Trawl-Net Selectivity and the Survival of Fish Escaping from Cod-ends

Proceedings of a Rhode Island Sea Grant and New England Fishery Management Council Stock Conservation Engineering Workshop

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Trawl-Net Selectivity and the Survival of Fish Escaping from Cod-ends

Proceedings of a workshop for northeast region fishery conservation engineers held May 16 and 17, 1988, at the University of Rhode Island Graduate School of Oceanography, South Ferry Road, Narragansett, Rhode Island.

Preliminary research results reported by John Main and Jack Robertson of the Marine Laboratory, Department of Agriculture and Fisheries for Scotland, Aberdeen, Scotland.

Workshop cosponsored by the Rhode Island Sea Grant Marine Advisory Service and the New England Fishery Management Council. Workshop organized by Sal Testaverde, NEFMC Conservation Engineering Coordinator, and Joseph DeAlteris, RI SGMAS Commercial Fisheries Specialist.

CONTENTS

Introduction

Perhaps the least desirable characteristic of trawl fishing gear is its tendency to indiscriminately capture large numbers of immature, sub-legal, or non-marketable fish. Typically, these fish are discarded at sea and their likelihood of survival is reduced. The reasons for this have been known for some time and have to do with the design of the trawl and its mode of operation. Recent studies of fish behavior around trawls with remote-controlled video cameras have shown why selection of fish of different sizes is imperfect (i.e., not "knife-edged") and that fish escape at different rates from different sections of the net. In particular, as a trawl made of diamond mesh fills with fish, meshes in the central portion of the cod-end become elongate in shape and the area for escape available to the smaller fish is reduced significantly. Because the reduction in escape area is considered to be the primary factor limiting trawl selection performance, attempts have been made to design trawl gear in which all the meshes remain open during fishing.

Groundfish management reliance on stock conservation harvest regulations

New England groundfish managers began to rely on stock conservation harvest regulations to conserve northwest Atlantic finfish resources with the adoption of the interim groundfish management plan in 1982. Reliance on these methods continued with the implementation of the multispecies Atlantic Demersal Finfish Plan in October of 1986 and ADFP Amendment 1 in October of 1987. Although Amendment 1 contained new fishing-gear regulations designed to increase protection of depleted groundfish resources, approval by federal departments charged with responsibility for oversight of fishery management programs came only after vigorous debate with state and industry managers concerning the potential of gear-oriented conservation regulations for achieving management objectives at reasonable cost. As fishing gear conservation engineers met in Rhode Island to hear first-hand preliminary findings of Scottish researchers John Main and Jack Robertson, many were anticipating with some ambivalence the increased attention that fishing gear conservation issues would receive in the trade press and at management hearings throughout the coming fall and winter. In possession of advance copies of National Marine Fisheries Service stock assessments indicating the entire traditional finfish resource base to be at or near historic lows, and aware of widespread fisherman noncompliance with management regulations, many realized that successful fishery management under the current regime would require a much higher level of knowledge concerning the effectiveness and possibility for enforcement of many of the management regulations recently promulgated to conserve northwest Atlantic finfish stocks.

Methods for measuring selectivity

Several methods are used to quantitatively evaluate the selectivity[1] of alternative mesh sizes and shapes for different sizes and species of fish. The simplest method is to fish square- and diamond-mesh

[1]The term selectivity is used in two different ways. A trawl may be designed to catch flatfish, or a particular species of fish, more efficiently. This characteristic is sometimes referred to as providing good selectivity for a target species, or good species selectivity. Typically, the increased rate of species capture is due to differences in the behavior of the species when encountering the gear. More often, the term selectivity refers to the selection of different sizes of fish as a consequence of the mesh size(s) used to fabricate the trawl.

cod-ends on alternative tows (or from alternate vessels on the same grounds). However, this method has disadvantages. First, since it gives incomplete information on the stock being fished, it is impossible to calculate the impact of alternative mesh shapes and sizes on the catch. Secondly, there is always uncertainty about local variations in the abundance of the fish during each alternate tow, which means that selectivity experiments will likely require many hauls (perhaps 50), carried out in a very prescribed manner, to obtain valid statistical comparisons. (Poor weather, a torn net, or a hang-up can all nullify the validity of a pair of tows.) The alternative-haul method does allow one to plot length-frequency distribution curves for the species caught, and these typically indicate that square-mesh cod-ends retain larger round-bodied fish than diamond-mesh cod-ends of equal nominal measure.

