish's girth, i.e. $M = G/2$.

Then, since by definition $\mu = \frac{G}{M}$ we find that

$\mu = 2$

This defines the maximum value that μ can have. In fact it has been shown in the underwater film "Trawls in Action" that the meshes of a trawl codend are fairly rigid, and diamond shaped. If they were completely rigid the maximum girth that could just slip through any mesh would be less than twice the mesh size. Just how much less would depend on the actual shape of the mesh and of the fish. This is illustrated diagrammatically in Fig. 1, and as a first approximation it has been supposed that the cross-sectional shape of a fish, in the region of its maximum girth, is elliptical, the ratio of the long and short axes of the ellipse being equal to the ratio of head depth to breadth, i.e. $\frac{d}{b}$ in Fig. 1.

From this assumption, the relationship between the coefficient μ and the angle θ (in Fig. 1) has been determined and values of μ have been

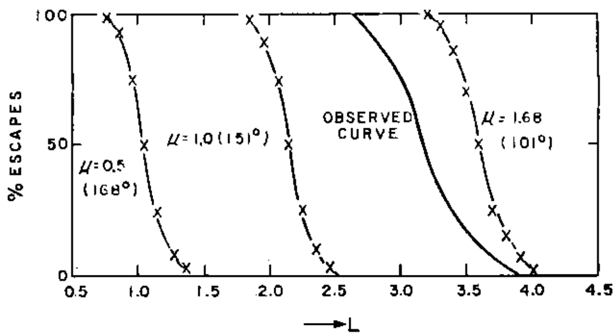

Fig. 1. Theoretical haddock ogives for a 100 mm trawl codend.

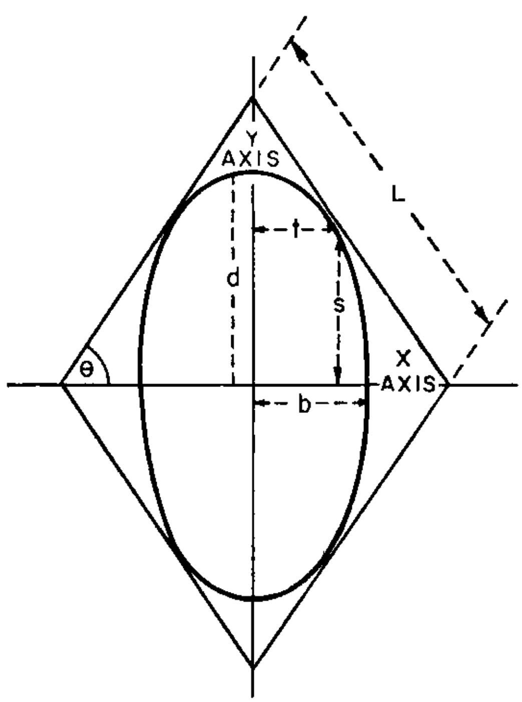

Fig. 2. Diagrammatic cross - section of an elliptical fish, just fitting a rigid diamond - shaped mesh.

plotted for different values of the larger internal angle of the mesh in Fig. 2. It is a curve with a maximum of about 1.65 at an angle about 107°.

The Slope of the Theoretical Selection Curve

Using the values of the various parameters determined above, theoretical selection curves have been determined from expression (6) for different values of μ, and are plotted in Fig. 3 for a 100 mm codend. The three theoretical curves shown are similar in shape but the position of the 50% release point can be tremendously affected by the shape of the meshes. An observed haddock ogive for a 100 mm codend is also shown, the position of its 50% escape length (32 cm) being equivalent to a value of μ = 1.47 or an angle of 127°. The interesting thing about this comparison, however, is that the theoretical curves are all much steeper at their 50% release points than is the observed curve, as was nearly always found to be the case.

The actual slope of the theoretical curve at its 50% release length is easily shown (next section) to be equal to

$$\frac{-\beta}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}} \quad \ldots\ldots\ldots\ldots (14)$$

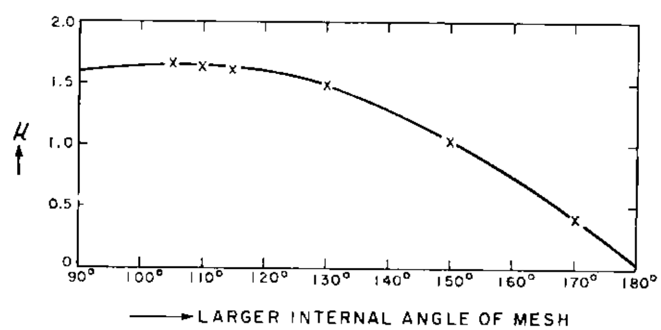

Fig. 3. Relationship between (μ) the girth/mesh size ratio and the larger internal angle of mesh for haddock.

Substituting the largest values of μ (1.65) and σ_a^2 (12.6) in this formula gives a minimum absolute slope of 0.21. Actual slopes determined from published and Scottish haddock selection data are shown in Fig. 4, plotted against mesh size. It is quite obvious that nearly all are well below the theoretical figure of 0.21. It appears,

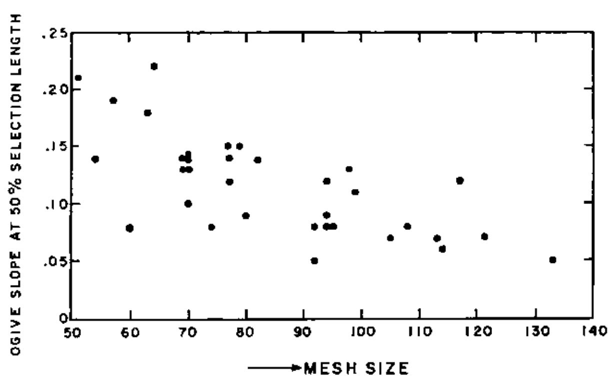

Fig. 4. Relationship between the slope of a haddock selection curve at the 50% release point and mesh size.

too, that there is a tendency for the slope to decrease with increasing mesh size.

This is a big discrepancy between theory and observation but before going on to consider what factors other than mesh and girth variation might contribute to the mechanism of escape let us enquire further into some of the implications of the simple theoretical model.

The Girth/Length Relationship in Codend and Cover.

If the basic assumptions of the simple theory are correct, one would expect that, length for length, the girths of haddock that had escaped into the small mesh cover would be smaller than those of fish retained in the codend. Two sets of samples have been analysed to investigate this effect and for each sample regression lines were fitted to the girths and lengths of haddock fiom the codend and cover separately. To reduce bias, fish from cover and codend were measured alternately by the same person throughout. In each sample it was found that for haddock of the same length the mean girths were 2 mm larger in fish taken from the codend. This difference is in the right direction, but theoretical considerations based on the simple theory (next section) suggest that the mean difference should have been not less than 6.6 mm. It seems necessary, therefore, to introduce additional factors into the theoretical model so as to satisfy both the observed ogive slopes and the difference in girths between codend and cover. There are several possibilities but in this report three in particular will be considered:

(a) the effect of duration of haul on the likelihood of escape
(b) the effect of behaviour differences between fish of different size
(c) the effect of variations in the shape of the meshes, i.e. variations in the coefficient μ.

(a) The effect of haul duration on the selection curve.

So far, selection has been treated as though each fish made only one attempt to escape. In fact it is likely that several attempts will be made, the actual number depending on the length of time for which each fish is in the codend. Thus, if it is supposed that the first caught fish made no attempts to escape and the last caught made one attempt it is possible to determine the resultant selection curves for different values of n. This has been done (next section equation 18) more conveniently in terms of the probability of being retained and the resultant curves for values of n = 1, 2, 4 and 8 are shown in Fig. 5.

The theoretical curves (Fig. 5) were all determined for a value of mesh shape (μ) = 1.5. Different values of μ have very little effect on the

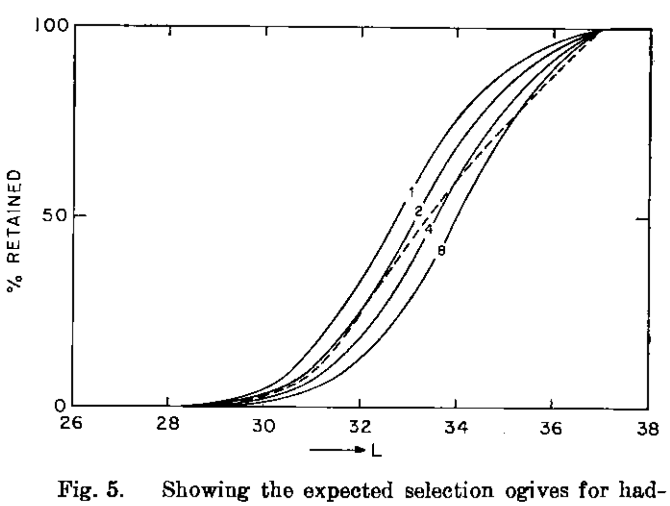

Fig. 5. Showing the expected selection ogives for haddock using a 100 mm codend assuming that up to 1, 2, 4 and 8 attempts at escaping are made respectively (μ = 1.5). The dotted line illustrates the sort of curve that might arise if the number of attempts at escaping increased with length.

ogive slopes, but merely affect the 50% selection point (Fig. 3) and it may be supposed therefore that the differences between the curves in Fig. 5 would be practically unaffected by changes in μ. Over the range of n chosen, it would appear that by doubling the duration of haul, which in turn may be supposed to double the value of n, there would be little change in ogive slope, but merely an increase of about 4 mm in the 50% selection point.

As the maximum possible number of escapes tends to infinity, the experiment tends to the state in which all fish have had at least one attempt at escaping through the largest mesh. The resultant selection curve would therefore be a finite distance to the right of the group in Fig. 5 and, since the component of mesh variation would have been eliminated, the ogive slope would be increased.

The effect of doubling the duration of a haul should therefore be to increase the 50% release point by not more than 4 mm and to increase very slightly the maximum slope of the ogive. This does not help to explain the relatively low slopes observed in practice.

(b) The effect on selection of behaviour differences between fish of different sizes.

So far, it has been supposed that all fish, irrespective of girth or length, are equally likely to come into contact with the codend meshes. Instead, we might suppose that the larger fish are better fitted both for making repeated attempts at escape and also for forcing an exit through part-open meshes.

The effect on the selection curve of making repeated attempts to escape has already been considered (Fig. 5). If it is now supposed that between the lengths 32 to 35 cm, say, the number of attempts at escape increases four-fold (i.e. from 2 to 8 in this example) the resultant selection curve will be as shown by the dotted line in Fig. 5. This has the effect of substantially reducing the ogive slope, but only at the expense of supposing that there was a four-fold increase in the rate of attempt to escape for a 3 cm increase in size of fish. To use this argument to explain the low ogive slopes of codends with mesh sizes ranging from 70 mm to 100 m we must suppose that a 35 cm haddock makes a thousand times as many attempts to escape as a 20 cm haddock, which seems absurd.

The same difficulty arises if it is argued that the larger fish are better able to force open any part-open meshes they encounter. This is effectively the same as supposing that the coefficient μ increases with the size of fish. However, when values of the 50% haddock lengths are plotted against mesh size as in Fig. 6 (based on published data summarized in Table 1) it is found that the data are reasonably fitted by a straight line, corresponding to a value of μ that remains almost constant at 1.47. The low observed ogive slopes cannot therefore be explained by supposing that μ increases with the size of fish.

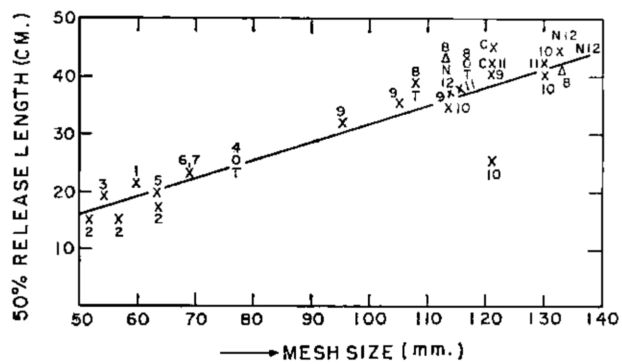

Fig. 6. Summary of trawl selection results - haddock. Straight line (L = .32M) is the haddock 50% length/mesh relationship adopted in the report of the *Ad Hoc* Committee.
1, Fulton, 1893; 2, Fulton, 1922; 3, Todd, 1911; 4, Russell and Edser, 1926 (Trouser codend); 5, Bowman, 1928; 6, Davis, 1929; 7, Davis, 1934; 8, Herrington, 1935 (Trouser codend + alternate hauls); 9, Clark, 1952; 10, McCracken, 1955; 11, McCracken, 1956; 12, Clark, 1956: < Covered codend - double twine; O Single twine; △ Alternate hauls; T Trouser codends; C Cotton; N Nylon; D Dacron.

(c) The effect on selection of variations in mesh shape.

Variation in mesh shape (i.e. the coefficient μ) can be either random or systematic. The random variations will probably be correlated with the individual mesh variations whilst systematic variations whilst systematic variations will arise from variations in the forces acting on different parts of the codend when the trawl is in motion. The actual shape of the codend meshes will depend on the resultant of two groups of factors, (i) the flow of water through the meshes, tending to keep them open, and (ii) the drag effect of the codend material and fish tending to close them. This is illustrated very diagrammatically in Fig. 7 A stationary codend (7A) can be expected to collapse completely due to the weight of material, except in so far as it may be supported at the end by fish inside (7C). This is borne out by the shots of the codend in the underwater film "Fish and the Seine Net". It will not open until there is passage of water through the top of the codend as in 7B. The actual lines of flow may be nearly horizontal, or diagonally upwards. In either case it is to be expected that the net will taper downwards towards its tip as in 7B. The degree to which the meshes are open at any point will then depend on the circumference of the codend and the number of meshes /row. The number of meshes /row remains constant at about 60 for the last 17 ft or so in an Aberdeen trawl codend, so that the effective mesh size will tend to decrease from front to back in an empty codend.

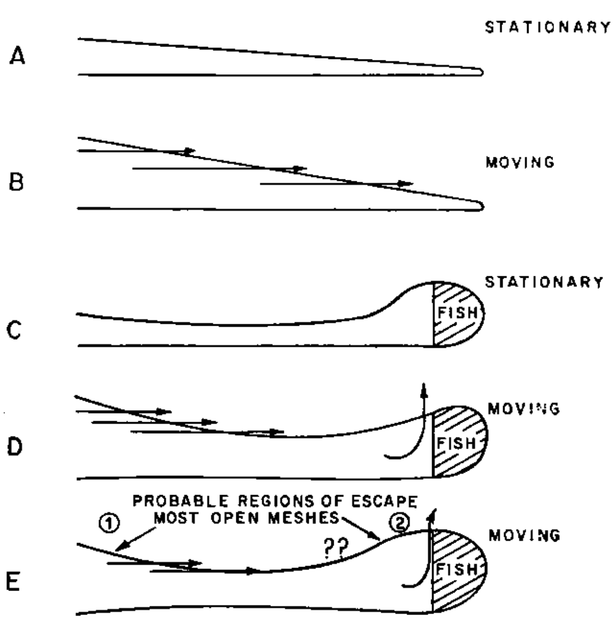

Fig. 7. Showing the possible shapes of a codend under different circumstances. The arrows indicate the probable direction of water flow.

The drag effect will be cumulative so that the meshes at the front of the codend will be under the greatest fore and aft tension. However we have already argued that these will be the most open meshes so they must also be under the greatest horizontal tension before they can remain open. It seems reasonable to conclude, in fact, that the meshes at the front of the codend will be open, rigid diamonds, and those at the back will tend to be more closed but proportionately easily distorted diamonds.

In a full codend (7D) the same arguments apply but in addition there will be a bulk of fish serving to stretch the codend and the codend meshes. The region just in front of the fish will consist of open meshes made fairly rigid by the drag of the solid fish mass. If the fish form a sufficiently solid barrier to the water, this may be deflected out at right angles to the net, also helping to open the meshes as shown in the film "Fish and the Seine Net". Just in front of this point it is difficult to predict what direction the flow will take.

These considerations lead us to the conclusion that the mesh shape almost certainly varies in different parts of the codend and also while the bag fills during the course of an individual haul. The effect on the selection curve of different quantities of fish will depend on which part of the codend releases most fish. If escapes occurred from the very end of the codend, then the presence of a large bag of fish might prevent any escapes after a time (Fig. 7E). More probably, if the majority of escapes were from regions (1) and (2) (Fig. 7E), then, within certain limits, the percentage escapes might be practically independent of the size of catch.

Without knowing the exact frequency distribution of mesh shapes, a rigorous theoretical treatment cannot be attempted. As a first approximation though, it is sufficient to plot several selection curves with different values of μ, and then average them. For example, in Fig. 8 are shown two theoretical ogives A and B represented as straight lines on normal probability paper. These have slopes at their 50% lengths of 0.21 and, assuming a 100 mm mesh, their 50% lengths (30 cm and 34 cm) correspond to values of μ of

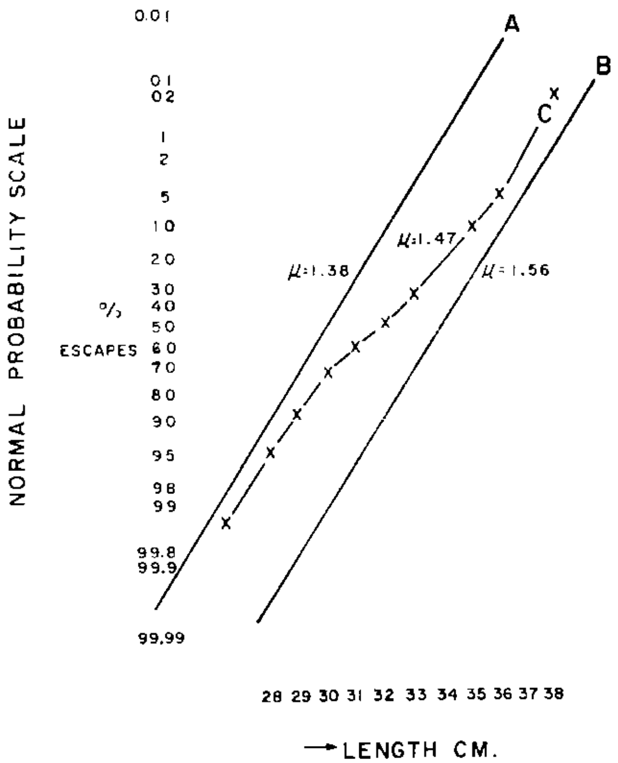

Fig. 8. Showing the effect of taking an average of two theoretical ogives (A and B) for a 100 mm cod-end to give a resultant ogive C.

1.38 and 1.56 respectively. The resultant curve (C) obtained by averaging these, has a slope of 0.12 and a 50% length of 32 cm, corresponding to a value of μ equal to 1.47. To be more realistic we could suppose that there was a gradual change in the coefficient μ, from 1.38 to 1.56, in which case it would be necessary to obtain the resultant of a whole family of curves like A and B. If this is done, with A and B as the extreme range of the distribution, it is found that the slope of the resultant curve (C) is not quite as low as 0.12. In order to make it equal to 0.12, it is necessary to suppose that in fact the range of mesh shape is a little larger than that corresponding to μ equal to 1.38 and 1.56, which is by no means improbable. Furthermore, this explanation can apply to the whole selection range, so that the low observed slopes of ogives from all mesh sizes can be explained. It is even possible to explain why there is a tendency for the ogive slope to decrease with an increase in mesh size (Fig. 4).

By definition, the mesh size is related to the 50% girth by the expression $G = \mu M$, and the 50% length (L) corresponding to this girth is such that $G = \alpha + \beta L$.

Therefore, $\mu M = \alpha + \beta L$.

For two values of μ and the corresponding 50% release lengths and

$$\mu_1 M = \alpha + \beta L_1$$
$$\mu_2 M = \alpha + \beta L_2$$

Therefore the difference in the release points corresponding to the two values of μ is simply

$$L_1 - L_2 = (\mu_1 - \mu_2) M / \beta$$

We see then that for a fixed range $(\mu_1 - \mu_2)$, the range of release points $(L_1 - L_2)$ will increase as the mesh size (M) increases, by a factor of M/β. This means (Fig. 8) that the two lines A and B will be further apart for large mesh sizes than for small, and the further they are apart, then the smaller will be the slope of the resultant curve (C), i.e. the ogive slope will decrease with increasing mesh size.

One other point that has to be explained is the fact that, length for length, the difference in girths of fish from the cover and codend, was not as large as expected. The effect of varying μ has been worked out in the next section, and for the simple case in which μ takes the two values, 1.40 and 1.65 with equal likelihood, it is found that the expected difference in girths is equal to 2 mm. This agrees exactly with the observed results.

Theoretical Considerations

The probable form of a selection ogive:

As a first approximation it is convenient to consider a fish of a particular girth faced by a particular mesh. It can escape if the mesh is greater than a certain size. Otherwise it cannot. If then, there were a hundred fish of different girths faced by a number of identical meshes, all those below a certain size should be able to get through. Selection in fact should be knife-edged. In practice, the meshes in a codend are subject to variations in size and shape so that the probability of a particular fish getting through is not 1 or 0, but depends on its chances of finding or encountering a mesh greater than a certain size. Selection would no longer be knife-edged.

Let us suppose that the effective mesh size in use (a) is distributed normally with mean M and variance σ_a^2

i.e. $$P(a)\,da = \frac{da}{\sigma_a\sqrt{2\pi}} \exp - \frac{1}{2\sigma_a^2}(a-M)^2 . (1)$$

For any fish of girth (G), there will be a critical mesh size, above which escape is certain and below which escape is impossible. It will be supposed that this critical mesh size is proportional to the girth so that

$$G = \mu\, a$$

where μ is a constant depending on the shape of the mesh and a is the size of the stretched mesh as normally measured.

The probability of a fish of girth 'G' escaping is therefore simply the probability of encountering a mesh of size a $= G/\mu$ or greater.

i.e. Probability of escape =

$$\frac{1}{\sigma_a\sqrt{2\pi}} \int_{G/\mu}^{\infty} \exp - \frac{1}{2\sigma_a^2}(a-M)^2\,da \quad .. (2)$$

In practice it is customary to consider the probability of escape of a fish of a given length (L) rather than of a particular girth. Measurements of the relationship between girth and length show that it is linear of the form mean girth (X) $= \alpha + \beta L$, and that there is a natural variation in the girths (G) of several fish of the same length. It will be supposed that this variation is normal, with mean X and variance σ_G^2.

i.e. $$P(G)\,dG = \frac{dG}{\sigma_G\sqrt{2\pi}} \exp - \frac{1}{2\sigma_G^2}(G-X)^2 . (3)$$

The probability of a fish of length 'L' escaping can therefore be obtained by summing the probabilities of escape of individuals of that size but with different girths

i.e. $$P(L/M) = \int_{-\infty}^{\infty} \left\{ \frac{1}{\sigma_a\sigma_G} \exp - \frac{1}{2\sigma_G^2}(G-X)^2 \int_{G/\mu}^{\infty} \exp - \frac{1}{2\sigma_a^2}(a-M)^2\,da \right\} dG \quad \ldots (4)$$

where P(L/M) stands for the probability of escape of a fish of length 'L', from a codend with mean mesh size 'M'. This expression can be simplified somewhat by first differentiating with respect to M, so that both integrations can be performed, and then integrating with respect to M. This leads to the form

$$P(L/M) = \frac{\mu}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}} \int_{\infty}^{m} \exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(\mu M - X)^2\,dM \quad \ldots (5)$$

which can be rewritten

$$P(L, M) = \frac{1}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}} \int_{X}^{\infty} \exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(X-\mu M)^2\,dX \quad \ldots (6)$$

where $X = \alpha + \beta L$

Expressed in this way, the relationship between probability of escape and length appears as a normal ogive.

The relationship between mesh shape and μ.

It has been supposed that the cross-section of the head of an escaping fish can be regarded as an ellipse, as is indicated in Fig. 1.

After some algebraic manipulation, it can be shown that

$$\mu = \frac{C}{\left[\dfrac{K^2}{\sin^2\theta} + \dfrac{1}{\cos^2\theta}\right]} 1/2 \ldots\ldots\ldots\ldots (7)$$

where K is the head depth/head breadth ratio, and C is the ratio of head girth to head breadth.

For haddock, K, the head depth/breadth ratio is equal to 1.67, and C the head girth/head breadth ratio is 4.37. Values of μ for different mesh angles are shown below and plotted in Fig. 2.

Larger internal angle	θ	μ
90°	45	1.59
106°	53	1.64
110	55	1.63
114	57	1.61
130	65	1.46
150	75	1.03
170	85	0.38

The slope of the theoretical ogive:

The theoretical selection curve expressed in (6) above is a normal ogive of which the 50% release point occurs when $X = \mu M$, i.e. at a length corresponding to the girth that could just slip through an average mesh when stretched during fishing.

The slope of the ogive can be obtained by differentiating (6) with respect to L, giving

$$\text{slope} = \frac{-\beta}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}} \exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(X-\mu M)^2$$

The maximum slope occurs at the 50% release length (when $X = \mu M$)

$$\text{i.e. max. slope} = \frac{-\beta}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}} \quad \ldots\ldots (8)$$

The expected difference between the girths of haddock in the codend and cover.

The probability of escape of a fish of length L is given by expression (4). This is an integral over the whole range of girths, so that the probability distribution of girths for a given length in the cover will be

$$\frac{d\,G}{P(L/M)}\left\{\frac{1}{\sigma_a\,\sigma_G\,2\pi}\exp - \frac{1}{2\,\sigma_G^2}(G-X)^2\int_{G/\mu}^{\infty}\exp - \frac{1}{2\,\sigma_a^2}(a-M)^2\,d\,a\right\}\ldots\ldots\ldots\ldots(9)$$

so that the mean girth will be given by

$$\overline{G}_E(L) = \frac{1}{P(L/M)}\int_{-\infty}^{\infty}\left\{\frac{G}{\sigma_a\,\sigma_G\,2\pi}\exp - \frac{1}{2\,\sigma_G^2}(G-X)^2\int_{G/\mu}^{\infty}\exp - \frac{1}{2\,\sigma_a^2}(a-M)^2\,d\,a\right\}d\,G\ldots(10)$$

After some rearrangement and simplification, this becomes

$$\overline{G}_E(L) = X - \frac{1}{P(L/M)}\left\{\frac{\sigma_G^2}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}}\exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(X-\mu M)^2\right\}\ldots(11)$$

Similarly, the mean girth amongst the retained fish will be given by

$$\overline{G}_R(L) = X + \frac{1}{P^1(L/M)}\left\{\frac{\sigma_G^2}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}}\exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(X-\mu M)^2\right\}(12)$$

where P^1 (L,M) is the probability of a fish of length L being retained. The difference between these means will therefore be

$$\frac{\sigma_G^2}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}}\exp - \frac{1}{2(\mu^2\sigma_a^2+\sigma_G^2)}(X-\mu M)^2\left\{\frac{1}{P^1(L/M)} + \frac{1}{P(LM)}\right\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

At the 50% release length, when $X = \mu M$ and $P(L/M) = P^1(L/M) = 0.5$, this simplifies to

$$\frac{4\,\sigma_G^2}{\sqrt{2\pi(\mu^2\sigma_a^2+\sigma_G^2)}}$$

which for a value of $\mu = 1.65$, is numerically equal to 6.6 mm. At some other length, conveniently chosen so that

$$\frac{(X - \mu M)}{\sqrt{\mu^2 \sigma_a^2 + \sigma_G^2}} = 1$$

the difference between the means becomes

$$1.64\ (.6065) \left\{ \frac{1}{.8413} + \frac{1}{.1587} \right\} = 7.5 \text{ mm}$$

It would appear therefore that the minimum difference between the mean girths for a given length should be about 6.6 mm.

Next, let us suppose that the codend can be divided into two groups, with shapes defined by μ_1 and μ_2 respectively.

Then, as a first approximation, the probability of escape (equation 6) becomes

$$P\,(L/M) = \tfrac{1}{2} \left\{ P\,(L,M,\mu_1) + P\,(L,M,\mu_2) \right\} . \quad (14)$$

where $P(L, M, \mu_1)$ is the probability of escape of a fish of length L from a codend with mean mesh size M and mesh shape μ. Let the corresponding probability of being retained be defined as

$$P^1\,(L,M) = \tfrac{1}{2} \left\{ P^1\,(L, M, \mu_1) + P^1\,(L,M, \mu_2) \right\} \quad (15)$$

The difference between the mean girths for a given length, in codend and cover, corresponding to (13) will then be

$$\left[F\,(\mu_1) + F\,(\mu_2) \right] \left\{ \frac{1}{2\,P\,(L,M)} + \frac{1}{2\,P\,(L,M)} \right\} \quad (16)$$

where $F\,(\mu_1) = \dfrac{\sigma_G^2}{\sqrt{2\pi\,(\mu_1^2 \sigma_a^2 + \sigma_G^2)}} \exp$

$$- \frac{1}{2\,(\mu_1^2 \sigma_a^2 + \sigma_G^2)} (X - \mu_1 M)^2$$

Now, let $\mu_1 = 1.65$ and $\mu_2 = 1.40$ say

Let M = 100 mm and X equal 152.5 mm (i.e. L = 33.3 cm)

Then, the difference between the mean girths in cover and codend is numerically equal to

$$\left[.5223 + .4679 \right] \left\{ \frac{1}{.9860} + \frac{1}{1.0140} \right\} = 1.98 \text{ cm}$$

The effect of systematic variations in mesh shapes would therefore be to reduce the expected difference between the girths of fish in the codend and cover.

The effect of duration of haul on the selection curve:

The probability of escape of a fish with a particular girth G, is given by equation (2). This expression only holds for one attempt at escaping. If several independent attempts were made its chances of escape would be increased.

Let $\Psi^{\bullet}\,(G)$ be the probability that a fish of girth G does **not** escape after one attempt, so that from (2),

$$\Psi^{\bullet}\,(G) = \frac{1}{\sigma_a \sqrt{2\pi}} \int_{-\infty}^{G/\mu} \exp - \frac{1}{2\,\sigma_a^2} (a - M)^2\, da$$

Then the probability that it does not escape after n trials will be simply

$$[\ \Psi^{\bullet}\ (G)\ ]^n$$

and the probability of escape after n trials

$$1 - [\ \Psi^{\bullet}\,(G)\ ]^n$$

Now, it seems reasonable to suppose that the number of attempts at escaping will be proportional to the duration of haul, so that the first caught fish will have n attempts and the last caught fish one attempt, the mean probability of a fish of girth G being retained will therefore be

$$\frac{1}{n} \left[\Psi^{\bullet}\,(G) + \Psi^{\bullet}\,(G)^2 + \Psi^{\bullet}\,(G)^3 + \ldots .\ \Psi^{\bullet}\,(G)^n \right] \quad \ldots\ldots\ldots (17)$$

Considering next all the different girths of fish of length L, the probability of a fish of length L being retained is given by

$$P^1\,(L, M) = \frac{1}{n} \int_{-\infty}^{\infty} \left\{ \frac{1}{\sigma_G \sqrt{2\pi}} \exp - \frac{1}{2\,\sigma_G^2} (G - X)^2 \left[\frac{\Psi^{\bullet}(G)\,[\,1 - \Psi^{\bullet}(G)^n\,]}{1 - \Psi^{\bullet}\,(G)} \right] dG. \right. \quad (18)$$

This expression can be integrated numerically, and selection curves for $\mu = 1.5$ and values of $n = 1, 2, 4$ and 8 are plotted in Fig. 5.

Discussion and Summary

In this report an attempt has been made to consider quantitatively the effects of different factors on the mechanism of escape. This was done with a view to obtaining a theory that could

(a) explain the observed form of a selection ogive
(b) account for the observed ogive slopes at the 50% release length
(c) explain why these slopes tend to decrease as the mesh size increases
(d) account for the observed difference in the girth /length relationship of haddock taken from the codend and cover

As a first approximation, a theoretical ogive was predicted and its maximum slope determined as a function of the slope of the girth / length relationship, a coefficient related to mesh shape, variation in mesh size, and variations in girth of fish of the same length.

The slope of this theoretical ogive at the 50% point was too great, however, and it was also found that the girth /length relationships of haddock from the cover and codend were expected to differ more than they actually did.

The effect of haul duration and repeated attempts to escape were first considered and it was shown that doubling the duration would probably increase the 50% point by not more than 4 mm and have little effect on the ogive slope.

The possibility that large haddock were better able to force their way through meshes, or were able to make more attempts at escaping than small ones was considered, but it was concluded that even if this did happen it was insufficient to explain the observed ogive slopes for all mesh sizes.

Finally, the possibility was considered that the shape of the meshes might vary throughout the codend. Considerations of the probable shape of a codend in motion suggested that this was quite probable and theoretical considerations indicated that if this were so, it would be possible to explain (a) why the observed ogive slopes were so low, (b) why they tended to decrease with increasing mesh size, and (c) why the girth /length relationships of haddock from codend and cover did not differ as much as might otherwise have been expected. These considerations are important in that they suggest that, apart from the nature of the codend twine, and the actual mesh size, perhaps the most important single factor affecting selection will be the range of shapes of the codend meshes. These will depend on the weight of the codend material and the flow of water through the codend which in turn will depend on various factors, including the shape of that part of the trawl to which the codend is attached and also on the whole rig of the net. It seems quite reasonable therefore to suppose that a codend could have different selective characteristics according to the type of net to which it was attached.

However, this is only a theoretical contribution. It now remains to see if haul to haul variations in selectivity can be correlated with variations in mesh shape by direct measurement. To do this an instrument suitable for measuring mesh shapes while the codend is being towed will have to be devised.

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11.

Some Estimates of Theoretical Minimum Expected Sizes of Perch in Gill Nets

by

C. KIPLING[1]

Abstract

Theoretical minimum sizes of perch caught in gill nets of various meshes are calculated from regressions of log. maximum girth on log. length and log. weight. Very little advantage is gained by using multiple regressions log. girth - log. length - log. weight. Differences in "condition" in different years and seasons can cause appreciable variations in the minimum sizes caught. Examples of length frequency distributions of perch caught in gill nets and by other methods are shown graphically for comparison with the theoretical results.

This short paper describes an attempt to calculate theoretically the expected minimum sizes of perch (*Perca fluviatilis* Linn) meshed by the body in gill nets. The method used is similar to that used by Margetts (1954) in studying mesh selection of trawled haddock and whiting. As opposed to the trawl, the gill net meshes can be assumed to be completely flexible, and, as the gill net is set for at least 24 hours, all undersize fish will have time to escape. The minimum lengths and weights of perch expected to be meshed by the body in gill nets of various mesh sizes were derived from length, weight and girth measurements of angled and trapped fish. Confidence limits were calculated for the estimates and the theoretical minimum lengths and weights were compared with actual catches from gill nets.

The data were taken from two samples of female mature fish caught in Windermere, the first (110 fish) angled in October 1948, the second (38 fish) trapped in November and December 1956.

The maximum girths were measured by encircling the fish with a piece of string, firmly but without constricting the flesh, and then measuring the string on a ruler. This is referred to by Margetts (1954) as the natural girth. This method of measurement may result in a slight underestimate of minimum sizes, as the fish which just squeeze through with some distortion of the body are omitted. This factor is probably of less importance for the perch, which has a relatively firm structure, than it would be for some other species (*e.g.* char and pike) which are more flexible.

Multiple regression equations of the logarithms of girth on the logarithms of length and the logarithms of weight, and also the multiple correlation coefficients, were calculated for each sample by the method of least squares. It was apparent that no appreciable advantage would be gained by using multiple regression equations and that the simple logarithmic regression equations were adequate for the present purpose.

It was assumed that the minimum size of fish held by a net was one whose maximum girth was equal to the circumference of the meshes. On this basis theoretical minimum lengths and weights of fish were calculated from the log length-log girth and log weight-log girth regression equations, by substituting the logarithm of the mesh circumference in centimetres for girth in each case. The results are shown in Table 1, together with the 0.95 confidence limits calculated from the standard errors of estimate. It should be noted that the samples consisted of ripening female fish all taken at the same time of year. Samples which included spent and ripe fish, or both sexes, or taken throughout several years would certainly have more variation, and hence wider limits; also no allowance has been made for possible slight variations in mesh size within a net.

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TABLE 1. **Estimated minimum sizes**

Date of sample	Mesh size (in) knot to knot	Weight (g)	0.95 confidence limits (g)		Length cm	0.95 confidence limits (cm)	
1948	$1\frac{1}{4}$	101	87	119	21.5	20.1	23.1
1948	1	56	48	66	18.2	16.9	19.5
1948	$\frac{3}{4}$	26	22	30	14.4	13.5	15.5
1948	$\frac{1}{2}$	9	8	10	10.6	9.9	11.4
1956	$1\frac{1}{4}$	128	102	160	23.5	22.0	25.1
1956	1	74	59	92	19.8	18.6	21.2
1956	$\frac{3}{4}$	35	28	44	15.8	14.8	16.9
1956	$\frac{1}{2}$	13	10	16	11.6	10.9	12.5

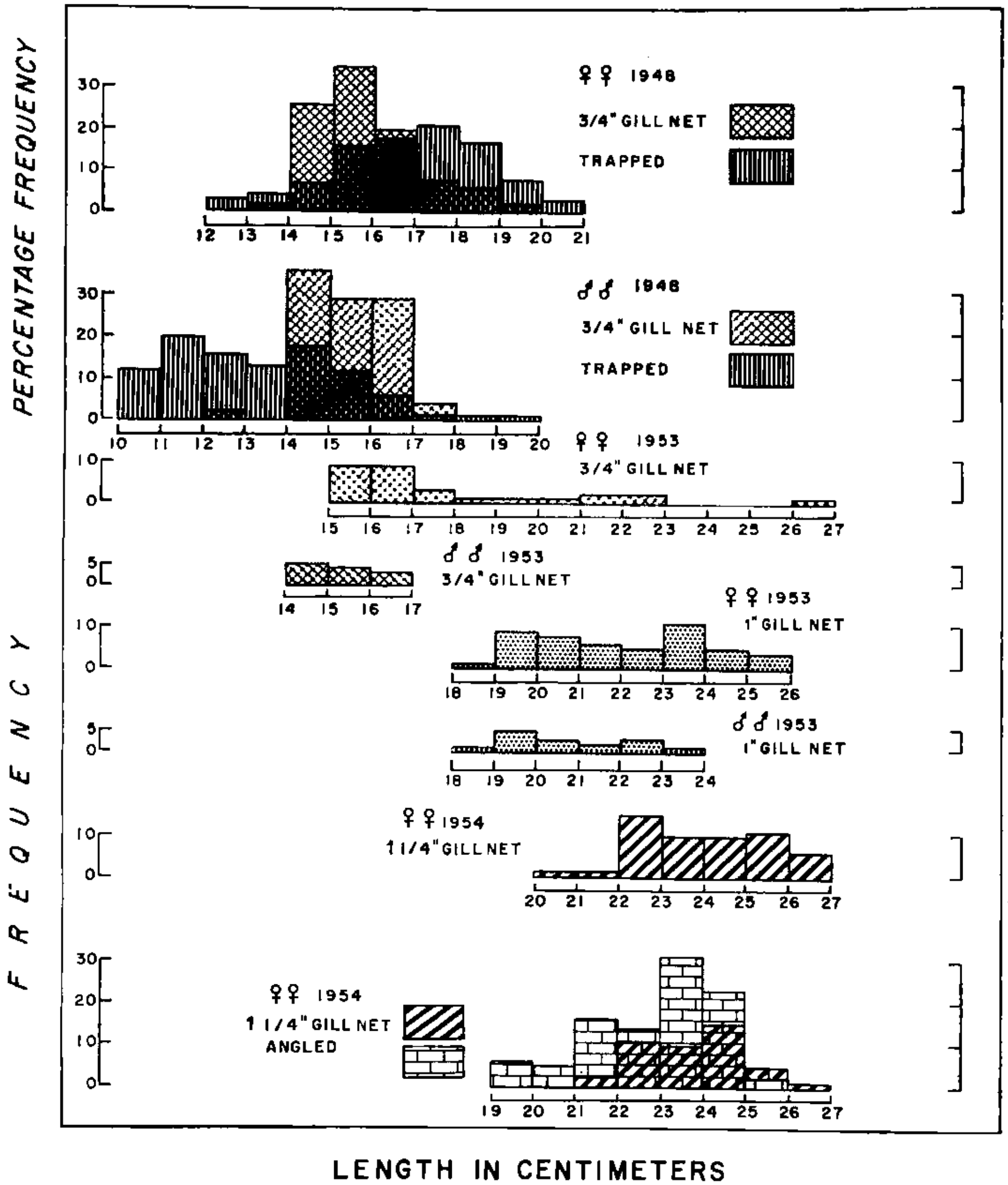

Fig. 1. Length frequency distributions of perch.

It can be seen that there is a considerable difference between the estimates from the two years. Fish of the same girth were longer and heavier in 1956 than in 1948 (*i.e.* fish of the same length were thinner in 1956). It seems possible that this can be accounted for by the particularly bad summer of 1956. Such differences in condition can affect selection for age by the nets. For example, in general perch in Windermere attain a mean length of about 10 cm in the second year of growth. In 1948 with an estimated minimum length of 10.6 cm for the $\frac{1}{2}$ inch gill net many of this age group would be vulnerable, whereas in 1956 with the estimated minimum 11.6 cm far fewer would be of the required size, even disregarding the likelihood that the mean length attained was probably less in the latter year. If equations of this type were to be used to predict the catching limit of a gill net in a particular year, it is possible that a satisfactory method of allowing for condition could be worked out by applying a correction.

Examples of length frequency distributions of perch caught in gill nets are shown in Figure 1. When strictly comparable samples were taken by other methods these are also shown. Comparison of the minimum lengths taken in the various nets with the calculated values given in Table 1 shows considerable agreement in general with the estimates made from the 1948 data.

I am most grateful to Mr. E. D. Le Cren for the use of the data and for helpful advice and criticism.

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12.