Size selectivity can be evaluated more thoroughly by placing a **small-mesh cover** over the cod-end. The sum of the catch in the cod-end and the cover indicates the total fish population in the water volume screened by the gear, and the proportion of the size distribution of a particular species retained in the cod-end can be calculated. However, researchers report (Cooper and Hickey 1988) that there is always a danger that the cover will collapse onto the cod-end and inhibit escape, and thus this method requires

Table 1. Summary of recent square mesh selectivity results for North Atlantic groundfish.*

Nominal mesh size	Species	50% retention length	Selection range	Gear type and experimental method
60	scup	22.0	2.5	otter trawl with cod-end cover
70	haddock	25.4	4.7	otter trawl with cod-end cover
	whiting	28.2	5.0	otter trawl with cod-end cover
75	sole	20.3	4.8	beam trawl with cod-end cover
90	haddock	28.6	5.0	otter trawl with cod-end cover
	whiting	32.8	5.3	otter trawl with cod-end cover
120	haddock	44.7	4.2	trouser trawl
	haddock	49.0	—	trouser trawl
	cod	54.0†	5.0	trouser trawl
	cod	57.0	4.7	twin cod-end Danish seine
130	haddock	47.3	5.7	trouser trawl
	cod	59.7	10.2	trouser trawl
135	haddock	51.8†	4.2	trouser trawl
	cod	60.2	9.5	trouser trawl
140	plaice	31.0†	5.5	trouser trawl
	haddock	53.5†	5.5	trouser trawl
	pollock	58.5†	5.5	trouser trawl
	cod	61.4†	7.6	trouser trawl
155	plaice	34.5†	4.5	trouser trawl
	cod	65.0†	6.0	trouser trawl

*Results summarized from research reports listed in Further Reading section, page 35.
†knotless mesh

almost continuous visual monitoring of the trawl with a remote-controlled camera. An alternative method, popular recently with Canadian and European researchers, requires the fabrication of a twin cod-end, or **trouser**, trawl. In this experimental design, a small-mesh cod-end and the cod-end to be evaluated are towed side by side on the same trawl. (A vertical separator panel running from footrope to belly extension is often attached to the top and bottom of the net.)

Trawl-selection experiment results are usually reported for each species of interest as a histogram of length frequency for the experimental and small-mesh cod-ends, and a graph of the cumulative frequency distribution curve of percent retained versus fish length for the experimental cod-end (selectivity curve). Selectivity curves are often reported summarily by tabulating the **50-percent retention length** and the **selection range** (distance between 25- and 75-percent retention lengths).[2] When the

[2]The **selection factor** (50-percent retention length divided by the mesh size) is also reported. The selection factor is used as a rough index of species shape and escape behavior and allows one to determine the 50-percent retention length for alternative mesh sizes.

Table 2. Summary of recent diamond mesh selectivity results for North Atlantic groundfish.*

Nominal mesh size	Species	50% retention length	Selection range	Gear type and experimental method
60	scup	22.0	3.0	otter trawl with cod-end cover
75	sole	20.6	5.6	beam trawl with cod-end cover
90	haddock	23.3	5.7	otter trawl with cod-end cover
	whiting	24.5	6.7	otter trawl with cod-end cover
120	haddock	47.0†	—	trouser trawl
	cod	49.2†	4.7	trouser trawl
	cod	55.0	13.5	twin cod-end Danish seine
130	whiting	26.9	9.1	otter trawl with cod-end cover
	haddock	38.9	12.3	otter trawl with cod-end cover
	haddock	43.0	7.6	trouser trawl
	haddock	44.4	4.6	trouser trawl
	haddock	45.8	5.5	trouser trawl
	cod	58.7	8.8	trouser trawl
135	haddock	46.5†	6.8	trouser trawl
	cod	52.0†	5.7	trouser trawl
	cod	56.0	8.7	trouser trawl
140	plaice	34.0†	7.5	trouser trawl
	pollock	46.4†	7.3	trouser trawl
	cod	56.2†	8.1	trouser trawl
155	plaice	36.5†	6.5	trouser trawl
	cod	61.3†	6.2	trouser trawl