Selection by Codend Meshes and Hooks on Cod, Haddock, Flatfish and Redfish

by

F. D. McCRACKEN[1]

Contents

A. EFFECT OF MESH SIZE VARIATION ON SELECTION SPAN

Abstract

A used, double-strand, heavy twine, manila codend had a similar, wide range of mesh sizes with the ICNAF "vertical pressure" gauge, a "longitudinal pressure" gauge, and a "non-pressure" gauge. The "vertical pressure" gauge (12-15 lb pressure) tended to give a mean mesh size about $\frac{1}{8}$ inch greater than the "longitudinal pressure" gauge (about 7 lb pressure) for the heavy manila codends. For different operators the mean mesh size obtained varied most with the "non-pressure" gauge. Variation between operators was similar for the other two gauge types when measuring this heavy manila codend.

The range of mesh size in used codends was greatest, about 1 to $1\frac{3}{8}$ inches (25-35 mm), for those of double-strand, 50-yard, 4-ply manila, and least, about $\frac{3}{8}$ inch (10 mm), for single-strand, 125 yard, 3-ply nylon codends. An intermediate mesh size range of about $\frac{1}{2}$ inch (13 mm) was found for double-strand, 75-yard, 4-ply manila and single-strand, 45-yard cotton codends.

The variability of mesh size in the codends had a marked effect on the selection span but not the selection factor. With heavy manila codends and a large variation between individual mesh sizes, the span between 25 to 75% retention lengths of cod was 11-12 cm. For light nylon codends and low variation in mesh size the span between the same retention lengths was about 6 cm. Intermediate selection spans of 8-9 cm were obtained with the lighter, double-strand manila and the heavy, single-strand cotton codends of intermediate variability in mesh size.

Introduction

Various techniques have been used by scientists, fishermen and net makers to measure mesh size of otter trawls. Among scientists the trend has been toward more precise measurement of the "internal longitudinal stretched mesh" wet, after use. Boerema (1954), Parrish *et al.* (1955), and von Brandt (1955) have described techniques, results, and the principles underlying a variety of mesh measuring methods.

Use of the internal mesh diameter and increased precision of measuring have reduced the variation in mesh selection results between

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areas and experiments. However, there are variations in mesh size for each net which are a part of its constructiou and use. These variations appear greater in nets of heavy twine. This chapter describes some of the variations in mesh size which have been encountered and their effect on the selection range of the net.

Mesh Size Variations and Measuring Methods

Comparative trials of three different types of gauges were conducted in 1955 with a heavy manila codend. Two were "pressure" gauges and the other a "non-pressure" gauge. Pressure gauge A was the "vertical pressure" gauge prescribed for mesh measurements in ICNAF regulations. Pressure gauge B was a "longitudinal pressure" gauge, the Scottish type as described by Parrish *et al.* (1955). The "non-pressure" gauge was similar to the blade of gauge A, but without the pressure handle.

In the comparison, meshes of a wet, used, untreated manila codend (50 yd/lb, 4-ply twine) of double-strand construction were measured by three different operators. The meshes measured by each operator were chosen at random throughout the length of the codend, but no meshes were measured near the laceage (selvage). Equal numbers of meshes were measured in each third of the codeud.

All gauges were marked in scale intervals of $\frac{1}{8}$ inch and readings were recorded to the nearest $\frac{1}{8}$ inch scale marking. In use the gauges were chosen at random for each operator. With gauge A the blade was inserted with a vertical pressure between 12-15 lb. Pressure exerted by gauge B was about 7 lb longitudinally. The operators were instructed to insert the non-pressure gauge with a force which they considered reasonably stretched the mesh.

TABLE 1. Variations in mesh size with different types of gauges and different operators.

Mesh size		Gauge A "vertical pressure" gauge			Gauge B "longitudinal pressure" gauge			Gauge C "non-pressure" gauge		
		Operator			Operator			Operator		
Inches	mm	1	2	3	1	2	3	1	2	3
$3\frac{3}{4}$	95						1			
$3\frac{7}{8}$	98									
4	101			1	1	2	1			
$4\frac{1}{8}$	105					2	1			
$4\frac{1}{4}$	108	1			1	4	3		1	
$4\frac{3}{8}$	111	1	2	1	3	5	5			1
$4\frac{1}{2}$	114	6	1	7	2	8	8		3	5
$4\frac{5}{8}$	117	3	2	6	7	3	6	1	3	8
$4\frac{3}{4}$	120	10	5	10	8	7	10	1	9	7
$4\frac{7}{8}$	124	13	10	7	11	3	7	7	13	10
5	127	7	13	8	4	8	4	7	7	12
$5\frac{1}{8}$	130	4	7	7	5	6	3	6	6	5
$5\frac{1}{4}$	133	5	4	2	4	1	1	12	2	2
$5\frac{3}{8}$	136		3		3	1		9		
$5\frac{1}{2}$	140		2	1	1			6	2	
$5\frac{5}{8}$	143							1		
$5\frac{3}{4}$	146		1						1	
$5\frac{7}{8}$	149									
Mean mesh size (in.)		4.96	4.99	4.82	4.85	4.68	4.65	5.18	5.00	4.84
Standard deviation (in.)		0.25	0.27	0.27	0.31	0.34	0.30	0.19	0.30	0.22

Results

For each gauge the measurements obtained by each operator, the mean mesh size and the standard deviation from the mean are given in Table 1. The results which seem most applicable to this series of studies are:

(1) With all three gauges the span between the smallest and greatest individual mesh size was large, from $\frac{7}{8}$ inch minimum to 1.5 inches maximum (22-38 mm). There was no marked difference between the span of mesh sizes recorded with the two pressure gauges.

(2) Mean mesh sizes tended to be highest for the non-pressure gauge, intermediate for gauge A, and lowest for gauge B. However, the range of mean mesh sizes determined by different operators for one gauge overlapped the range of means for each of the other gauges.

(3) The difference between mean mesh sizes recorded by different operators was greatest for the non-pressure gauge. For all three gauges, however, at least one mean recorded by an operator differed significantly from the other two recorded with the same gauge.

The results agree with those of Parrish *et al.* (1955) in that the "non-pressure" gauge gave greater operator differences than the pressure gauges and the "longitudinal pressure" gauge produced lower mean mesh sizes than the "vertical pressure" gauge with the pressures used. Parrish *et al.* (1955) found that the "vertical pressure" gauge gave significant differences in mean mesh size between operators but the "longitudinal pressure" gauge did not. However, in the series of tests reported here, operator differences were similar for both types of gauge. The "longitudinal pressure" gauge was considered easier to use.

It is particularly relevant to this paper to note that for both pressure gauges and for all operators, the span of individual mesh sizes in a single codend was not markedly different. The wide span of individual mesh measurements appears to result from codend construction rather than measurement differences.

Selection Curves and Mesh Size Variation

Covered net mesh experiments to test the selective properties of codends of various materials were carried out in the Gulf of St. Lawrence in 1954 and 1955. Three small otter trawlers (26-50 gross ton range) were used at various times to fish for cod and plaice. Codends tested were of double-strand manila and single-strand nylon and cotton. Mesh sizes were measured with a standard ICNAF wedge gauge. Catches in the codend and fine-mesh cover were measured and recorded separately in the usual manner. Cotton covers of $1\frac{1}{2}$ inch mesh (between knot centres, stretched measure, new) and the same construction were used throughout.

Details of the codend construction, mean mesh size and mesh size variation are presented in Table 2. Codends A, B and C were of double-strand manila construction. Codends D and E were of single-strand cotton and nylon, respectively. The manila and nylon twines were untreated, the cotton twine was tarred.

Average mesh size was from 4.3 to 4.7 inches (109-122 mm), but the range of mesh sizes in a particular codend varied widely. Codend A of heavy manila twine and with the largest catches had the greatest mesh size range, about $1\frac{3}{8}$ inches (35 mm). Codend B of heavy manila twine but smaller catches had a somewhat smaller mesh size range of about 1 inch (25 mm). Codend C, lighter manila twine, and D, cotton twine, had similar mesh size ranges of about $\frac{1}{2}$ inch (13 mm). Codend E, light nylon twine, had the lowest mesh size range, about $\frac{3}{8}$ inch (10 mm).

Some characteristics of the selection curves for cod produced by these codends are summarized in Table 3. The selection factor for cod is greatest with the single-strand nylon twine, lowest with the double-strand manila twine, and intermediate with the single-strand cotton twine. These results are consistent with others obtained for both cod and haddock with twines of these characteristics (McCracken, 1957). Of particular interest to the discussion here is a correlation between the shape of the selection curve and the range of mesh size in the codend.

TABLE 2. Mesh measurements for heavy and lighter manila codends and cotton and nylon codends used in covered net experiments with small draggers in the Gulf of St. Lawrence.

Codend		A	B	C	D	E
Material		Manila	Manila	Manila	Cotton	Nylon
Twine size		50-yard	50-yard	75-yard	45-yard (120 thread)	125-yard
Construction		Double-strand	Double-strand	Double-strand	Single-strand	Single-strand
Mesh size		Frequency	Frequency	Frequency	Frequency	Frequency
Inches	mm					
4	102	13	5			
$4\frac{1}{8}$	105	6	8	12		
$4\frac{1}{4}$	108	9	11	25		
$4\frac{3}{8}$	111	7	15	32	1	
$4\frac{1}{2}$	114	11	16	18	18	7
$4\frac{5}{8}$	117	2	9	4	26	33
$4\frac{3}{4}$	120	6	8	1	28	43
$4\frac{7}{8}$	124	6	4		16	17
5	127	11	2		11	1
$5\frac{1}{8}$	130	5				1
$5\frac{1}{4}$	133	5				
$5\frac{3}{8}$	136	3				
$5\frac{1}{2}$	140	1				
Mean mesh size (in.)		4.6	4.4	4.4	4.7	4.7
Mean mesh size (in.)	Quarter 1 (aft)	4.9	4.5	4.4	4.8	4.7
	Quarter 2	4.7	4.4	4.3	4.8	4.8
	Qnarter 3	4.5	4.3	4.4	4.6	4.7
	Quarter 4	4.2	4.4	4.3	4.6	4.8
Tows used		35	24	25	40	25
Range of catches (estimated)		8-1200 lb	3-700 lb	3-700 lb	2-800 lb	3-700 lb

TABLE 3. Characteristics of selection curves for cod with manila, cotton and nylon codends (details of codends given in Table 2.)

	Codend Type	Mean mesh size Inches	Mean mesh size mm	50% Retention length cm	Selection* factor	Span between 25-75% retention lengths cm	Span between 10-90% retention lengths cm
A	Manila, heavy	4.6	117	41.0	3.5	11.7	22
B	Manila, heavy	4.4	111	37.5	3.4	12.3	23
C	Manila, lighter	4.4	111	37.4	3.4	9.0	17
D	Cotton, heavy	4.7	119	44.5	3.6	8.2	18
E	Nylon, light	4.8	122	47.5	3.9	6.4	12

$$\text{*Selection factor} = \frac{50\%\ \text{retention length cm}}{\text{mesh size cm}}$$

The span between the 25 to 75% retention lengths and 10 to 90% retention lengths is correlated with the range in individual mesh sizes for a particular codend. Heavy twine manila codends with a wide range of mesh sizes had the greatest span between retention length intervals. The light nylon twine codend with the narrow mesh size range had the least span between retention intervals. The heavy single-strand cotton and medium-weight, double-strand manila codends with similar, intermediate mesh size ranges, had similar, intermediate spans of length between retention intervals. For all types, the 25 and 75% retention lengths were about equidistant from the 50% retention length.

Discussion

Twine size and construction seem to be the most important factors determining individual mesh size variation in a single codend. The variation of mesh size shows up independently of either the type of gauge used to measure the meshes or the operator. Uniform construction of heavy twine codends is presumably more difficult than for codends of light twines. Large catches and differences in shrinkage may also contribute to lack of uniformity in the codend.

Variation of mesh size in individual codends affects the selection of the codend. Sharpest selection was obtained with codends having the least variability in mesh size. Flatter selection curves were obtained with codends of more variable mesh size. Selection curves of similar shape were obtained with codends of single- and double-strand construction when the mesh size range was similar in each.

Other less directly comparable data for both cod and haddock follow the same general pattern (McCracken, 1957). An increased span between 25 to 75% retention lengths occurs with increased variability of mesh size in the codends. With heavy manila codends the increased variability in mesh size has been generally associated with increased average mesh size. The effects of these two factors on the sharpness of the selection curve were difficult to separate. However, with nylon codends, increased average mesh size has not meant increased variability of meshes. In these cases, selection curves were similar in shape.

Various other factors may affect the sharpness of selection. These could include speed of tow, weather, size of catch, other species present, and quantities of debris. The results presented in this paper are averages for a series of tows with each codend. Most were made under fairly uniform conditions, and any variations between single tows probably averaged out.

The spans between 25 and 75% retention intervals reported here are much larger than those generally reported for European selection experiments. The 1956 report of the *ad hoc* committee of the Permanent Commission suggests that, from mesh experiments in the North Sea, the span between 25 to 75% retention length is 5 cm for cod and 4.8 cm for haddock. Only the light nylon codend used here had a selection span of this order. The heavy manila codends had a selection span of about 12 cm while the medium-weight manila codend had a selection span of 9 cm. Margetts (1954) indicates that for North Sea trawls the range of mesh sizes in an 80 mm, double-strand, manila codend is about 10 mm, about the same as that for the light nylon codend. In contrast, the range between the smallest and largest meshes in the heavy, double-strand, manila codends used here was 25-35 mm. These large differences in individual mesh size range are correlated with the markedly longer span of the selective range in the heavy manila codends. It may be noted in support of this conclusion that Beverton (1956) reports a selection span of 7-8 cm for Arctic cod with heavy manila and sisal codends, and that Clark (1952) reports a similar selection span for haddock with heavy manila codends.

Classification of nets according to construction and material in relation to mesh size variation probably becomes of greatest importance where catches and mesh sizes are both large. Both these conditions increase the need for strength in the net and result in bulkier twines being used. Larger vessels also use heavier twines than small. Heavier twines will tend to increase the variability in codend meshes, although some heavy synthetic nets have quite uniform mesh sizes. Increased variability in codend meshes probably has little effect on the selection factor but results in markedly longer selection spans.

Optimum size at first capture, particularly for cod, may be considerably higher than that now recommended for ICNAF Subarea 4. As mesh size is increased to achieve this aim, the material and construction of the net related to its selection span probably become more important. These results suggest that it is desirable to increase strength in the codend by using lighter but stronger synthetic twines rather than heavier, bulkier, natural fibres. Whether single-strand, heavy twine codends or double-strand, lighter twine codends of equivalent overall strength are most effective in reducing the selection span should also be resolved.

B. SELECTION FACTORS FOR COD AND HADDOCK WITH CODENDS OF DIFFERENT MATERIALS

Abstract

Covered net experiments show the greatest difference between selection factors of both cod and haddock for codends of different materials and construction. Smaller variations seem related to size of catch and size of vessel. Mean selection factors of about 3.3 and 3.2 for cod and haddock, respectively, were obtained with heavy manila codends and moderate catches. Numerical values of selection factors for cod tend to be about 0.1-0.2 greater than for haddock with all materials used under similar conditions.

Very large catches tended to reduce slightly the selection factor for haddock. Selection factors for both cod and haddock are about 0.1-0.2 greater with small vessels than with large vessels, using similar codends. Within ICNAF Subarea 4 differences in selectivity, for cod and haddock, between regions are not apparent. However, limited selection data for St. Pierre Bank haddock suggest a selection factor of about 2.8 with manila codends and moderate catches, considerably lower than for Subarea 4 haddock.

High selection factors, about 3.9 for both species, are shown for single-strand, light nylon codends. Selectivity of single-strand, heavy cotton and double-strand, medium, braided nylon is between that for single nylon and double manila. For cod, selection factors of 3.6 for single cotton and about 3.8 for double nylon are considerably higher than the values of 3.3-3.4 for manila. Similarly for haddock, selection factors of 3.5 for single cotton and 3.4 for double nylon are compared with selection factors of 3.1-3.2 for manila.

The results of these experiments support the use of an average selection factor value of about 3.3 for both cod and haddock with manila codends in Subarea 4. They indicate relatively unimportant differences between selectivity for similar materials with large and small vessels, but support the need for differentiation in minimum mesh size between various materials.

Introduction

From 1953 through 1956 mesh selection experiments with large-mesh codends were carried out. Materials tested included manila, twisted and braided nylon, and cotton. Types and construction of codends tested were similar to those used by trawlers of the Canadian fishing fleet. Double-strand manila codends are used most often by all sizes of otter trawlers, but some large and small vessels also use nylon codends. Cotton codends are used only by the smallest otter trawlers.

Experiments were carried out with small research vessels and with large and small commercial trawlers. Experiments with chartered trawlers presented both disadvantages and advantages. At times the economics of the situation prevented following up the reasons for irregularities which were noted. On the other hand, catches with the commercial vessels were sometimes larger than is usual with research vessels.

The covered net technique was used throughout these experiments in which cod and haddock were the major species caught. Typically, haddock predominated in the catch of large vessels fishing on offshore Nova Scotian Banks and St.

Pierre Bank. Cod catches were usually incidental. The small research vessels and the small commercial trawlers fishing in the Gulf of St. Lawrence caught mainly cod. Haddock predominated in the catch of a research vessel fishing in Passamaquoddy Bay, off the Bay of Fundy. These results compare selection factors for cod and haddock under a variety of conditions with the gear materials most commonly used by Canadian otter trawlers.

Methods and Materials

Fish escaping through the meshes in the top of the codends tested were trapped in a fine mesh cover. These covers were of 24-thread, untreated cotton with a mesh size of about 1½ inches, between knot centres, new. All covers were of the same general construction. They were attached across the forward end of the codend, along the laceage (selvage) on each side and across the top of the codend just forward of the codend knot. The cover lay loosely on top of the codend, with about 15-20% slack. A pocket at the aft end of the cover trailed for 6-10 feet, forming a separate codend for the cover. On large nets, 2 or 3 cowhides covered most of the under surface on the codend. With the small otter trawlers and smaller nets, one cowhide covered about half the under surface of the codend.

Details of the boat sizes, nets and materials used are presented in Table 4. Unless otherwise stated, all mesh sizes given are measures of the internal longitudinal diameter of the mesh in the used, wet net. These mesh measurements were made with the standard ICNAF gauge with a pressure of 12-15 lb.

The experiments can be divided into several series. In 1953 and 1956 mesh selection trials were carried out from large commercial trawlers on offshore banks in Subarea 4, with some fishing in 1953 on St. Pierre Bank in Subarea 3. In 1953, 45 yd/lb, double-strand codends with mean

TABLE 4. Details of vessel, gear, and mesh sizes used in mesh experiments from 1953 through 1956.

Year	1953	1954 A
Trawler size	Commercial vessel 245 gross tons	Research vessel 29 gross tons
Net	1¼ Iceland	¾ No. 35
Twine	Manila	Cotton
Headline	78 feet	39 feet
Footrope	116 feet	52 feet
Mesh size (new)		
Wings	6 inches	5 inches
Square	6 inches	5 inches
Belly	5-4 inches	4½-3½ inches
Where fished	Offshore Banks Subareas 4 and 3	SW Gulf of St. Lawrence
Length of tow	ca. 1½ hours	ca. ¾ hour
Main species	Haddock and some cod	Cod and plaice
Codends tested		
Material	45-yard, 4-ply manila	50-yard, 4-ply manila
Construction	Double-strand	Manila: Double Cotton: Single
Mesh size range (internal, used measure)	4⅜-5⅛ inches	Manila: 4⅜-4⅞ inches Cotton: 4-4¾ inches
Codend treatment	Untreated	Manila: Untreated Cotton: Tarred

TABLE 4 (continued)

Year	1954 B	1955	
Trawler size	Commercial vessel 50 gross tons	Research vessel 49 gross tons	
Net	No. 35	¾ No. 35	
Twine	Cotton	Cotton	
Headline	50 feet	39 feet	
Footrope	68 feet	52 feet	
Mesh size (new)			
Wings	5 inches	5 inches	
Square	5 inches	5 inches	
Belly	4½-3½ inches	4½-3½ inches	
Where fished	SW Gulf of St. Lawrence	W Gnlf of St. Lawrence	Bay of Fundy
Length of tow	ca. 1½-2 hours	ca. 1 hour	ca. 1 hour
Main species	Plaice and cod	Cod and plaice	Haddock
Codends tested			
Material	45-yard, 4-ply manila	125-yard, 3-ply twisted nylon 75-yard, 4-ply manila	
Construction	Double-strand	Nylon: Single Manila: Double	
Mesh size range (internal, used measure)	4½-4⅝ inches	Nylon: 4¼-4⅞ inches Manila: 4⅜ inches	
Codend treatment	Untreated	Both untreated	

TABLE 4. (continued)

Year	1956
Trawler size	Commercial vessel 245 gross tons
Net	1½ Iceland
Twine	Manila
Headline	78 feet
Footrope	116 feet
Mesh size (new)	
Wings	6 inches
Square	6 inches
Belly	5 inches
Where fished	Offsbore Banks Subarea 4
Length of tow	ca. 1½ hours
Main species	Haddock and some cod
Codends tested	
Material	80-yard, braided nylon
Construction	Donble-strand
Mesh size range (internal, used measure)	4⅜-4⅞ inches
Codend treatment	Dyed?

mesh sizes of from $4\frac{3}{8}$—$5\frac{1}{8}$ inches (112-132 mm) were tested. In 1956, 80 yd /lb, double-strand, braided nylon codends of $4\frac{3}{8}$ and $4\frac{7}{8}$ inches (112 and 122 mm) mean mesh sizes were tested. In addition, a few hauls were made with a 50 yd /lb, double-strand, manila codend of $4\frac{1}{2}$ inch mesh (114 mm). For all these experiments the forward part of the trawl was of manila twine. Haddock was the principal species caught; cod was of secondary importance.

In 1954 and 1955 the experiments were carried out with small otter trawlers. In 1954 a small research vessel and a small commercial trawler were used in the southwestern Gulf of St. Lawrence. Codends of 45 and 50 yd/lb, double-strand manila and 120 thread (about 45 yd/lb) single-strand cotton were tested. Internal, used, mean mesh sizes of the manila codends ranged from about $4\frac{3}{8}$ to $4\frac{7}{8}$ inches (111-125 mm), and those of the cotton codends were 4 and $4\frac{3}{4}$ inches (102 and 122 mm).

In 1955, 125 yd/lb, single-strand, nylon codends and a 75 yd/lb, double-strand, manila codend were fished from a small research vessel in the western Gulf of St. Lawrence and in Passamaquoddy Bay. Internal, used, mean mesh sizes of the nylon codends ranged from about $4\frac{1}{8}$ to $4\frac{7}{8}$ inches (107-125 mm), that of the manila codend was $4\frac{3}{8}$ inches (112 mm). Throughout these experiments with the small vessels, the trawl was of 42-thread, tarred cotton (about 45 yd /lb). In the Gulf of St. Lawrence cod and American plaice, *Hippoglossoides platessoides*, were the principal catch, in Passamaquoddy Bay mainly haddock.

In experiments with research vessels, all fish of the main species in the codend and cover were usually measured and recorded, although large catches of very small fish were occasionally sampled. In experiments with commercial vessels, total catch of the principal species was measured and recorded whenever possible. Large catches were either sampled as randomly as possible or all fish judged to be in the selection range (once this was known) were measured and recorded.

Treatment of these selection data followed the usual methods used in covered net selection experiments. Length frequencies were generally grouped in 3 cm intervals and "selection curves" derived by determining the percentage of each length group retained in the codend. The "50% retention length", the length of fish at which 50% are retained in the codend and 50% released, has been used as an index of selectivity for a particular mesh size. As noted in the report of the *ad hoc* committee of the Permanent Commission (1956), there is a closely proportional relation between mesh size and 50% retention length over a wide range of mesh sizes. This relationship can be expressed as:

$$\frac{50\%\ \text{retention length}}{\text{mesh size}} = \text{constant}$$

This constant has been termed the "selection factor". The "selection factor" has been used to compare the selectivity of meshes of different materials for cod and haddock. It is apparent that once the numerical value of the selection factor for a species of fish and a type of material has been determined by experiment, the 50% retention length can be calculated for any specified mesh size.

Some Sources of Variation in Selectivity

Size of catch: Catch per tow varied widely in mesh experiments with large otter trawlers on offshore banks. Selection factors for cod and haddock related to size of catch are presented in Figure 1A for medium-weight nylon codends and Figure 1B for heavy manila codends. The data for nylon and manila materials are separated, since the selection factors with nylon are greater than with manila codends. It will also be noted that selection factors for cod tend to be greater than for haddock. Other data supporting these conclusions will be presented and discussed more fully later.

Although selection factors for individual tows vary considerably, the average selection factors for haddock in catches of like size up to at least 1,000 fish per tow are quite similar. For the nylon codends they are between 3.3 and 3.4. For manila codends they are between 3.0 and 3.2. For catches above 1,000 fish per tow, the selection factor for haddock tends to be lower with both materials. Catches between 1,000-2,000 haddock per tow gave an average selection factor of about 3.1 and 2.9 for nylon and manila, respectively. Occasional hauls of over 2,000 fish also tend to show lowered selectivity.

The high selection factors for cod of about 3.8 with nylon codends are quite variable. Selection curves for these small numbers of fish are less precise than for larger catches and most were obtained from catches in which haddock predominated. Only one tow, selection factor 3.4, caught both a large quantity of cod and more cod than haddock. With the manila codends

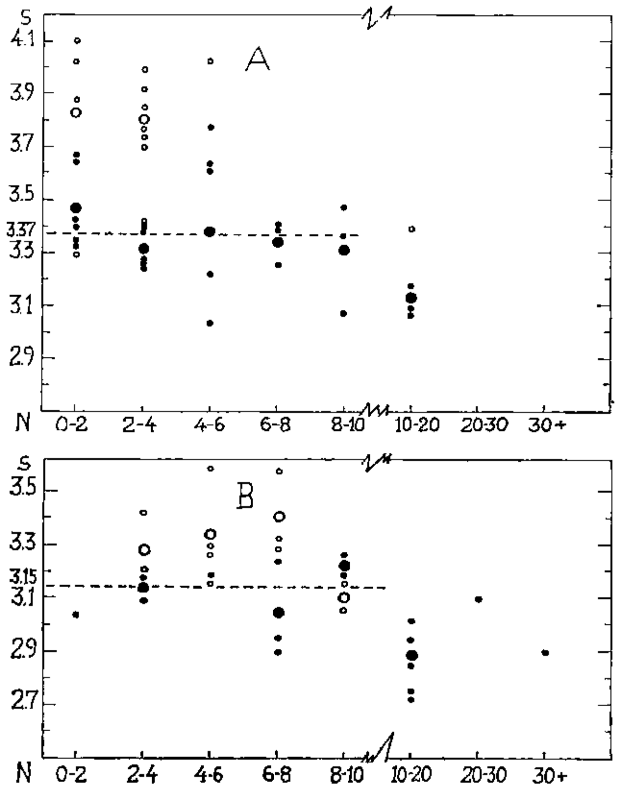

Fig. 1. Selection factors in relation to number of haddock and cod caught per haul by large otter trawlers.
A. With double-strand, braided, nylon codends.
B. With double-strand, manila codends.
Cod—open circles (small circles, single hauls; large circles, mean);
Haddock—full circles (small circles, single hauls; large circles, mean);
S (ordinate: selection factor; N (abscisse): number of cod and haddock per haul (hundreds).
Mean selection factor for moderate catches of haddock shown by dotted lines.

(selection factors circled in Fig. 1B) a number of tows took medium quantities of cod and in these hauls cod was the major species. Thus, the data obtained with manila codends seem more reliable than those with nylon. They show no consistent variation in selection which can be related to size of catch in the range of catches encountered.

A variety of reasons can be suggested for the lower selection factors for very large tows. Probably some fish do not reach the codend while it is being towed, and thus have little chance to escape into the codend cover. Escapement through meshes ahead of the codend, without the escaping fish being trapped in the cover, would reduce the apparent selectivity of the codend. With large tows the forward part of the codend, with generally smaller average mesh size than the aft part, may be more important in allowing fish to escape. This would also tend to reduce escapement. In addition, large tows may make the meshes less flexible, which should also be expected to lower the selectivity. It is impossible to decide from the data which of these factors is most important.

Catch per haul with small vessels and smaller nets has been more uniform. At least the spread in catch has not been sufficient to provide variation in selectivity which could be related to size of catch.

Area fished: Variations in selectivity for either cod or haddock related to region fished in Subarea 4 have not been apparent. There appears, however, to be a difference between escapement of St. Pierre Bank haddock and Subarea 4 haddock under similar experimental conditions.

On August 21-22, 1953, a series of tows was made with manila codends on Banquereau in Subarea 4 and St. Pierre Bank in Subarea 3. The selection factors for haddock for 6 tows on Banquereau and 7 tows on St. Pierre Bank are plotted in Figure 2B, related to size of catch. All tows on Banquereau and 2 of those on St. Pierre Bank were made with the same $5\frac{1}{8}$ inch mesh (129 mm) codend. The other tows on St. Pierre Bank were made with a $4\frac{3}{4}$ inch mesh (122 mm) codend. For catches with comparable numbers of fish, the mean selection factor for Banquereau haddock is about 3.2, while that for St. Pierre Bank haddock is about 2.8. In both cases, complete hauls were measured and recorded. In addition, 3 hauls on St. Pierre Bank, which were sampled, show very low calculated selection factors for haddock between 2.5 and 2.6. These are much lower than selection faetors for haddock in similar size hauls on banks in Subarea 4.

Grouped selection curves for the Banquereau haddock catches and the St. Pierre Bank haddock catches are shown in Figure 2A. Those for St. Pierre Bank haddock have been grouped by size of haul for the 2 mesh sizes used. In 1953 most St. Pierre Bank haddock were between 36-45 cm with peak numbers between 38-40 cm. Most belonged to the slow-growing 1949 year-class (Templeman, 1955). According to the selection factors for manila codends on Subarea 4 banks and the performance of the 5.1-inch mesh manila codend on Banquereau, the 50% retention length for St. Pierre Bank haddock should be around the modal size frequency. Actually it is much lower than this and occurs where numbers of haddock were very small. For the large catches, the 50% retention length is estimated from the shape of the upper part of the selection curve. Larger numbers of fish at the 50% retention length and below would have increased the reliability of the results. It will be noted, however, that the upper part of the selection curves for the medium-size hauls are quite regular and similar in shape to that for Banquereau haddock.

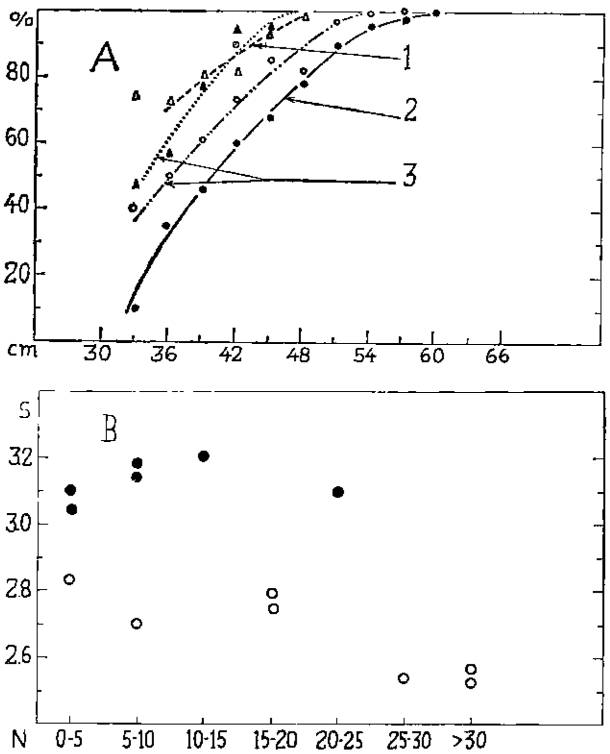

Fig. 2. Comparison of selectivity for Banquereau and St. Pierre Bank haddock with double-strand, manila codends.
A. Grouped selection curves for Banquereau and St. Pierre Bank:
1—St. Pierre Bank (large hauls) $4\frac{3}{4}$ mesh;
2—Banquereau (medium hauls) $5\frac{1}{8}''$ mesh;
3—St. Pierre Bank (medium hauls) $5\frac{1}{8}''$ and $4\frac{3}{4}''$ mesh.
Ordinate: % retained; abscisse: length 3-cm gronps.
B. Selection factors (ordinate) for single hauls in relation to number of haddock caught per haul, hundreds (abscisse); full circles: Banquereau; open circles: St. Pierre Bank.

Other than the difference in length distribution of the haddock being caught, there are no apparent differences between the mesh selection experiments on Banquereau and St. Pierre Bank. Methods and equipment used were the same. Part of the difference could be related to their girth since stocks of haddock on St. Pierre Bank are believed to be separate from those in Subarea 4. Margetts (1954) has related variations in selectivity for different species to differences in their length-girth relationship. This might also be the case for the different stocks of haddock on St. Pierre Bank and in Subarea 4. Length-girth measurements of haddock have not been carried out in Subarea 4. In lieu of further mesh selection experiments, length-girth comparisons could provide worthwhile information. However, within Subarea 4 the variation in selectivity of a particular type of codend is relatively small and some of these small variations may be related to size of vessel and gear used.

Size of vessel and gear: Selectivity of manila codends for cod and haddock was tested with both large otter trawlers and small otter trawlers. Although experiments with the two vessel sizes were not carried out on the same grounds, the results seem worth comparing (Table 5).

TABLE 5. Comparison of selection factors for cod and haddock with manila codends and by large and small otter trawlers.

	Cod			Haddock	
	OTL Commercial	OTS Commercial	OTS Research	OTL Commercial	OTS Research
Selection factors					
Mean	3.3	3.4	3.4	3.1	3.2
Range	3.1-3.5	3.2-3.5	3.3-3.5	2.9-3.3	(1 only)
Mean selection span 25-75%					
retention			11		
lengths (cm)	10	11	9	11	9
Mesh size range (in.)	$4\frac{3}{8}$-$5\frac{1}{8}$	$4\frac{1}{4}$-$4\frac{5}{8}$	$4\frac{3}{8}$-$6\frac{5}{8}$	$4\frac{3}{8}$-$5\frac{1}{4}$	$4\frac{3}{8}$
Twine size (yd/lb)	45 and 50	45 and 50	50 and 75	45 and 50	75

Mean selection factor for cod and haddock is slightly greater with small vessels than with large vessels. However, the difference (about 0.1) is less than the difference between individual experiments in a series with either size of vessel. It is possible that differences in length-girth relationships for cod and haddock between grounds on which the various sizes of gear were used could have a compensatory effect. However, the order of difference between large and small vessels is so small that extensive trials would have to be conducted on the same grounds and at the same time to determine whether the difference is real. Other variables seem relatively more important.

Selectivity for Species and Materials

Having considered sources of variation in selectivity for a species with a particular material, the difference in selectivity between materials for cod and haddock can be compared. Selection factors for cod with codends of different materials and construction are presented in Table 6 in relation to mesh size. Similar data for haddock are presented in Table 7. The codends compared include heavy, double-strand manila; medium, double-strand manila; heavy, single-strand cotton; medium, double-strand, braided nylon; and light, single-strand, twisted nylon. Average selection factors for each type of codend and each species are summarized in Table 8. The data support the conclusion that the 50% retention length/mesh size ratio is proportional over a wide range of mesh sizes.

Selection factors for cod, with the exception of the light nylon codends, are consistently higher than those for haddock. The least difference occurs with light uylon, heavy cotton and medium manila codends. For these codends the average difference hetween mean selection factors for cod and haddock is about 0.1. All these codends were used only by small otter trawlers. Selection factors for each species with these codends are for hauls in which they predominated in the catch.

Greatest variation between mean selection factors for cod and haddock occurs with the medium nylon codends. The difference, about 0.4, is believed to be too high. Earlier discussion in this paper shows that the comparison is based on catches in which haddock predominated and numbers of cod were small. It seems probable that the difference should be about 0.2.

Part of the difference (about 0.3) in mean selection factors for cod and haddock with heavy manila codends seems related to variables other than those between species. Some of the selection factors for cod with heavy manila codends are for experiments with small vessels. All those for haddock with similar codends are with

TABLE 6. Selection factors for cod with different materials in relation to mesh sizes tested. (Refer to Table 11 for further details.)

Mesh size, used, wet, internal diameter		Manila Double-strand 45 and 50 yd	Manila Double-strand 75 yd	Cotton Single-strand 45 yd	Nylon Double-strand 80 yd	Nylon Single-strand 125 yd
In	mm					
4.0	102			3.6		
4.2	107					3.8
4.3	109	3.2				
4.4	112	3.4	3.4		3.8	3.9
		3.5				
4.5	114	3.5				
4.6	117	3.5				
		3.5				
4.7	119			3.6		3.9
4.8	122				3.8	3.9
4.9	125	3.3				
5.1	129	3.3				
		3.1				
6.6	168		3.4			
Average		3.4	3.4	3.6	3.8	3.9

TABLE. 7. Selection factors for haddock with different materials in relation to mesh sizes tested. (Refer to Table 12 for further details.)

Mesh size, used, wet, Internal diameter		Manila Double-strand 45 and 50 yd	Manila Double-strand 75 yd	Cotton Single-strand 45 yd	Nylon Double-strand (braided) 80 yd	Nylon Single-strand 125 yd
In	mm					
4.0	102					
4.2	107					3.8
4.3	109					
4.4	112	3.1	3.2		3.3	
4.5	114	3.0				
4.6	117					
4.7	119			3.5		
4.8	122				3.4	4.0
4.9	125					
5.1	129	3.1				
5.2	132	3.3				
6.6	168					
Average		3.1	3.2	3.5	3.35	3.9

TABLE 8. Average selection factors for cod and haddock with different materials and construction.

Material and construction	Cod	Haddock
Heavy, double manila	3.4	3.1
Medium, double manila	3.4	3.2
Heavy, single cotton	3.6	3.5
Medium, double nylon	3.8	3.4
Light, single nylon	3.9	3.9

large vessels. Earlier comparisons of selectivity for small and large vessels suggested that selectivity with small vessels was slightly higher. It is believed that the difference between selection factors for cod and haddock with heavy manila codends should be about 0.2 or less. Results presented in Figure 1B suggest this order of difference.

Major consistent differences in selectivity between type of codend are shown for both cod and haddock. Mean selection factors are highest for light, single-strand, nylon codends, and lowest for heavy, double-strand and medium double-strand manila codends. Numerical values of the spread are about 0.5 for cod and 0.8 for haddock. This difference occurs with the same size vessel and gear, and for cod, on the same grounds.

Heavy, single-strand cotton and medium, double-strand nylon codends give selection factors of intermediate value. Previous consideration of the data on selectivity with the medium nylon codends suggests that the selection factor for haddock is more realistic than for cod. Probably the selection factor for cod with this type of codend should be about 3.6.

Discussion

Experiments with codends of different materials and construction indicate that escapement of cod is generally greater than escapement of haddock. The best estimate of the numerical value of the difference between the selection factors for the two species is about 0.2. This divergence is in the same direction but not the same numerical value as that reported by Beverton (1956) and von Brandt (1956). From limited data Beverton (1956) shows a difference between selection factors for Arctic cod and haddock of about 0.2-0.5. A difference in selection factors for Spitzbergen cod and North Sea haddock of about 0.5-0.8 is reported by von Brandt (1956). On the basis of length-girth relationship, Margetts (1956a) suggests that for North Sea cod and haddock the difference between selection factors should be small. Girth measurements of Subarea 4 cod and haddock have not been carried out. However, it appears that differences in girth for cod and haddock of similar lengths are the most likely reason for the divergence shown in their selectivity. The differences in selection factors for cod and haddock of Subarea 4, shown here, are such that to produce equal 50% retention lengths, internal mesh diameter should be about 3/16 inch (4-5 mm) smaller for cod than for haddock.

The very marked differences in selectivity for codends of different materials shown by these experiments probably result from variations in the effective escape space or lumen of the meshes. With the light nylon twine codends, the meshes are presumably most flexible and thus more readily fit the shape of the escaping fish. It also seems probable that the meshes of single-strand, heavy cotton, even though tarred, are more flexible than the heavy, double-strand, untreated manila. Knots are smaller and the single-strand material probably increased the effective mesh opening. Differences between selection factors for the medium-weight, double-strand manila codends and the medium-weight, double-strand nylon codends are difficult to explain. Various factors, such as towing speed and size of catches should tend to increase the selection factor for the manila and reduce those for the nylon codends. However, the selectivity of the manila codends was considerably lower than for the nylon codends.

The results of these experiments emphasize the importance of material and construction in determining selectivity for cod and haddock. A similar conclusion for whiting was reached by Boerema (1954) in experiments with manila and hemp codends. Selection factors for cod and haddock with "Perlon" codends were shown to be much higher than those for manila codends (von Brandt, 1956). Margetts (1956b) shows rather inconsistent results for selectivity of whiting for codends of double sisal, double cotton and single cotton. Part of his results indicates higher selectivity for cotton than for sisal, but the others show little difference. Selectivity of haddock for single-strand nylon codends was shown to be higher than that for double sisal and single cotton codends (Margetts, 1956b). Clark (1956) also reports greater selectivity for nylon than for manila codends.

The results presented in this paper suggest that nylon twines (and probably a similar conclusion applies to other synthetics) have greater selectivity than manila twines of similar weight and size. It appears that properties of the twine itself alter the effective mesh opening when it is being towed. The results for cotton twines are less comparable but indicate that, for the standard construction of codends used by Canadian trawlers, there is a difference in selectivity between cotton and manila. The results shown here, coupled with those for other regions, suggest that conclusions about variations in selectivity with different codend construction and material are probably applicable to other roundfish.

It is difficult to know how directly comparable the selection factors shown here are with those reported for North Sea haddock and cod. Trends and direction of differences in selection factors between species and materials seem reliable. The actual selection factors for the same species and type of codend are in relatively close agreement (Table 9). There are, however, major differences in conditions under which the selection results were obtained. The close agreement of numerical values may be fortuitous.

Besides the possibility of differences in the fish themselves (length-girth relationship) most of the codends used for the Canadian experiments are considerably heavier than those tested in the North Sea. For example, Margetts (1956b) used double sisal codends of 150 yd/lb material, and single, braided nylon of about 150 yd/lb. Experiments with double sisal codends of 125-150 yd/lb and cotton codends of 150, 180 and 224 yd/lb are also reported by Margetts (1955). In contrast, the lightest double manila codends used here are of 75 yd/lb twine, and the single cotton of 45 yd/lb twine. Only the single nylon is of light twine, about 125 yd/lb.

Mesh sizes in codends tested in the North Sea are considerably smaller (probably about 60-80 mm) than those tested in the Canadian experiments. In addition the mesh measuring techniques differ. Measurements of meshes in the Canadian experiments are with the wedge-shaped ICNAF gauge inserted with a pressure of 12-15 lb. Most European measurements, whether with the wedge gauge or "longitudinal pressure" gauges, are made with considerable less pressure, about 5-9 lb (Margetts, 1955; von Brandt, 1956; and Boerema, 1956). For relatively light manila codends, Parrish (1955) shows differences in mean mesh size of about 3 mm, using the ICNAF wedge gauge (12-15 lb pressure) and a longitudinal pressure gauge (about 8 lb pressure). Similar differences are recorded with heavy manila codends using the same types of gauge (McCracken, 1957). In both cases, the ICNAF gauge produces the larger mean mesh size. If European measuring techniques were used, the selection factors shown here for manila codends would probably be about 0.1 higher. The relationship between measuring techniques for the cotton and nylon codend was not tested; possibly it would be similar to that for manila.

It is of interest to compare the selection factors presented in this paper, summarized in Table 10, with the present minimum mesh size recommendations for ICNAF subareas. According to Graham (1952), the minimum mesh size recommended for Subarea 5 haddock was designed to produce 50% retention at 40 cm. For the

TABLE 9. Selection factors for cod and haddock with otter trawls in Canadian and European waters.

	Cod		Haddock	
Material	Canada	North Sea	Canada	North Sea
Manila	3.4	3.0-3.5*	3.1-3.2	3.2*
Cotton	3.6	—	3.5	3.5*
Nylon (single)	3.9	—	3.9	3.9**

*from Report of *ad hoc* committee of the Permanent Commission
**from Margetts (1956b)

TABLE 10. Estimates of selection factors for cod and haddock, related to material and construction of codends, area, and size of vessel.

	Cod		Haddock				
	Subarea 4		Subarea 4			St. Pierre Bank	
	OTS	OTL	OTS	OTL		OTL	
Material		Moderate catches		Moderate catches	Large catches	Moderate catches	Large catches
Double manila	3.4	3.3	3.2	3.1-3.2	2.9?	2.8	2.6?
Donble nylon		3.8?		3.4			
Single nylon	3.9		3.9				
Single cotton	3.6		3.5				

4½ inch, internal measure, used, wet, manila mesh recommended, this would suggest a selection factor of 3.5. This selection factor is higher than those shown for haddock in this paper, and higher than the selection factors of 3.2-3.3 for haddock with manila meshes shown by Clark (1952a and 1952b). Since these selection data were used as the basis for minimum mesh size recommendations in Subarea 5, it is suggested that the 50% retention length expected should be between 37-38 cm, with a selection factor of about 3.3.

A selection factor of 3.3 for manila codends is intermediate to those shown for haddock and cod in Table 5. For present mesh regulation recommendations in ICNAF subareas, the selectivities of cod and haddock have been considered equivalent. The difference in selectivity between the two species is believed to be of minor importance to the overall aim of maximum sustained yield. Similarly, the same minimum mesh regulation applies to both large and small otter trawlers using nets of the same construction and material. Differences in selectivity between large and small nets seem small enough that recommendation and enforcement of different minimum mesh sizes seem unwarranted. Disparity of selectivity between types of materials and in some cases construction has been considered important enough to warrant diversity of minimum mesh sizes. The results presented in this paper support this point of view.

The "pooled" information on selectivity which is available seems adequate to recommend minimum mesh sizes to produce comparable selectivity for most of the gears and materials now used in ICNAF Subarea 4. Introduction of synthetics other than nylon, *i.e.*, "Dacron" and "Perlon" (von Brandt, 1955) poses problems. Since the "kinds" of synthetic twines may be large, some method of grouping them seems desirable to avoid carrying out selection experiments with each new type developed. If grouping is impossible, short cuts in determining their selectivity should be sought.

Insufficient consideration has been given to the suggested difference in selectivity between Subareas 4 and 3 haddock. This is of particular importance since the minimum mesh sizes recommended for these regions are now different. If continued experimentation should substantiate the results shown here, minimum mesh sizes for Subarea 3 should be increased to produce the present calculated 50% retention length.

It seems probable that, to produce optimum size at first capture for cod in Subarea 4, mesh sizes should be considerably above present levels (Martin, 1957). More experimentation with very large mesh trawls is needed but the information required probably goes beyond mere selectivity of gear and includes design and efficiency of operation.

Table 11. Cod mesh selection experiments with details of twine, mesh sizes, hauls, number of fish, and retention lengths.

Date	Codeud and Twine (yd)		Mesh size (internal, used, wet) (in.)	(mm)	Hauls	No. of fish Codend	Cover	50% retention length (cm)	50% retention span (cm)
July/53	45	double manila	4 3/8	112	2	716	187	38.5	6
Aug./53	45	double manila	5 1/8	129	3	1148	522	43.0	10
Sept./53	45	double manila	5 1/8	129	2	569	480	40.0	12
June/54	50	double manila	4 7/8	125	10	87	55	41.0	11
June/54	50	double manila	4 3/8	112	18	642	934	37.5	12
Aug./54	50	double manila	4 5/16	109	9	1865	469	35.0	10
Aug./54	50	double manila	4 5/8	117	7	633	332	41.0	11
Aug./54	50	double manila	4 5/8	117	7	600	1095	41.0	12
July/54	45	single cotton	4 11/16	119	16	338	953	44.5	8
Aug./54	45	single cotton	4	102	4	353	117	37.0	8
July/55	125	single nylon	4 3/4	122	29	1673	588	47.5	6
July/55	125	single nylon	4 11/16	119	28	1233	879	46.0	6
Aug./55	125	single nylon	4 7/16	112	12	1010	1885	44.0	8
Aug./55	125	single nylon	4 3/16	107	16	2286	3468	41.0	6
Aug./55	75	double manila	6 5/8	168	11	186	107	58.0	10
Sept./55	75	double manila	4 3/8	112	12	1415	2774	37.5	9
July/56	50	double manila	4 1/2	114	3	1018+	1097	39.5	10
Aug./56	80	double nylon	4 3/8	112	14	1658+	1303	42.0	7
Aug./56	80	double nylon	4 3/4	122	5	1461+	798	46.5	9?

TABLE 12. Haddock mesh selection experiments with details of twine, mesh sizes, hauls, number of fish and retention lengths.

Date	Codend and Twine (yd)		Mesh size (internal, used, wet) (in)	(mm)	Hauls	No. of fish Codend	Cover	50% retention length (cm)	50% retention span (cm)
July/53	45	double manila	4 3/8	112	3	2609	1422	35.0	9
Aug./53	45	double manila	5 1/8	129	6	3681	1740	40.0	12
Sept./53	45	double manila	5 1/4	132	4	1770	2780	43.5	11
Aug./53*	45	double manila	4 1/8	129	2	1582	734	36.0	?
Aug./53*	45	double manila	4 3/4	122	5	12000	2950	ca. 30-33	?
July/54	45	single cotton	4 11/16	119	16	244	49	41.5	8
Oct./55	75	double manila	4 3/8	112	12	780	346	35.5	9
Nov./55	125	single nylon	4 3/16	107	27	1881	1225	40.5	8
Nov./55	125	single nylon	4 3/4	122	15	379	853	48.5	7
Aug./56	80	double nylon	4 3/8	112	17	5900+	2751	36.5	7
Aug./56	80	double nylon	4 3/4	122	8	5300+	1755	41.5	9
July/56	50	double manila	4 1/2	114	2	7400+	1160	34.0	9

*St. Pierre Bank

C. SELECTION BY LARGE-MESH CODENDS OF FLATFISH AND REDFISH

Abstract

Selectivity for several flatfish species and for redfish, *Sebastes* sp., was determined by covered net experiments. Best estimates of selection factors for American plaice, *Hippoglossoides platessoides* (Fab.), are 2.0 with double-strand manila codends and 2.2 with single-strand nylon codends. Less adequate data indicate similar selectivity for yellowtail, *Limanda ferruginea* (Storer), and winter flounder, *Pseudopleuronectes americanus* (Walb.). For redfish, a selection factor of about 2.3 was obtained with double-strand manila codends.

Minimum mesh sizes now recommended for fishing cod and haddock in regulated portions of the ICNAF area have not interfered with landings of important flatfish species in Subareas 3 and 4. Although these large-mesh nets can take incidental catches of redfish, some redfish normally retained by small-mesh redfish nets would be lost. Recommendations for increased mesh sizes for fishing redfish will have to be related to fishing efficiency or optimum size for first capture of this species.

Introduction

Mesh selection experiments were carried out in the Gulf of St. Lawrence in 1954 and 1955 with small otter trawlers (26-50 gross tons). Cod was the main species taken but incidental catches of several species of flatfish provide information about their selection by large-mesh codends. Of the flatfish caught, the American plaice was most numerous. Smaller numbers of yellowtails and winter flounders were captured.

In 1956 mesh selection experiments for redfish, were carried out in the northern Gulf of St. Lawrence. Double-strand manila codends were tested from a large otter trawler using covered net techniques. Catches were relatively large, but few small redfish were taken. Most of the redfish caught were between the 50% and 100% retention length intervals for the mesh sizes used, and thus the upper limbs of the resulting selection curves are most reliable.

Methods and Materials

Covered net techniques were used throughout these experiments and the details reported by McCracken (1957) apply. Total catches of flatfish were usually measured, although occasional catches of American plaice were sampled. In the redfish selection experiments, total catch of redfish in the cover was always measured and recorded, but the large catches of redfish retained in the codend were always sampled.

Information about the selectivity of American plaice was obtained with codends of double-strand manila, single-strand nylon, and single-strand cotton. Information about selection for the other flatfish species is more variable. For the redfish mesh selection experiments only double-strand manila codends were used. Details of twine size, construction of codends, type of gear used and vessel size are presented in Table 13. Meshes wére measured with the standard ICNAF wedge gauge.

Selectivity of American Plaice

The size frequency of American plaice catches retained in the codend and trapped in the cover for 6 different codends is presented in Table F-1. Selection factors, the 50% retention length/mesh size ratios for American plaice with these codends, are summarized in Table 14. The bracketed selection factor estimates in the table are derived from relatively small numbers of fish. They are generally higher and seem less reliable than estimates from the larger catches. The best estimate of the selection factor for American plaice with double-strand manila codends seems to be about 2.0, and for single-strand nylon codends about 2.2. The less reliable selection factor for the single-strand cotton codend is about 2.5. The higher selectivity with single-strand nylon and cotton than with double-strand manila is consistent with similar results for cod and haddock (McCracken, 1957).

TABLE 13. Details of vessels, gear and mesh sizes used in mesh experiments for flatfish and redfish.

Year	1954		1955	1956
Trawler	A Research Vessel	B Commercial Vessel	Research Vessel	Commercial Vessel
Size	29 gross tons	50 gross tons	49 gross tons	198 gross tons
Net	3/4 No. 35	No. 35	3/4 No. 35	Peter Carey
Twine	Cotton	Cotton	Cotton	Manila
Headline	39 feet	50 feet	39 feet	92 feet
Footrope	52 feet	68 feet	52 feet	96 feet
Mesh size (new, Wings	5 inches	5 inches	5 inches	6 inches
Square	5 inches	5 inches	5 inches	6 inches
Belly	4½-3½ inches	4½-3½ inches	4½-3½ inches	5-4 inches
Where fished	SW Gulf of St. Lawrence	SW Gulf of St. Lawrence	W Gulf of St. Lawrence	N Gulf of St. Lawrence
Length of tow	ca. ¾ hour	ca. 1½-2 hours	ca. 1 hour	ca. 2-3 hours
Species	Plaice, yellowtail, winter flounder	Plaice	Plaice	Redfish
Codends tested Material	50-yard, 4-ply manila 45-yard cotton	45-yard, 4-ply manila	125-yard, 3-ply nylon	50-yard, 4-ply manila
Construction	Manila, double Cotton, single	Double-strand	Single-strand	Double-strand
Mesh size range (internal, used measure)	Manila: 4⅜-4⅞ in. Cotton: 4 11/16 inches	4½ inches	4 7/16-4¾ in.	4½ inches
Codend treatment	Manila: untreated Cotton: tarred	Untreated	Untreated	Untreated

TABLE 14. Selection factors for American Plaice in relation to mesh size and codend material.

Mesh size		Codend type and material		
(in.)	(mm)	Double manila	Single nylon	Single cotton
4⅜	112	(2.2)	(2.4)	
4½	115	2.0		
4 11/16	119			(2.5)
4¾	122		2.2	
4⅞	125	2.0		

( ) from small, irregular catches

Selectivity of Yellowtail and Winter Flounder

The data for escape of yellowtail and winter flounder through large-mesh codends (Table F-2) are inadequate to provide precise estimates of 50% retention lengths. Most winter flounder and yellowtail caught were above the selection range of the codends tested. The data show that for double-strand manila meshes up to $4\frac{7}{8}$ inches, internal measure, wet, after use, most fish above 30 cm are retained. Considering these data, along with those for American plaice and also the shapes of all 3 species of flatfish, it seems reasonable to conclude that the selectivity for all 3 species is quite similar. The numerical value of the selection factor for winter flounder and yellowtail is probably close to 2.0 for meshes of double-strand manila twine.

Selectivity of Redfish by Manila Codends

Selection curves for redfish obtained in covered net experiments with double-strand manila codends are shown in Figure 3. The 50% retention length for redfish is between 25 and 27 cm for codends of about 4-1/2 inch mesh, internal, wet, used measure. Most of the redfish caught were relatively large, 30 cm or more in length

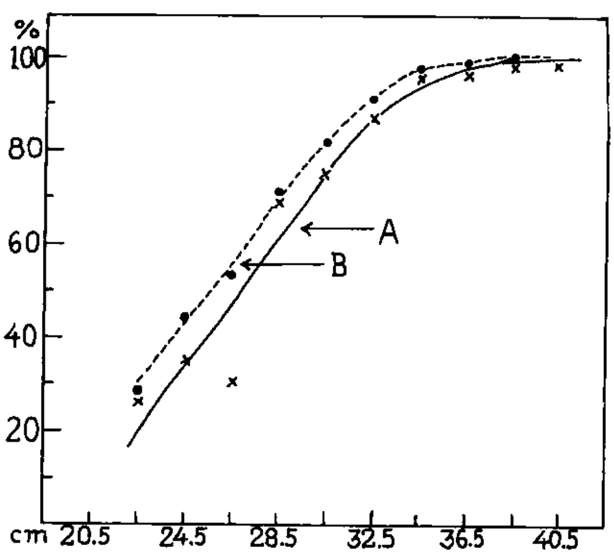

Fig. 3. Selection curves for redfish with 4 1/2 inch mesh, internal, used, wet measure, double - strand manila codends. Codend A – full line; codend B – stippled line; ordinate – % retained in codend; abscisse – length 2-cm groups.

(Table III F-3 gives details of size frequency). Relatively small numbers of redfish occurred around the 50% retention length and below. However, the values for percentages retained in the codend at these smaller sizes are in good agreement with the extension of the upper limb of the selection curve, based on large numbers of redfish. Estimates of the 50% retention lengths are thus believed to be quite reliable.

Mean mesh sizes of the 2 codends tested are quite similar, about $4\frac{1}{2}$ inches (114 mm), but the 2 codends differ considerably in the way this average is made up (Table 15). Codend B had larger meshes in the aft end and smaller meshes in the forward end than codend A. Prior use of codend A in groundfishing and the large "hoists" of redfish presumably contributed to these variations in mesh size. Percentages of redfish retained at succeeding length intervals are higher for codend B than for codend A. Codend B had smaller meshes in the forward end. The difference in selection between the 2 codends is consistent with the belief that the forward part of the codend plays an important part in releasing fish when catches are large.

The results of these mesh selection experiments suggest that the selection factor for redfish is about 2.3 with double-strand manila codends. The various characteristics of the experiments described above should be kept in mind in considering the precision of this estimate.

Discussion

Selection factors for American plaice show the same general relationship between materials as was reported for Subarea 4 cod and haddock (McCracken, 1957). Greater escapement occured through single-strand nylon and cotton codends than through double-strand manila codends of like mesh size. The very high selection factor of 2.5 for American plaice with the single-strand cotton codend may result from inadequate data for this material. It is of interest to note that the selection factor of 2.0 for American plaice with double-strand manila meshes is slightly lower than that reported for the European plaice, *Platessa platessa* (L.), 2.2, for similar material (from Report of the *ad hoc* committee of the Permanent Commission, 1956).

TABLE 15. Mesh size of manila codends used in redfish mesh selection experiments.

	Quarter No. 1 (aft)		Quarter No. 2		Quarter No. 3		Quarter No. 4 (forward)		Mean	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
Codend A	4.6	117	4.6	117	4.5	114	4.4	112	4.5	114
Codend B	4.7	119	4.7	119	4.4	112	4.1	102	4.5	114

TABLE 16. Relation between selection of flatfish and redfish with 4½ inch mesh manila nets and minimum sizes landed.

	American Plaice	Yellowtail	Winter Flounder	Redfish
Selection factor	2.0	(2.0)	(2.0)	2.3
50% retention length (cm)	23	23	23	26
90% retention length (cm)	28-29	28-29	28-29	32-33
Cull size (cm)	35	35	25-30	30

Selectivity of flatfish and redfish may in the future be of importance in considering the relation between size at first capture and maximum sustained yield for these species. But, at present, population studies for stocks of flatfish and redfish from the northwest Atlantic are generally inadequate for conclusions about maximum sustained yield. A knowledge of the selectivity for these species is important, however, in relation to the regulation of fisheries for cod and haddock. From the information summarized briefly in Table 16, it is apparent that the largest minimum mesh size now recommended for cod and haddock fishing in the ICNAF area has caused little interference with mixed fisheries for important flatfish species in Subareas 3 and 4. If further increases in mesh size are contemplated for either cod or haddock fishing, the selectivity for flatfish will have to be considered more thoroughly.

While nets of the largest minimum mesh size can take incidental catches of redfish, some redfish normally retained in small-mesh redfish nets would be lost. Recommendations for increased mesh sizes in the redfish fishery will have to be related to fishing efficiency or optimum size for first capture of this species.

D. HOOK SELECTION FOR COD AND HADDOCK

Abstract

Controlled fishing experiments with different sizes of baited hooks show that size at first capture for cod and haddock can be increased by increasing hook and bait size. Hook selection curves, less sharp than those for otter trawls, can be compared by 50% retention lengths.

A no. 14 Mustad hook with a 50% retention length of about 46-48 cm for cod appears equivalent to a manila trawl of 5½ inch internal measure, wet mesh. The no. 17 Mustad hook, smallest used by Canadian groundfish fishermen, probably releases as many small cod and haddock as the 4½ inch mesh (internal, wet measure) manila trawls prescribed for ICNAF Subarea 4.

If minimum mesh sizes are increased beyond those now recommended for portions of the ICNAF area, the possible regulation of hook size (and bait size) would have to be considered. Further experimentation would be necessary to define more precisely the selective properties of hooks in relation to otter trawls. Adequate methods of measuring hooks and baits would also have to be developed.

Introduction

Cod and haddock are caught by various gears in the northwest Atlantic Ocean. The important gears are: otter trawls, traps and hooks. The selective properties of these gears affect size of fish at first capture, and this in turn affects the quantities of fish landed. Controlled mesh sizes for otter trawls have already been introduced in the ICNAF area. For balanced management, it is important to know the selective properties of the other important gears.

Catches of cod and haddock by different sizes of hooks were compared directly in hook selection experiments carried out in inshore waters off Nova Scotia in 1954. The sizes of cod caught by small-mesh otter trawl and by hooks in the western Gulf of St. Lawrence have also been compared. However, for both cod and haddock precisely controlled experiments comparing selectivity by otter trawls and hooks have, so far, been unsatisfactory. For haddock, comparison has been possible only from commercial landings.

Methods

Four hook sizes were tested: no. 17, no. 15, no. 14, and no. 11 mustad hooks, although only three sizes were used at any one time. The no. 17 hook is the smallest, the no. 11 the largest. The no. 17 hook size, used as a standard in all tests, is the size most commonly used in longline fishing off Lockport, N. S., where most of the experiments were carried out. It is the smallest hook used for groundfish by Canadian fishermen. The no. 15 and no. 14 hooks are generally fished where small-mouthed haddock is not an important part of the catch. The no. 11 is about the size of a handline hook and is not used in longlining.

Longlines were set along bottom and left to soak for 1 to 2 hours before starting to haul. Each string usually had 45 to 54 lines, 15 or 18 fifty-fathom lines of 50 hooks per line for each hook size. Each hook size was fished in 3-line units. The units were distributed alternately in the string, and their positions changed each set.

Experienced fishermen carrying out the operation cut baits according to the size of hook. This was believed to be the most realistic approach. Herring was used for bait throughout the tests. Fish caught by each hook size were measured and weighed separately.

Cod

The selection of cod by hooks follows a regular progression from smaller to larger hooks (Fig. 4). Each succeeding larger hook caught fewer small cod and the maximum size at which fish "escaped" increased. But both large and small hooks took similar quantities of large fish.

Using the catch of the no. 17 hook as an estimate of the size composition of the stock fished, selection curves have been derived for the other hooks. These selection curves are similar

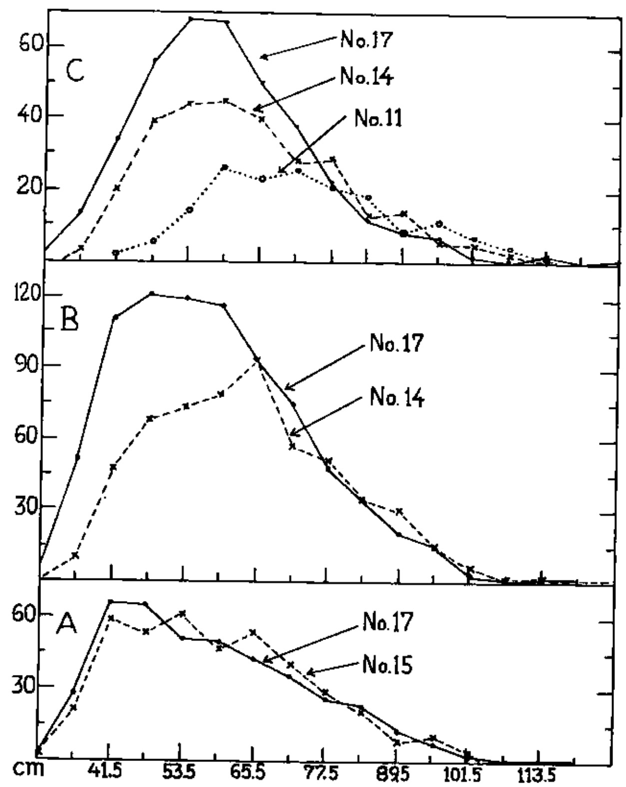

Fig. 4. Size frequency of cod catches with different sizes of hook.
A. With Mustad hooks No. 17 and No. 15 (9150 hooks each);
B. With Mustad hooks No. 17 and No. 14 (15,500 hooks each);
C. With Mustad hooks No. 17, No. 14 and No. 11 (5400 hooks each);
Ordinate: number of fish; abscissa: length of fish 6-cm groups.

in shape but less sharp than for otter trawls (Fig. 5A). It seems reasonable, then, to compare the selectivity of the various hooks in the manner used for otter trawls, *i.e.*, 25, 50, and 75% retention lengths. Thus, for cod the 50% retention length for the no. 11 hook was about 65 cm, for the no. 14 hook about 46 cm. Probably the selection ranges for the no. 17 and no. 14 hooks overlap and the lower limb of selection curve 1 should show smaller percentages of cod retained. Its shape probably should be more like curve 2, for the no. 11 hook, and the 50% retention length is probably also 1 or 2 cm low. Data for the no. 15 hook are insufficient to provide an adequate selection curve.

Comparison with otter trawls. Preliminary attempts to compare directly cod catches by otter

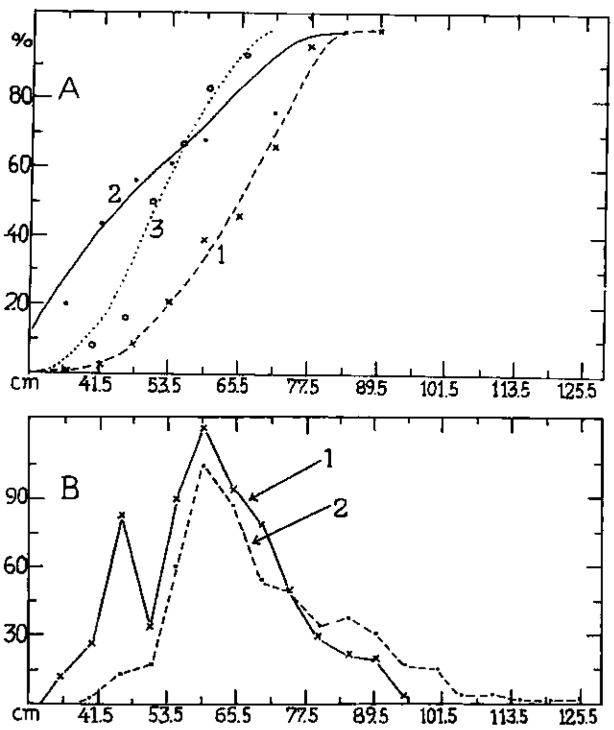

Fig. 5. A. Cod selection curves for 1, No. 11 vs No. 17 hooks; 2, No. 14 vs No. 17 hooks; and 3, No. 14 hooks vs small-mesh otter trawl.
B. Size frequency of cod taken in the northern Gulf of St. Lawrence by: 1—small-mesh otter trawl (2¾" mesh, internal, wet, used manila); and 2—No. 14 hook. Hook samples multiplied by factor equalizing numbers of fish in both samples between 63 and 92 cm. (Data from Marcotte, 1952). N (ordinate): number of fish at each length group in samples.

trawl and hook have been unsuccessful. Longlines fished at the same place and same time as an otter trawl, on otter trawl grounds in the western Gulf of St. Lawrence, caught few cod. More typical longline grounds were too rough for otter trawls.

Cod catches by small-mesh otter trawl (about 2¾ inch mesh, internal, wet, used measure) and by no. 14 hooks from this same general region in the Gulf of St. Lawrence are compared (Fig. 5B) (data from Marcotte, 1952). While the samples were taken in alternate weeks and the gear was not necessarily fished on precisely the same grounds, the size composition of the cod catch seems sufficiently similar for comparison.

Number 14 hooks caught fewer small cod and slightly more large cod than the otter trawl. The selection of small cod by these hooks is presented as curve 3, Figure 5A. The 50% retention length thus obtained is about 48 cm, a few cm larger than that obtained by comparing the no. 14 hook and the no. 17 hook. The difference between the lower limbs of these two selection curves supports the suggestion that the selection ranges of the no. 14 hook and no. 17 hook overlap.

Haddock

Selection of haddock by hooks of different sizes was less regular than for cod (Fig. 6A). At least part of the irregularity results from the lower availability of haddock. The largest no. 11 hook caught few haddock of any size. The no. 14 hook caught fewer haddock of all sizes than either the no. 15 or no. 17 hooks. Small haddock were scarce and their capture shows little regularity. While the data suggest the same general pattern of selection as for cod, they are inadequate to provide good hook selection curves for haddock.

Comparison with other trawls. Comparison of sizes of haddock caught by hooks and by otter trawls depends on samples of commercial landings. Samples of haddock landings by otter trawl and longline fishing in about the same area, same depth, and the same time, off western Nova Scotia, are available for March and April, 1954 (Fig. 6B and 6C). Length distributions for the March haddock landings by the two gears are similar. Only negligible quantities of haddock were discarded in both cases. In April the no. 17 hook landed fewer small haddock than the small-mesh otter trawl (about 2¾ inch mesh). Discards from the catch by hooks were negligible. The otter trawler discarded considerable quantities of haddock below about 40 cm, but attempted to retain all fish above this size.

It is not practicable to produce selection curves for the no. 17 hook from these data. It will be noted that in March the two gears caught similar numbers of large fish. Thus, the right-hand limbs of the length frequency curves have similar slopes. In the April samples this is not true. The right-hand limb of the curve for otter trawl landings has a greater slope than that for the hooks. It is thus difficult to equalize the length frequency curves, and, in fact, the distribution suggests that there may have been some differences in the stocks of haddock fished. However, it seems likely that the 50% retention length for haddock with a no. 17 hook is as large as that for a 4½ inch mesh.

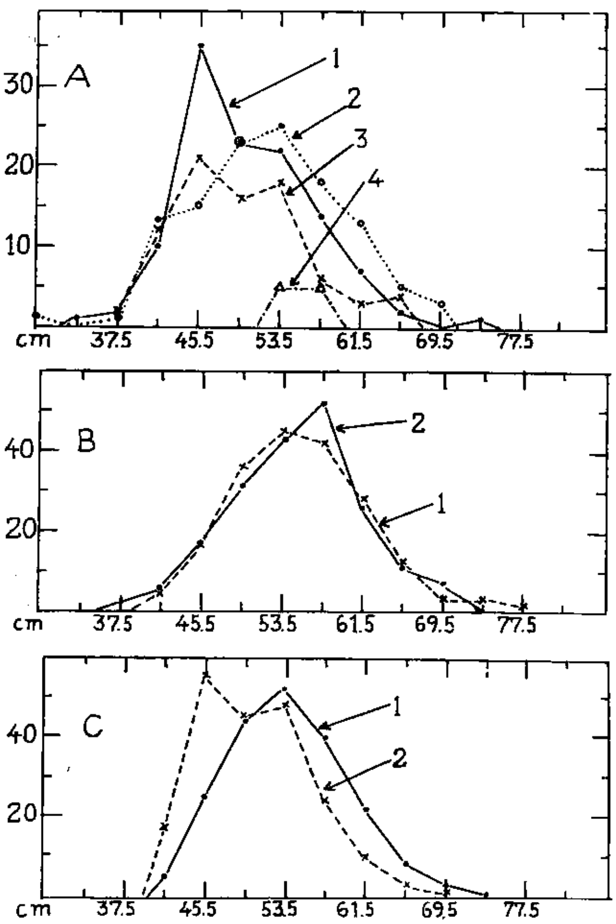

Fig. 6. A. Size frequency of haddock catches with different sizes of hook; 1—No. 17; 2—No. 15; 3—No. 14; and 4—No. 11 (all 9150 hooks each).
B. Size frequency of haddock landings from LaHave Bank in March, 1954; 1—otter trawl (2¾" mesh); 2—No. 17 hook.
C. Size frequency of haddock landings from LaHave Bank in April, 1954; 1—otter trawl 2¾" mesh); 2—No. 17 hook. (Samples of equal numbers were weighted according to the weight of large and small fish landed.)

Summary and Discussion

Size at first capture for cod and haddock can be increased by increasing hook and bait size. Selection is not as sharp as that for otter trawls. Selection curves for the various hook sizes can be compared from 50% retention lengths in a manner similar to that used for mesh selection curves. For cod the 50% retention length with a no. 14 Mustad hook, appears equal to that for about a 5½ inch mesh, internal measure, wet, used, manila trawl. Indirect evidence suggests that the no. 17 hook, the smallest hook used for groundfish by Canadian fishermen, releases as many small cod as a 4½ inch mesh, internal, wet, used, manila trawl.

Rather inadequate hook selection results for haddock also indicate that the smallest hook now used releases as many small haddock as a manila trawl of 4½ inch mesh, internal, used measure.

Large and small hooks fished in equal numbers caught about the same numbers and sizes of large cod. This result is important to the comparison of catches by different sizes or kinds of gear. From comparison of the percentage size composition of their catches, it is often concluded that large-mesh otter trawls catch more large fish than small-mesh otter trawls. Comparison of the percentage size composition of the catches by large and small hooks would suggest a similar relationship. This result emphasizes the need for equating catches on an effort basis before comparing selectivity of different sizes of gears.

If minimum mesh sizes are increased beyond those now recommended for portions of the

ICNAF area, the possible regulation of hook size (and bait size) would have to be considered. Further experimentation would be necessary, and some adequate method of measuring hooks and baits would have to be developed.

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List of Tables Including Basic Data

The Tables F-1 to F-3, listed below, give detailed data on length measurements of fish from the experiments referred to in the paper above. These tables – not printed in the paper – are filed in the ICNAF Secretariat, from where they can be requested for reference.

F - 1. Size frequency of American plaice in covered net experiments with estimated 50% retention lengths and selection factors.

F - 2. Size frequency of winter flounders and yellowtails and % retained in the codend for covered net mesh experiments.

F - 3. Size frequency of redfish taken in covered net experiments with % retained in codend.

13.

An Illustration of Differing Selectivities in Two Trawls

by

A. R. MARGETTS[1]

Abstract

Describes an experiment in which two trawlers, one with a heavy trawl and double sisal codend and the other with a light trawl and single cotton codend of the same mesh size, fished together for whiting. The differences in gear were such that selectivity differences might reasonably have been expected to be near the maximum possible. The selectivity of the single cotton codend was markedly higher than that of the double sisal. The selection factor for the single cotton light trawl codend of 50 mm mesh was estimated as 4.6.

Introduction

In recent years a number of separate experiments have been made to measure the mesh selection of trawl codends made of different materials such as sisal, cotton and nylon, of various thicknesses and braided either double or single. Many of these experiments have employed the covered codend technique, using one trawl and changing the codend periodically to provide comparison. Reports have already been presented at previous meetings of ICES.

Results, between experiments, have been variable, showing sometimes slight, sometimes big, and sometimes no differences between the selectivities of the various codends tested, but always such differences as have been found indicate that codends made from thinner (thus usually more pliable, especially when single-braided) twines such as cotton and nylon have a higher selectivity. Similarly, a cotton seine has been shown to have higher selectivity than a double sisal trawl of the same mesh size.

The Experiment

In the mesh selection experiments carried out from Lowestoft, *M.V. Platessa* (100 ft overall) has returned with variable and rather inconsistent results from covered net experiments and there has not been a satisfactory agreement or explanation of differences between the results of *Platessa* and *Sir Lancelot* (135 ft overall). An experiment was therefore arranged in which two trawlers with their widely different typical gears would fish together and compare catches; they were at first to fish with their typical trawls with codends not covered but with the codend mesh size (on the gauge) the same for each, and then one ship would subsequently vary the type of codend used and also introduce a covered codend into the comparison. Unfortunately, bad weather seriously restricted work to the first comparison and even that could not be made as complete as might have been wished for. However, the results obtained were fairly conclusive.

The two ships involved were *Platessa* with a typical rather heavy Lowestoft deep-sea trawl, the netting of which was made of sisal, the codend of double-braided twine, runnage 150 yards per lb, and *Irenic* of Brixham, an inshore trawler about 50 ft overall in length, with a light trawl, the wings, square and top belly of which were made of 15-21 thread cotton and the codend of single braided 36-42 thread cotton. Whiting was the principal species to be caught. To take advantage of the size range of fish expected to be available and so that any difference in selectivity might, according to theory, be near maximum, the chosen codend mesh size was 50 mm on the gauge; in fact, in use, the single cotton codend fished at 50 mm and the double sisal at 49 mm. At that mesh size the ratio of mesh lumen area to twine area was very much greater in the cotton than in the double sisal codend; the double sisal codend appeared and handled not unlike coconut matting while the single cotton codend was much more flexible and easier to handle.

[1])Fisheries Laboratory, Lowestoft, England.

Results

Platessa and *Irenic* fished together on four days, each ship totalling 13 hours' fishing. From the results two hauls were rejected because of damage sustained by one of the trawls and one haul because the two ships did not keep sufficiently close together all of the time. *Platessa* towed slightly faster than *Irenic*. The sum of six comparable pairs of whiting hauls are plotted in the histogram in Fig. 1. The relevant basic data are given in Table F-1 (filed in the ICNAF Secretariat).

The length distribution of whiting fished showed two main groups, the 15-25 cm and 30-37 cm fish. Both groups were caught on all but one of the hauls (from that haul the small ones were missing). *Irenic* with the single cotton trawl caught more of the big fish and very few indeed of the small fish which, however, made up a large part of the catch in *Platessa's* double sisal codend.

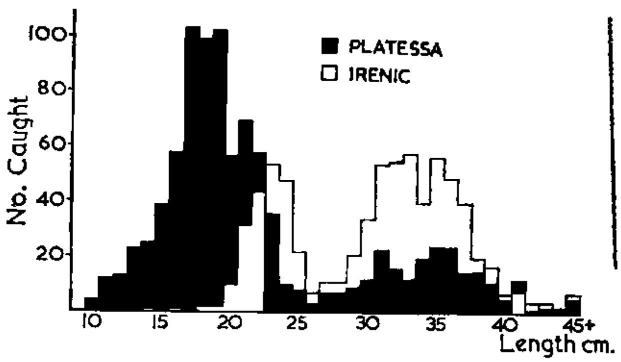

Fig. 1. The sum of six comparable pairs of whiting hauls by vessels *Platessa* and *Irenic*

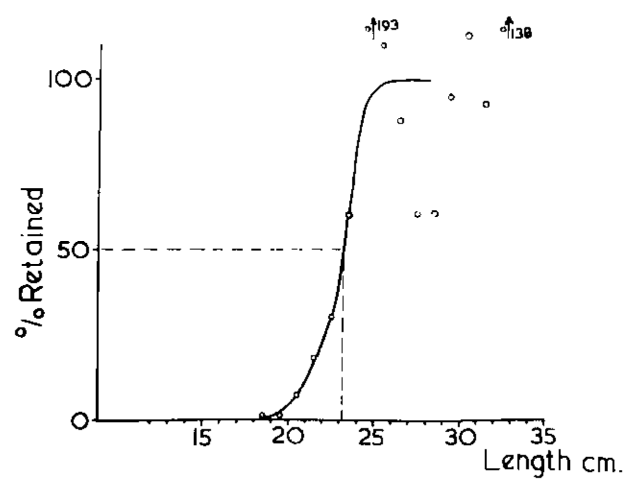

Fig. 2. Selection by 50 mm cotton trawl codend of Whiting.

On the larger fish *Irenic* was outfishing *Platessa* by 2.5:1; this is attributable to *Irenic's* cotton trawl having been specially evolved for whiting fishing and to *Platessa's* primarily flatfish trawl not being efficient for catching whiting, partly because some of them escape it before reaching the codend.

The cotton trawl was clearly selecting sharply in the 20-25 cm length range of whiting; this is attributable to codend selection, as are *Platessa's* larger catches of small whiting. By raising *Platessa's* numbers caught at each centimetre length by the factor 2.5 (representing the comparatively greater efficiency of *Irenic's* trawl) and then assuming *Platessa's* raised catch to represent the fish present, a selection ogive for *Irenic's* cotton codend is easily obtained. This (Fig. 2) shows selection to be sharp over a total range of only 6 cm with 50% point at 23.1 cm, indicating a selection factor of 4.6. Had *Platessa's* catch not been raised and if it were assumed that for all sizes of whiting less than 24 cm the fishing capacities of the two trawls were equal, then the 50% point would be at 21.6 cm and factor 4.3.

Conclusions

A light cotton trawl with single braided 42 thread cotton codend showed markedly higher selectivity of whitings than did a heavier sisal trawl with double braided 150 yds per lb sisal codend.

The 50% selection length of whiting by the 50 mm cotton codend was 23.1 cm, selection factor 4.6, or, as a minimum, 21.6 cm, factor 4.3. The former figures are likely to be more correct.

Table Including Basic Data

Table F-1 referred to in the paper above, is not printed here, but filed in the ICNAF Secretariat for reference, headed as follows:

F - 1. Length distributions of whiting caught by trawlers *Platessa* with 49 mm double sisal codend and *Irenic* with 50 mm single cotton codend.

14.

Escapes of Fish Through the Component Parts of Trawls

by

A. R. MARGETTS[1]

Abstract

Describes two experiments in which different trawlers each fished with the codend and one other part of the trawl covered on each haul in order to determine the sorts, sizes and numbers of fish escaping through the various parts of trawl nets. Particular attention is paid to the results obtained for plaice, dab, whiting, sprats and herring, and horse mackerel. Escape patterns varied with species and quantitatively between ships. Generally escapes through the wings were nil, through the square negligible, through the forward belly variable but mostly relatively few, and through the after belly often frequent. For example, in one experiment, 3 or 4 whiting of length 10-15 cm and 20-25 cm went into the codend for every 1 through the belly, while in the other experiment, of the 20-35 cm whiting, 1 escaped through the forward belly and 9 through the after belly for every 3 entering the codend, and, of the 11-18 cm whiting, 1 escaped through the forward belly and 12 through the after belly for every 3 entering the codend.

It is suggested that inter-ship differences in the relative escape patterns of fish through the various parts of trawls will be associated with the shapes and rigging of the nets as well as with mesh size. Escape of some sorts of fish before reaching the codend can be, on present evidence, only partly responsible for some of the observed differences of catches in two-ship comparative fishings. Differences in fish behaviour and a suggested critical angle at which a fish meets a wall of netting are thought to affect fish escapes.

Introduction

Comparative fishing experiments in which two ships have fished together have revealed not only overall differences in quantities of catches but also some striking differences between the species composition of the catches of the ships concerned, (Margetts 1949). For instance, when the two research trawlers *Sir Lancelot* and *Explorer* fished together their catches were consistently diffferent, with *Explorer* taking very many more of the whiting and three times as many haddock as *Sir Lancelot*, which caught many more of the flatfish. Their catches were so different in appearance that they might well have been thought to come from two quite different grounds. When the trawlers *Platessa* and *Vier Gebroeders* (TX14) fished together, the latter took relatively more whiting and horse mackerel. In another trial *Dana* with her small trawl, though outfished by *Platessa* on other species, caught more of the few horse mackerel than did *Platessa*. More recently *Platessa* was outfished on whiting by the much smaller trawler *Irenic* (Margetts, this volume). Yet when *Sir lancelot* and *Platessa* fished together the species composition of their catches was the same, the larger *Sir Lancelot* catching more than the smaller *Platessa*, roughly in proportion to the size of their trawls.