*Results summarized from research reports listed in Further Reading section, page 35.
†knotless mesh

selection range is exceedingly narrow (selectivity curve near vertical), selection is said to be "knife-edged."

Selectivity experiments on Northwest Atlantic groundfish

In 1929, experiments by the Savings Trawl Net Company of London found that cod-ends with square-mesh sections retained fewer small fish. Recent experiments comparing the size selectivity of square- and diamond-shaped cod-ends tend to indicate that, for round-bodied fish and equivalent nominal mesh sizes, square-mesh cod-ends possess larger 50-percent retention lengths and smaller selection ranges than diamond-mesh cod-ends (see research reports listed in Further Reading section, page 35). In practical terms, this means that use of square-mesh cod-ends could result in significant reductions in catches of small round-bodied fish (said another way, a square-mesh cod-end retains a larger proportion of large round-bodied fish). However, in most cases the experimental results have been quite variable (see Tables 1 and 2) and, due mainly to differences in the choice of experimental method, have not always been of the type useful for building industry consensus concerning the short- and long-term benefits of fishery management regulations requiring square-mesh cod-ends.

Biological and economic effects of mesh size and shape regulations

Requiring larger mesh or square mesh in the cod-end has biological and economic impacts similar to those of increasing the minimum legal possession size — that is, a short-term reduction in the marketable catch (some of the previously retained but smaller marketable fish now escape through the cod-end) and a longer-term catch effect due to the released fish growing larger and more of them joining the mature part of the stock and increasing the spawning biomass. The magnitudes of these effects will depend on the type of regulation considered and will differ among species for any particular regulation. Both short- and long-term effects for the alternative mesh sizes or shapes evaluated can be predicted given knowledge of the length composition of the catch and the fish population on the grounds, and the growth rates and natural and fishing mortalities of the primary species caught (Burd 1986). When knowledge of the fish population on the grounds is available (for example, from data generated using a small-mesh cover or trouser trawl), more of the information needed for evaluating the biological and economic implications of the experimental results is available.

In a single-species management framework, managers typically evaluate alternative cod-end designs by using the length-frequency histograms and selection curves to analyze how the 50-percent retention lengths relate to the minimum legal possession or market size, and to calculate the likely short-term impacts on catch. For a single-species fishery, a narrow selection range is always preferred.

In a multispecies framework, the evaluation of alternative trawl designs is a more complex undertaking as it requires analysis of biological and economic impacts on many species. These impacts may be of quite different magnitudes, each known with varying degrees of certainty, and — depending on relative species economic value, length at maturity, recruitment response to increases in the spawning stock, and natural and fishing mortality — determination of the "best" practical cod-end may require accepting a design with less than optimal selection performance for some species. To simplify the determination of fishing gear conservation regulations on the harvest from a multispecies fishery, gear researchers are attempting to uncouple interspecies management effects through the development of fishing gears with superior species selectivity. Because different species behave differently when encountering fishing gear, work to improve species selectivity has required the concomitant development of remote-controlled underwater observation systems. (Workshop participants viewed videotapes of a shrimp "separator" trawl obtained using a towed underwater gear-observation system developed at the Massachusetts Institute of Technology.)