A feature common to all the above trials is that the two ships *Platessa* and *Sir Lancelot* were relatively not very good at catching whiting and horse mackerel but caught flatfish quite satisfactorily. The reasons for the differences between catches in such comparative experiments are to be sought in the set-up of either or both the ships and their gear.

Sir Lancelot and *Explorer* were of similar size and power and fished in much the same manner; there was little difference between the towing powers or speeds of *Platessa* and *TX* 14; *Platessa* towed rather faster than *Irenic*. Thus it does not seem as though the ships alone could

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account for much of the differences in catches. *Sir Lancelot* and *Platessa* used trawls basically of much the same design and, except on one occasion, similarly rigged with accessories, *Sir Lancelot's* trawl being proportionately bigger, so that one ship with its complete gear could be considered as a scaled-up version of the other; catches proved to be similarly so. The specifications of the nets provided for a large square and plenty of rather slack netting in the upper part of the net with most of the towing strain imparted to the groundrope and lower netting; headline floats were used. *Explorer* used a trawl similar in overall size to *Sir Lancelot's* but with smaller square, longer wings and tighter upper netting, with no floats on the headline. The mesh sizes in different parts of the *Explorer* and *Sir Lancelot* trawls were virtually the same. The trawl used by *TX* 14 was of lighter construction than *Platessa's*, with a very small square, long wings, no headline floats and with the towing strain imparted mainly to the upper netting. *Irenic's* trawl was lightly built of cotton and small meshed throughout top wings, square and top belly. The impression gained was that, whereas the trawls used by *Platessa* and *Sir Lancelot* in action had top sides arched both crosswise and, to a lesser extent, lengthwise, the top netting of the trawls used by *Explorer* and *TX* 14 was practically flat. This was shown to be the case by the 1951 underwater filming experiments which provided the material for "Trawls in Action." The net with the raised headline must have the greater mouth area and thus filter more water, most of this "extra" water passing through the upper netting. Thus, with the changed flow characteristics and shape of the net, there might be some change in the direction of swimming and behaviour of some fish in the net.

Todd (1908) carried out and reported on extensive trials primarily aimed at discovering what fish escaped through which parts of a trawl, how escapes through the body of the trawl compared with escapes through the codend, and at measuring codend size selection. Todd's results (given in 10 pages of tables plus 8 text tables) can be broadly summarized as showing escapes through the batings to be the only significant ones in the forward trawl netting, and there escapes were mainly of small dabs and whiting at a rate of not more than 11% of that through the codend. These results were of importance and lasting value, but were limited in so far as they were obtained by beam trawl, the specifications of which were not given; the flow characteristics of an otter trawl would be expected to differ from those of a beam trawl.

Method

A broadly similar technique to that of Todd's of applying cover netting to the backs of trawls has been used in two experiments with otter trawls towed by *Sir Lancelot* and *Platessa*. The trawls used were those broadly typical of Lowestoft North Sea trawlers and as normally used by the ships (Margetts, 1949). *Sir Lancelot's* codend was of 74 mm mesh, wings and square were of 137 mm, forward belly was of 118 mm, and after belly of 76 mm. *Platessa's* codend was of 69 mm mesh, wings and square were of 137 mm, forward belly was of 123 mm, and after belly of 85 mm. There were two covers, one always attached by four edges to cover the whole of the topside of the codend and overhang the end of it by some three feet. The other was attached to the various areas of the topside trawl netting for several consecutive hauls. This cover had a square mouth, the four 16 ft. sides of which were laced to the trawl. It had a short tapered sac leading backwards from the after edge in which its catch collected. Both covers were of cotton shrimp netting, approximately 80 rows per yard or 18 mm stretched mesh size.

In the *Sir Lancelot* experiment the forward cover was attached down the midline of the back of the net over (a) the whole of the after belly, (b) 59% of the forward belly, (c) on the after part of the square representing about 10% of its area, and (d) on the after part of the top wing. In the *Platessa* experiment the forward cover was attached in six positions, three down the midline of the back of the net over (a) 73% of the after top belly (or batings), (b) 24% of the forward top belly, (c) 13% of the square, and three to the side of the back of the net against the laced-ridge or lateral seam over (d) 68% of the after top belly, (e) 34% of the forward top belly, and (f) 14% of the square.

Results

To tabulate here the full results would be very lengthy. The minimum of figures are quoted in the text and tables. The original data are available, if required, on application to the author at Lowestoft. The catches by numbers of each fish species in the codend itself, the codend cover, and the forward cover, for several hauls combined are given in Tables 1 and 2.

It is at once clear that escapes through the top wings are nil or negligible, through the square very few, through the forward top belly few except for herring and horse mackerel, and through the after top belly numerous, particularly towards the sides of the net, and dependent upon species, herring, sprat, whiting and horse mackerel especially escaping from this region. Some species of fish, *e.g.* haddock, were not caught at all in these experiments.

Plaice

In the *Platessa* experiment none were caught in any of the forward cover netting. The numbers within or below the selection range of the after belly and codend meshes were very few. In the *Sir Lancelot* experiment where plaice lengths were mostly 18-32 cm only two 16 cm plaice escaped through the codend, 3 of 21-23 cm out of 702 less than 24 cm long escaped through the forward belly, and one of 13 cm out of the after belly. As these numbers are so small, no attempt is made to allow for the cover netting not completely covering all parts of the net.

Dab

Platessa: Small dabs 7-18 cm were abundant, with lesser quantities 19-28 cm. Codend mesh selection with a 50% point near 15 cm was obvious. The escapes through the forward net-

TABLE 1. *Sir Lancelot* – **number caught.**

Species		Forward Coverage 100% After top belly	50% Forward top belly	10% Square
Plaice	Codend	1303	1106	1753
	Codend cover	0	0	0
	Forward cover	1	5	3
Dab	Codend	902	1057	610
	Codend cover	1541	1737	1572
	Forward cover	237	21	0
Sole	Codend	74	126	39
	Codend cover	10	23	15
	Forward cover	5	0	0
Solenette	Codend	0	0	0
	Codend cover	101	256	130
	Forward cover	93	6	0
Horse Mackerel	Codend	21	371	531
	Codend cover	41	41	118
	Forward cover	51	35	11
Herring	Codend	30	49	87
	Codend cover	36	26	3299
	Forward cover	63	29	0
Sprat and small Herring	Codend	25	1	193
	Codend cover	4085	12	3667
	Forward cover	2905	5	5
Gurnard	Codend	65	15	39
	Codend cover	22	11	46
	Forward cover	25	0	1
Whiting	Codend	1008	1227	470
	Codend cover	245	300	271
	Forward cover	284	18	3

TABLE 2. *Platessa* – **number caught.**

Species		73% Midline after top belly	68% Side after top belly	Forward Coverage 24% Midline forward top belly	34% Side forward top belly	13% Midline square	14% Side square
Plaice	Codend	257	236	264	244	550	120
	Codend cover	0	0	0	26	0	0
	Forward cover	0	0	0	0	0	0
Dab	Codend	691	353	934	551	375	230
	Codend cover	1349	1530	1428	2191	880	867
	Forward cover	296	322	0	46	1	5
Sole	Codend	29	33	48	55	176	34
	Codend cover	11	2	0	20	0	0
	Forward cover	0	0	0	3	0	0
Solenette	Codend	1	0	0	0	0	20
	Codend cover	375	176	262	2025	152	1200
	Forward cover	172	56	0	11	0	54
Sprat and	Codend	5	18	3	1	0	2
small herring	Codend cover	191	217	20	36	4	138
	Forward cover	3416	1238	42	4	5	1
Gurnard	Codend	26	93	7	16	22	18
	Codend cover	179	299	74	12	116	0
	Forward cover	143	152	0	4	18	0
Whiting	Codend	183	232	98	154	195	127
	Codend cover	2403	1491	2451	2432	1284	2523
	Forward cover	3698	4147	6	469	10	67

ting were of the smaller fish, except for two of 19 and 22 cm through the side of the forward top belly. Whereas escapes in the midline region of the forward belly and square were negligible, through the sides of these parts they were more numerous although still very few. In the after top belly escapes were about the same in the middle and towards sides (the two cover areas did overlap considerably) and about 24% of the fish of the same size range as those escaping the codend actually escaped the after belly instead of entering the codend.

Sir Lancelot: Small dabs of 12-21 cm were plentiful but there were few at 22-28 cm. Escapes through the midline of the forward belly and square were negligible, but about 13% of the fish of the same size range as those escaping the codend actually escaped the after top belly instead of entering the codend.

An incidental result of these two experiments was the provision of data on double sisal trawl codend mesh selection of dabs. Numbers of fish over the selection ranges were high (Table 3) and the ogives were both smooth with 5 and 3.5 cm ranges between 10% and 90% points. The 50% lengths were, for *Sir Lancelot's* 74 mm mesh 16.3 cm, and for *Platessa's* 69 mm mesh 15.2 cm, both providing a selection factor of 2.2.

Horse Mackerel

These were caught only by *Sir Lancelot* and mostly in small numbers. Their length distribution fell into two groups 8-13 and 23-30 cm Of the larger fish in the square and forward belly, the ratio of numbers caught in the cover netting to those in the codend was quite variable from haul to haul; sometimes more would be caught in the cover netting while at other times, especially with larger numbers, almost all of the fish would go into the codend. This might be caused by shoaling of the fish and a uniformity of action of the fish in a shoal coming into the trawl net. Very few horse mackerel were available when the forward cover was over the after top belly.

TABLE 3. Mesh selection of Dabs by double sisal trawl codend.

	Sir Lancelot 74 mm mesh			*Platessa* 69 mm mesh		
Length cm	Nos. caught Codend	Cover	% Retained in codend	Nos. caught Codend	Cover	% Retained in codend
5					130	0
6					102	0
7				2	524	0
8				6	696	1
9				0	182	0
10	2	48	4	12	229	5
1	21	249	8	28	1173	2
2	39	407	9	48	1564	3
3	137	990	12	157	1266	11
4	246	1049	19	375	840	31
15	305	595	34	585	428	58
6	298	243	55	537	62	90
7	302	62	83	356	2	99
8	206	13	94	211	0	100
9	136	2	99	152		
20	82	0	100	118		
1+	135	0		352		
2	35			57		
3	17			56		
4	7			47		
25	7			19		
6	5			30		
7	7			29		
8	3			18		
9				8		
30	1			5		
1				2		

Herring and Sprat

Platessa: Shoals of mixed herring and sprat all of about the same size, 9-18 cm, were caught spasmodically. The great majority went through the belly netting before reaching the codend. Numbers were variable, but very approximately for every 1 fish retained in the codend: 21 escaped through the codend, 384 through the mid-line and 116 through the side of the after top belly, 40 through the midline and 2 through the side of the forward top belly, and 28 through the midline and 1 through the side of the square. These figures represent escapes into the covers; whereas the cover areas overlap on the after belly they cover only a part of the more forward trawl netting. Escapes through the midline regions were apparently more numerous than through the side regions, and this may not have been entirely due to errors caused by variation in catches.

Sir Lancelot: Few 20-27 cm herring were caught; it appeared that, of those reaching the after belly, about half escaped it and half entered the codend, while escapes through the forward belly were proportionately fewer. Sprat and small herring sometimes occurred in very large quantities. Negligible quantities went through the square; few were available when the cover was on the forward belly, and in the after part of the trawl about half of them went through the after belly and half into the codend. Again, from haul to haul there was considerable variation in the ratio of numbers escaping the belly to numbers entering the codend, from 2.5:1 to

1:2.5; this may be an effect of shoaling behaviour. No evidence of differing escape patterns between daylight and dark was obtained because numbers caught fell off in darkness.

Whiting

The results for this species will be considered in more detail since it was the species particularly sought for the experiments and has greater commercial significance.

Sir Lancelot: The length distribution of the population of whiting fished was bimodal with the major mode at 22 cm and a minor at 13 cm, the two groups having ranges of 20-25 and 10-15 cm.

Three whiting of 20-27 cm were caught in the square cover, which, even allowing for only the 10% coverage of the square, represent only about 10% of the fish of the same size reaching the codend. In the forward top belly the 18 fish caught by the cover were of sizes 20-33 cm and represented less than 10% of the fish of the same size reaching the codend.

In the after top belly 284 whiting were caught by the belly cover, compared with 245 by the codend cover and 1008 by the codend itself.

The meshes were 76 and 74 mm in codend and belly respectively, and the whole of both the codend (7,400 holes or meshes) and after belly (10,700 holes) were covered. Comparing actual numbers caught, about 3 times as many of the 10-15 cm whiting were caught in the codend cover as in the after belly cover, yet more of the 20-25 cm fish escaped the after belly than escaped the codend. The numbers of 20-25 cm fish caught in belly cover, codend cover and codend were respectively 201, 70 and 781. Mesh selection or some other form of size selection was apparently operating over this 20-25 cm range, both in the codend and in the belly. The size selection ogive for the codend estimated from these data has a 50% point at about 20.5 cm; this would suggest a mesh selection factor of 2.7 which seems unreasonably low. The reason for this low value may be associated with the very small numbers of fish around 20 cm. The large quantities of sprat caught in some hauls might have been expected to affect this selection, but there were no very obvious differences in the size ranges of whiting in codend and codend cover between hauls whether or not large quantities of sprat were caught also. The rigging of the codend cover might have affected the selection, yet all sprat went through the codend into the cover and selection of dab seemed unaffected. In the belly cover catch there was a downward trend from about one-third of the available 19 cm fish passing through into the belly cover to none at 29 cm.

It is interesting to note that, although haul to haul variation was considerable, the ratios of numbers of 20-25 cm whiting caught in the belly cover to those caught in the codend cover were much higher for the two hauls when a large number of sprat were caught, and on these two hauls the ratios of numbers in the codend to numbers in the codend cover were the highest, thus indicating that the sprats had some effect on the whiting, perhaps "masking."

In this experiment the after belly cover was rigged twice, for two sets of hauls separated by a day or so. The population of whiting fished each time was the same but certain differences between catches during each haul, such as relatively more of the 22-28 cm fish going into the codend rather than into the belly in the first hauls, suggest that the rigging of the cover might have influenced its catches.

Platessa: This experiment was characterized by the abundance of small whiting; the vast majority were 11-18 cm, hardly any 20-23 cm and few 24-33 cm. Conspicuous features were that catches of the belly covers were very large and that catches by the covers along the side of the net were all relatively greater than the corresponding catches of the covers in the midline of the net.

Escapes through the square were nearly negligible, yet higher to the side than in the middle.

Numbers in and near the selection range of the codend meshes were too small to provide measurement of selection, but no fish longer than 24 cm ever escaped from the codend to the codend cover.

For convenience the two modal size groups will be considered separately. The group of small whiting were well below the range of any mesh selection. In the after top belly where the midline cover covered 73% and the lateral cover 68%, these covers caught, respectively, one and a half times as many and two and a half times as many of the small fish as those which entered the codend. On combining the catches of side and midline covers it is estimated that 4 small whiting escaped through the after belly for every 1 that entered the codend; the actual catches were 3414 in the midline belly cover, compared with 2482 in the codend and its cover, and 3960 in the side cover compared with 1630 in codend and cover. In the forward belly, escapes through the midline were negligible, but 438 were caught by the side cover compared with 2515 simultaneously in the codend and its cover. Thus it is estimated that for the whole of the forward belly 876 small whiting would escape for every 2515 entering the codend; then, from the 4:1 ratio above, it is estimated that 10,060 would be escaping the after belly, *i.e.* 1 fish escaping the forward belly for every 14 that continue on down the trawl. Summarising approximately, of every 16 small whiting entering the belly, 1 would be expected to escape through the forward belly, 12 the after belly, and three would go into the codend.

Catches of the larger 20-35 cm. whiting were small and since the large numbers of smaller fish necessitated sub-sampling, these two factors combined to make the figures rather unreliable; they should therefore be treated with reserve. Nevertheless, for the two after belly cover positions the catches of codend, codend cover, and belly cover were respectively 66, 36 and 251 for the midline region and 38, 15 and 101 for the side region, which shows some uniformity and suggests that about 3 fish escaped for every 1 that entered the codend. In the forward belly side cover 11 fish in the 20-35 cm size range were caught compared with 44 in the codend and 24 in the codend cover, *i.e.* 1 escaping for every 3 entering the codend.

Discussion

These experiments show that in certain trawls under particular conditions sometimes very considerable quantities of fish get out of the net through the netting in the body of the net, especially that just in front of the codend, so that the codend catches (or codend plus its cover) are under these circumstances not necessarily representative of the fish entering the mouth of the net. The escapes of whiting from *Platessa's* forward trawl netting were more numerous than those from *Sir Lancelot's* trawl. However, on present evidence, the escapes of larger whiting which should be able to pass through the bigger meshes in the forward netting, although occurring, do not appear to take place on a scale large enough to account for all of such large differences in catches as were found when *Sir Lancelot* and *Explorer* fished together; in that experiment the whiting caught were mainly of 26-35 cm, or bigger than those caught in this covered net experiment in which no more than 40 20-25 cm whiting escaped the forward netting for every 100 that entered the codend.

The dissimilarity between *Platessa* and *Sir Lancelot* results illustrates how different can be the release effects in two separate trawls. Apart from size of trawls the towing speed of *Sir Lancelot* was faster than that of *Platessa*; underwater films have shown *Platessa's* trawl to have marked curvature of the after belly where it draws in to the codend, while *Sir Lancelot's* net had a smoother taper and merging of the two parts. Such a shaping would certainly be expected to result in a different release pattern between various parts of the net, but on the occasion of the photography it may only have been a temporary artifact, as the smooth joining of belly and codend was once eliminated when a codend was replaced. Minor changes in rigging, such as the working length of the top belly being slightly longer than that of the lower belly, (which could well happen as the parts are made separately by different braiders), could produce some pouching effect in the belly and hence alter the patterns of fish escapes. In this respect it should be noted that trawling on the turn, especially if always turning one way as is common practice, would be expected to alter the balance of escapes through the two sides of the trawl, and inexact "squaring up" of the trawl would produce much the same effect. The covers themselves may have affected the trawl and the results, although here it is to be expected that the effect of the covers on the forward netting would be to reduce escapes through the parts beneath them. The way the covers on *Sir Lancelot's* trawl belly were rigged at two different times, did appear indeed to affect their catches. A masking effect caused by large quantities of fish was noticed in the *Sir Lancelot* experiment.

Such experiments are liable to many errors. The results should perhaps be considered only as indications of what may usually happen; certainly the findings are not absolute for trawls in general, the variation between trawls being most important.

These results indicate that the behaviour of fish in relation to the trawl varies between species. For instance, horse mackerel escaped well forward, if erratically, small herring and sprat tended to escape more in the midline of the trawl back, while, of the small whiting, more escaped through the sides than the midline. A possible interpretation is that, when confronted with the trawl, whiting would tend to seek escape to the side while herring and horse mackerel would tend to go upwards. However, this may be affected by many factors including the relation of fish to the part of trawl which it meets, the distance of evasive swims or darts, shoaling habits etc. It is suggested above that shoaling of fish inducing a "follow the leader" movement through or away from the netting has contributed to the between-haul differences in escape patterns of sprat. It is reasonable to expect that, for any fish meeting an inclined sheet of netting, there will be a critical angle of the netting in relation to the direction of swimming of the fish which will contribute towards determining whether the fish will or will not try to go through that netting. This critical angle could be resolved into the vertical and horizontal planes. It would be expected that the size of meshes in the netting and the critical angle between fish and netting would be complementary to the extent that it might be the size of mesh opening apparent to the fish on its course towards the netting or the water flow through the meshes that would be important. At angles between a fish's course and the slope of the netting which were above the critical angle the fish would try to go through the netting, but at angles below the critical angle the fish would be guided elsewhere. This factor would be expected to operate in the forward parts of trawls, the function of which is to collect fish towards the codend and in so doing have as little water flow resistance per unit area as possible so as to allow the trawl to be as big as possible; it is noteworthy that trawls designed or evolved primarily for catching such fish as herring and whiting tend to have a longer taper to the belly than do some other trawls.

The between-ship differences in escape patterns emphasize the importance of standardising as far as possible eveything other than the single items to be compared in any two ship comparative fishing. In Davis' classical North Shields mesh experiment it is not unlikely that some degree of error was introduced by the uses, for some of the time, of two different trawl nets. Mesh selection experiments with covered codends should not be affected by escapes of fish from other parts of the trawl.

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15.

Some Remarks on Selection Processes in Fishing Operations

by

B. B. PARRISH[1]

Abstract

A selection process in fishing may be defined as any process which gives rise to differences in the probability of capture among the members of the exploitable fish.

The main selection processes which arise in fishing operations are:

(i) those caused by differences in the distribution of the fishing fleet and the components of the exploitable fish stock;

(ii) those caused by variations in habits and behaviour of components of the fish stock in the exploited area;

(iii) those caused by the inherent properties of the fishing gear.

Each of these processes operates to some extent in all commercial fisheries and each requires identification and measurement in order to understand observed spatial and temporal differences and changes in the size and structure of the commercial catch.

While the broad features of each of these processes are known, and their relative importance in some fisheries have been gauged, much remains unknown about the factors governing them and their magnitudes in different situations.

A selection process in fishing may be defined as a process which gives rise to differences in the probability of capture among the members of the exploitable body of fish.

When defined in this way it is clear that a large number of different processes taking place in a practical fishery come into the category of selection processes. The first task therefore is to identify the main selection processes which may be encountered in a fishery and to examine the major types of problems which each creates.

For convenience these processes can be examined under 3 headings:

(1) those caused by the distrihution of the fishing fleet in relation to the distribution and general biology of the fish stock;

(2) those caused by the behaviour and habits of the fish in the fished area;

(3) those caused by the inherent properties of the fishing gear.

Distribution of Fishing Fleet and Fish Stock

Fish can be caught only in areas in which the fishing vessels operate. Therefore "selection" as defined above may operate whenever a fishery fails to cover the whole distribution of the body of fish represented in a "unit stock" or multi-species resource. Selection from this cause may be (1) between species in a multispecies fishery; (2) between abundance levels of the whole biological structure of a single species; (3) between different biological components (sizes, ages, sexes, etc.) of a single stock. The last of these is perhaps the most important; it will arise when, for example, the biological components of the stock are stratified spatially across the area occupied by it, and the fished area. This is the case for many exploited species.

This type of selection process can be identified with the concept of "*availability*," which has been defined by Widrig (1954) as "*the number of fish in the population that are within the scope of the fishing operations during a season to the number of fish in the total population.*"

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1) Marine Laboratory, Aberdeen, Scotland.

The factors causing this type of selection process are numerous. They may be economic, technological, legislative or biological in origin. Economic factors may, for example, restrict the activities of a fishing fleet to regions within daily landing distances from the fishing port; they may also direct the fleet's activities to regions of particular sizes or "qualities" of fish. Technological factors may prohibit fishing on certain grounds occupied by the species under exploitation, as for example, the limitations of range and fishing facilities among small fishing vessels. Legislative factors may result in areas being closed to fishing at certain times, as for example, spawning grounds and nursery areas. In addition biological factors may make part of a body of fish inaccessible to fishing or result in the stratification of tbe biological components of the species.

All of these factors will result, collectively, in an unequal distribution of fishing intensity on the different groups of individuals represented in the area occupied by the "resource" or "unit stock," and give rise to selection.

Selection of this type can be relatively easily detected if exploratory and experimental fishing surveys are conducted over the full extent of the resource or unit stock. From such surveys, the relative abundances of fish of different species, and of biological components of each species inside and outside the fished area, can be gauged and the "availability" factors determined.

The magnitude of this type of selection process may be approximately constant with time or may vary. Some of the factors governing "availability" are unlikely to change markedly over short time periods (*e.g.*, legislative and technological factors) but many of the others will vary markedly between seasons, (*e.g.*, economic and some biological ones).

One well known example of a fishery in which "availability" changes of large magnitude have taken place is the California sardine fishery, and there are many others, particularly among the pelagic fisheries.

All of these temporal variations in "availability" require identification and measurement. The basic information required for the identification of this type of selection process at any time and the estimation of the "availability factor" for any exploited resource or "unit stock" are as follows:

(i) the total distribution and abundance of each species of fish under exploitation by a fishery;

(ii) their distribution and abundance in the fished area;

(iii) the distribution and abundance of the main biological variates (age, size, sex, etc.) of each species comprising the total stock in the fished area.

Behaviour and Habits of Fish

It is well known that all of the fish present in the locality of the fishing operation do not make contact with the gear even if all of the ground is swept by it. This may be due to many different factors but of major importance are behaviour responses of the fish to the gear and vertical distribution of the fish relative to the sphere of operation of the gear. These may vary between species and between biological components of a single species and hence give rise to a second form of selection process. This can be identified with the concept of "vulnerability," defined by Gulland (1955) as "*the ratio of the density of a standard fish to that of a given fish when the catch per unit fishing time by a standard vessel is the same.*"

Again, the "vulnerability" differences between species, or between areas and biological components within a species, may be approximately constant, or they may fluctuate widely over short term periods. This type of fluctuation creates the greatest difficulties in interpreting changes in catch and estimated stock density over short term periods. Again it is most likely to arise with the active pelagic species, *e.g.*, herring and sardine which are known to respond readily to changes in enviromental factors, and which are fished widely by gears such as gill nets and traps which rely for their efficiency on a particular type of behaviour pattern.

The "vulnerability" factor and hence the selectivity of the gear may also be changed markedly by technological advances. This has been demonstrated by numerous developments in fishing techniques during the present century. The introduction of sweep wires and kites for trawls, and the use of lights, lures and "chumming" techniques for line and purse-seine fishing are examples. The effect of these techniques may change not only the overall efficiency of capture of the unit operation of the gear but also the structure of the catch.

At present, the magnitude of this source of selectivity, its variability between the stock components, and the factors influencing it are little known for most of the major species and gear. These require further detailed investigation. Changes in "vulnerability" and selectivity due to technological differences in fishing gear can be gauged with reasonable facility from well-planned comparative fishing experiments, and these can be allowed for in studies of changes in abundance of the stock over periods of time when technological changes in fishing have taken place. The difficulties are greater, however, in obtaining measures of the differences in "vulnerability":

(1) between areas at any given time;
(2) between biological components at any given place and time;
(3) between times in any given area.

However, some idea of these can usually be obtained from extensive fishing surveys over a long period of time, and from comparative fishing experiments using different types of gear. Also, new types of equipment and methods of direct underwater observation (*e.g.*, cameras, U.T.V., frogmen) are used in studying the behaviour of fish to the fishing gear, and hence in obtaining direct information on the "vulnerability" of fish of different sizes.

Some of the "vulnerability" changes are due to the changes in behaviour and habits of fish in response to changes in environmental factors. This has been clearly demonstrated both between seasons and between years for a number of species. It is important, therefore, in the investigation of "vulnerability" changes to identify the type of response which takes place and relate these responses to the environmental influences which generate them.

Inherent Gear Selectivity

The two types of selection process dealt with so far are concerned with the fish which fail to come in contact with the gear. The remaining type is the selection of fish by the gear itself. It includes the wide range of well-known processes such as mesh selection of trawls, seines and gill nets and hook selection by lines.

"Inherent gear selectivity" is, in general, the easiest of the selection processes to investigate. This is because it is an inherent property of the gear, and is not, like "availability" and "vulnerability," subject to fluctuations and changes from a wide range of external factors. Within limits, it is a constant process for each type of gear used and for each species; furthermore, for most gears in commercial use it is relatively easily measured experimentally. This does not mean that the subject is of minor importance or that there are no longer any outstanding problems in relation to it, but merely that the field is one in which quantitative evaluations of the process can usually be made.

The biological character in relation to which inherent gear selectivity can usually be most conveniently investigated is length, although it is most often not length which is the primary variable involved in selection, but others related to it, which, in practice, are more difficult or time-consuming to measure. The nature of length selectivity differs according to the type of gear used; and for the present purpose, most commercial gears in use today can be placed in one of two main categories:

(1) those which select at one end of the length range only;

(2) those which select at both ends of the length range.

The first of these is the simplest and easiest type of situation to handle and best known. Examples of this type of gear are trawls, seines, ring-nets, pound nets and net traps, from which escapes take place through the meshes up to a length corresponding approximately with body girths of the same size as the lumen of the mesh. Above this size no escapes occur. The second type is more complex and more difficult to investigate. Gill net selection is of this type. In gill nets, fish will fail to be caught at the lower end of the length range due to their being able to pass through the meshes, and again at the top of the length range due to their girth being too large to penetrate the meshes.

Inherent selectivity by hooks may be in either category, depending on the hooks used and the growth characteristics of the fish. It will operate at the lower end of the length range as a function of hook size, and it may operate at the upper end, as well, as a function of hook size.

Whatever the gear, selection by length is seldom knife edged. This is due to a number of factors; for mesh selection by trawls and seines for example, there are:

(1) variation of girth with length;
(2) variation in mesh size and shape over the selective part of the net;
(3) variations in the behaviour of the fish inside the net.

The usual effect is a generally symmetrical "curve of selection" or "ogive" starting from the smallest sizes of fish retained, and ending at some larger size at which all or some maximum proportion of the fish are retained. The main task in inherent gear selectivity work is to determine the parameters of the selective "ogive," particularly its mean and variance. Gears such as trawls and seines have a single selective ogive representing the spread of escapement from the gear from 0 - 100%, but gill nets may have a selection ogive at each end of the length scale, with a range of lengths in between over which the escapement is zero or at a minimum. For these gears, therefore, the task is to determine both of the selection ogives and the range of minimum retention in between. Gill-net selectivity may, in fact, be even more complex, with a number of different selection processes superimposed one upon another. (Holt, this volume). Herring, for example, may have maximum retention in drift nets at lengths corresponding with girths of different parts of the body. This is one of the most difficult types of selection processes to investigate experimentally to obtain absolute measures of selectivities, but a method for doing so is described by Holt (this volume).

Much the same general selection picture is obtained for hooks, but with these the factors causing the range of selection will be such factors as:

(1) the range of mouth size at length;
(2) variability in hook size;
(3) variability in bait size.

The importance of (3) is illustrated by Allen (this volume).

The net result will usually be a fairly smooth selection curve similar to those of trawls, or of gill-nets, depending on the type of fish and the fishery.

Factors Affecting Inherent Gear Selection

While the general nature of inherent gear selection is reasonably easily identified and measured, a major task arises in determining the differences in the magnitude of the selectivity of gear types, rigs of gears and parts of gears, and in identifying the factors which govern this magnitude. It is now well known that in nets the size of the mesh is the primary variable in this selection process, and that there is a reasonably constant relation between mesh size and the mean selection length. However, investigations by many workers have shown that other "gear" factors also affect the process and lead to different mean selection lengths for a given mesh size. Mesh selection by trawls has been shown for example to be influenced by the type of material from which the net is made, the dimensions and overall rig of the gear, the size and composition of the catch and the behaviour of fish in the net. The identification and measurement of the effects of such factors is an important current research item, especially with regard to systematic differences in the selection parameters, for a type of gear, caused by the material or rig factors. This task is easiest in fisheries which are exploited by one type of gear (*e.g.*, trawls), and is greatest in the mixed gear fisheries, particularly when the various gears are widely different in operation (*e.g.* trawls, seines, gill nets and lines). The identification and measurement of the factors other than mesh size which give rise to systematic differences in selectivity for each of these gears is a fundamental requirement for population assessments of mixed fisheries and for the application of conservation measures based on their selective properties.

This short review does no more than lay the foundation for the workshop's main deliberations, which will be reviewed in sequence as the deliberations proceed. We have seen that the whole process of selection in fishing can be divided into three components: "*availability*," "*vulnerability*" and inherent "*gear selectivity*." Each of these governs the relative probabilities of capture between species and between biological components of a single species, and each must be identified and measured for each fishery before observed catch data can be interpreted in terms of abundance of the exploited stock. The broad features of these processes are known, but much remains unknown about the factors governing each and their magnitudes in different situations.

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16.

Results on the Effects of Using Small-Mesh Covers: Effects on the Catches of the Escape Sizes of Fish[1]

by

B. B. PARRISH AND J. A. POPE[2]

Abstract

Experiments have been carried out to determine the effect of the use of a small-meshed cover on the size composition of the catches of fish in codends with mesh sizes of 81.2 and 98.5 mm, and with hauls varying in duration between one to three hours.

No significant differences in size composition between the catches of haddock in the covered and uncovered hauls were observed but markedly greater catches of whiting in the 20-25 cm size category were obtained in the covered hauls in one series.

It is concluded that the covered net method is a simple and usually reliable means for determining the selection curve for haddock at existing stock levels, but that apparent masking, resulting from the operation of a combination of factors, may sometimes be experienced. The use of covered and uncovered hauls in a properly designed experiment enables the existence of masking to be detected.

Introduction

In a paper delivered to ICES Comparative Fishing Sub-Committee in Copenhagen in 1950, (Parrish 1950), results were presented which showed that the fitting of a small-meshed cover over the codend of a standard otter trawl resulted in no significant increase in the numbers of the escape sizes of haddock, whiting and dabs retained in the codend. The view was expressed that covered net experiments provided the simplest and most reliable method for determining the mesh selection ogives for codends of different mesh sizes. This was contrary to the conclusions reached by Davis (1934) who claimed that bias was caused with this method due to a masking effect of the cover on the release of the smaller categories of fish.

In view of the conflicting nature of these results and their importance in experimentation, two further experiments were carried out in October 1950 and June 1951 with codends of different mesh size and with hauls of different duration. In these experiments hauls of 1, $1\frac{1}{2}$ and 3 hours' duration were carried out with and without a small-meshed cover. The order of the hauls was randomized each day.

The gear used in each experiment was an otter trawl with a 46 ft groundrope and without sweeps. In the covered hauls the upper surface of the codend was covered with a loosely fitting bag of 32/30 cotton twist, 3/4 inch mesh. The underside of the codend was covered with netting to prevent escapes. The details of the mesh size, number of hauls and duration of hauls are shown below.

All fish caught in the codend and cover in each haul of each experiment were counted and measured to the nearest centimetre and samples of codend meshes were measured after each haul using the Scottish spring gauge. These showed that the mesh size remained constant throughout the experimental period.

		No. of hauls	Duration of hauls	Mean codend mesh size
Experiment 1	(October 1950)	6	1 hr	81.2 mm
Experiment 2	(June 1951)	(a) 18	$1\frac{1}{2}$ hr	98.5 mm
		(b) 18	3 hr	98.5 mm

1) This paper was first presented to ICES Comp. Fish. Sub.-Comm., 1951.

2) Marine Laboratory, Aberdeen, Scotland.

Results

Catches of haddock and whiting from Experiment 1, and of haddock from Experiment 2 have been analysed, these being the only species caught in sufficient quantities from haul to haul to permit detailed analysis. The numbers of each of these species caught in the codend in the covered and uncovered hauls in the two experiments are presented in Tables F-1, F-2, F-3, and F-4 (filed in the ICNAF Secretariat).

A glance at the figures shows that, with the exception of whiting in Experiment 1, the size compositions of the codend catches in the covered and uncovered hauls were approximately the same, and no marked differences in the numbers of different size categories of fish in the two gears were evident. It was clear, however, that in Experiment 1, many more whiting in the 20-25 cm size category were retained in the codend in the covered net hauls than in the uncovered ones. A more detailed analysis of these data has been carried out using the analysis of variance technique to test the significance of differences between the mean lengths of fish, the within-haul variances and the numbers of fish of less than 29 cm in the covered and uncovered hauls. The results of these analyses are presented in Tables 1-3.

TABLE 1. Analysis of mean lengths.

	Overall mean lengths in cm			
	Hauls with small mesh	Hauls without small mesh	Difference between means in cm	Level of significance
Exp. 1 Haddock	32.2	32.3	0.1	
Whiting	26.6	33.9	7.3	P <0.001
Exp. 2 Haddock 1½ hr. hauls	27.6	27.1	0.5	P <0.05
Exp. 2 Haddock 3 hr. hauls	27.9	28.2	0.3	

TABLE 2. Analysis of within-haul variances.

	Mean variance			
	Hauls with small mesh	Hauls without small mesh	Difference between means in cm^2	Level of significance
Exp. 1 Haddock	23.4	21.9	1.5	
Whiting	27.5	33.9	6.4	P <0.001
Exp. 2 Haddock 1½ hr hauls	15.5	15.5		
Exp. 2 Haddock 3 hr hauls	15.8	14.8	1.0	

TABLE 3. Analysis of numbers of small fish.

	Mean no. of fish less than 29 cm		Difference between means	Level of signifi-cance
	Hauls with small mesh	Hauls without small mesh		
Exp. 1 Haddock	19	18	1	
Whiting	93	5	88	P <0.001
Exp. 2 Haddock 1½ hr hauls	63	60	3	
Exp. 2 Haddock 3 hr hauls	87	79	8	

Discussion

The results of these analyses show that, with the exception of the whiting catches in Experiment 1, the covered codend did not retain significantly greater quantities of the smaller size categories of fish than the uncovered one. Thus the mean lengths and inter-haul variations of the haddock catches revealed a close similarity between the size compositions of this species in the two series of hauls, and the catches of the escape sizes (fish less than 29 cm) indicated that their numbers were the same within the limits of sampling variation.

It is evident, however, that significantly more whiting over this size range were caught in the covered than in the uncovered hauls in Experiment 1, a result which is difficult to interpret in the light of the observed catches of haddock in the same experiment. It is interesting to note also that this phenomenon was not observed in earlier experiments (Parrish 1950) when whiting of the same lengths and in greater quantities were caught from haul to haul, with codends of smaller mesh size. It seems that the escape of fish from the codend iuto the cover, or their subsequent return to the codend from the cover can vary markedly. This is demonstrated by the differences between the selection results obtained from individual covered hauls during a single experiment and in different experiments. A satisfactory explanation of the marked apparent masking of the cover for whiting in experiment 1 cannot be given from the available data but they suggest that masking by a cover rigged in the manner used in these and earlier experiments does not produce a systematic experimental bias. Rather, it seems that apparent masking may result from a combination of factors, including the operation of the cover, in some circumstances. It is probable that the size and rigging of the cover, the size and composition of the catch and the time of entry of the fish into the codend during the haul are important contributory factors. Experimental studies of the effects of these factors on selectivity are required.[1]

The results of these experiments show that over the range of codend mesh sizes investigated and with hauls varying in duration from one to three hours, no significant masking effect on the release of haddock over the selection range of sizes has been observed with the use of a small-meshed cover. It would appear conclusive therefore that with the type of gear used, and over the range of stock densities encountered in these experiments, the covered net method provides a simple and reliable means for determining the percentage release curves for codends of different mesh sizes. Its merits over other methods are evident in that each haul provides data from which a selection curve may be drawn, which is independent of the haul to haul variations in size of catch due to changes in stock density. Furthermore, it provides a means for studying statistically, the effect of other factors on the release of small fish.

[1]Since this paper was prepared an important contribution to the study of the effects of sizes and rigging of the cover has been made by Cassie (1955). His experiments show that masking may be large with small tight covers, but it is small or absent with loosely fitting covers.

TABLE 4. Percentage release of haddock (Experiment 2).

Length cm	3-Hour Hauls				1½-Hour Hauls				All Hauls			
	c.e.	cov.	Total	% Retained	c.e.	cov.	Total	% Retained	c.e.	cov.	Total	% Retained
16	1	3	4						1	3	4	
17		11	11	100		9	9	100		20	20	100
18	9	62	71	87	3	47	50	94	94	12	109	90
19	19	300	319	94	12	158	170	93	31	458	489	93
20	58	661	719	92	36	364	400	91	94	1025	1119	92
21	98	754	852	89	56	447	503	89	154	1201	1355	89
22	63	354	417	85	71	192	263	73	134	546	680	80
23	31	132	163	81	27	87	114	76	58	239	297	80
24	23	47	70	67	15	25	40	63	38	72	110	65
25	27	36	63	57	23	26	49	53	50	62	112	55
26	82	51	133	38	63	38	101	38	145	89	234	38
27	170	73	243	30	116	40	156	26	286	113	399	28
28	222	50	272	18	159	23	182	13	381	73	454	16
29	192	43	235	18	130	29	159	18	322	72	394	18
30	147	16	163	10	90	11	101	11	237	27	264	10
31	98	10	108	9	64	6	70	9	162	16	178	9
32	65	3	68	5	47	3	50	6	112	6	118	5

That consistent results may be obtained by the application of this method is demonstrated from the data obtained in Experiment 2 for haddock. The percentage release at each cm length has been determined from the codend aud small-mesh catches in the 1, 1½ hour and 3 hour series of hauls respectively. These figures are presented in Table 4.

It is clear that remarkably consistent results were obtained in the two series, which gave percentage release points through which smooth curves could readily be drawn. The selection factors calculated from these data are consistently low for the 1, 1½ and 3 hour hauls compared with results obtained for haddock by other workers using the covered net method (Clark 1952).

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List of Tables Including Basic Data

The tables F - 1 to F - 4, listed below, give detailed data on length measurements of fish from the experiments referred to in the paper above. These tables – not printed in the paper – are filed in the ICNAF Secretariat, from where they can be requested for reference.

F - 1. Length freqnency distribution of haddock in the codend (Experiment 1).

F - 2. Length frequency distribution of whiting in the codend (Experiment 1).

F - 3. Length frequency distributions of haddock in the codend for 1½ hour hauls (Experiment 2).

F - 4. Length frequency distribution of haddock in the codend for 3 hour hauls (Experiment 2).

17.

A Note on Experimental Design

by

J. A. POPE[1]

Abstract

Recent years have seen a growing need for the collection of accurate information to facilitate the study of factors affecting mesh selection, gear efficiency, etc. In designing experiments for these purposes certain basic principles must be followed. Correct experimental designs will give accurate estimates of the effects of different factors and a measure of the reliability of results, whereas poor designs may easily give biased and inaccurate results.

It is essential, if useful work is to be done, that the experimenter appreciate the value of good design. The main purpose of this paper is to show the essential need for randomization in experimental design.