Factors influencing selectivity experiments

An interesting result of the selectivity experiments so far conducted concerns the wide variety of factors that influence cod-end size selectivity and its measurement. Investigators report that selection performance is influenced to a greater or lesser extent by: choice of experimental method, ambient light levels and direction of currents and tides, species feeding and escape behavior, catch rates, tow speed and duration, whether the cod-end mesh is knotted or knotless, and the manufacturing quality standards of the mesh manufacturer. Given the need to establish management and industry consensus concerning the benefits of alternative management regulations, U.S. trawl-gear researchers should consider seriously the issue of developing a standard experimental procedure for the production of selectivity curves. Items worth considering include (1) standardization of experimental method and publication of specifications and instructions for experimental design and standard trawl fabrication; (2) establishing a standard mesh fabrication design and minimum sampling criteria for determining the correspondence of nominal mesh size to average mesh size measured using a standard technique (many Canadian and European researchers use an ICES mesh gauge under 4 kg tension); and (3) establishing minimum tow and fish numbers and tow duration, and requiring monitoring of trawl-mouth geometry with acoustic net-sounding equipment. The advanced nature of Canadian selectivity research, the fact that Canadian and U.S. fishermen catch the same species, and the reality of both nations' managing transboundary stocks all argue for an increased emphasis on **cooperative** development of research methods and experiments by U.S. and Canadian researchers.

Do square-mesh escapes have a higher survival rate?

A second issue concerns preliminary research results indicating increased mortality of fish escaping through diamond-mesh cod-ends when compared to square-mesh (DeAlteris and Reifsteck 1988; Main and Sangster, this publication). Obviously, if the purpose of cod-end mesh-size regulations is to reduce the catch of juvenile fish so that they may grow larger and contribute to future stock recruitment, the existence of a significantly higher survival rate for square-mesh escapes favors the introduction of regulations requiring square-mesh cod-ends. Although present results are based on very small samples, and widely accepted methods for evaluating this issue are not yet developed, the importance of this issue to the future management of regional groundfish stocks is indisputable. In addition to directing increased resources at verifying whether significant differences in cod-end escape mortality exist between square- and diamond-mesh cod-ends, more work needs to be done to evaluate the selectivity of alternative cod-end designs on northwest Atlantic by-catch species and flatfish. Once accomplished, this work would provide the required foundation upon which efforts to better assess the economic and biological impacts of alternative cod-end designs could be based.

Ed Richardson, Director
Rhode Island Sea Grant Marine Advisory Service

Square and Diamond Mesh in Trawl and Seine Net Cod-end Selectivity

J. H. B. Robertson

INTRODUCTION

COD-ENDS OF MANY types of trawl have been observed with remote-controlled underwater television and normally have the shape sketched in Figure 1(a). The netting is hung so that the meshes are diamond shaped and elongate under tension. As the cod-end fills with fish the end meshes are obstructed, water flow is diverted, and the end becomes bulbous. In the central part of the cod-end the meshes are stretched and closed, preventing the escape of all but the smallest fish. In the forward part of the cod-end the diameter broadens to join the net and the meshes are more open. Most escapes are seen to take place from the open meshes on the front of the bulb. Only a small proportion of the meshes in a cod-end are opened widely enough to allow fish to escape. This was suspected during earlier work on cod-end mesh selection and was investigated by Beverton (1963), who used divided small-mesh covers on the various sections of a cod-end to demonstrate that fish escaped mostly from the front and rear parts and not from the central sections.

The degree of opening of the meshes of a cod-end depends on various aspects of its construction. Both the number of meshes around the circumference of a cod-end and the length of the extension piece joining the cod-end to the net affect selectivity. Increasing the number of meshes around the cod-end and lengthening the extension piece both reduce mesh opening. If selvedge ropes are attached to a cod-end, some of the tension in the netting is transferred to the ropes, and under load the meshes are less stretched and more open.