Introduction

The increasing concern of fishery scientists in problems associated with methods of exploiting fish populations has led in recent years to a need for increased experimentation at sea. A proper appraisal of the effects on catches of various factors (such as different codend mesh sizes, a small-mesh cover over the codend, sweeps, etc.) can follow only from a carefully planned experimental design and a sound statistical analysis of the results. The growth in use of statistical techniques in the analysis of numerical data led, in the years between the two world wars, to the formulation of experimental designs which would allow the most efficient use of experimental resources and material, and at the same time provide for unequivocal interpretation of results. The subject matter of experimental design was largely built up with reference to agricultural experimentation and has adopted a nomenclature appertaining to this field of research but the basic principles involved are applicable to many other fields of research including fishery research.

Most fishery workers nowadays wish to subject their experimental data to statistical analysis in order to place their conclusions on a firm basis. It is perhaps not as well known as it should be that a correct statistical analysis of the effects of different factors introduced into an experiment can only be achieved provided the hauls made to assess the effects of these factors are appropriately randomized. The use of randomization as a method of eliminating bias due to uncontrolled variation is generally appreciated, but the principle has deeper implications. It is the purpose of this paper to attempt to explain why the need for randomization is essential if valid inferences are to be drawn from experimental material. In addition several experimental designs which have proved useful in the author's experience are mentioned.

A Simple Experiment

The need for randomization in experimental design can best be brought out by considering a simple hypothetical example.

Suppose we have two trawls differing in their construction in some clearly defined way but having the same average codend mesh size. We wish to determine experimentally whether there is a real difference in the number of fish of a given species caught by these trawls. We will also suppose that it is possible to make only two hauls each day but that seven days are available so that a total of fourteen hauls are possible. (It will almost always be possible to make more than two hauls per day but this number is chosen here for simplicity of discussion).

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As it is to be expected that fishing on any one day will give hauls more alike than hauls on different days, a sensible procedure would be to make one haul with each net each day. This is also a wise precaution to offset the possible loss of days from adverse weather conditions. Under these conditions we may suppose that the following results have been obtained.

Day	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Trawl A	62	49	83	71	64	85	89
Trawl B	76	60	67	94	66	76	107
Difference (B-A)	14	11	−16	23	2	−9	18

The object of our experiment is to determine whether the difference in construction between two trawls influences the number of fish caught. That is, if the number of hauls with each trawl were to be indefinitely increased, would the average difference in catches be zero or differ from zero? The former possibility is referred to as the *null hypothesis* and it is relative to this hypothesis that a test of significance is to be formulated. It is important to realise that the null hypothesis is never proved but may be disproved. The test of significance is a method of using the information supplied by the data to calculate the probability of having, on the assumption that the null hypothesis is true, obtained the average difference observed in this experiment. On the basis of the null hypothesis the possible results of our experiment may be divided into two classes by the test of significance, all those having a probability of occurrence greater than a certain amount being in one class while those with a probability less than this amount are in the other. This critical level of probability is called the level of significance of the test. Conventionally the critical level of probability chosen is the 5% level and all sets of observations which, on the null hypothesis, would have arisen with a probability of less than 0.05 are regarded as leading to the conclusion that the null hypothesis does not, in fact, hold. In actual practice, however, no scientist is likely to keep a fixed level of significance in all his work but is rather more likely to compound the probability computed by the test of significance and his own knowledge of the experimental material with which he is working to arrive at a greater understanding of his subject. It is clear from this way of procedure that by rejecting the null hypothesis at the 5% level the experimenter will, when the null hypothesis is true, be wrong in exactly 5% of cases. In this connection a remark by Yates (1955) is worth quoting: "Scientific research workers do not reject a hypothesis once and for all if a certain set of observations show a significant departure at the 5 per cent point, any more than they accept it if the observations do not show any significant departure from the hypothesis. If scientific research proceeded on these lines it would in a very short time be in a state of inextricable confusion."

On the null hypothesis any differences between catches by the two nets are to be regarded as due to factors other than differences in construction. Some of these disturbing factors can be anticipated and may perhaps, if necessary, be eliminated. However, there will always remain a certain amount of residual variation which it will be impossible to eliminate. Such variation may arise from the state of the tide at the time the hauls are made, the direction of towing, etc. These disturbances need not, of course, be considered as invalidating the experiment for it is essential that an experiment such as the one we are considering be carried out under realistic conditions. The important point is that variability will always be present and that a good experiment will allow the removal of the effect of the more important factors from the comparisons which are to be made. One precaution which we have already assumed to have been taken in our experiment is the use of both trawls on each day of the experiment. In this way the effects of those factors whose disturbances do not change over the period of a day are eliminated in the difference between catches. It is to be observed that repeated hauls with the same trawl need not be made under identical or nearly identical conditions but that it is highly desirable that contrasts be made between trawls of different types tested under as uniform conditions as possible.

Now, if the null hypothesis is true the variability in the data is due solely to differences in the state of the tide, differences in the "instantaneous" density of fish in the path of the trawl, etc. which result in one haul of each pair having a higher value than the other. If the order of use of the trawls is randomized each day, that is, if on each day it is just as likely that trawl A will be used first as trawl B, the difference B-A will be ensured of having an *equal* and *independent* chance of being positive and negative. The differences, therefore, will have a true sampling distribution which is symmetrical with zero mean. On the null hypothesis the observed set of differences may be regarded as one set out of the 2^7 (=128) possible sets which may be generated by giving each difference alternatively a positive and a negative sign. The significance of the observed set of differences may be judged by ascertaining in how many of these 128 sets the average difference is as great as or greater than that observed. Of these 128 sets there will at most be 64 different averages if sign is ignored. The 64 averages are listed below:

0.1	0.4 (4)	
1.0 (6)	1.6 (5)	1.9
2.1 (3)	2.4 (2)	2.7
3.0 (4)	3.6 (5)	
4.1 (3)	4.4	4.7
5.0 (3)	5.3	5.6 (4)
6.1 (4)	6.7 (2)	
7.0	7.6	
8.1 (2)	8.7 (2)	
9.3	9.6	
10.1 (2)	10.7	
12.7		
13.3		

An average difference deviating from zero by as much as 6.1 or more (6.1 being the actual average observed) would therefore occur 38 times in a total of 128, *i.e.*, with a probability of 0.297. There is clearly nothing outstanding about this value and, on the basis of this test, we would conclude that there is no evidence of a real difference between trawls.

"Student's" t-Test

Although the results from any experiment which has been properly randomized could correctly be treated in the manner outlined above, such a method of procedure would be tedious if several treatments were involved. The usual method of testing our hypothesis is to regard the two groups of seven observations as being independently drawn from the same population, assumed normal, and refer the ratio of the average difference to its standard error to "Student's" t-distribution (Student, 1908), the percentage points of which have been tabulated (see, for example, Fisher & Yates, 1953). The validity of this test rests on the close agreement between the null probability given by the permutation test that given by the t-test, a fact first pointed out by Fisher (1935). The value of t for the data we are dealing with is 1.13 (degrees of freedom = 6) which on the null hypothesis has a probability of occurrence of 0.302 very close to that given by the permutation test, namely 0.297. The probabilities corresponding to five other sets of the same permutation distribution as given by the two tests are compared below:

Mean Difference	P (R)	P (t)
10.1	0.078	0.063
8.7	0.141	0.120
4.1	0.484	0.504
2.1	0.734	0.732
1.6	0.812	0.796

R = randomization test
t = t-test (d.f. = 6)

The important point which emerges from this discussion is that the validity of the simpler t-test is guaranteed by the process of randomization. If this essential step in the planning of an experiment is omitted no method of testing the data is available for then no permutation distribution exists.

One further point should be noticed, namely the fact that no assumption whatever has been made about the statistical distribution of the observations in deriving the randomization test. It is thus of wider applicability than the t-test which requires a normal distribution of observations. The t-test is not unduly influenced, however, by departures from normality provided the distribution remains symmetrical. As the permutation distribution is symmetrical the t-test will continue to provide a good approximation even for data which deviate appreciably from normality. Recently a correction to the t-test which takes account of non-normality has been proposed by Box and Anderson (1955). This correction takes the form of a modification to the degrees of freedom.

Some Experimental Designs

The experimental design discussed above is one of the simplest possible and is known as a randomized blocks design. It may be enlarged to allow the comparison of more than two treatments but generally the number of treatments which can be compared is limited by the number of hauls which can be made each day. Units of two or more days might of course be considered but these will generally lead to less precise results due to dissimilarity of fishing on different days.

One criticism of the randomized blocks design is that conditions may vary systematically each day resulting in a definite trend in catch. If the order of use of the different types of trawls is completely randomized over the whole day it is possible that some of the factors under study may be more favoured than others and true effects may be overestimated. Under such circumstances a more appropriate design would be one which allows each trawl to be used at all trawling times during the day. This is achieved by using a design known as the Latin Square design in which each factor occurs once at each trawling time and once each day. The number of days required for a complete square is equal to the number of trawling times per day and this will normally not be greater than eight. Examples of Latin squares for four to twelve treatments are to be found in Fisher and Yates (1953). One of the 4 x 4 squares given there is reproduced below:

Day / Time	1	2	3	4
1	A	B	C	D
2	B	C	D	A
3	C	D	A	B
4	D	A	B	C

If an unbiased estimate of experimental error is required, and this is essential if a test of significance is to be made, it is necessary that the rows and columns of the square be appropriately randomized. It is not advisable, however tempting it may at first sight seem, to use a particular systematic arrangement, for such an arrangement may, for example, distribute the different treatments over the trawling times in such a way that they are affected by uncontrolled variation to a less extent than they would have been if the design had been randomized. Now the experimental error is estimated from the remaining variability in the data after eliminating from the total variability the component due to treatments, the component due to days, and the component due to trawling times. The two latter components are the same whether a random or a systematic arrangement is used and so the variation due solely to treatments plus the remaining variation is independent of whether a random or a systematic arrangement is adopted. Hence if the systematic arrangement diminishes the treatment variability, the remaining variability, which is used to estimate the experimental error, will consequently be increased.

The existence of bias in systematic squares has been demonstrated experimentally by Tedin (1931) using agricultural uniformity data, *i.e.* data obtained from experiments where the same treatment has been applied to all experimental units. As far as the author is aware no similar study has been made of experimental conditions at sea. This is an aspect of experimental work which clearly ought to receive more attention.

In some types of experiments it may be that unrestricted randomization of the order of hauls is not practicable and that accordingly a systematic design appears to be the only one possible. For example, in an experiment to study the selection characteristics of three types of trawl A_1, A_2 and A_3 by the covered codend technique it may be desirable to estimate whether the small-mesh cover, C, over the codend, by which selectivity is to be measured, is affecting the normal catch of the trawl. This leads to six different types of haul A_1, A_1C, A_2, A_2C, A_3, A_3C. Complete randomization may lead to more change-overs each day than time will permit. The number of changes may be kept at the minimum by using each trawl twice in succession, once with and once without a cover. The requirements of a valid statistical test procedure will be satisfied if the order of pairs and the order within pairs are randomized. Such a design belongs to the class known in agricultural experimentation as "split-plot" designs. The pairs may, if desired, be arranged in a Latin square as below:

Day Haul	(1	2)	(3	4)	(5	6)
1	(A_1	A_1C)	(A_3C	A_3)	(A_2	A_2C)
2	(A_2	A_2C)	(A_1	A_1C)	(A_3C	A_3)
3	(A_3	A_3C)	(A_2	A_2C)	(A_1C	A_1)

The split-plot type of design is useful when a comparison of treatments common to each member of a pair is of less importance than comparisons of treatments within pairs and the interaction between these two groups of treatments. This is the case if, for example, A_1, A_2 and A_3 represent the same trawl with codends of three different average mesh sizes and the analysis is of number of fish caught in the codend in each haul. Differences between A_1, A_2, and A_3 will usually be of secondary importance (being due simply to differences in codend mesh size) to differences for each trawl between catches with and catches without a cover and to the comparison of the cover effect for different mesh sizes.

Randomization

There is a correct and easy way to randomize any number of objects. The experimenter should not write down the order of hauls "as he pleases" but should use a method which shall ensure that each trawl has an equal chance of being used at any one time. This may be done by using a pack of numbered cards, re-shuffling them every time a card has been drawn. It is easier, however, to use tables of random numbers such as those found in Fisher and Yates (1953). If 6 objects are to be randomized we may use two-figure numbers and if 91 is the first random number used it is taken as corresponding to the first treatment, for 91, on division by 6, leaves a remainder of 1. Numbers exactly divisible by 6 are taken to correspond to treatment 6. To allow all possible remainders from 0 to 5 to occur with equal frequency any four numbers between 1 (which appears as 01) and 100 (which appears as 00) which leave remainders 1, 2, 3, and 4 (such as 97, 98, 99, and 00) must be consistently omitted.

In this way a randomization of treatments may be carried out with ease and rapidity and need not be omitted on the grounds that it is troublesome.

Incomplete Data

One unfortunate feature of a good deal of experimental work in marine research is the loss of observations due to adverse weather conditions, torn nets, etc. This might be thought to preclude the use of any but the simplest types of design. Although the gain brought about by introducing restrictions (such as in the Latin square) is lost when several observations are missing, it is possible to extract the information provided by the available observations. The experiment will not, of course, be as accurate as if no observations had been lost.

The effect of missing observations on the interpretation and analysis of results will vary with the type of design used, being greater for the more complicated types, but, if only one or two values are missing the computational aspects of the analysis are not rendered too complex. More often, however, whole days may be lost usually because of weather conditions and, in such a case, designs of the Latin square type are seriously upset in contrast to the randomized blocks type where all treatments are equally affected by the loss of a day's work.

Although the effects of a consistent trend in catch during the day may be allowed for in the analysis, even if it has not been allowed for in the design, it is not recommended that Latin square designs never be considered. On several occasions when they have been used by Scottish workers they have proved more efficient than if a randomized blocks design had been used.

An example of one method of analysing experimental results with missing observations is given by Parrish (1951)

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18.

Sampling Catches at Sea

by

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Abstract

The sampling of catches aboard research vessels requires careful consideration if bias is to be avoided.

The accuracy of a proposed sampling scheme should be properly assessed before being adopted as standard practice.

A method used in Scotland when dealing with catches which have been sorted into baskets is explained and an experiment to assess its validity is discussed. This method, which has been found suitable, includes in the sample as many baskets as possible and ensures taking fish from all parts (top, middle and bottom) of each basket.

It is suggested that, where relevant, a measure of the accuracy of every sample should be given when data are published.

Introduction

There appears to be no account in published literature of the methods used by research workers in different countries for sampling catches at sea on board either commercial or research vessels. Although some form of sampling is often used it is probably true to say that such sampling as is done is usually regarded as an emergency operation put into practice only when treatment of the entire catch is impossible. On these occasions the data are probably regarded as of considerably less value than would have been the case had the entire catch been treated, which need not be the case if suitable precautions have been taken in drawing the sample. This, in all likelihood, accounts for so little attention having been paid to the sampling techniques employed on these occasions.

When it is remembered that an individual catch is itself only a very small sample from what is usually a very large population it will be realised that any errors of estimation introduced by sampling are, provided the sampling techniques are sound, likely to be of minor importance in comparison with haul-to-haul variability. Of course detailed examination of a catch is in no way harmful provided it does not clash with a more desirable wider distribution of effort. For example, experience has shown that in many investigations planned for and undertaken by research vessels, more useful and reliable information would have been obtained by increasing the number of hauls per unit time, even at the expense of decreasing the amount of work (measuring, etc.) on each haul. As the amount of time available for any one investigation is usually limited, any increase in the number of hauls would usually be accompanied by a reduction in the duration of haul. Such reduction in haul duration should not be undertaken without prior investigation of any effect on catch composition brought about by the reduction.

On any given occasion the decision as to whether sampling should be undertaken will depend on the problem under investigation. For example, when estimating the mesh selection ogive of a codend by the covered net method, a record of all length measurements will usually be made although it is not essential that this be done. In Scottish mesh selection experiments any sampling is usually confined to fish in the small-mesh cover as the size range of these fish is likely to be less than that of fish retained in the codend and the sampling error for the cover correspondingly less than for the codend. Again, if interest is confined to the total number of fish of a given species in a catch, it will often be as

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easy to make a complete count as to estimate this number from a sample. This is certainly true for mixed catches as a count can be made simultaneously with the sorting. On the other hand, if only one species is represented in the haul (as is usual with catches of herring by drift-net) the total number may be easily estimated from a small representative sample. In this connection it is likely that even a complete count of fish will not always be free from error as fish will often be lost before the net is hauled aboard. In addition there are errors in counting. Although the latter type of errors are unlikely to, or certainly should not, exceed 1 to 2%, the number lost may, on occasions, be substantially higher. From general observation it seems advisable that any analysis of numbers of fish caught should be carried out on data rounded-off to the nearest 10.

Whatever sampling technique is adopted, and for any given situation there will usually be more than one possible, it is clearly of great importance that

(a) the method should be reliable (*i.e.*, free from bias) and its reliability be capable of assessment.

(b) enough information concerning the method adopted and its margin of error be made known to all users of the data.

The present paper gives details of a method used at the Marine Laboratory, Aberdeen, when dealing with mixed catches aboard research vessels, and of an experiment to appraise its validity.

Length Distributions

In the series of hauls to which the present data refer the major species were haddock and whiting although as a rule some ten to twelve different species were caught in each haul. Because of the mixed nature of the catches the fish were "sorted" by members of the crew immediately the haul came aboard, and before examination by the scientific staff, this being normal procedure aboard Scottish research vessels. This sorting procedure is merely to separate the different species and is not intended to separate size groups within species. Haddock and whiting, being most plentiful, were sorted into baskets first, usually simultaneously. The remainder of the catch was classified as flatfish or round-fish and sorted accordingly, that is, usually without much reference to species. In this paper discussion is confined to haddock and whiting.

During the entire investigation the members of the crew were never informed that their method of sorting was being studied as this might well have influenced their normal practice, thereby affecting one aspect of the experiment which was to ascertain what distribution of fish between and within baskets could be expected under normal conditions of sorting.

Although in most cases conscious selection was probably not being practised, nevertheless fish were clearly not being chosen at random in the strict sense. Any method of selection involving a truly random element would be impossible under existing conditions. It was to be expected that the more accessible or "attractive" fish would be picked first. Understandably the more accessible were the larger. Of course the crew were never instructed to select fish at random or to make each basket a representative selection of the whole catch of each species. There were occasions, however, when deliberate selection was introduced in order to keep the larger sizes of fish together, these being subsequently cooked for the evening meal. The difference in mean length between the "mess basket" and the others would usually be quite marked. The mean lengths in samples of equal size from baskets of haddock from one such haul are shown below in order of filling.

Basket	"Mess"	2	3	4	5
Mean length (cm)	31.1	26.4	26.0	26.3	24.6

Sampling Scheme

In devising any sampling method a number of basic considerations must be kept in mind. The major ones in the present context are:

(a) the nature of the quantity or quantities to be estimated;

(b) the accuracy to be aimed at;

(c) the time available;

(d) the coverage of the sample;

(e) the method of selecting individuals;

These are not all independent. Provided the best sampling method is being used the accuracy can only be increased by increasing the sample size which in turn increases the time involved in drawing and treating the sample. In most routine work accuracy need usually be only roughly gauged but one or two broad principles need to be remembered. For example, if the number of individuals bearing a specified characteristic (such as having a length in a specified size range or being infected with a particular parasite) is to be estimated, the sample size necessary to ensure a maximum error not greater than some specified fixed amount increases rapidly as the true proportion bearing this characteristic decreases. (We need a large sample when looking for a "needle in a haystack.")

In view of the expected variation in length composition between baskets discussed in the previous section, it is clear that a reliable scheme must include as many baskets as possible. In the work under discussion it was found possible to include all baskets in the sample in every case but with large hauls this may not always be so. In such cases some baskets may have to be omitted although wherever possible this should be avoided. Indeed, as variability in respect of size between baskets is always likely to be greater than variability within baskets greater accuracy is to be expected by including more baskets in the sample even at the expense of reducing the number sampled from each basket.

Lastly the actual selection of the sample remains to be considered. Ideally the sample should be a random sample to ensure unbiased estimates of population characteristics. True randomization almost inevitably requires some numbering of individual fish, a process which is clearly impossible under normal working conditions at sea. The best that can be hoped for at the present time is a method of selection which, though not strictly random, reduces as far as possible the human element in the choice of fish.

The method adopted in the experiment discussed here was as follows. Each basket was brought into the ship's fish working room in turn and its entire contents emptied out along a bench. Starting at one end the fish were counted as they came. The sampling fraction throughout the experiment was set at a quarter and the 7th and 8th, and 15th and 16th, 23rd and 24th fish, etc. were set aside for measuring. In this way a sample of approximately a quarter of each basket and hence of the whole catch was obtained. (At the time of writing a sample of a quarter would be obtained by taking the 4th, 8th, 12th fish, etc. but all such systematic selections are presumably equivalent.) The length of each fish in the sample was recorded to the nearest centimetre (using, as is customary in Scottish routine measuring work, grouping intervals 16.5-17.4 cm, 17.5-18.4 cm, 18.5-19.4 cm, etc.) and the total number of fish in the sample, thereby giving the total number in each basket. The sizes of haddock and whiting were the same in each haul ranging from 20 to 42 cm.

The samples from each haul were used to assess the significance of basket-to-basket variability with respect to length. This was done by testing the differences between mean lengths of samples from different baskets by means of analyses of variance. Of the 45 hauls which provided haddock data 17 showed significant differences between baskets and 28 no significant differences. Only in 10 cases did the sets consist of more than two baskets and 8 of these showed significant differences. Eleven sets of whiting data showed on analysis no significant difference between means while 4 sets showed significant differences. Only 3 of these 15 sets contained more than 2 baskets and of these 2 gave significant differences.

On the average, for both species, the test of significance used was such as to show differences in mean lengths of 1.5 cm or more between baskets, as significant.

The results give definite evidence therefore that real basket-to-basket differences existed in a substantial proportion of cases and that such differences are likely to be accentuated as the size of catch and therefore number of baskets increases. These results might all have been anticipated.

These tests of significance are, of course, only of strict validity under conditions of random choice of the individual fish. The requirement of a correct sampling scheme is also that choice be random or at least that the samples be such that there is no bias in any characteristic. The most suitable method of assessing the representativeness of the samples chosen in the present experiment would have been to treat the whole catch simultaneously and compare all sample characteristics with the corresponding ones for the catch as a whole. Unfortunately owing to lack of sufficient time, this could not be done but it was possible to compare the estimated number of haddock above 28 cm and of whiting above 29 cm with the actual number in each basket. This was done as follows:

If n is the total number of fish in the sample, p the observed proportion in the size range under consideration, and N the total number of fish in the basket, the estimated number in the size range for the whole basket is Np. The variance of this quantity is $N^2(1\text{-}f)p(1\text{-}p)/n\text{-}1$ where f is the sampling fraction. In all, 48 such estimates were available, 30 for haddock and 18 for whiting. Only in 4 cases, 2 for haddock and 2 for whiting, were the estimates found to differ significantly from their true values. It should be pointed out, however, that the coefficient of variation of these estimates was of the order of 35%. This meant that differences between the estimated number of fish, and the true number (usually about 30) had to exceed 6 to be judged significant. That is, this test for randomness of sampling is not very stringent. However, it was found that in 28 cases the estimates were above their true values, in 2 cases they were equal, and in 18 cases they were below. From this it does not seem unreasonable to assume that the sampling metbod adopted was such as to give unbiased estimates of the characteristics from which they were drawn.

Combination of Estimates

When samples are taken from separate baskets in the way outlined here estimates for the whole catch are easily obtained by combining the separate results in the appropriate way.

Thus, if there are M baskets containing N_1, $N_2 \ldots N_M$ fish and samples of size n_1, n_2, ... n_M are taken, the true mean length in the whole catch is estimated by

$$\bar{\bar{y}} = \sum_{i=1}^{M} N_i \bar{y}_i \Big/ \sum_{i=1}^{M} N_i$$

where $\bar{y}_i$ is the mean length of the sample from the i^{th} basket.

In a similar manner the estimated total number of fish in a specified size range, or bearing a specified characteristic, is

$$A = \sum_{i=1}^{M} N_i p_i$$

where p_i is the observed proportion in the i^{th} basket.

These formulae are valid only when all baskets are included in the sample. If only m baskets are included the corresponding formulae become

$$\bar{\bar{y}} = \frac{M}{m} \sum_{i=1}^{m} N_i \bar{y}_i \Big/ \sum_{i=1}^{m} N_i$$

and

$$A = \frac{M}{m} \sum_{i=1}^{m} N_i p_i$$

It will be seen that for y the total number of fish in the haul, or a reliable estimate of it, is required.

General Remarks

Taking samples from baskets of fish sorted by hand (or by mechanical device) clearly requires care as substantial differences may exist between baskets. In particular it could be extremely dangerous to "select" a "representative" basket as the sample. The most satisfactory method of selection is one which includes all baskets and ensures taking fish from the top, middle and bottom of each.

Any attempt to select representative samples before sorting is also likely to produce substantial bias. Striking examples of bias introduced in subjectively chosen samples are to be found in the references at the end of this paper.

In many cases fish are not sorted into baskets or no sorting is required because the catch consists wholly of a single species. The particular dangers inherent in the use of baskets are not then present but other possible sources of "hidden" segregation may exist. It is likely, for example, that there is always a segregation by size on the deck of a vessel when fish are released from the codend, the larger fish being at the outer edges of the fish-pound. One possible method of sampling under such conditions would be to divide the catch on the deck by a real or imaginary cross through its centre and take as a sample all fisb in one quadrant with, possibly, a different quadrant for each haul.

Whichever method of sampling is used it is essential that it be subjected to a number of tests to ascertain its accuracy, for, only when unbiasedness has been proved should a method be properly adopted.

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19.

A Note on the Methods Used in Mesh Selection Experiments

by

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Abstract

A review of the available data on mesh selection experiments with paired (or alternating) hauls seems to reveal that this technique gives significantly higher values of selection than does the cover method for both haddock and cod. No such difference is found in comparable experiments on plaice.

For cod and haddock the discrepancies amount to 11-16% of the selection factors found by the cover method.

No satisfactory explanation of this difference can be offered at present, but it is suggested that escapement of fish through other parts of the trawl than that usually covered by a fine meshed net in mesh selection experiments may be a factor of importance.

The two methods which have been used in mesh selection experiments, *viz.*, paired (alternate) hauls and covered nets, have been discussed on several previous occasions by Davis (1929 and 1934), Jensen (1949) and others.

In his review of a large number of earlier mesh selection trials Jensen (1949) mentions several cases in which paired hauls (or trouser-trawl experiments) appear to have given higher values of selection factors than those from covered nets. Jensen is, however, of the opinion that most of these higher selection values are caused by the influence of various other factors such as type of gear used, type of thread and absolute size of mesh. These explanations do not seem to cover all cases. Further analysis of these earlier investigations is, however, complicated by the inaccurate method generally used in the mesh measurement. The Davis material of haddock from 1933 comprising 400 paired hauls has later been worked up by Beverton and Holt (1958). The selection factor found here (3.3) is probably significantly higher than the mean value of a number of later covered net experiments (3.1).

Although the major part of the mesh selection work in later years has been based on the covered net method, some trials with paired and alternate hauls have also been made. Thus Graham (1954) refers to several series of paired hauls of seiners. The value of the selection factor for haddock appears to be approximately 4.3 in a series of 10 paired hauls with single cotton seines, and 4.4. in another series of 8 hauls.

Lucas *et al.* (1954) describe a number of series of alternate hauls of seiners fishing for haddock. A series of 32 hauls, in which codends of 80 and 64 mm. were compared, gave a selection factor of approximately 4.2 (single cotton seines) whereas a large number of covered net experiments carried out at the same time produced a mean selection factor of only 3.8 (verbal information from B. B. Parrish, Aberdeen).

In Graham's series of paired hauls the difference in the size of the two meshes compared was small, viz. 82 and 73 mm and 81 and 72 mm. The 50% length of the larger mesh therefore probably lies within the selection range of the smaller mesh. Graham is of the opinion that this had but little influence on the determination of the 50% length in the case of the first series of 10 hauls, because of a difference in the efficiency of the two gears used. If we take the value of 4.3 as a probable mean of the paired and alternate hauls, this is 0.5 higher than the figure 3.8 shown by the covered net method.

In a report to the *ad hoc* Committee of the Permanent Commission, Beverton refers to a

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[1]Institute of Marine Research, Bergen, Norway.

TABLE I. Mesh Selection Data for Arctic Cod. Codend: Double White Manila.

Method	Parallel hauls Thor Iversen, 82 ft. Peder Ronnestad, 86 ft.						Cover G. O. Sars, 168 ft.				Cover Ernest Holt, 190 ft[1]	
Locality	Bear Island Banks						Skolpen Bank		Tiddly Bank	Finmark	Spits-bergen	Bear Island
Date	May 1954						Nov. 1956		March 1957	April 1957	July - August 1956	
Vessel	T.I.	P.R.	T.I.	P.R.	T.I.	P.R.						
No. of hauls	12	12	12	12	10	10	6	1	1	5	1	6
Duration of hauls	1 hr. 25′		1 hr. 45′		1 hr. 20′		$1\frac{1}{2}$ hr.	$1\frac{1}{2}$ hr.	$1\frac{1}{2}$ hr.	$1\frac{1}{3}$ hr.	1 hr.	1 hr.
Total catch all species (baskets)	35(av)	18(av)	10(av)	40(av)	14(av)	5(av)	15(av)	30	12	25 (av)	62	40 (av)
Mean codend mesh size, cm.	10 cm	13 cm.	13 cm.	10 cm.	10cm.	13 cm.	14.4	14.4	14.4	14.4	10.9	10.9
No. of fish in selection range (Cover/c.e.)	5485	2111	856	6065	1932	416	176/ 562	70/ 248	65/ 74	525/ 490	525	206
25% - l.cm	48		52		50		47		52	42		
50% - l.cm	54		58		ca 57		51.5	ca 49	55	49.5	39.5	41.5
75% - l.cm	58		62		60		56		60	57		
Selection factor	4.1		4.4		4.3		3.6	(3.4)	3.8	3.4	3.6	3.8
Stomach							Medium feeding		Empty	Feeding heavily on capelin		

[1]The Ernest Holt data has been taken from a paper presented at the ICES Meeting 1956 by R. J. H. Beverton: Mesh selection of cod and haddock.

mesh selection experiment on plaice carried out by Holt and himself (unpublished). The results, derived from two series of twelve paired hauls each, showed no increase of selection compared with the quite extensive data from covered net experiments which are available for this species.

Some further material of interest is available from recent selection trials in the Barents Sea Area. Table 1 shows data on mesh selection of cod. The selection factor of 3.4 found with the "G. O. Sars" on the Finnmark Banks in April 1957 is probably unusually low and was caused by very heavy feeding on capelin. The mean stomach girth of these fish was 13% higher than the head girth, whereas in empty fish the two girth measurements have been found to be nearly equal. No information is available on the feeding condition of the fish from the Bear Island experiments of 1954, but heavy feeding is improbable in this area in the spring.

If we accept 3.7 as a probable mean value of the selection factor of "normal" cod in covered net experiments there is a difference of 0.5 to 0.6 between this value and that of the paired hauls. The vessels used in the paired hauls were smaller than those of the covered net trials, but the resulting lower towing speed could account only for a small part of the discrepancy.

Table 2 shows the available selection data for Arctic haddock. The material from the paired hauls is meagre, consisting of only two successful comparable tows. But there is also here the same tendency of the paired hauls to give higher values of selection factors than the covered net method, in this case the difference is 0.3 to 0.4.

TABLE 2. Mesh Selection Data for Arctic Haddock. Codend: Double White Manila.

Method	Parallel hauls Thor Iversen, 82 ft. Peder Ronnestad, 86 ft.				Cover G. O. Sars, 168 ft.	Cover Ernest Holt, 190 ft.[1]		
Date	April 1957				April 1957	July - August 1956		
Locality	East Finmark Grounds				E. Finmark Gr.	Svalbard Waters		
Date	April 1957				April 1957	July - August 1956		
Vessel	T.I.	P.R.	T.I.	P.R.				
No. of hauls	1	1	1	1	4	1	1	1
Duration of hauls	1½ hr.		1½ hr.		1½ hr.	1 hr.	1 hr.	1 hr.
Total catch all species (baskets)	10	40	10	15	25 (av)	62	31	30
Mean codend mesh size, cm	15.2	10.0	10.0	13.3	14.4	10.9	10.9	10.9
Number of fish in selection range (cover/c.e.)	120	434	118	166	591/720	1022	213	175
25%-l cm	53				43			
50%-l cm	57.5		ca. 48		49	36.5	35.5	35.5
75%-l cm	62				54			
Selection factor	3.8		3.6		3.4	3.4	3.3	3.3
Stomach	Feeding on capelin							

[1]The Ernest Holt data has been taken from a paper presented at the ICES Meeting 1956 by R. J. H. Beverton: Mesh selection of cod and haddock.

Some of the evidence presented here is not conclusive, but it seems justifiable to say that there are severe indications that the method of paired hauls gives higher values of selection than the cover technique both for cod and haddock. No such tendency can be shown in the experiments on plaice.

In papers on mesh selection the "masking effect of the cover" is often mentioned, but there is little evidence to show that such an effect is really present. In an attempt to test the effect of a cover on the selective properties of the codend, Davis (1929) did several series of alternating hauls with and without a cover. An analysis of the percentage frequency distribution of the catches (haddock and dab) in the codend showed only small differences. The same method was used by Clark (1952) in mesh selection experiments ou Georges Bank haddock. In two series of paired tows with uncovered and covered codend he found that the mean length of the fish retained in the codend was almost exactly the same. It seems improbable therefore that the discrepancy between the results of the two methods is caused by a masking effect of the cover.

Whether or not a fine meshed net covering the upper side of the codend collects all the fish which escape from the trawl is important in this connection. Although it seems generally accepted that the major part of the escapement takes place through the upper side of the codend, there is evidence which shows that some fish may escape also through other parts of the trawl, cfr. Todd (1911), Borowik (1930), Margetts (1949). Further experiments testing the significance of the escapement outside that part of the trawl which is usually covered in mesh selection trials may help to elucidate the problems raised here.

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20.

Selectivity of Long Lines

by

GUNNAR SAETERSDAL[1]

Abstract

An analysis is made of extensive data on length measurements of cod caught by longliners and trawlers on the Finnmark Grounds in northern Norway. As the selectivity of the trawl is known, it is possible to compute a theoretical size composition of the population on which the long lines have been fishing. A comparison with the size distribution of the fish caught on the long liues shows the selective properties of this gear. The data indicate the following approximate values of selection figures for hook no. 7:

50% - length; 55 cm

Range between 25% and 75% - length; 14 cm

Total range : 35 cm

The most direct way of obtaining information about the selective properties of long lines appears to be by comparing the catches taken with this gear with those of other gears of known selectivity such as, for instance, the otter trawl.

In order to make a comparative study of this type, special sampling was carried out on the east Finnmark Banks in October, 1956. The total catches of cod from a long liner and a small trawler (74 ft.) were measured during a week's fishing. The vessels were operating on nearby grounds abt 6 nautical miles apart. The length distributions from this sampling are shown in Fig. 1A. They have been smoothed according to 1/4 (a + 2b + c) and recalculated per 10,000.

The trawl catches with which we want to compare the catches taken on long lines must, in order to give a correct picture of the size composition of the population fished, be adjusted for the selective process exercised by the trawl itself. It is generally assumed that the selective properties of the trawl are dependent on the mesh size only, *i.e.*, that above its mesh selection range the trawl gives us an unbiased sample of the population fished. If we know the selection ogive we can calculate a theoretical size composition of the part of the population which comes within the selection range. The relatively few data available at the moment indicate a rather high value of the selection factor for the Arctic cod. For the purpose of this calculation a value of 3.8 was used with a range of 8 cm between the 25% and 75% retention lengths.

We will thus assume that our partly rearranged trawl curve gives an unbiased picture of the true size composition of the population. The difference between the two curves can then be described by the relation between the numbers in each five cm group in the two sets of data. The relative numbers, long line/trawl + calculated release, obtained in this way, are shown in Fig. 2 (top). Up to and including the size group 66-70 cm there is a continuous increase, but above this there is no increasing or decreasing trend but rather an indication of a constant relation. This means that the selection range of the long line extends to approximately 61-65 cm. Fish of larger size are caught representatively. In this upper range of non-selection the two length distribution curves should accordingly show a good fit if reproduced on the same scale. This was tested by multiplying the number per 10,000 in each cm group of the trawl data by the mean value of the relation long line/trawl in the range 66-86 cm. The result illustrated in fig. 1A shows that above 65 cm the two curves run very close together.

Some further material on length measurements from long liners and trawlers is available

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from sampling during the spring cod fishery in Finnmark in 1953 and 1955. This sampling was not carried out for the special purpose of comparing the two gears. In each of the seasons approximately five weeks were covered and the samples were taken from a rather large area. Since there is usually in the spring cod fishery a segregation of fish size with regard to both time and locality it was necessary to split the data in weekly time intervals and to use only samples which had been taken on the same main fishing banks. The length distributions are shown in Fig. 1 B-E and F-J.

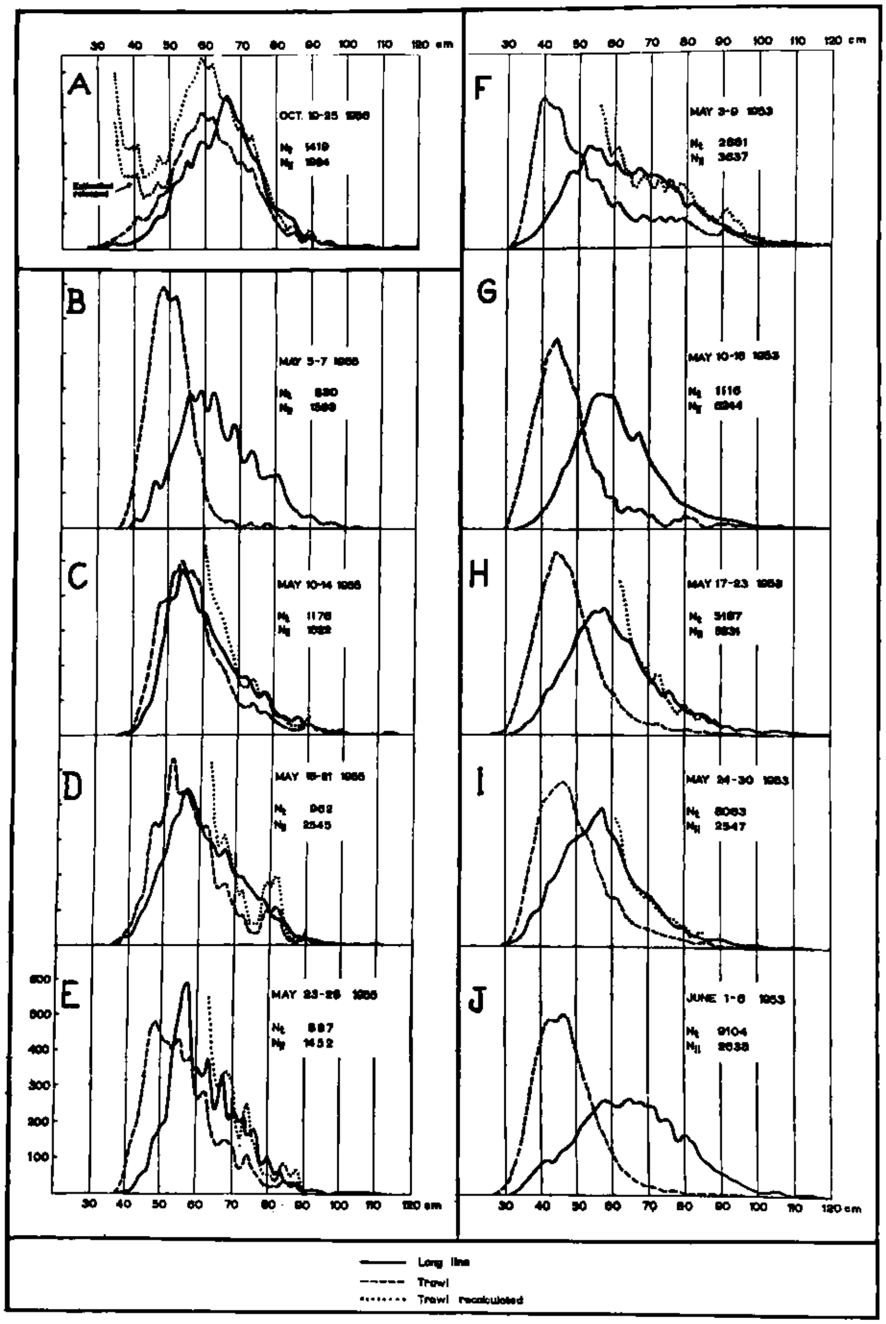

Fig. 1. Length distributions (per 10,000) of cod caught by long lines and by trawl. East Finmark banks 1956 (A), 1955 (B-E) and 1953 (F-J).

Because of the danger of damage to each other's gear, trawlers and long liners are generally not found on exactly the same fishing grounds. Even in this selected material we cannot therefore assume that in each case the two types of gear have been fishing on the same size categories of fish. This was obviously not the case in the 2nd and 5th week in 1953 (Fig. 1 G and J) and in the 1st. week in 1955 (Fig. 1 B), and further analysis of these data has therefore not been attempted.

The relative numbers, long line/trawl + calculated release for the remaining weeks are given in Fig. 2 together with the average values for each season. In all cases there is at first a continuous increase of this relation. In the 1953 data this increase extends to the size group 66-70 cm and in 1955 to the 71-75 cm group. From these groups upwards the observations indicate a nearly constant relationship.

Within the same size categories there is a considerable difference in the actual values of the relative numbers, long line/trawl in the various years and partly also within the season. This is caused by variations in the size composition of the exploited population. Since 1953 there has been a continuous increase in the mean size of the cod in these waters and the larger the fish size the smaller the difference between the two gears. If all the fish were larger than the selection ranges of both types of gear, we must expect that the two size distributions would be identical.