Cod-ends are imperfect selectors of fish. Investigation of the discard rates of haddock and whiting on Scottish commercial vessels has shown that this is particularly true for fish smaller than the permitted minimum landing size. Since most discarded roundfish die, any means of sharpening the selectivity of the net and the cod-end would be beneficial. A cod-end constructed with the netting rigged to hang with the bars parallel and perpendicular to the flow has squared-shaped meshes (see Figure 1[b]) (Robertson 1986). Such a "square-mesh" cod-end retains its shape under load and the meshes are not stretched and constricted. The use of netting hung like this in a cod-end was first described by Holt (1895), who reported that "it caught considerably less small fish than an ordinary cod-end with mesh of the same size." In a paper to ICES in 1929, J. Gelder of the Netherlands described the insertion of a small square-mesh section at the end of the top panel of a four-panel diamond-mesh cod-end. This cod-end was held open by a wooden frame and it was claimed that fewer small fish were retained.

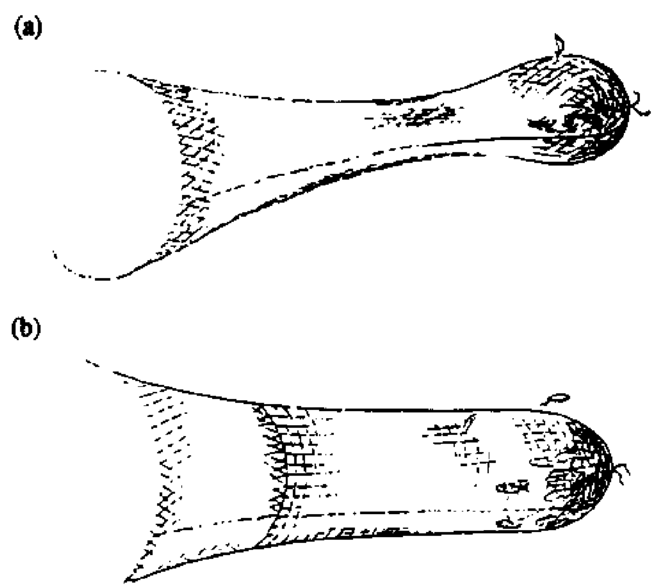

Figure 1. The shapes of (a) a conventional "diamond-mesh" cod-end and (b) a novel "square-mesh" cod-end, when attached to a trawl and towed.

This paper describes a series of comparative fishing experiments in which the size selectivity of "square-mesh" cod-ends was compared with that of conventional "diamond-mesh" cod-ends. Cod-ends of a range of mesh sizes were tested on both trawls and seines. Fishing trials took place on chartered commercial vessels. Small-mesh cod-end covers were used to retain the fish escaping from the test cod-ends. The covers were of the totally enclosing type recommended by Pope et al. (1975); i.e., 1.5 times the size of the cod-end in length and width. There is always some doubt about the use of covers, since they are capable of obstructing the cod-end meshes and preventing fish escape.

To be more selective than a conventional cod-end for a given mesh size, a novel cod-end would require a narrower selection range at the same 50-percent retention length. The objective of the exercise described here was to measure and compare the 50-percent retention lengths and selection ranges of the two types of cod-end over a range of mesh sizes. The catches consisted mainly of haddock *(Melanogrammus aeglefinus)* and whiting *(Merlangus merlangus)*, and only data on these species are presented.

MATERIALS AND METHODS

Cruises

The work took place between 1982 and 1985. Table 1 gives for each cruise the date; the name, type, and size of vessel; the type of fishing gear used; and the total number of hauls.

Cod-ends and Covers

The cod-ends and covers for the experiments are listed in Table 2, which gives for each the measured mesh size, length in meshes, width in meshes, and information on the twine (Rtex [g/km], single or double, braided or twisted). Some of the cod-ends were used on more than one cruise. All were made from polyethylene, mostly colored green, with a few colored orange. The mesh sizes (stretched inside mesh lengths) were measured, with netting wet, using a 4 kg ICES gauge. In both types of cod-end mesh sizes were measured in the same way, in the "N" direction of the netting (ISO 1974), between opposite corners of a mesh. The diamond-mesh cod-ends were of the type typically used in the Scottish fishing industry — that is, two-panel construction and 120 meshes around at a mesh size of 80 mm. Practical aspects of the design, construction, rigging, and use of square-mesh cod-ends are described in detail by Robertson (1986). The covers were attached to the extension piece three rows ahead of the front of the cod-end. The square- and diamond-mesh cod-ends of each mesh size contained the same numbers of twine bars, were the same stretched length, and had the same number of meshes around the circumference.