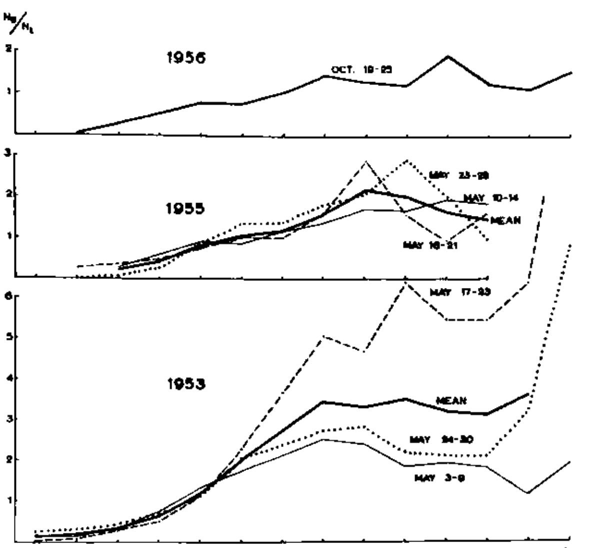

Fig. 2. Relation of percentage frequency in each 5 cm long-lines/trawl group.

The curves shown in Fig. 2 are thus long line selection curves. They indicate that in a long line fishery the probability of a fish being caught is dependent on its size provided it is smaller than a certain critical size. At and above this critical size the proportion of each size group which will be caught is constant. Let us call this proportion P. Below the critical size the proportion of each size group caught is less than P and decreases continually with decreasing size. The fish length at which 0.5 P is caught corresponds with the 50% release length of trawl selection curves.

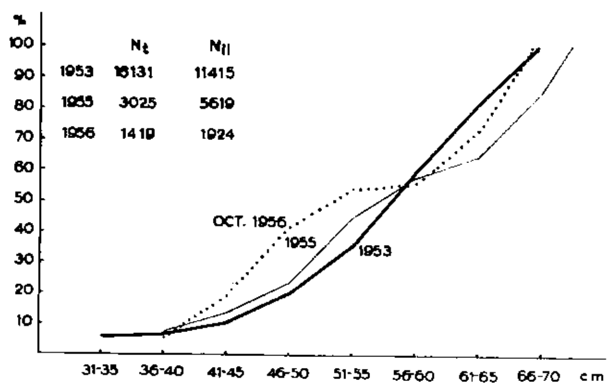

Fig. 3. Percentage selection curves for long lines.

The curves in Fig. 2 were transformed to percentage selection curves (Fig. 3) by calculating the mean of the relative numbers in the interval 66-86 cm for each season and taking the values of the lower size groups as percentages of this mean. The special form of the 1956 curve in Fig. 3 may be caused by the types of hooks used. In this case half the hooks were No. 7 (for cod) and half No. 9. (for haddock), fig. 4. The cod caught on the small haddock hooks were unfortunately not kept apart from the rest of the catch. Hook No. 7 is commonly used during the spring fishery.

It should also be noted that there is a considerable difference in the number of observations on which the three curves are based. It is probable therefore that the 1953 data give the most reliable selection curve.

If these facts are borne in mind it seems permissible to list the following approximate values

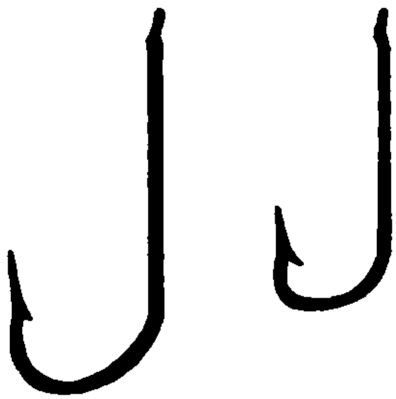

Fig. 4. Hooks No. 7, (left) and No. 9 (right) full scale.

of the selection figures for hook No. 7:

50% length: 55 cm

Range between 25% and 75% length: 14 cm

Total range: 35 cm

Little is known of the nature of the selectivity of hooks. Different feeding habits of the various size categories may produce a size-dependency in the fish which are lured by the bait. Competition may also result in a size selection of the fish which take the bait. Finally, it seems fairly obvious that the relation hook size/fish size must greatly influence the chance of the fish actually being caught when it has been lured by the bait.

21.

The Stretch of Net Meshes

by

WITOLD STRZYZEWSKI AND JANUSZ ZAUCHA[1]

Abstract

The changes in the sizes of wet and dry net meshes, as a function of the stretching force of the mesh, have been determined in this paper. The experiments were carried out on meshes braided from sisal, manila, rami and steelon twine. Net fabrics differed from each other in respect of mesh size and thickness of twine. The measurements were made by means of a Schopper dynamometer, adapted for this purpose by the addition of a special device.

It was stated, that although the curves of tensile strength of both dry and wet net meshes are always the same, the meshes of the net fabric are subject to diminishing or increasing size; this phenomenon depends mainly on the kind of raw material used for the braiding and the technical construction of the twine.

The rate of increase of the mesh tensile strength of the dry and wet meshes depends in the first place on the kind of raw material used.

Introduction

The object of the work was to establish the general tendencies in the changes of net mesh stretch under the influence of a stretching force of 1-10 kg. The samples of net tested were braided from single sisal, manila, rami and steelon twines. They differed from each other not only in material but also in mesh sizes, in thickness of twines and in time of use (the samples were both new and from codends which had been in use). Comparative measurements were taken of air-dried and wet meshes.

Methods Applied

The measuring of meshes braided from single twine was done by means of Schopper's dynamometer specially adapted for this purpose by the addition of a mesh-gripping arrangement. The actual reading of the size of meshes was made by an ordinary measurement gauge and determining the size of the meshes (from knot to knot) with an accuracy of 0.1 mm. The speed of the downward movement of the mobile jaw of Schopper's dynamometer when measuring the meshes was 100 mm/min. The average result of 30 measurements was accepted as a basis on which to draw conclusions. The wet meshes were measured in the same way as the dry meshes. In this case the tested samples were previously submerged for 48 hours in distilled water at room temperature. The thickness of twine was determined with an accuracy of 0.01 mm by means of a Czechoslovakian instrument and the metric number by a gravimetrical instrument. The irregularity factor in the mesh sizes was calculated according to Sommer's rule.

Samples of hand-braided nets with the technological features given in Table 1 were used for testing purposes.

The Results of Testing

Manila: Figures 1-3 and 10 show, at the beginning, a considerable increase of stretching in spite of the fact that small force was applied. The curves rise rather steeply. In the next phase the increase in stretching is slower in spite of greater force being applied – the bend in the curve; later a proportional increase in stretch can be seen – the straighter part of the graph. The load which causes the rise in the graph to become proportional was found by our investigations to be 4-5 kg.

The part of the graph showing the dry mesh stretch is distinguished by smaller tangents of the angle with the abscissae – the curves rise

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TABLE 1. Technological data samples used in the tests.

Sample Number	Figure No. for Reference	Material	Nominal Size of Mesh mm	Nominal Diameter of twine mm	Actual diameter of dry twine mm	Actual diameter of wet twine mm	Metric number of twine	Number of twists per m	Irregularity (*after Sommer*)[1] of dry mesh sizes under the load of 4 kg %	Irregularity (*after Sommer*)[1] of wet meshes size under the load of 4 kg %
1	I	Manila, new	80	2.50	2.41	3.21	0.32		1.7	2.5
2	I	Manila, new	80	1.75	2.06	2.71	0.34	350	2.0	1.4
3	I	Manila from used codends	80	2.50					2.8	4.3
4	II	Manila, uew	70	2.50	2.41	3.21	0.32		3.3	2.0
5	II	Manila, new	70	1.75	2.06	2.71	0.34	350	1.9	1.8
6	III	Manila, from used codends	40	2.50	2.59	2.72			3.0	3.1
7	IV	Sisal, new	80	2.00	2.05	2.30	0.33	300	1.6	2.4
8	IV	Sisal, new	70	2.00	2.05	2.30	0.33	300	1.8	3.0
9	V	Rami, from used codends	90	2.00	2.17			160	1.6	1.7
10	VI	Rami, new	80	2.00	2.09	2.35	0.44	160	1.9	1.8
11	VI	Rami, new	70	2.00	2.09	2.35	0.44	160	1.3	1.8
12	V	Rami, from used codends	40	2.00	2.17			160	2.2	2.1
13	VII	Steelon twine, new	80	1.50	1.50	1.45			1.6	1.5
14	VIII	Steelon plaited line with a core of two steelon twines	60	2.50	2.33				2.3	2.2
15	IX	Steelon plaited line with a core of three steelon twines	30	3.00	2.66				5.0	3.7

[1]Explanation of the Sommer's pattern in the paper "The Polish measuring gauge with accuracy tests", W. Strzyzewski, J. Zaucha.

Sommer's formula: $P = \frac{2n1}{n}\left(\frac{S-S1}{S}\right) 100$; P = % degree of irregularity; n1 = quantity of measurements with their value below mean 1; n = quantity of all measurements; S = arithmetic mean of all measurements; S1 = arithmetic mean of measurement with a value below mean one.

more gradual than those for wet meshes. This is due to the fact that the tensile strength of dry meshes under the influence of the stretching force is smaller than the tensile strength of the wet meshes. The stretch with an applied load of 10 kg to the tested medium-sized dry meshes (70-80 mm) increases by 14-20% in relation to the same meshes under the load of 1 kg; but this increase for wet meshes amounts to 25-30%. The mesh size has a certain influence on the increase of stretch which is quite noticeable when comparing the medium-size meshes (70-80 mm) with the smaller ones (40 mm).

The stretch of smaller meshes is much greater than that of medium-sized ones both when dry and wet, but the small differences in mesh sizes and thicknesses of twine used have no great influence on the changes in relation to the force applied.

Comparing the mesh sizes under the load of 1 kg in dry and wet conditions we observed a decrease in the size of the wet meshes. It has been established that the shrinkage of the meshes under the influence of water amounts to about 17%. This is true for all new manila samples

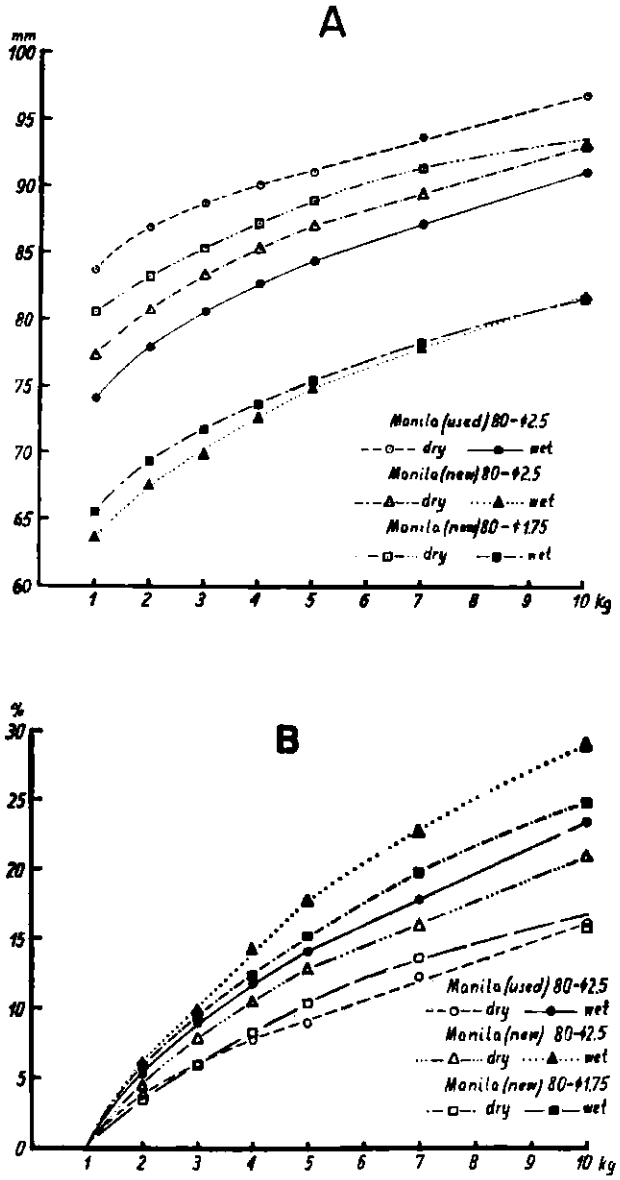


Fig. 1. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, of the same size (80 mm), made of manila twine of different thickness (diameter 2.5 and 1.75 mm) as well as of different degree of consumption (new and used), were tested dry and wet.

B. The same dependences as in 1A (in %) in relation to the mesh size loaded with 1 kg that is accepted as a basis of calculation.

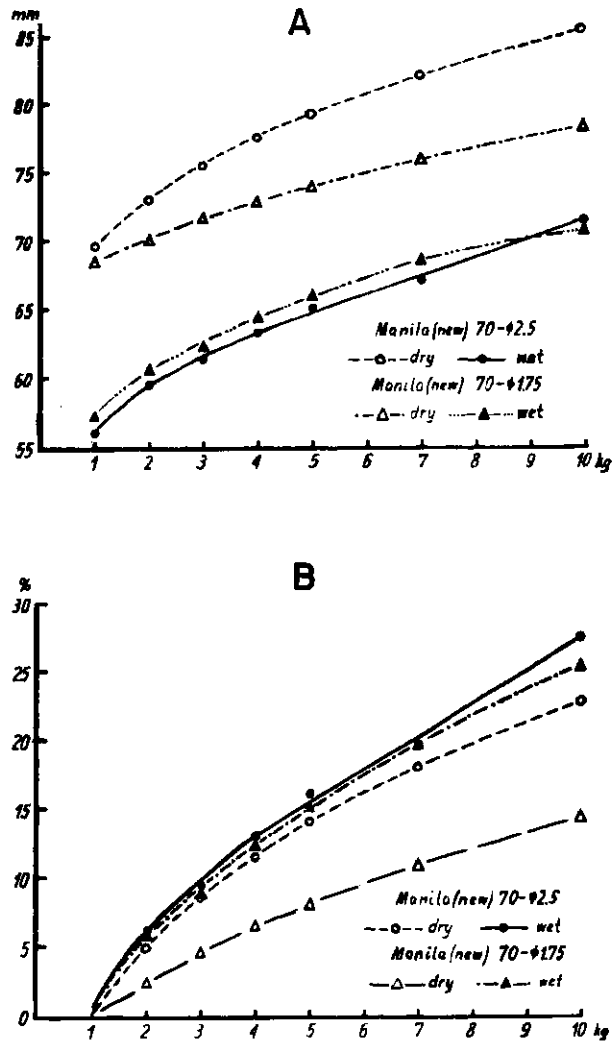


Fig. 2. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, of the same size (70 mm); made of manila twine of different thickness (diameter 2.5 and 1.75 mm), were tested dry and wet.

B. The same dependences as in 2A (in %) in relation to mesh size under a load of 1 kg.

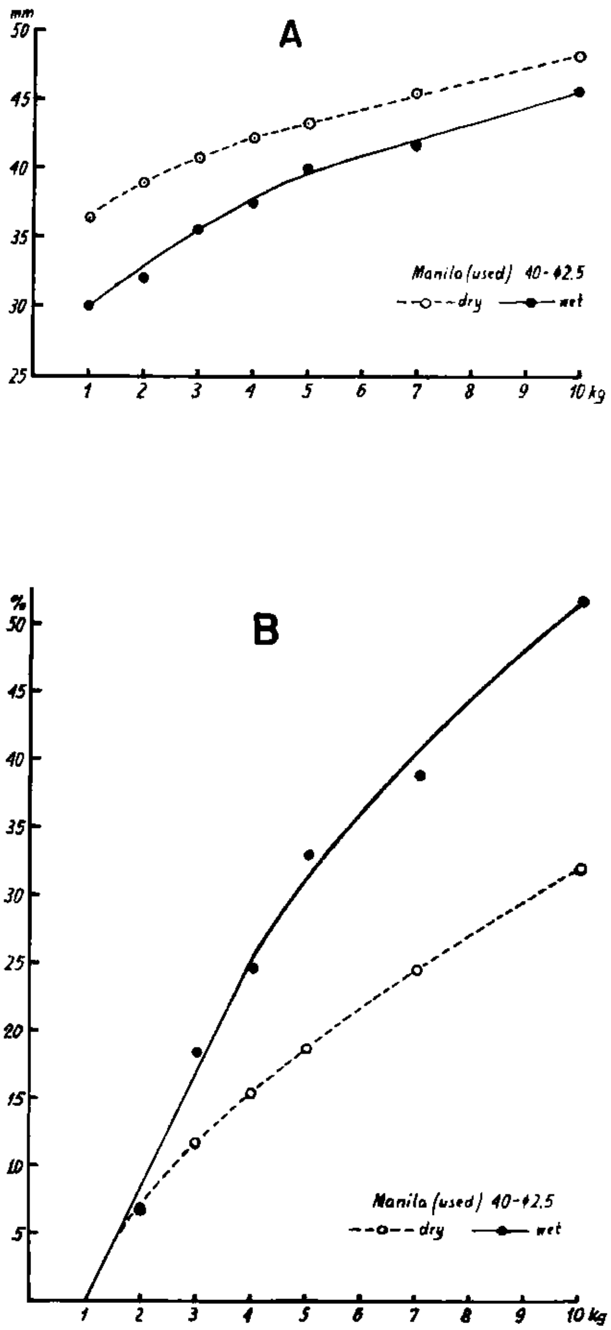


Fig. 3. A. Dependence of small mesh elongation (40 mm) upon the force stretching the mesh. The meshes, made of manila twine of 2.5 mm diameter, taken from used codend, were tested dry and wet.

B. The same dependences as in 3A (in %) in relation to the mesh size under a load of 1 kg.

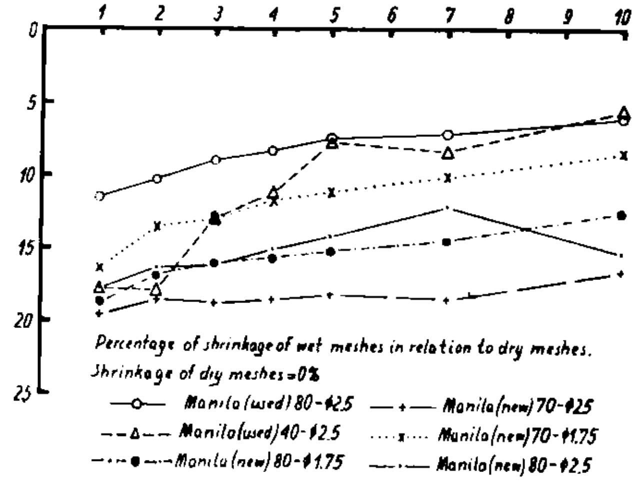


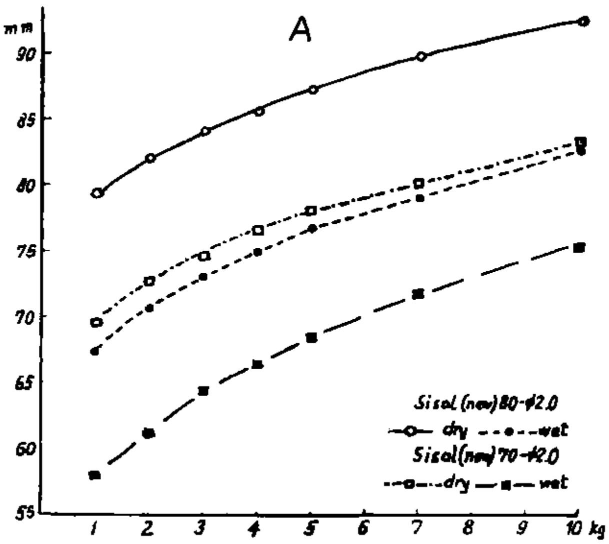
Fig. 10. Shrinkage of manila meshes when wet (in %) in relation to the same meshes when dry. Diagrams of dependence of increase of meshes elongation represented in this figure are presented in Figs. 1A, B; 2A, B; and 3A, B.

regardless of the mesh sizes and thickness of twine, and of the used fine-mesh samples. The used medium-size-mesh samples shrink rather slowly at first (about 10% – Figure 10) but the stretch of these meshes is, on the whole, smaller than in the case of fine meshes of used nets or the medium-size meshes of new nets.

Sisal: Sisal shows almost the same properties as manila described above (Figures 4 and 11).

Rami: Although the character of the stretch graphs for the meshes braided from rami twine (Figures 5, 6, and 12) is in general the same as for manila and sisal, the mutual relation of the graphs for dry and wet meshes is quite different. The tangents of the curve angle in their proportional sections are almost the same for dry and wet meshes. This is because the stretch of meshes (dry and wet) changes almost in the same way as the applied force increases. It is not surprising, therefore, that both lines corresponding to the tensile strength of dry and wet meshes are almost parallel.

The initial shrinkage for the new and used fine mesh samples (40 mm) amounts to about 10%, while the shrinkage of used medium-size net samples (90 mm), about 5%.



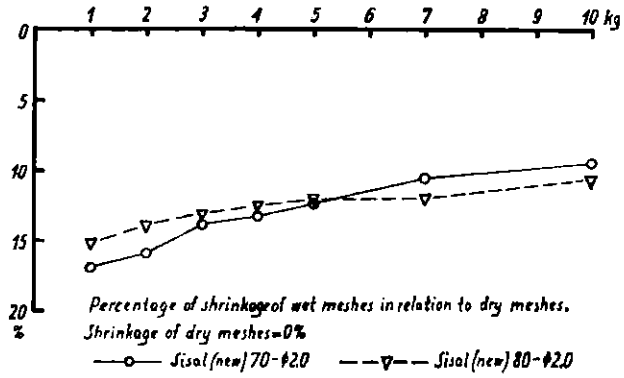


Fig. 11. Shrinkage of sisal meshes wheu wet (in %) in relation to the same meshes when dry. Diagrams of dependence of increase of meshes elongation represented in this figure are presented in Figs. 4A, B.

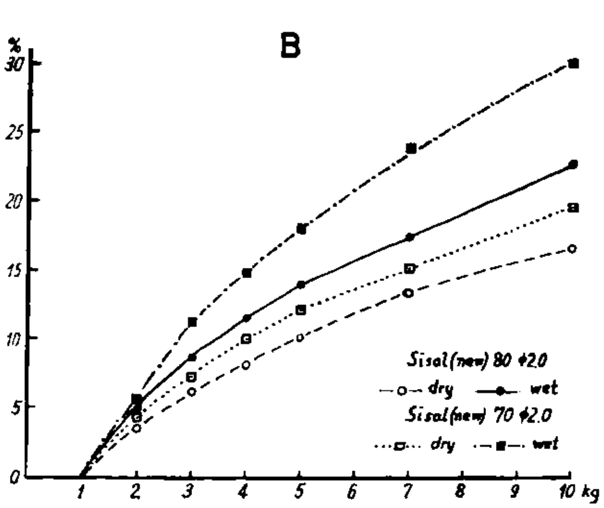


Fig. 4. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, made of sisal twine of diameter 2 mm (80 and 70 mm of size), were tested dry and wet.

B. The same dependences as in 4A (in %) in relation to the mesh size under a load of 1 kg.

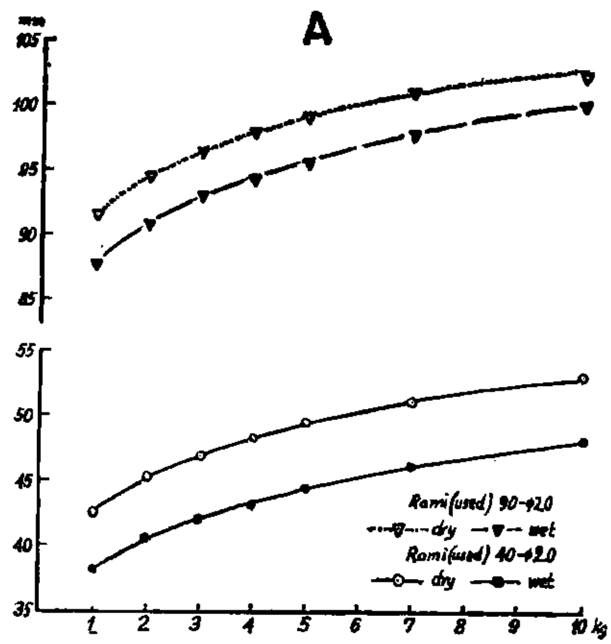


Fig. 5. A. Dependence of increase of mesh elongation. upon the force stretching the mesh. The meshes, made of rami twine of diameter 2 mm, taken from used codend (90 and 40 mm of size), were tested dry and wet.

The stretch of dry and wet meshes under the load of 10 kg amounts to about 15% in relation to the meshes stretched by a load of 1 kg, with the exception of used small meshes for which the stretch in the same conditions amounts to 25%.

Steelon: Steelon, a synthetic material of the polyamide group, possesses different features from the group of natural raw materials mentioned above (Figures 7-9). The meshes of nets braided from steelon twine increase in size when wet. The change in the size of meshes under

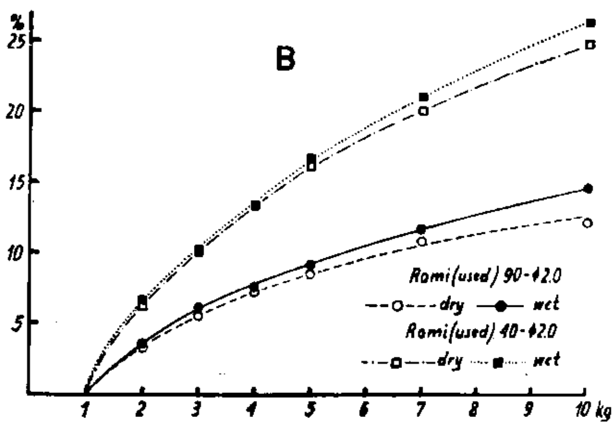


Fig. 5. B. The same dependences as in 5B (in %) in relation to the mesh size under a load of 1 kg.

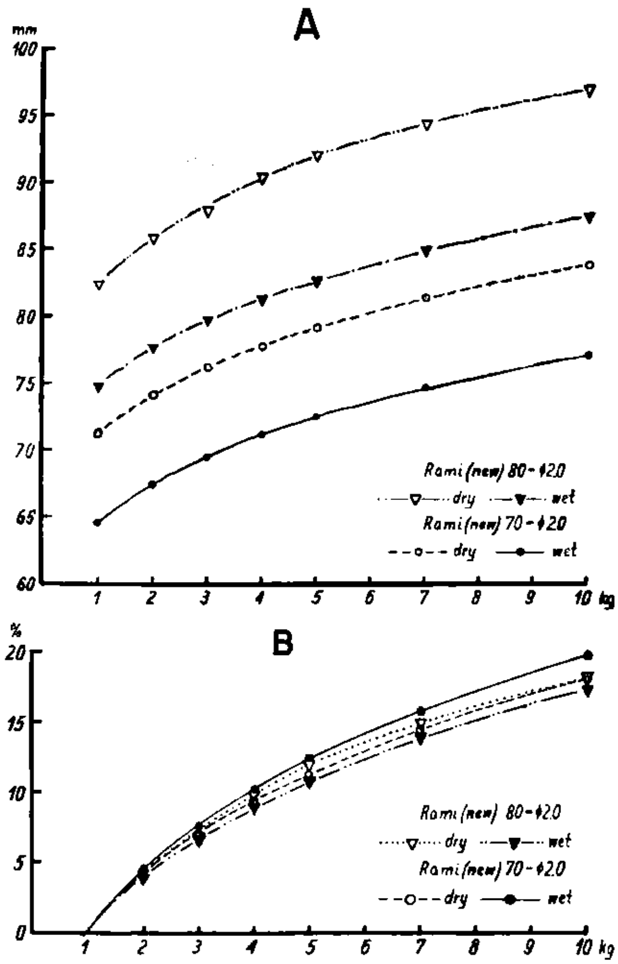


Fig. 6. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, made of rami twine of diameter 2 mm (80 and 70 mm of size), were tested dry and wet.

B. The same dependences as in 6A (in %) in relation to the mesh size under a load of 1 kg.

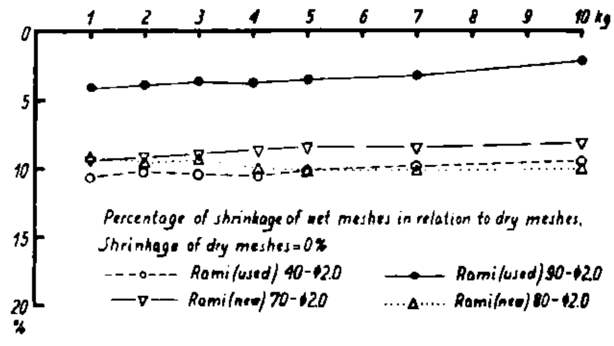


Fig. 12. Shrinkage of rami meshes when wet (in %) in relation to the same meshes when dry. Diagrams of dependence of increase of meshes elongation represented in this figure are presented in Figs. 5A, B; and 6A, B.

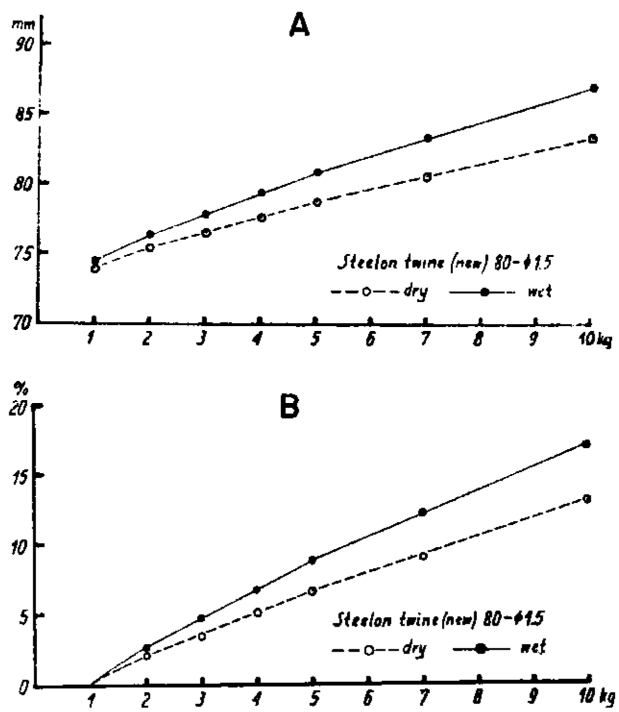


Fig. 7. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, made of steelon twine of diameter 1.5 mm, were tested dry and wet.

B. The same dependences as in 7A (in %) in relation to the mesh size under a load of 1 kg.

smaller forces applied (up to 5 kg) is so small (up to 3%) that it is practically negligible. This stretch under wet and dry conditions with greater loads applied (from 5-10 kg) does not show much difference and amounts to 13-16% under the load of 10 kg.

A plaited steelon line with a core of three steelon twines has quite different properties. The size of wet meshes increases about 15% and the stretch increases more rapidly when the meshes are wet than when dry.

The section of the proportional stretch curve begins for sisal and manila under a 4 kg load; for rami and steelon under about 4.5 kg. Therefore, Beverton's proposal to measure the codend meshes under the force of 3 kg may be justified for double braided meshes but does not seem to be right for single braided meshes. Our investigations suggest that the meshes should be measured under a force of 4 kg which is in accordance with Brandt's proposals. (The two aforementioned proposals have been made at recent ICES meetings.)

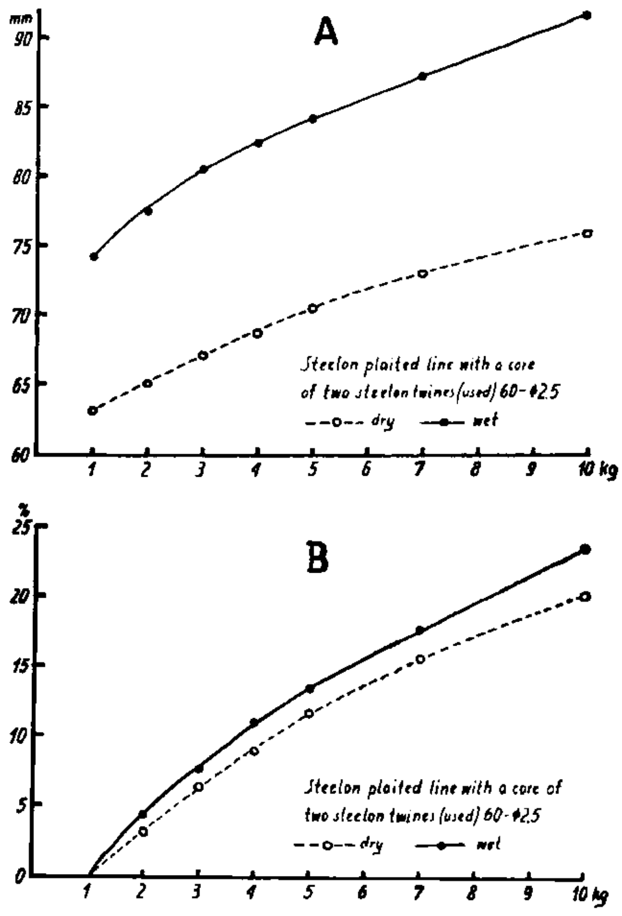


Fig. 8. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, made of plaited steelon twine with a core of two steelon twines, taken from used codend of diameter 2.5 mm (60 mm of size), were tested dry and wet.

B. The same dependences as in 8A (in %) in relation to the mesh size under a load of 1 kg.

Conclusions

1. The character of stretch graphs of both wet and dry meshes is always the same irrespective of the material used, the

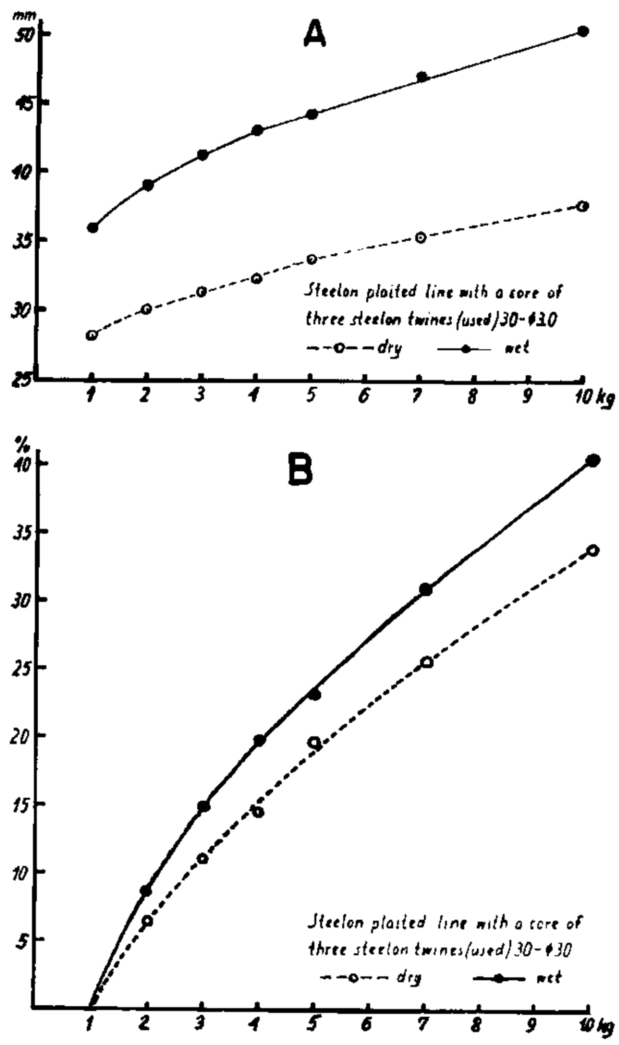


Fig. 9. A. Dependence of increase of mesh elongation upon the force stretching the mesh. The meshes, made of plaited steelon twine with a core of three steelon twines taken from used codend of diameter 3 mm (30 mm of size), were tested dry and wet.

B. The same dependences as in 9A (in %) in relation to the mesh size under a load of 1 kg.

size of meshes, thickness of twine of plaited lines, and use in fishing.

2. Natural materials are subject to shrinkage under the influence of water; this shrinkage amounts to 5-20% and depends upon the kind of material and tightening of knots (new or used samples).

3. The size of the materials belonging to the group of synthetic polyamidic materials increases up to 15%. This increase depends upon the technical construction of the twine.

4. It is a characteristic feature of manila and sisal material that its stretch is greater when wet than when dry. Wet and dry rami have an almost identical stretch.

22.

Otter-Trawl Covered Codend and Alternate Haul Mesh-Selection Experiments on Redfish, Haddock, Cod, American Plaice and Witch Flounder: Girth Measurements of Haddock, Cod and Redfish and Meshing of Redfish in the Newfoundland Area

by

WILFRED TEMPLEMAN[1]

Contents

Abstract

In some of the otter-trawling cruises of the research vessels *Investigator II* and *Marinus* from 1954 to 1956 selection experiments were carried out, sometimes by using a small-mesh shrimp-net cover over the upper part of the codend and at other times by the method of alternate tows without a cover over the codend. The fish investigated were redfish, haddock, cod, American plaice and witch flounder.

Redfish selection factors averaged 2.6 at internal mesh sizes of 4 to 4.6 inches (10.2-11.7 cm). The selection factors for whole nets of large mesh averaged slightly higher and for covered codends slightly lower than 2.6. Alternate haul selection factors agreed well on different cruises while covered net selection factors sometimes varied widely.

In alternate haul experiments the catch of redfish at the larger sizes in the large mesh net with the internal mesh size of the after parts approximately 4.6 inches (11.7 cm) was greater than that of the smaller mesh net with the after parts about 2.9 inches (7.4 cm).

In both covered codend and alternate haul experiments male and female redfish differed in their percentage retention at various sizes.

Using covered codends with meshes of internal size 4.0 and 4.4 inches (10.2 and 11.2 cm) the 50% selection factors for haddock from the

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Grand Bank and St. Pierre Bank were 3.0 and 2.9, respectively. For meshes of the same size the selection factors were respectively 3.3 and 3.2 for cod and 2.3 and 2.2 for American plaice from the same areas. For witch flounder with covered codend meshes of 3.9 and 4.4 inches (9.9 and 11.2 cm) the selection factors were respectively 2.2 and 1.8. For alternate hauls the selection factor for witch, for a net with after parts 4.6 inches (11.7 cm), was considerably higher – 2.5.

Haddock from 18 to 34 cm in length possessed a body girth at the posterior end of the operculum about 46% of the fork length and beyond this size the girth gradually rose to over 50% of the fork length at 66 cm. Indications are that the increase in girth relative to the fork length begins at sizes approaching sexual maturity. The smaller haddock in the cover probably possessed a greater girth than those of the same length remaining in the codend while at greater lengths the haddock in the cover had a lesser girth than those remaining in the codend.

Cod body girths, taken at the posterior border of the operculum, averaged about 4% of the fork length less than haddock girths and rose from about 42% of the fork length for cod 15 cm in length to 44.6% at 50 cm and beyond this point for the sexually maturing fish increased more rapidly to 49% at 93 cm.

Girths of *mentella*-type redfish, measured vertically from the anterior border of the spine of the pelvic fin, rose gradually from about 62% of the fork length at 9 cm to about 72% of the fork length in males of 27 cm and females of 31 cm; and thereafter the girth of the male fell rapidly to about 68% of the fork length at 39 cm, while the girth of the female levelled off or increased slowly to 73% at 42 cm.

In the alternate hauls of large and small mesh otter trawls for redfish, in the small mesh double-twine codend (2.9 in, 7.4 cm) the greatest percentage of the catch (27%) meshed at 21 cm and the greatest numbers meshed at 23 cm. The large mesh double-twine codend (4.6 in, 11.7 cm) had the greatest percentage (4.6% of the probable numbers entering the net) and also the greatest numbers meshed at 33 cm. In the wings of both nets (single twine 5.4 in, 13.7 cm) the highest percentages meshed were about 2% at 39 to 44 cm fork length.

The highest percentage of meshed fish in the small mesh codend was at the same redfish length as the 100% retention point of covered codends with meshes of approximately the same size. The highest percentage of redfish meshed in the large mesh codend was at the same redfish length as the 95% retention point of covered codends with meshes of approximately the same size.

Few meshed redfish were noted in the parts of the net other than the codend and wings.

A detailed account is given of the nets and sizes of meshes used in the various experiments in the attached Appendix, p.216.

Introduction

From 1954 to 1956 data relative to mesh selection of groundfish by otter trawls were obtained at the Fisheries Research Board of Canada, Biological Station at St. John's, during some of the cruises of the research vessels *Marinus* and *Investigator II*. The *Marinus* is a wooden dragger 62 feet in over-all length, 16 feet wide, 8 feet deep, 45 gross tons, powered by a 225 h.p. Caterpillar engine. The *Investigator II* is 82 feet in over-all length, 21 feet wide, 9 feet deep, 124 gross tons, and is powered by a 250 h.p. heavy duty Atlas engine. The *Marinus* is a typical Atlantic coast dragger type dragging from the starboard side with an approximate speed of 3 knots, whereas the *Investigator II* is a Pacific coast type with the house forward, dragging the trawl from two after gallows with a speed of 3.8 knots.

During the experiments the *Investigator II* used a No. 36 trawl while the *Marinus* used a modified No. 35 trawl which we have named the No. 35A Nfld. research trawl. The nets were of manila.

Fish lengths given in this paper are from the snout in cod and haddock and from the anterior tip of the chin with the mouth closed in redfish to the end of the mid-fork of the caudal fin. For American plaice and witch the length is the greatest total length with the mouth closed.

The measuring board used was offset 0.5 cm, *i.e.* the first space was 1.5 cm and the fish were measured to the nearest centimeter except in girth measurements where both length and girth were usually measured to the nearest millimeter.

Selection of Redfish

Total: Figures 1, 2 and 3 and Tables F-1 and F-2 (filed in the ICNAF Secretariat) give data on redfish escapement as indicated by covered codends and by alternate hauls of large and small mesh otter trawls.

These data supply considerable information near the 4-1/2-inch (11 cm) mesh size but fewer data are available at smaller mesh sizes.

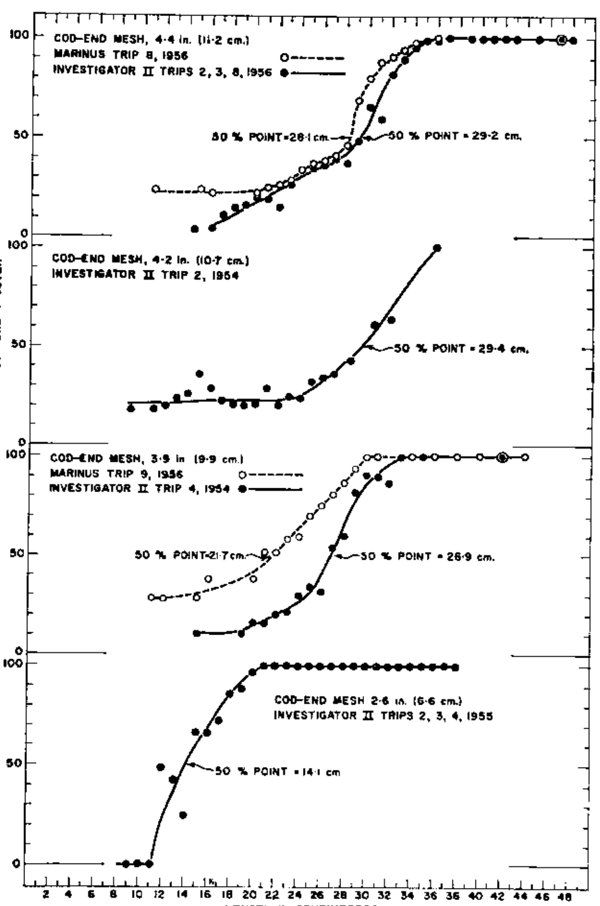


Fig. 1. Redfish escapement through the codend as determined by the use of codend and cover in trips of the *Investigator II* and the *Marinus* in 1954 to 1956. (*Investigator* trips on Grand Bank and St. Pierre Bank, *Marinus* trips in Hermitage Bay. F - 1.

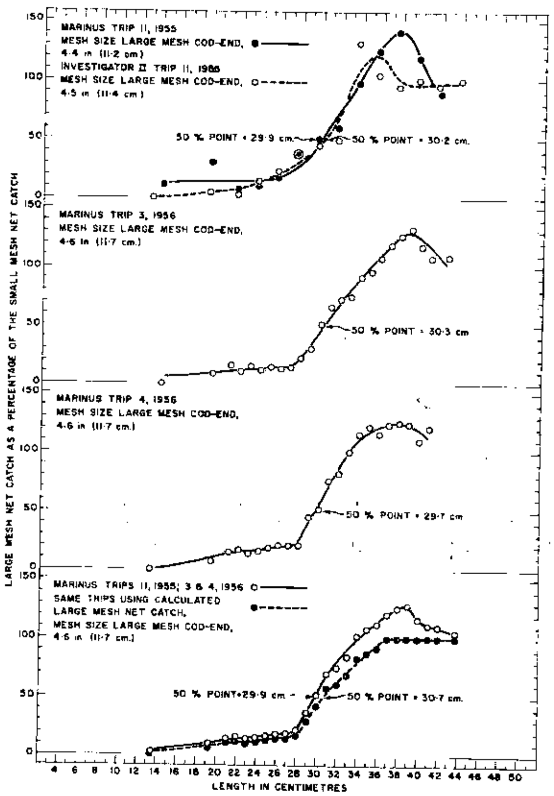


Fig. 2. Comparison of redfish captures by alternate hauls of large and small mesh otter trawls in trips of the *Investigator II* and the *Marinus* in the same locality of Hermitage Bay in 1954 to 1956. F - 2.

The 50% escapement point varies from about 30 cm at a mesh size of 4.5 inches (11.4 cm) down to 14.1 cm at a mesh size of 2.6 inches (6.6 cm). At the 4.4 to 4.6 inch (11.2-11.7 cm) mesh size the 50% escapement sizes for both covered codends and alternate hauls agree well. However, the *Marinus*, which fished especially for redfish in the one area of Hermitage Bay, showed 50% points on the average lower for covered codends than for alternate hauls.

All the alternate haul 50% points are in excellent agreement; the values for three expements by the *Marinus* with the same large mesh net (with codend average mesh sizes ranging from 4.4 to 4.6 inches (11.2-11.7 cm) being 29.7, 29.9 and 30.3 cm and the single alternate haul trip of the *Investigator II* gave a 50% point of 30.2 cm for a codend mesh size of 4.5 inches (11.4 cm).

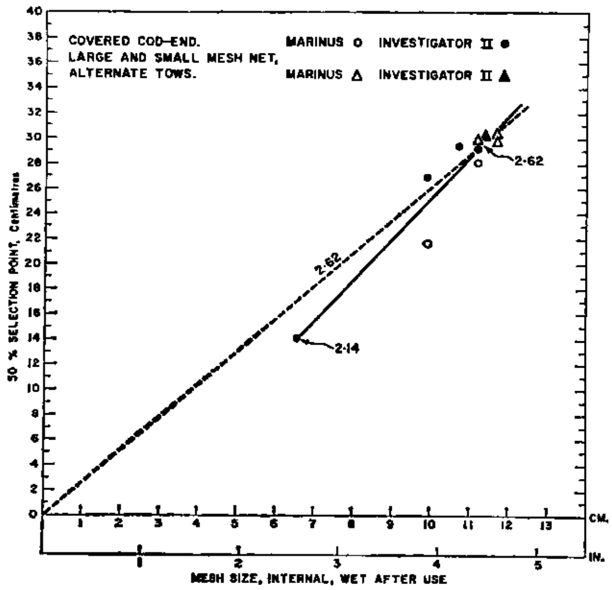


Fig. 3. Relation of internal mesh size to the 50% selection point in covered codend and alternate hauls of large and small mesh nets by the *Investigator II* and *Marinus*, 1954 to 1956. (Data from Fig. 1 and 2.).

Covered codend 50% points varied widely. The *Investigator II* 50% points were higher than those of the *Marinus*. The unusually low 50% point of 21.7 cm for the *Marinus* experiment with 3.9 inch (9.9 cm) mesh codend represents an average from 44 redfish sets with a total catch of 26,000 redfish (of which 62% were measured) in the same area of Hermitage Bay where the alternate net hauls were taken. A cover of the same adequate dimensions as that used for *Marinus* trip 8 was prescribed for this trip, but no actual count of cover meshes was taken and the codend and cover were lost in a set near the end of the trip. Thus the adequacy of the cover for this trip is in doubt.

In Figure 3 which shows all the mesh sizes, 50% escapement points for both covered codends and alternate hauls of large and small mesh nets, the upper part of the solid line has been drawn through a point representing the average of all 50% selection points for codend mesh sizes above 4 inches (10.2 cm), and the lower part of the line has been drawn directly to the 50% point for the smallest mesh size. The upper point which is based on an adequate number of experiments has a selection factor (50% selection length/mesh size ratio) of 2.62. The dashed line is the 2.62 line which probably represents the possible upper limits of the redfish sizes at the 50% selection point.

Where, as in Figure 1 for the same size covered codend, the 50% escapement size is lower for the *Marinus* than for the *Investigator II*, the numbers retained at the smaller sizes are also greater and the 100% escapement size is lower.

In all cases in the *Marinus* experiments the alternate net hauls showed that at the larger sizes the catch of the large mesh net was greater than that of the small mesh net. The *Investigator II* curve in Figure 2 is a calculated one using equal numbers of large fish 35 to 44 cm for both nets. The *Marinus* large and small mesh net catches are actual catches. In each separate experiment and especially in the total of all sets of all *Marinus* experiments there is considerable evidence that in relation to the catch of the small mesh net the catch of the large mesh net rises to a peak of 125 to 140% of the catch of the small mesh net at the intermediate large sizes and at the largest sizes falls again to close to 100%

Male and Female

Figure 4 and Table F-3 shows data for covered codend experiments using 3.9 to 4.4 inch (9.9-11.2 cm) mesh. In all three sets of experiments, at sizes ranging in the various experiments from about 23 to 27 cm up to 32 to 36 cm, the percentage of females retained in the codend at a given size was less than that of males. The 100% retention size of the female redfish was in all cases 2 cm beyond that of the males.

Similarly in Figure 5 and Table F-4 for the comparisons of the catches of large and small mesh nets, at sizes from 29 to 40 cm, in the total of all three experiments the large mesh net showed a smaller percentage capture of females than of males. Each individual experiment also shows the same kind of differences between the capture of males and females. The individual curves for males and females and the totals (except the females of *Marinus*, trip 4) show a return to the 100% point at the larger sizes, when compared with the numbers captured by the small mesh net.

Discussion

The variable nature of the covered net results, especially with regard to variability in the liberation of very small fish of which sometimes 100% and sometimes only 75% were liberated, indicates that various unknown favourable and unfavourable factors are at work. This method also cannot show how the efficiency of the gear, in capturing the larger fish, changes with increase in mesh size. While this method is suitable for a first approximation so as to decide the mesh sizes to to be used in future experiments, other methods, such as paired tows where possible or otherwise alternate tows, are needed to evaluate fully the effects of large mesh. The superiority of the large net catches at larger sizes is far too great to be due to increased distance travelled, since the number of engine revolutions and all other controllable factors were kept constant for both large and small mesh drags and the differences in distances travelled were not great enough to be evident. Doubtless, however, this factor had some effect. It is most likely that the superiority of the large mesh results from the better water straining of the large mesh net. In the small mesh net there may be a water build up near the mouth of the net and the water may be strained mostly through the wings, square and anterior part of the belly. In the large mesh net these forward parts of the net were similar to those of the small mesh net, but the remainder of the net was of larger mesh. Therefore, in the large mesh net there should be much more water straining through the posterior parts of the net.

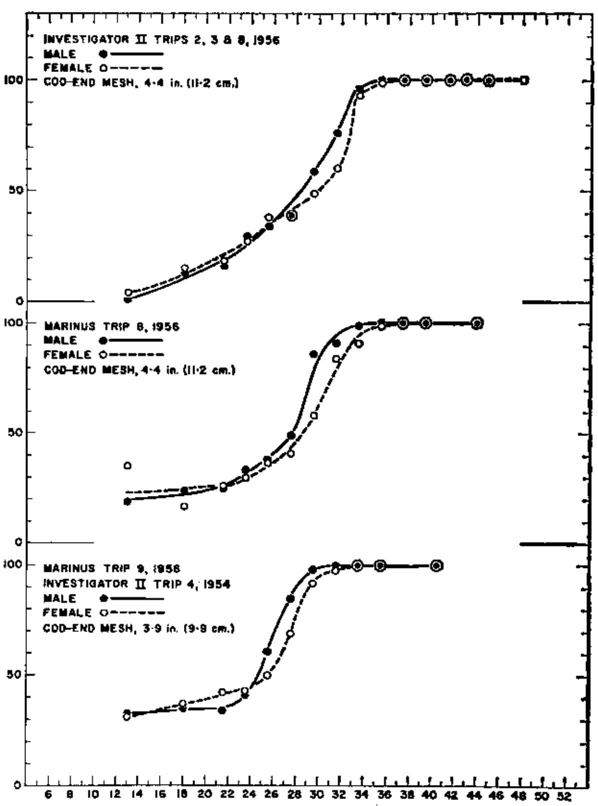


Fig. 4. Escapement of male and female redfish through the codend in covered codend experiments (Data from Table F - 3).

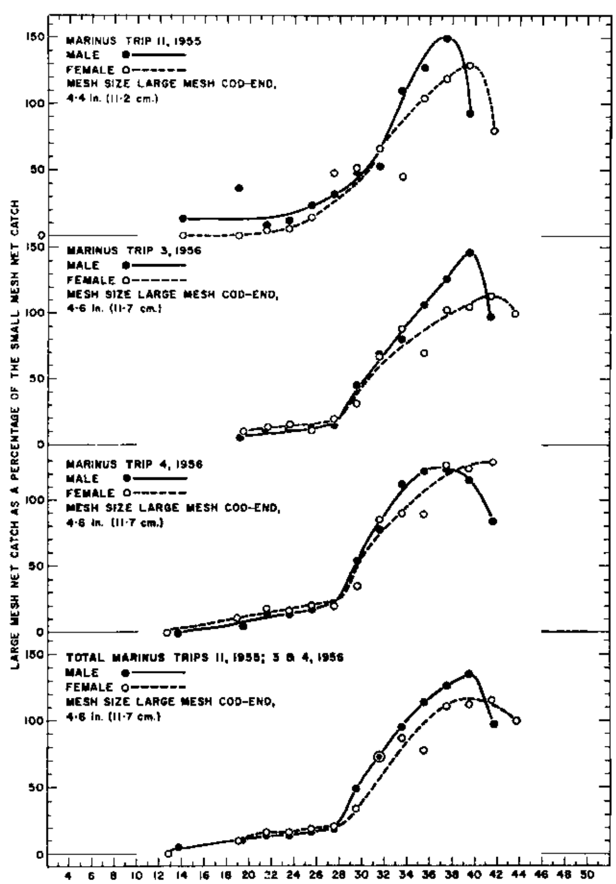


Fig. 5. Comparison of captures of male and female redfish by alternate hauls of large and small mesh otter trawls. (Data from Table F - 4).

As a result we may suppose that in the small mesh net the fish spend more time in the anterior part of the net and are thus selected by the large light single twine and large mesh of the wings, square and anterior belly while in the large mesh net the water current carries the fish back more quickly to be selected by the larger double-twine smaller mesh codend.

The *Marinus* net had a 6-inch (15.2 cm) mesh size, external, as ordered, (5.4-inch or 13.7 cm internal wet after use) in the anterior part of the net. It is quite probable that the return almost to equality, of the large and small mesh net captures at the largest sizes is due to the fact that the fish have attained a size where they cannot pass through the meshes of the anterior part of the net, and thus the superiority of the large mesh net selection in the codend over small mesh net selection in the anterior part of the net is lost.

It will also be evident by referring to Figure 5 that the early part of the downturn in Figure 2, at the largest sizes from the peak catch, is due to females being much more numerous relative to males at these large sizes than at the smaller sizes where the curve is at its highest point, and to the percentage excess of females in the large mesh net catch at all large sizes, except the very largest, where it is considerably less than that of males.

The *Investigator II* used a 5-inch (12.7 cm) external, as ordered, (4.7 inch or 11.9 cm internal wet) mesh in the anterior parts of its net. In Figure 2 the return of the *Investigator II* curve to the 100% level occurs at smaller sizes than for the *Marinus* net, thus agreeing with our hypothesis. The *Investigator II* curve is, however, weak, resulting from only a few sets and has been adjusted by equalizing the total number of large redfish, 35-44 cm in length, in both large and small mesh nets while the *Marinus* results are of actual catches.

It is also possible that from lack of straining power the small mesh net pushes water ahead of itself or ahead of the posterior small mesh parts of the net and that this causes fish to be assisted away from entering the mouth of the net or causes them to remain in the net but so close to the mouth that many escape through the mouth. The larger and most vigorous fish could thus receive the extra assistance needed to escape while they would be caught by the more freely straining large mesh net. This hypothesis does not explain the return almost to equality of captures by both large and small mesh nets at the largest sizes, unless it is assumed that these largest sizes are also less vigorous than those at the intermediate large sizes. This, of course, is possible.

If the relatively greater percentages of large males than of large females captured by the large mesh net (Figure 5) are considered, it is obvious that one may argue that these females, which are almost all mature, are less vigorous than males and that, therefore, the probable faster movement and less piling up of water in or in front of the forward part of the net will result in a greater advantage in capturing faster males than slower females. In the small mesh net the more vigorous males would be more in the front part of the net and be in a better position to escape through the mouth or be selected more by the wings than the females. In the large mesh net both males and females should move back faster and have less tendency than in the small mesh net to be selected by the wings and anterior large mesh part of the net.

The differential escape of sexes into the cover over the large mesh codend (Figure 4) indicates, however, that the females in the middle sizes, whether from increased vigour or from their shape, are better able to get through the meshes of the large mesh codend. At these medium sizes, at which greater percentages of females escape, most of the females are immature and all the males are mature.

It is obvious that whereas in the covered codend experiments one is studying the selection by the codend, hindered or helped as it may be by the presence of the cover, in the comparison of small mesh and large mesh nets one is comparing the selection by the two whole nets. Unless the assumption can be made that equal numbers of fish of the selected sizes enter both nets the comparison is that of the relative efficiency of the nets rather than the relative selection.

In view of the variability between catches in alternate hauls there is a high degree of chance in the actual picture received from any but a very large number of hauls. Consequently it is doubtless a better practice, in general, to equalize catches of the larger fish in the two nets under comparison and to adjust the part of the frequency, under selection, accordingly before calculating the selection characteristics of the net. With an experiment including a very large number of drags the actual results can be assumed to reflect the actual relative efficiencies of the nets.

To obtain an approximation of the large mesh net selection, as independently as possible of the relative efficiencies of the large and small mesh nets, we have equated, in both large and small mesh nets, the numbers of redfish beyond the point of 100% retention in the codend in covered codend experiments with approximately the same size mesh, and have used the same conversion factor to bring the large mesh net catches into line with the numbers of redfish in the small mesh net (Figure 2). The 100% retention point in thus raised from 34 to 37 cm, which corresponds with covered net results and the 50% escapement point increased from 29.9 to 30.7 cm. Thus the approximate agreement for redfish in 50% escapement points indicated by covered codend catches and comparisons of catches by large and small mesh nets very likely does not represent a real comparison of the relative escapement in nets without codend covers and with the after parts of large and small mesh respectively. In the latter case the actual 50% selection points are likely to be higher.

Quantities of Redfish Caught by Small and by Large Mesh Nets

In six one-hour sets by each of the large and small mesh nets used by the *Investigator II* in 1955 the large mesh net caught only one-third the amount caught by the small mesh net. Even at the larger sizes, 35 to 44 cm, where all or almost all the redfish should have been retained by the codend, the large mesh net caught only 34% of the numbers caught by the small mesh net. Catches by the large mesh net of fishes normally found on or near the bottom and much too large to pass through the meshes, such as skates, large witch flounder and cod, were correspondingly lower compared with the catches of the small mesh net. Evidently the large mesh net was passing too far above the bottom and many of the fish were passing beneath it. The relative quantitative catches of the small and large mesh nets in this instance are without significance.

For the *Marinus*, data are available on a total, in three separate trips, of 46 one-hour drags for the small mesh and 47 for the large mesh net (Figure 2). The average redfish catch per hour's dragging was 1,320 lb for the small mesh and 1,250 lb for the large mesh net, *i.e.* the large mesh catch was 95% of the small mesh catch. The standard errors of the two average catches were 179 and 169 lb respectively and the difference between these catches was thus not statistically significant. Redfish as small as 20 cm (8 in) can be used by fish-plants and only 19 lb or 0.03% of the redfish caught by the small mesh net were below this size. However, 2,390 lb or 4% were below 25 cm (10 in) and although they could be used these fish would not be welcomed in Newfoundland fish-plants since they are costly to fillet and difficult to sell. At sizes from 25 cm (10 in) and upward the large mesh net caught 101% of the weight of redfish caught by the small mesh net, at 30 cm (12 in) and larger the large mesh net caught 108%, and for 34 cm (13-1/2 in) and upward, 116% of the weight of redfish of the same size ranges caught by the small mesh net.

In the United States Fish and Wildlife Service, Boston Fishery Products monthly summary for February, 1957, the wholesale price of redfish fillets in 10 lb packages was 23% higher for large than for small fillets. In the Boston Fishery Products daily reports for March and early April, 1957, the landed prices at Gloucester for large redfish were 27 to 29% higher than for medium and 50 to 58% higher than for small redfish.

The large mesh net had a codend averaging 4.6 inches (11.7 cm) internally, and in the remaining parts of the net with single twine the meshes ranged from averages of 4.5 to 5.4 inches (11.4 to 13.7 cm) internal measurement. The small mesh net had a codend with meshes of 2.9 inches (7.4 cm) and lengthening piece and after belly with meshes of a similar size.

It is obvious that in Hermitage Bay, the area studied, because of the greater value of the larger fish it would have been more profitable to use a net with codend and other meshes, in the after part of the net, of about 4-1/2 inches (11 cm) rather than a net with these meshes averaging less than 3 inches (8 cm). The size-distribution of redfish in the Gulf of St. Lawrence in recent years is approximately the same as in Hermitage Bay and the same conclusion is probable.

In other areas with smaller redfish a smaller mesh may be more profitable but it is quite possible that a net with codend and other meshes no smaller than 4 inches (10.2 cm) will on the average over the whole area be the most profitable for redfish. Where, as in many parts of the northern area, redfish are large, the larger mesh, either 4 or 4-1/2 inches (10.2 to 11.4 cm), will very likely be more profitable.

It will be seen from Table IV that at the time the comparisons of the catches of large and small mesh nets were carried out in Hermitage Bay the large mature females were very scarce. If these large females had been present in their usual numbers the results would have been less favourable for the large mesh net since, for females about 27 to 28 cm, the large mesh, in comparison with the small mesh net, is less effective than for males (Figure 5, total *Marinus* trips). It would be interesting, therefore, to repeat the experiment at a time and place with a plentiful supply of large females as well as large males.

Selection of Haddock, Cod and American Plaice

All the selection experiments for haddock, cod and American plaice discussed in this paper involved the use of codends lined with shrimp netting below and covered on the upper side with a loose bag of shrimp netting. The experiments were carried out especially for haddock. Some information on the selection of cod and American plaice was also obtained.

The haddock selection experiments (Figure 6 and Table F-5) were carried out on the Grand Bank and St. Pierre Bank by the *Investigator II* using a No. 36 otter trawl. For codend mesh sizes of 2.6, 4.0 and 4.4 inches (6.6, 10.2 and 11.2 cm) the 50% selection points were 19.4, 31.3 and 32.2 cm respectively and the 100% retention points 23, 49 and 49 cm. In the same selection experiments and for the same mesh sizes the 50% selection points for cod (Figure 6 and Table F-6) were respectively 17.3, 33.4 and 35.5 cm and the 100% retention points 35, 51 and 53 cm. Also in the same experiments and for the same mesh sizes the 50% selection points for American plaice, *Hippoglossoides platessoides* (Fabricius) (Figure 6 and Table F-7) were respectively 15.4, 23.1 and 25.1 cm and the 100% retention points 17, 33 and 35 cm. The 50% points for the smallest mesh size for haddock, cod and American plaice are not very reliable as few fish were present, during the experiment, in the selection range of this mesh.

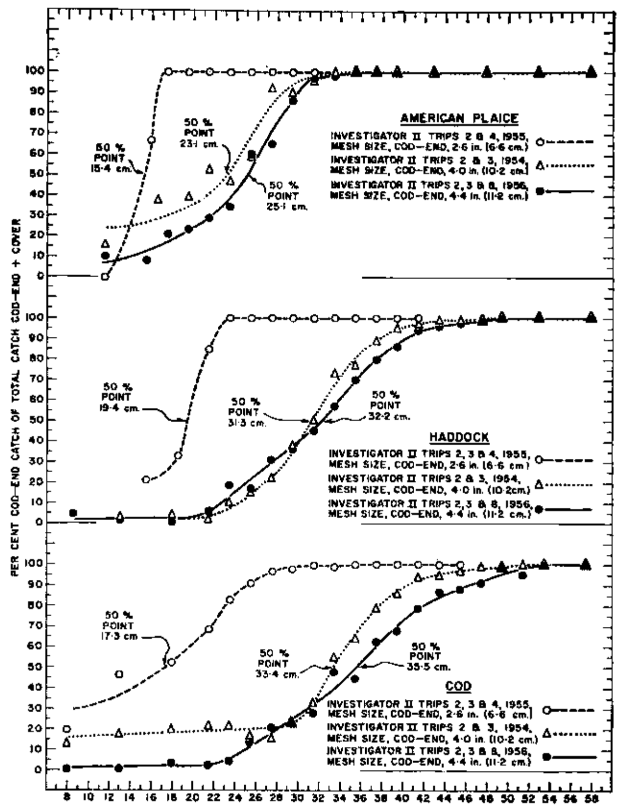


Fig. 6. Selection of American plaice, haddock and cod, through codends with internal mesh sizes of 2.6, 4.0 and 4.4 inches (6.6, 10.2 and 11.2 cm) in experiments using a shrimp net cover over the codend. (Data from Tables F - 5, F - 6 and F 7).

Selection of Witch Flounder

In the covered codend and alternate haul experiments of the *Marinus* in Hermitage Bay for redfish, 1955 and 1956, all witch flounder, *Glyptocephalus cynoglossus* (L.), were measured. Compared with a total of 151,000 redfish in all the experiments there were only 8,900 witch.

The results of the covered codend experiments are shown in Table F-8, the alternate haul experiments in Table F-9, and in Figure 7 the two covered codend experiments are compared with the total of the alternate haul experiments.

The 50% selection points were 20.5 and 21.9 cm respectively for the two covered codend experiments with codend meshes of 4.4 and 3.9 inches (11.2 and 9.9 cm). The alternate drags (46 with each type of net in the same area of Hermitage Bay) of the small mesh net and of the large mesh net with codend 4.6 inches (11.7 cm) gave a widely different 50% selection point, 29.0 cm.

The 100% selection points also differed widely, ranging from 37 and 33 cm, respectively, in the covered codend experiments with codend meshes of 4.4 and 3.9 inches (11.2 and 9.9 cm)

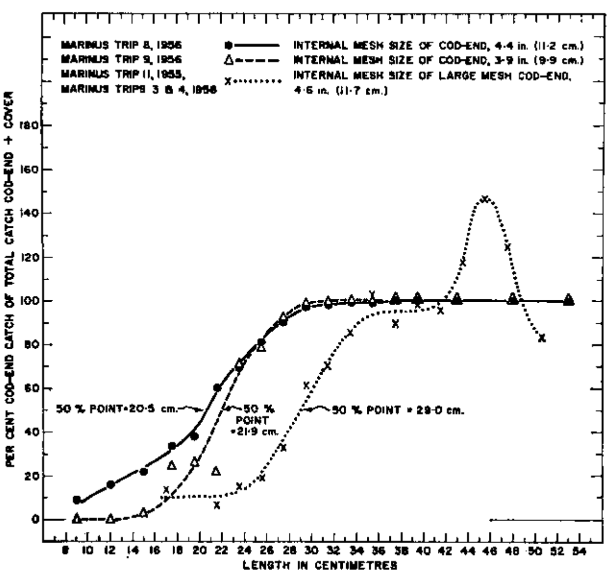


Fig. 7. Selection of witch flounder: covered codend and alternate haul experiments of the *Marinus*, 1955 and 1956. (Data from Tables F - 8 and F - 9).

to 41.7 cm for the series of alternate hauls with codend meshes of 4.6 inches (11.7 cm).

At sizes larger than 41 to 42 cm the large mesh net caught more witch than the small mesh net. At the largest sizes, at which only small numbers were caught, the relative catches by the large mesh net were reduced.

The codends used for the covered codend experiment, *Marinus* trip 8, and the large mesh codend in the alternate haul experiments were part of the same order: 100 yd, 3 ply, manila 5-1/2 inch (14.0 cm) mesh. The 0.2 inch (0.5 cm) excess in mesh size in the alternate haul experiments is due either to the same large mesh net having been used in this experiment for three trips or to differences in measurements by different individuals.

The redfish alternate haul and covered codend experiments gave somewhat similar 50% points while the witch results are widely different. The redfish alternate haul selection curves, apart from the sections after the 100% point is reached, are very similar to the covered codend selection curves. The witch alternate haul curve shows very much higher selection sizes and levels off before passing into the phase superior to 100%. Each of the three alternate haul experiments, as well as the total, gave essentially similar results with regard to the 50% point but the experiments varied more in their 100% points. The numbers of witch in the alternate haul experiments were relatively few and it is not worth while to argue too closely. It is possible that in these alternate haul experiments the 100% point is less than 41.7 cm, but it is likely that the preliminary levelling off in the selection curve below the 100% level may mark the 100% selection point of the codend although witch are still passing through the single twine parts of the net in front of the codend.

The redfish experiments with covered codends, *Marinus* trip 8, 1956, gave normally high 50% escapement points and a good escapement at the small sizes while trip 9 gave what appears to be unusually low escapement at the smaller sizes and an unusually low 50% selection point. In witch the reverse occurred; and trip 8, with codend meshes of 4.4 inches (11.2 cm), gave a lower

50% escapement point and a lower escapement at the smaller sizes than did trip 9 with codend meshes a half-inch (1.3 cm) smaller, 3.9 inches (9.9 cm).

It is likely, therefore, that witch and redfish are different with regard to the section of the large mesh net through which they escape. The difference between covered codend and alternate haul selection points may possibly be due to differences in the passage of witch through the covered and uncovered codends. In view of the great difference, however, it is, due more likely to differences in the action of the witch and redfish in relation to the forward parts of the trawl.

In both large and small mesh nets the wings, square and forward part of the belly are of the same 6-inch (15.2 cm) mesh. The main differences are in tbe lengthening piece which is 3-1/2 inches (8.9 cm) external in the small mesh net and 5 inches (12.7 cm) external, 4.5 inches (11.4 cm) internal, in the large mesh net, and in the after half of the belly which declines from 4-1/2 inches (11.4 cm) to 3-1/2 inches (8.9 cm) external in the small mesh net and is of 5-inch (12.7 cm) mesh external, 4.5 inches (11.4 cm) internal, in the large mesh net. These parts of the net also are of single twine which would select at a higher level tban the double twine codend.

The witch, however, is a difficult fish to catch with an otter trawl, the slower bottom-hugging Danish seine being much more efficient in witch fishery. Small differences, therefore, in the large mesh net and in the distribution of small and large witch in relation to the bottom, may produce considerable differences in the numbers of witch at various sizes captured by large and small mesh nets.

Girth Measurements of Haddock, Cod and Redfish

Haddock: Haddock girths were measured at sea during savings gear experiments, separately for fish in the codend and cover. The girth measurement was taken to the nearest millimetre completely around the fish, firmly but without constricting the body in any way, directly vertically along the side of the body touching the extreme posterior point of the operculum. The total length of the haddock from the snout to the mid-fork of the caudal fin was measured to the nearest millimetre. Figure 8 and Table F-10 show the resulting average girth measurements.

In the three curves, Figure 8A, 8B, and 8C, showing girth as a percentage of the fork length, the curve was drawu for 8C – total of all haddock measured from codend and cover – and the same curve was superimposed on 8A and 8B which contain the same data, but in 8A the fish from codend and cover and in 8B males and females are expressed separately.

The smaller fish from about 18 to 34 cm have a girth about 46% of the fork length, and beyond this size the girth gradually rises to over 50% of the total length at 66 cm. While further data are needed it is indicated that the rise in the curve begins at sizes which are approaching sexual maturity.

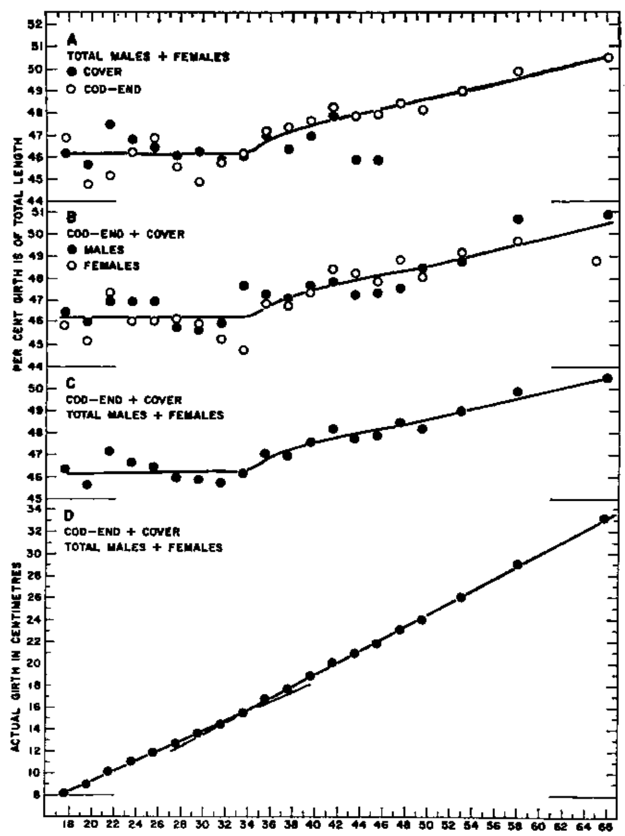


Fig. 8. Haddock girth, *Investigator II*, trip 2, 1954 and trips 2, 3 and 8, 1956. (Data from Table F - 10).

Tbe codends used in the selection experiments during which these measurements were taken were from 4.2 to 4.4 inches (10.7 to 11.2 cm) internal dimesnsions, and the haddock 50% selection points ranged from 31.3 to 32.2 cm. Figure 8A indicates that at the smaller sizes, below and near the 50% selection point, the fisb in the cover did not possess a lesser and probably possessed a greater girth than the fish of the same length in the codend, while the larger sizes, above the 50% selection point, penetrating into the cover apparently had a lesser girth than the fish of the same length in the codend.

Figure 8B does not show consistent differences in the girths of male and female haddock. For more definite conclusions larger numbers of measurements would be necessary to reduce the spread of the averages, but it can be seen from this figure that the differences are not great.

The haddock girths described above were measured with a string. Subsequent to the original preparation of this paper, haddock girths were measured at sea in May and June, 1957. Girths were measured in the same position described above but using a cloth tape. The girths obtained averaged 1 to 2% of the fork length higher than those shown in Figure 8 and Table X.

Cod: Cod girths were taken at sea by the method described for haddock. There were many fewer measurements of cod than of haddock girths and the resulting averages for cod are more variable (Figure 9 and Table F-11).

The curve, for girths expressed as a percentage of the fork length, was drawn for the averages of the total from codend and cover in Figure 9B, and this same curve was superimposed on Figure 9A in which the data are the same but are divided between codend and cover.

Cod girths, expressed as a percentage of the fork length, average about 4% less than haddock girths at the same fish length and rise from about 42% of the fork length at 15 cm to 44.6% at 50 cm, and from this point on, for the sexually maturing fish, the curve apparently increases more steeply to 49% at 93 cm.

In the selection experiments in which cod girth was measured the codend had an internal mesh size of 4.4 inches (11.2 cm) and the 50% selection point was at 35.5 cm. The small number of cod measured at the smaller sizes and the variability of the results (Figure 9A) do not allow a conclusion as to whether varying girth affected the ability of fish of the same length to penetrate the codend meshes.

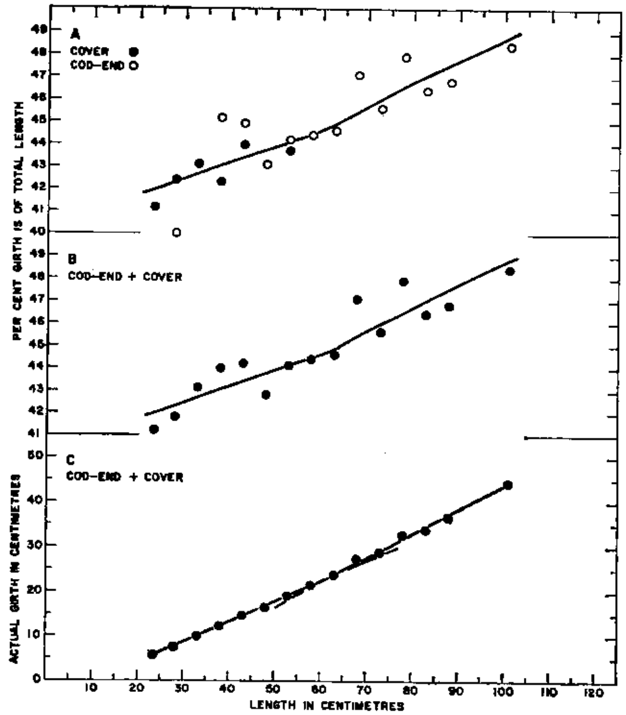


Fig. 9. Cod girth, *Investigator II*, trips 2, 3 and 8, 1956. (Data from Table F - 11).

Redfish: Redfish girths were measured on shore from fish well iced in boxes and several days old. The girth measurement was taken to the nearest sixteenth of an inch using a cloth tape. This measurement was taken completely around the fish, firmly but without constricting the body, from the anterior base of the spines of the pelvic fins vertically upward around the pectoral fins and when necessary around the flattened dorsal spines. Lengths were taken in millimetres from the tip of the chin beak with the mouth closed to the end of the mid-fork of the caudal fin. The redfish measured were of the *mentella* type (*Sebastes marinus mentella* Travin).

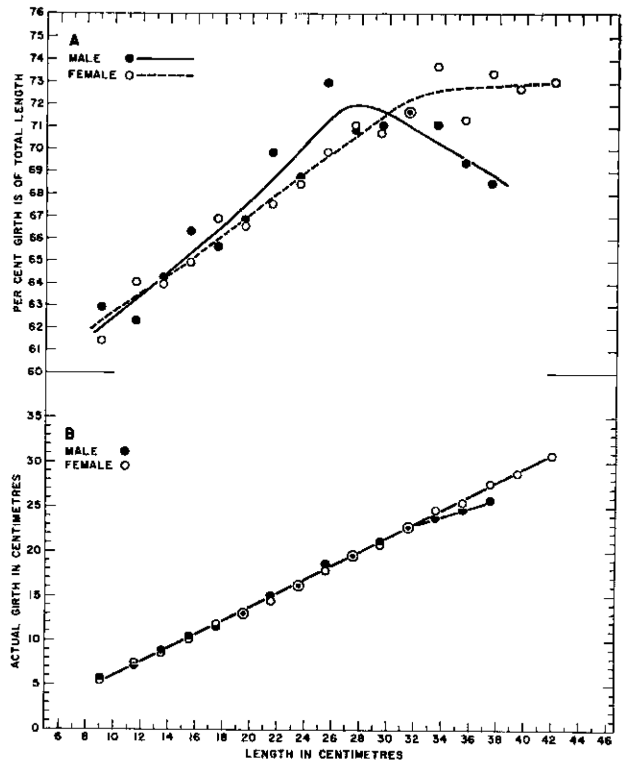


Fig. 10. Redfish girth, *Marinus* trip 2, 1957. (Data from Table F - 12).

The resulting average girths (Figure 10 and Table F-12) show girth rising rapidly from about 62% of the fork length at 9 cm to about 72% of the fork length in males of 27 cm and females of 31 cm; and thereafter the girth of the male falls rapidly to about 68% of the fork length at 39 cm, while that of the female levels off or increases slowly to 73% at 42 cm.

More measurements are needed to reduce the variability of the averages but the differences indicated between the girth of males and females at the largest sizes are probably real.

The redfish girths of Figure 10 were taken onshore in April, 1957 from redfish which had been caught in Hermitage Bay and preserved in ice in boxes for several days. The girth and fork lengths of half of these redfish were measured by the author and half by E. J. Sandeman. The length-girth relationships agree so well that the data could be combined with confidence.

Subsequently, in June, 1957, Sandeman took a series of length-girth measurements of similar *mentella*-type redfish within an hour or two of capture by the research vessel *Marinus* in Hermitage Bay. In this sample the girths of male redfish rose from 71.0% of the fork length at 13-20 cm to a high point of 73.4% at 27-28 cm and declined to 69.8% at 37-44 cm. The girths of the female redfish rose from 70.3% of the fork length at 13-20 cm to 74.1% at 29-32 cm and fell to 71.4% at 37-44 cm. It may be that the smaller redfish are compressed relatively more than the larger ones during storage in ice and consequently that sea measurements particularly of the small fish will differ from shore measurements. The girth region used, however, although near the greatest girth of the redfish which is not affected by the swelling of the swim-bladder, is also sometimes over and sometimes in front of the anterior part of the dorsal fin and is also near the point where the head slopes anteriorly downward. Thus slight differences in technique and in the slope of the tape away from the vertical will give somewhat different results.

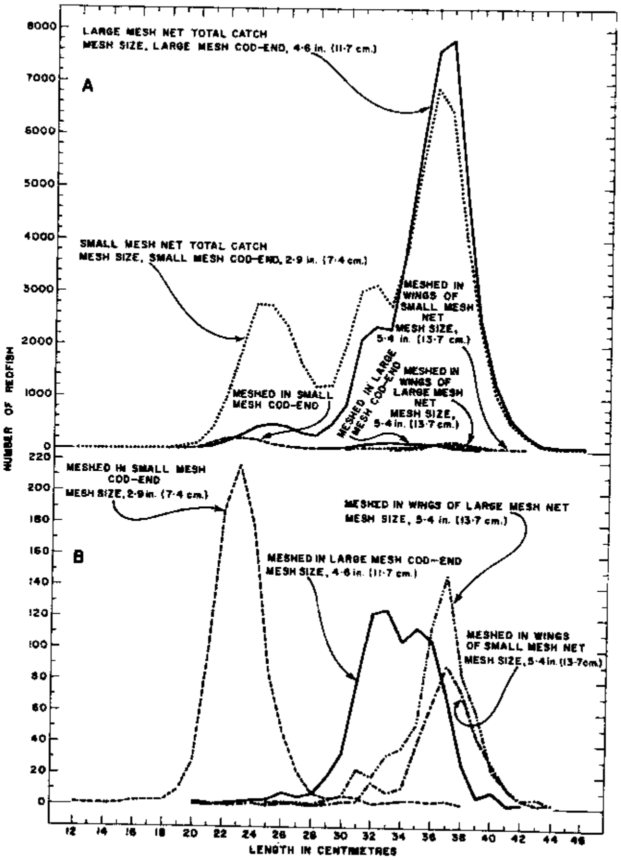
Redfish Meshing

In the alternate hauls with large and small mesh otter trawls, carried out by the *Marinus* in Hermitage Bay during trip 11, 1955, and trips 3 and 4, 1956, the same large mesh net was used in all experiments.

In these experiments all redfish meshed in the codends and wings of both large and small mesh nets were removed at the end of each set and measured (Figure 11 and Table F-13).

In Figure 12 and Table F-14 the meshed redfish are shown as a percentage of the number of redfish caught in the net and in the case of the large mesh net as a percentage of the approximate number which passed into the net.

For comparison, in Figure 11A the numbers of meshed redfish are shown in relation to the frequencies of the total catches of the large and small mesh nets; in Figure 12A the percentages meshed in the small and the large mesh codends are drawn in relation to the selection curve of all experiments with covered codends having meshes corresponding in size to the small mesh and the large mesh codends, respectively, of the alternate haul experiments.



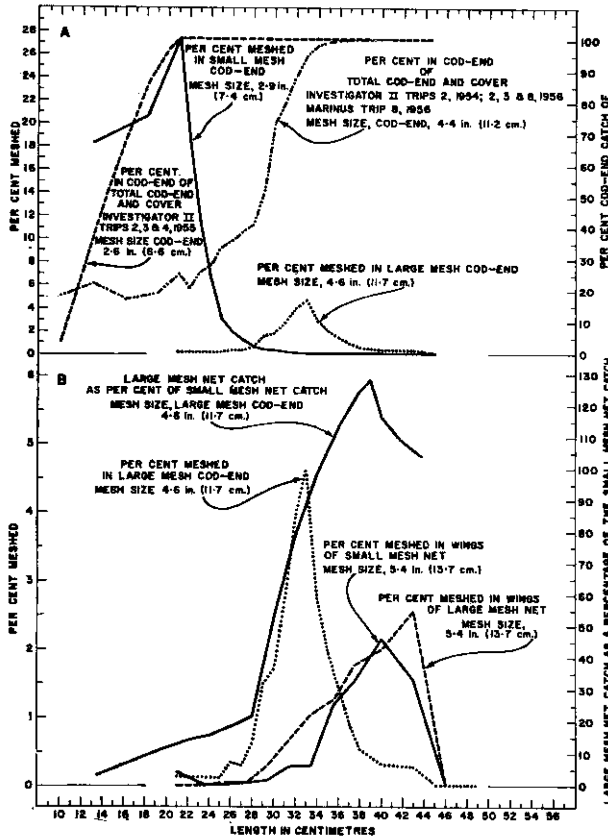


Fig. 11 A. Comparison of actual numbers of redfish of various lengths caught in the small and large mesh otter trawls in *Marinus* trip 11, 1955, and trips 3 and 4, 1956 and the actual numbers of redfish meshed in the codends and wings of the small mesh and large mesh trawls.

Fig. 11. B. Comparison of length frequencies of redfish meshed in codends and wings of small and large mesh otter trawls in these experiments. (All data from Tables F - 13 and F - 14).

Fig. 12. A. Percentages of the total catch of redfish of each size meshed in small mesh and large mesh codends in *Marinus* trip 11, 1955, and trips 3 and 4, 1956, compared with the covered codend selection curves for a 2.6 inch (6.6 cm) mesh codend and a 4.4 inch (11.2 cm) codend.

Fig. 12. B. Percentages of the total catch of redfish of each size meshed in the large mesh codend and in the wings of the large and small mesh net in the above experiments, compared with the selection curve developed from the comparison of the large mesh net catch with the small mesh net catch in the alternate hauls of these experiments. (Percentage data from Table F - 14).

In Figure 12B the percentages meshed in the large mesh codend and in the wings of the small and of the large mesh nets in the alternate haul experiments are shown in relation to the selection curve calculated from the redfish catches in alternate hauls of large and small mesh nets.

The small mesh codend (double twine, internal size 2.9 inches, 7.4 cm) showed a very high proportion, 11 to 27%, meshed at sizes from 10 to 23 cm, with the highest percentage meshed at 21 cm and greatest numbers meshed at 23 cm; large redfish were rarely meshed in the small mesh codend.

The large mesh codend (double twine, internal size 4.6 inches, 11.7 cm) showed the greatest percentage meshed, 1.4 to 4.6% at sizes 29 to 36 cm, with both highest percentage and greatest numbers meshed at 33 cm.

In the wings (single twine, internal size 5.4 inches, 13.7 cm) in both small and large mesh nets the highest percentage meshing, 1.2 to 2.1% for the small mesh net and 1.0 to 2.5% for the large mesh net, occurred between 35 and 44 cm and 33 and 44 cm, respectively, with the highest percentages meshed at 39 to 41 and 42 to 44 cm. The greatest numbers meshed in the wings occurred at 36 cm for the small mesh and 37 cm for the large mesh net.

The *Marinus*' trawl gallows are on the starboard side. In each net the starboard wing had only about one-third as many redfish meshed as the port wing. More fish were meshed in the wings of the large mesh net. The redfish meshed in the wings of the small mesh net were on the average 0.37 cm larger than those in the wings of the large mesh net. The difference is statistically significant at the 95% level. Average sizes of meshed redfish were respectively 23.3, 33.6, 36.7 and 36.3 cm for double manila codends 2.9 inches (7.4 cm), 4.6 inches (11.7 cm) and small mesh net and large mesh net wings all of 5.4 inches (13.7 cm) single manila.

The much greater number of redfish meshed in the port than in the starboard wings of both nets may be due partially to the same causes which produce greater catches in the port leg of the trouser trawl when this trawl is fished from the starboard side. In control experiments with both trouser trawl legs of the same size mesh, Davis (1934) found 56.4% of the total fish in the port leg. Davis attributes the difference to uneven fishing by the two sides of the net, due to the majority of turns made by the trawler during hauling being toward the side on which the gear is towed and a tendency, therefore, for the fish to be collected on the port side of the net. Additionally, with relation to wing meshing, in finally swinging the net broadside to the vessel near the surface the starboard wing is pulled forward which tends to shift fish backward toward the port side of the net.

The meshing of greater numbers of redfish in the wings of the large mesh net is related to the greater numbers of redfish at the larger sizes (at which most of the wing meshing occurred) caught by the large mesh compared with the small mesh net.

The highest percentage of meshed fish in the small mesh codend is at the same redfish size as the 100% retention point of covered codends with meshes of approximately the same size (2.6 inches, 6.6 cm). The highest percentage of redfish meshed in the large mesh codend (4.6 inches, 11.7 cm) is at the same redfish size as the 95% selection point of covered codends with meshes of approximately the same size (4.4 inches, 11.2 cm) and the 89% selection point of the large mesh /small mesh, alternate haul, selection curve. Although we have no data it is thus probable that the highest meshing percentages for the wings (with meshes of 5.4 inches, 13.7 cm) are close to and probably a little below the 100% retention points of these parts of the net. These highest meshing percentages in the wings occur at sizes where the advantage of the large mesh net over the small mesh net, in additional redfish captures, is disappearing (Figure 12).

The data showing that the greatest percentage meshed is not at the 50% selection point but close to the 100% retention point and that the percentages meshed at the 50% point are relatively low (Figure 12) indicate that the 50% point is not due to approximately 50% being unable to escape at this point because their girth is beyond the mesh size. The 100% retention point on the other hand does appear to be due to the fact that the fish have grown beyond the largest girth at which they can penetrate the meshes.

Only 1.6% of the 57,000 fish caught in the net with the small mesh codend were meshed in the codend. Since these meshed fish were on the average the smallest fish caught, the meshing in the small mesh codend can be considered to be insignificant from a commercial point of view. The large mesh codend had 1.4% meshed. This percentage, however, is based on the approximate number of fish passing into the net and the actual percentage of the large mesh catch meshed was 1.8%. These are considerably larger fish than were meshed in the small mesh codend and, therefore, the meshing has some commercial significance but the operational hindrance through meshing in the large mesh codend is not serious. The wings have the same mesh size in both nets and the meshed fish are still larger but again not a serious hindrance to commercial operations.

In the particular case under discussion the highest percentage meshing in the small mesh codend occurred at sizes where few redfish were retained by the net; the highest percentages meshing in the large mesh codend also occurred at sizes where fewer redfish were caught than at larger sizes; the largest percentages meshing in the wings were at sizes where the numbers of redfish were declining. When the particular redfish frequency present in an area happens to match the highest meshing frequency of the large mesh codend the meshing nuisance could he several times as great. It is unlikely that much redfish fishing would occur at depths and in areas where the highest point of the frequency was at the same size at which the greatest percentage meshed in the small mesh codend occurred.

Few meshed redfish were noted in the parts of the net other than the codend and wings and no records beyond the general statement above were kept of redfish in these parts of the net during *Marinus* trips 3 and 4, 1956.

In *Marinus* trip 11, 1955, in 9 sets and 8 hours dragging of each net 10 redfish were meshed in the belly of the small mesh net and 13 redfish in the belly of the large mesh net.

This compares with 132 and 57 redfish meshed in the codend and 41 and 20 redfish meshed in the wings of the small and large mesh net respectively. The redfish meshed in the belly were large, 32 to 41 cm. in the small mesh net and 29 to 38 cm in the large mesh net. This indicates that even in the small mesh net the redfish were meshed in the forward rather than the after part of the belly, and renders it likely that some but not large numbers of redfish pass out through the forward part of the belly while few pass out through the after part.

In trip 11 of the *Investigator II*, 1955, in 8 sets with a total of 8 hours dragging by each net only 3 redfish were meshed in the square of the small mesh net and none in the square of the large mesh net while the numbers of redfish caught in the wings of the two nets were 39 and 46 respectively.

It was noted in the various savings gear trips that the redfish meshed in the codend tended to be in the extreme end around the codend opening and doubtless some of these were forced into the meshes by the weight of the fish in the codend when it was hoisted on board. Large catches also affect the relative percentage of redfish meshed in the codend since by the time many bags of fish have been taken many meshed redfish have been knocked out or torn out in handling.

The general picture of meshing in large mesh as against small mesh nets indicates that meshing is a slightly greater problem in the large mesh codend due not to larger numbers but to the greater weight of the large fish meshed in the large mesh codend. There may be more meshing in the wings of the large mesh net but more large fish are being caught by the large mesh net. The general commercial importance of the meshing differences between the large and small mesh nets may be only of small importance. Meshing in large mesh codends may be more troublesome, however, in the greater catches per set obtained by the larger commercial trawlers.

Investigators working on the Pacific Coast of the United States on a similar species have come to different conclusions regarding meshing. In the Seventh Annual Report of the Pacific Marine Fisheries Commission for the year 1954 it is stated that studies of the selectivity of trawl nets for the Pacific ocean perch, *Sebastodes alutus*, indicate that probably the 4-1/2 inch (11.4 cm) mesh net is too large for efficient commercial operations because it permits escapement of fish of commercial size and because of excessive gilling of these fish in the meshes.

References

DAVIS, F. M., 1934. Mesh experiments with trawls 1928-1933. *Fish Invest. Lond.*, Ser. 11, 14 (1): 1-56.

PACIFIC MARINE FISHERIES COMMISSION. *Seventh annual report for the year* 1954, pp. 1-20.

APPENDIX: OTTER TRAWLS AND MESH MEASUREMENTS FOR SELECTION EXPERIMENTS

Contents

Otter Trawls Used by *Investigator II* in Selection Experiments (No. 36 Net)

Standard No. 36 net
Headline 60 feet Footrope 80 feet
Wings upper: 10/60, 64 meshes long, 5″ mesh, 125/3 ply single
Wings lower: 30/45, 108 meshes long, 5″ mesh, 125/3 ply single
Square: 180/140, 30 meshes long, 5″ mesh, 125/3 ply single
Belly: 140/60, 90 meshes long, 5″ declining to 3-1/2″ mesh, average 4-1/2, 125/3 ply single
Lengthening piece: 60/60, 70 meshes long, 3-1/2 mesh, 125/3 ply single
Codend: 60/60, 70 meshes long, 3-1/2 mesh, 125/3 ply double
All netting treated manila.

No. 36 large trawl for alternate haul experiment, trip 11, 1955
Headline, footrope, wings and square same as in standard trawl
Belly: 140/40, 77 meshes long, 5″ mesh throughout, 125/3 ply single
Lengthening piece: 40/40, 40 meshes long, 5″ mesh, 90/3 ply single
Codend: 40/40, 45 meshes long, 5-1/2″ mesh, 90/3 ply double
All netting treated manila.

Codends with the same specifications as those in the large mesh No. 36 were used in the *Investigator II* covered codend experiments trips 2, 3 and 4, 1954 and in trips 2, 3 and 8, 1956, and the codend of the standard net was used in trips 2, 3 and 4, 1955.

Otter Trawls Used by *Marinus* in Selection Experiments (No. 35A, Nfld. Research Net)

Standard No. 35A
Headline 50 feet, Footrope 70 feet
Wings upper: 8/46, 50 meshes long, 6″ mesh, 125/3 ply single
Wings lower: 25/35, 85 meshes long, 6″ mesh, 125/3 ply single
Square: 138/110, 25 meshes long, 6″ mesh, 125/3 ply single
Belly: 110/50, 80 meshes long, 10 meshes 6″, 15 meshes 5-1/2, 15 meshes 5″, 15 meshes 4-1/2, 15 meshes 4″, 10 meshes 3-1/2, 125/3 ply single
Lengthening piece: 50/50, 40 meshes long, 3-1/2″ mesh, 125/3 ply single
Codend: 50/50, 70 meshes long, 3-1/2″ mesh, 125/3 ply double
All parts of net treated manila.

No. 35A large mesh net for alternate haul experiments, trip 11, 1955, trips 3 and 4, 1956 (Same large mesh net used in all sets. Same standard small mesh net used trip 11, 1955, 3, 1956 and 4 sets of trip 4, 1956. New standard small mesh net used after 4 sets trip 4, 1956).
Headline, footrope, wings and square same as in standard net.
Belly: 110/36, 73 meshes long, 10 meshes 6″, 15 meshes 5-1/2″, 48 meshes 5″, 125/3 ply single
Lengthening piece: 36/36, 28 meshes long, 5″ mesh, 100/3 ply single
Codend: 36/36, 45 meshes long, 5-1/2″ mesh, 100/3 ply double
All parts of net treated manila.

No. 35A standard net but with large mesh codend covered with shrimp netting

Marinus, trip 8, 1956, covered codend
Large mesh codend: same specifications as above for *Marinus* trip 11, 1955 and trips 3 and 4, 1956.

Marinus, trip 9, 1956, covered codend
Codend: 36/36, 49 meshes long, 5″ mesh, 90/3 ply double manila
Shrimp-net cover – manila – 1-3/4 inch mesh.

Cover

For the *Investigator II* experiments the cover had a width 5 feet greater and a length 8 feet longer than the codend and for the *Marinus* experiments the cover was 8-1/2 feet wider and 6-1/2 feet longer thau the codend, the widths and lengths in each case being stretched mesh sizes overall as manufactured.

The cover extended above the whole codend and was attached to the side lacings and to the junction of the lengthening piece and codend. Posteriorly the cover was attached 6 free meshes in front of the cod-line but all of these free meshes and the whole bottom part of the codend were lined with 1-3/4 inch manila shrimp netting. The cover had a codend opening of its own.

Alternate Hauls

The otter trawls used for the alternate hauls by the *Marinus* had no protective chafing gear either above or below the codend. The *Investigator II* codend used in alternate hauls had the usual cow-hide protection below but no chafing gear above the codend. In the experiments using a covered codend the length of each haul on bottom was a half hour whereas in the alternate haul experiments the length of each haul on bottom was one hour.

Comparative Results from Use of the American-type and the Scottish-type Gauges

Meshes of the same codend were measured internally at random with the American-type pressure gauge and also with the Scottish-type mesh expansion gauge, each under 12 pounds pressure, with the result below:

Gauge type	No. of meshes measured	Average internal mesh size	
		inches	mm
American	117	4.87	124
Scottish	114	4.72	120

List of Tables Including Basic Data

The tables F - 1 to F - 15, listed below, give detailed data on length measurements of fish from the experiments referred to in the paper above. These tables – not printed in the paper – are filed in the ICNAF Secretariat, from where they can be requested for reference.

F - 1. Redfish escapement (by cm) through the codend in experiments using a codend with a shrimp net cover; 90,045 spec.

F - 2a. Length measurements of redfish caught by alternate hauls of large and small mesh otter trawls in same locality of Hermitage Bay; 61,942 spec.

F - 2b Supplementary data for Table F - 1.

F - 3. Escapement (by 3 cm groups) of male and female redfish through the codend in covered codend experiments; 66,318 spec.

F - 4. Numbers (by 3 cm groups) of male and female redfish caught by alternate hauls of large and small mesh otter trawls; 110,904 spec.

F - 5. Selection of haddock in covered codend experiments with the *Investigator II*; length measurements (2 cm groups); 100,243 spec.

F - 6. Selection of cod in covered codend experiments with the *Investigator II*; length measurements (2 cm groups); 13,623 spec.

F - 7. Selection of American plaice in covered codend experiments with the *Investigator II*; length measurements (2 cm groups); 2589 spec.

F. - 8 Selection of witch flounder: covered codend experiments of the *Marinus*, 1956; length measurements (2 cm groups); 4229 spec.

F - 9. Selection of witch flounder: Alternate one-hour hauls of large and small mesh nets by the Marinus, trip 11, 1955 and trips 3 and 4, 1956; length measurements (2 cm groups); 2589 spec.

F - 10. Haddock girth % – (averages by 2 cm length groups), *Investigator II*, trip 2, 1954, and trips 2, 3 and 8, 1956.

F - 11. Cod girth (% averages by 5 cm length groups), *Investigator II*, trips 2 and 3 and 8, 1956.

F - 12. Redfish girth (% averages by 2 cm length groups), *Marinus*, trip 2, 1957.

F - 13. Length frequencies of all redfish meshed in codends and wings of large and small mesh otter trawls in *Marinus* alternate experiments, trip 11, 1955 and 3 and 4, 1956 (50 sets and total of 50 hours dragging in Hermitage Bay by each type of net); 4909 spec.

F - 14. Length frequencies of redfish meshed in codends and wings of large and small mesh otter trawls in *Marinus* experiments, trip 11, 1955, and trips 3 and 4, 1956, and as % of total catches; (102,407 spec.).

F - 15. Mesh measurements of the no. 36 otter trawl used by the *Investigator II* and of the no. 35A NFLD research net used by the *Marinus* in Selection experiments.

23.

On the Selectivity of Trawls and Drift Nets

by

A. TRESCHEV[1]

Abstract

A review is given of the results of Soviet studies on selecticity of bottom trawls used for cod fishing in the Barents Sea and on selectivity of herring drift nets in the North Atlantic.

Selectivity of trawls is greatly affected by the design of the codend. In trawling, codend meshes of conventional design assume a shape of considerably elongated diamonds and this circumstance hampers the elimination of undersized cod, even if the size of mesh is increased to 120 mm. Attempts to improve the opening of mesh and, consequently, the selective capacity of codend merely by tightening the trawl net to belly-lines, have proved unsuccessful.

Success has been gained when a new codend made of several pieces of net webbing with different meshes was experimented.

On the selectivity of drift nets, some authors (in the process of studying the relation between selective capacity of nets and the size of mesh as well as other factors influencing the selectivity) have come to the conclusion that variations in the shape of bodies, elongation of threads and shrinking deformation of fish's body are due to the tension on the thread.

As world fishing intensity is increasing, the catching of young fish of commercial species may affect the abundance of their stock. That is why the study of gear selectivity is becoming more important. The general theory of this problem, and especially its application to various species of fish, may evidently be worked out only on the basis of generalization of studies conducted in different countries. Therefore it is worthwhile to consider some investigations which have been carried out recently in the USSR as to the selective capacity of bottom trawls used for cod fishing in the Barents Sea and drift nets used for herring fishing in the North Atlantic.

It is still commonly thought that trawl selectivity depends largely on the size of mesh. To increase the mesh-size is thought to be sufficient for providing complete escape of undersized fish. Therefore all arguments are generally concentrated on determination of optimum sizes of mesh, techniques of mesh-measuring, etc.

The size of mesh is certainly of major importance. If the mesh is so small that undersized fish cannot squeeze through it, the selective effect of such mesh can be disregarded.

However, investigations conducted by Soviet scientists during recent years showed the impossibility of achieving selective trawling by merely changing the size of the mesh. Even meshes of the codend double in size will not secure a complete elimination of young though it will sharply decrease the catches of marketable fish.

Selectivity of trawls depends greatly on the design of the codend. Codends of modern trawls (Fig. 1) generally differ in size and cut, (number of meshes in breadth, extent of bating decrease and number of lateral rows). The shape of their meshes is determined by the hanging of the net web to the ropes and characterized by the

u_1 and u_2 (Fig. 2) $u_1 = \dfrac{OC}{a} = \sin\alpha$

$$u_2 = \frac{OB}{a} = \cos\alpha$$

Hanging of the forward section of the net to the head line and ground rope is usually taken

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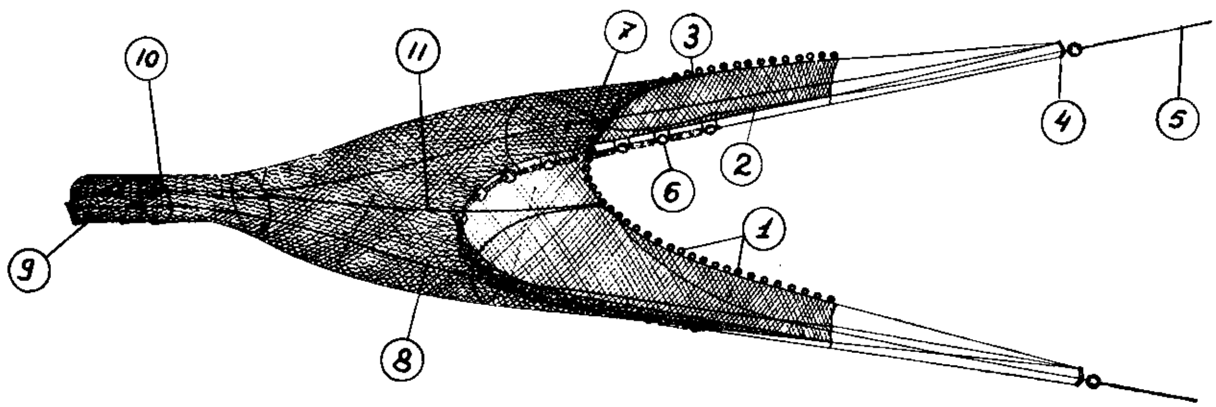

Fig. 1. Diagram of the bottom trawl. 1 - floats, 2 - foot rope, 3 - head line, 4 - butterfly, 5 - ground cable, 6 - ground rope, 7 - quarter rope, 8 - bellyline, 9 - hides, 10 - double bag. 11 - pokeline.

equal $u_1 = 0.33$ or $u_1 = 0.50$. The web is spread along the length of the bellylines at the hanging coefficient u_1 close to 1, sometimes with the bellylines even slackened to a certain degree.

In trawling, this way of hanging the codends results in their meshes narrowing diamond-shaped which practically keeps the meshes closed. The strain on the net twines reaches several kilogrammes. One should also bear in mind that codends are usually made of double web and are fitted underneath with preservative aprons; sometimes for safety reasons in hauling, the codends are also fitted with half-size netted covers. It is quite evident that in trawling the

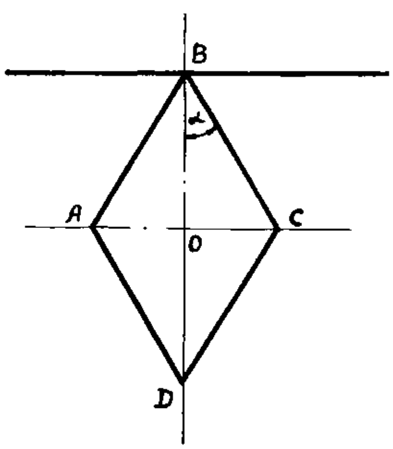

Fig. 2. Diagramatic representation of a mesh.

codends of such construction would not liberate even a smaller fish, no matter whether the mesh is a few mm wider or narrower.

Special investigation into this matter has been continued in the Barents Sea by Mrs. V. I. Fedorkova, the Polar Institute of Marine Fisheries and Oceanography, since 1954. One of the experiments was to put a regular commercial codend inside a larger fine-meshed (54 mm) cover made of N20/60 cotton thread. To protect this fine-meshed cover it was put in another bag made of stouter material.

Observations, followed by thorough analyses of catches in both main and supplementary codends, showed that enlarging the mesh of the existing type of the codend even up to 120 mm would not wholly eliminate the non-marketable fish.

It was proved by the experiments that from 2 to 10% of the catch gets in the fine-meshed cover; mainly it is fish of 30-40 cm, whereas great numbers of smaller fishes up to 30 cm are retained in the large meshed codend This is credited to the fact that the fish may escape only during the haul owing to periodical releases of the strain on the net.

After such results were obtained attempts were made to attain an elimination of smaller fish from the codend by changing the manner of hanging the codend to the bellylines. A hanging which would ensure the best opening of meshes under the coefficients $u_1 = u_2 = 0.707$ was experimented. Such a hanging of codends with 110 mm mesh proved to be quite satisfactory from the point of selection of young codfish. Catches of fish up to 36 cm made with the experimental codend were on the average less by 53% in comparison with the codend having a hanging $u_1 = 0.5$. At the same time the experiments showed that with catches over 1.5 tons the net shifts (creeps) along the bellylines under the strain of the twine caused by hydrodynamic resistance of the catch, so the hanging is gradually changing; the meshes of the forward part of the codend are getting stretched and the hanging coefficient on the bellyline is approaching 1. Strain in the end-part of the codend is then released and an excessive slack in this part hampers the normal process of trawling. This effect could not be overcome by merely tightening the net to the bellylines so other ways had to be devised to secure the opening of meshes in trawling.

In 1956 a new trawl codend was designed and tested by Mrs. V. I. Fedorkova; it was characterised by a change in shape of meshes ensured by gradual increase of size without altering the hanging coefficient $u_1 = 0.95$-1. To have this done, narrow strips of webbing each of 8 meshes high with a knot to knot lumen = 90 mm were hung to the bellylines in regular manner, *i.e.* at $u_1 = 0.95$. To these strips were added the strips of 5 meshes breadth with a lumen between knots = 100 mm; the main web of needed breadth and a mesh-size of 110 mm was inserted between the edges of the aforesaid strips (Fig. 3). This construction of a codend excluded shifting of meshes

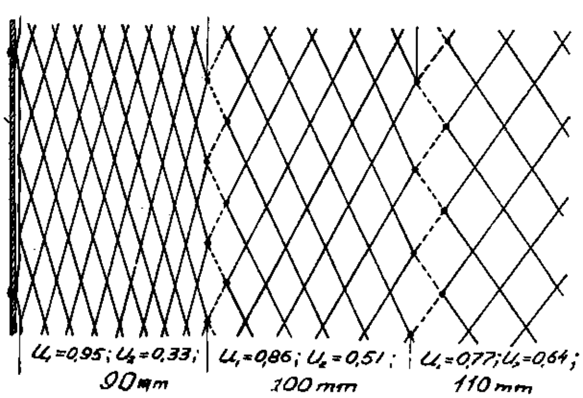

Fig. 3. Joint parts of different mesh sizes in the experimental trawl codend.

along the bellylines and ensured their proper opening.

Trials of these codends in the Barents Sea demonstrated their high selective capacity. Due to a different distribution of tension in such net the codends should be manufactured of highly resistant substances such as capron, nylon, etc.

In contrast to the case with trawl, the selectivity of herring drift nets is determined largely by the size of mesh; 1 mm deviation in this case is of major importance.

All herring drift nets have about the same construction, so apart from the mesh-size their selectivity is generally influenced by the following factors:

1. Variation in the shape of fishes.
2. Different mesh-sizes.
3. Stretching (lengthening out) of the threads caused by exertion efforts of fish.
4. Shrinking (deformation) of fish's body due to the tension on the thread.

We do not take into account here the diameter of the thread, elasticity and coloration of webbing, such factors affecting the catching capacity of the net rather than its selectivity.

Selectivity of nets in relation to the specific dimensions of fish (girth, length and weight) has been investigated for a long time now; thus were established such empirical formulae as:

$$a = k_1 . l \; ; \; a = k_2 \sqrt[3]{G}$$

(where a = size of the mesh; k_1 and k_2 = empirical coefficients; 1 = length of fish, G = weight of fish). Professor Baranov who has studied this problem proved that the curve of selectivity is similar to the curve of normal distribution.

Its peak corresponds to fish with $\frac{S}{4a} = xo$; where S = the girth at which the fish is meshed; a = size of the mesh; xo = the ordinate corresponding to the peak of the selection curve.

Using the principle of mechanical similarity he inferred that the shape of the selection curve of fishes of different sizes but of the same species remains constant provided that deviations from the optimum size are expressed in fractions of the optimum size:

$$\mathcal{S}(l) = e^{-h^2\left(\frac{l - l_o}{l_o}\right)^2}$$

where e = the Napier number
h = degree of precision
l = characteristic size of fish
l_o = optimum value of characteristic size of fish. The index of precision value -h is different for different species.

During 1954-56 U.A. Isnankin, using Professor Baranov's method, studied in the North Atlantic the influences of imperfect mesh sizes on the selectivity of herring nets. He came to the conclusion that the distribution of mesh sizes in the net, as determined by numerous factors in the process of manufacturing and exploitation, also conforms to the law of normal distribution.

The selection curves of a net with imperfect mesh sizes differ only in the value of the coefficient of variation.

Taken together the changes of shape of the fish and the imperfect mesh considerably smooth out the catching efficiency curve.

The body of the fish is shrinking due to its efforts to squeeze through the mesh which itself is enlarged owing to elasticity of the twine. Thus if herring nets are made of Nos. 34/6 and 34/9 cotton twine their meshes stretch by an average of 6%.

Entangling of fish in the mesh mostly occurs when the actual perimeter of the mesh is about 5% less than the maximum girth of the fish, according to the observation data obtained by V. N. Girenko, who investigated the relation of the mesh perimeter to the girth of Pacific herring. So these two factors fully compensate one another and thus do not substantially affect the curve of catching efficiency. Consequently, the decisive factor determining the selectivity of herring drift nets as well as of any other nets of similar construction is the mean (nominal) size of the mesh.

The nominal mesh size for each species of fish must be determined on the basis of biological data assuming the principle that the young of commercial fish should not be taken.

There is a minimum and a maximum size of fish caught by a net with a given mesh size.

The minimum limit of the net (mesh) selectivity is determined by the fish whose girth size (S) behind the extreme back opercle is equal to the perimeter of the mesh. These fish are entangled by catching the opercle in the twine of the net.

The maximum limit of the net (mesh) selectivity will be theoretically determined by those fish whose maximum girth (S max.) is equal to the perimeter of the mesh. To have the fish securely retained by the net, the perimeter of the mesh lumen should in fact be just a little less than the maximum girth of the fish.

Hence the girth of the fish retained by the net (mesh) lies within the limits S - S max. The relation between the girth and the length of each species of fish is easily derived from measurements.

This offers a possibility to describe the limits of gill net selectivity directly in terms of the length-range of the fish caught by a given net (selection-range). This will allow more precise selection of the needed assortments of nets.

The relation of mean length of fish, corresponding to the selection-range to the average size of netting mesh can serve as an index of selectivity of a given net. The percentage difference between above mentioned relation and the relation of the length to the girth of minimum sized fishes, permitted for catching, will show to what extent this net correlates with requirements of fishing.

24.

Experiments on the Fishing Effectiveness of Trawls Using Wire Cable Bridle and Wire Cable Bridle with Manila

by

Š. ZUPANOVIĆ[1]

Abstract

The present paper deals with fishing effectiveness and selectivity of trawls as indicated by experiments with wire and with manila bridles. The purpose was to examine the possibility of applying a common wire cable bridle instead of the generally used thicker one, of manila. Italian and Yugoslav fishermen have always preferred long and thick manila bridles since they believe that better catches are obtained with such gear. Our experiments have so far shown no significant difference between the two procedures. Investigations to establish clearly how the bridles operate at the sea-bottom, and how fish behave in front of the net opening, how in the codend itself, etc. will continue. Assistance in this connection has been promised by the Production Committee of the General Fisheries Council for the Mediterranean, particularly as regards the use of an underwater camera.

Introduction

The present analysis has the purpose to establish, on the basis of variations of the size of catches during a given period of time, the fishing effectiveness of trawls resulting from experiments made using wire cable bridle or wire cable bridle with manila.

The experiments, performed during the cruises of the M.V. *Bios*, took place south of Cape Ploče, at 43° 22′N, 15° 53′E and 43° 15′N, 15° 55′E, 14th to 19th June 1956 (24 hauls), 21st to 23rd October 1956 (12 hauls), 25th to 28th November 1956 (12 hauls), and from 1st to 6th February 1957 (24 hauls). The results obtained from 21st to 23rd October and from 25th to 28th November 1956 are given as a whole. The vessel, the net, the locality, the haul duration, etc., were the same for all experiments.

Experimental Design

Four daily standard hauls, each of one hour's duration, were alternatively made in the course of the experiment: two with a wire cable bridle and two with a wire cable bridle with manila. The trawl was hauled each day within the same sectors of area (marked by buoys). An insignificant southward shifting of sectors took place on each subsequent day. The hauls were made at random during the trawling operations. The purpose was to exclude, as much as possible, any "privilege" of one mode of proceeding over the other during the corresponding time intervals, closely connected with biological and other factors of behaviour of fishes.

Dimensions of the Main Components of the Employed Trawl

The trawl employed was of a home-made type. The dimensions of its main components were: wing, height 170 meshes; mesh size 55 mm; headline 18 m; groundrope 22 m; total length of net 46 m. The net was made of cotton. The mesh size of the codend was 22 mm. The codend was enveloped in a loose cover of netting of 40 mm mesh. In the course of the experiments either an 11 mm thick and 100 m long wire cable bridle or a 40 mm thick and 120 m long cable bridle with manila was used. The length of the cable towing warps was 450 m.

Both Yugoslav and Italian fishermen prefer wire cable bridle with manila measuring up to 300 m, being convinced that the thicker the cable the better the catch effect.

The purpose has been to prove that common wire cables can successfully be used as bridles instead of the usually applied wire cable with manila which are much thicker and more expensive.

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A more detailed statistical analysis of the significance of catch variations as to hauls, species, nets, bridles (with and without manila), and the outside uncontrollable factors of stock density in the experimental area will be dealt with in one of the publications of the Institute of Oceanography and Fisheries at Split.

Results

In consideration of the economic and biological values of single fish species and edible catches, and in order to provide an easy survey, we have divided the whole catch into five principal groups:

1. *Merluccius merluccius*
2. Selachians
3. Economically important fishes
4. Economically unimportant fishes
5. Edible catch

Table 1 contains the obtained results. The total weight difference and the numerical difference between the catches taken in both ways i.e. wire cable bridle minus wire cable bridle with manila are:

		Weight difference	Numerical difference
Experiment I.	(June 1956)	6.18	3.80
Experiment II.	(Oct. + Nov. 1956)	6.50	0.28
Experiment III.	(Feb. 1957)	1.08	—5.26

ABLE 1. Weight and percentage distribution of economically important and unimportant fishes and edible catch taken using wire cable bridle and wire cable bridle with manila. (b = Wire cable bridle; a = Wire cable bridle with manila.)

		Experiment I. June 1956				Experiment II. October and November 1956				Experiment III. February 1957			
Species and group:		kg	%	No.	%	kg	%	No.	%	kg	%	No.	%
'erluccius merluccius L.	b	105.20	12.65	663	2.75	42.01	7.37	224	1.27	40.45	8.02	279	1.26
	a	116.43	15.20	816	3.38	47.10	8.29	268	1.53	40.78	8.08	391	1.76
lachians	b	118.92	14.30	507	2.10	81.33	14.27	395	4.53	44.00	8.72	391	1.76
	a	74.53	8.96	528	2.19	44.79	7.85	311	3.54	26.71	5.29	263	1.19
conomically important fishes	b	109.83	13.20	1932	8.01	87.41	15.34	1610	9.20	68.55	13.59	1512	6.81
	a	94.20	11.32	1434	5.95	71.29	12.50	1113	6.36	67.40	13.36	1303	5.87
onomically unimportant fishes	b	78.81	9.47	8281	34.36	60.29	10.58	5159	29.47	68.94	13.66	6933	31.24
	a	76.58	9.20	7676	31.86	68.83	12.07	5596	31.97	81,31	16.12	8131	36.64
lible catch	b	28.71	3.45	1055	4.79	32.48	5.69	1339	7.66	33.07	6.55	1397	6.30
	a	28.32	3.40	1104	4.58	34,46	6.05	1487	8.50	33.33	6.61	1638	7.38
	b	441.47	53.09	12508	51.90	303.52	53.25	8727	49.86	255.01	50.54	10512	47.37
otal	a	390.06	46.91	11588	48.10	266.47	46.75	8775	50.14	249.53	49.46	11678	52.63

It is evident that the weight difference is larger than the numerical difference. It follows from the ratio that the average lengths and weights of the species fished with a wire cable bridle were larger than those fished when a wire cable bridle with manila was used.

Analysis of Results

From the number of benthonic invertebrates (Crustacea, Echinodermata, Cephalopoda, etc.) present in the catches by the two different procedures, we are able to estimate the effectiveness of the nets. By comparing the numbers of the most important benthonic invertebrates taken in the course of the 3 experiments, we obtain the following ratio: (b = wire cable bridle; a = wire cable bridle with manila):

Experiment No.		I	II	III
Nephrops	b	559	709	498
norvegicus	a	564	747	518
Stichopus	b	216	133	245
regalis	a	218	106	170
Echinaster	b	24	42	25
sepositus	a	24	23	25
Cephalopoda	b	596	630	899
	a	540	740	1120
Total	b	1395	1514	1667
	a	1346	1616	1833

From the number of bethonic invertebrata in the catches we are able to conclude that there was hardly any difference between the two procedures as regards the contact of the net with the sea bottom.

The fish catches, however, showed some variations as to the behaviour of single species. Thus *Merluccius merluccius* was always fished in larger numbers whenever a cable bridle with manila was used; *Raja clavata*, *Scylliorhinus canicula*, *Gadus capelanus*, and *Paracentropristis hepatus*, on the contrary, were more numerous when a wire cable bridle was applied;

wire cable bridle was applied; a rather insignificant divergence was shown by *Argentina sphyraena* and *Zeus faber* during experiments I and III. The numbers of several characteristic species (reacting in different ways) present in the catches taken by the two different procedures, during each of the three experiments, are as follows (b = wire cable bridle; a = wire cable bridle with manila):

Experiment No.		I	II	III
Scylliorhinus	b	222	132	41
canicula	a	322	146	61
Raja	b	272	248	301
clavata	a	199	162	227
Argentina	b	3071	2539	3669
sphyraena	a	2963	3552	5504
Gadus	b	1216	849	677
capelanus	a	842	432	531
Merluccius	b	663	224	279
merluccius	a	816	268	391
Zeus	b	40	58	42
faber	a	66	63	41
Paracentropristis	b	1491	390	472
hepatus	a	891	186	385

TABLE 2. Length average values of various fish species taken with application of wire cable bridle and wire cable bridle with manila.

Species	Experiment I.			Experiment II.			Experiment III.		
	Without manila Average cm A	With manila Average cm B	Difference A-B	Without manila Average cm A_1	With manila Average cm B_1	Difference A_1-B_1	Without manila Average cm A_2	With manila Average cm B_2	Difference A_2-B_2
Merluccius merluccius L.	28.07	24.69	3.38	26.85	26.46	0.39	26.27	26.08	0.19
Gadus capelanus Risso	13.21	11.53	1.68	13.50	12.30	1.20	14.07	13.82	0.25
Zeus faber L.	29.96	28.36	1.60	23.48	26.62	–3.14	22.65	25.05	–2.40
Lepidorhombus whiff jagonis Walb.	19.56	20.32	–0.76	20.04	21.15	–1.01	19.14	21.04	–1.90
Lepidorhombus bosci Risso[1]	21.91	21.77	0.14	22.15	22.00	0.15	21.38	24.00	–2.62
Lophius budegassa Spin.	29.21	28.22	0.99	25.00	26.10	–1.10	27.96	26.33	1.63
Raja clavata L.	44.00	37.20	6.80	37.05	31.86	5.19	34.89	32.43	2.46

[1] The only specimen of 44 cm, taken when a wire cable bridle with manila was used, has not been considered here.

Beside disclosing that the behaviour of fishes may vary, the experiments also direct our attention to the fact that the average length of the economically more important species was greater with a wire cable bridle than with a cable bridle with manila. The difference in average length values of various species is shown in Table 2. The difference in length is likely due to the varying extent to which the codend meshes are opened. When a wire cable bridle with manila is used (particularly if it be a longer and thicker one) the codend is likely to shrink owing to the effect of the bridle weight during trawling. This hypothesis, however, should be verified by further experiments.

A summary of the average lengths in Table 2 from experiments made with both kinds of bridle, reveals:

1. A decrease of the average length of predatory species:

Experiment No.	I	II	III
Average length	cm	cm	cm
Raja clavata	40.60	34.45	33.66
Lophius budegassa	29.16	25.05	26.33
Zeus faber	28.71	25.55	23.85

2. An increase of the average length of other economically important species:

Experiment No.	I	II	III
Average length	cm	cm	cm
Merluccius merluccius	26.38	26.65	26.18
Gadus capelanus	12.37	12.90	13.82
Lepidorhombus whiff-jagonis	19.94	20.59	20.09
Lepidorhombus bosci	21.84	22.07	22.69

The decrease of the average length of predatory species and the increase of the average length of other economically important species occurring at one locality suggest the existence of an important biological problem of relation between the species. By reducing the reproduction of predatory species (especially *Selachia* and *Lophius* sp.) in a locality, a quicker and unhindered development of other species is obtained. The awareness of these changes in the composition of the ichthyocoenoses, produced by man, can be of considerable importance for the examination of the extent to which stock density influences recruitment, mortality and dispersion, i.e. the three basic factors controlling population growth.

Conclusion

The fishing effectiveness of trawls used either with wire cable bridle or with wire cable bridle with manila was examined. Randomized blocks were used.

The results of the analysis do not disclose any significant difference between the two experimental designs. The application of the wire cable bridle with manila had contrary to what was expected, a negative effect on the catch of some species. The catches taken when the wire cable bridle was used, generally showed a greater average length of the economically important species. We have attempted to explain this difference by assuming a shrinkage of the codend mesh when the wire cable bridle with manila is used, owing to the effect of the bridle weight during the trawling operation. This hypothesis, however, should be verified by further experiments with both kinds of bridle and by underwater photographic pictures as well.

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