Experimental Procedure

During each cruise, the diamond- and square-mesh cod-ends were used on the same net and exchanged at convenient intervals, usually daily. The length of each trawl haul

Table 1. Details of the experimental cruises.

Cruise	Date	Name	Vessel LOA (m)	HP	Gear type	No. of hauls
1	Dec 1982	Harvest Reaper	17 FR 177	280	Trawl	44
2	Feb 1983	Edelweiss	17 FR 104	410	Trawl	27
3	Sep 1983	Heather Sprig	17 BCK 153	250	Trawl	35
4	Mar 1984	Orkney Reiver	22 K 49	550	Trawl	18
5	Feb 1985	Orkney Reiver	22 K 49	550	Trawl	20
6	Dec 1983	Boy Andrew	24 WK 171	600	Seine	25
7	Jun 1984	Boy Andrew	24 WK 171	600	Seine	46

Table 2. Construction of cod-ends and covers.

Cruise	Type	Measured mesh size (mm)	Meshes long	Meshes around	Twine Rtex	Twine Single/ double	Twine Construction
1	Diamond	123.5	49	82	4310	Double	Braided
	Diamond	86.5	70	120	4310	Double	Braided
	Square	89.4	136	120	4310	Double	Braided
	Square	67.9	179	155	3050	Single	Twisted
	Cover	**27**	**681**	**464**	**1720**	**Single**	**Twisted**
2	Diamond	122.3	49	82	4310	Double	Braided
	Diamond	87.1	70	120	4310	Double	Braided
	Square	87.4	139	120	4310	Double	Braided
	Square	74.9	162	150	3570	Single	Braided
	Cover	**27**	**681**	**464**	**1720**	**Single**	**Twisted**
3	Diamond	85.8	71	120	4310	Double	Braided
	Diamond	99.5	55	98	4310	Double	Braided
	Diamond	121.8	50	88	4310	Single	Braided
	Square	67.9	179	120	4310	Single	Braided
	Square	74.4	162	120	4310	Double	Braided
	Square	86.0	141	120	4310	Double	Braided
	Cover	**28.2**	**681**	**464**	**1720**	**Single**	**Twisted**
4	Diamond	81.0	71	120	4310	Double	Braided
	Square	78.4	162	120	4310	Double	Braided
	Cover	**26.0**	**656**	**460**	**1720**	**Single**	**Twisted**
5	Diamond	80.8	71	120	4310	Double	Braided
	Square	80.5	71	120	4310	Double	Braided
	Cover	**28.0**	**656**	**460**	**1720**	**Single**	**Twisted**
6	Diamond	86.1	70	120	4310	Double	Braided
	Diamond	79.1	77	120	4310	Double	Braided
	Square	86.1	141	120	4310	Double	Braided
	Square	79.0	154	120	4310	Double	Braided
	Square	60.7	200	146	4310	Double	Braided
	Cover	**26.3**	**656**	**460**	**1720**	**Single**	**Twisted**
7	Diamond	87.0	70	120	232	Double	Braided
	Diamond	79.1	77	120	232	Double	Braided
	Square	86.1	70	120	232	Double	Braided
	Square	79.0	77	120	232	Double	Braided
	Square	60.7	100	146	232	Double	Braided
	Cover	**27.0**	**656**	**460**	**580**	**Single**	**Twisted**

Note: The cod-ends were constructed from polyethylene; the covers for cruises 1, 2, and 3 from nylon; and the covers for cruises 4, 5, 6, and 7 from polyethylene.

was the same as that normally practiced by the vessel when fishing commercially; i.e., between one and three hours. After each haul, the catches in the cod-end and cover were boxed and sorted separately. Catches of less than six boxes (40 kg per box, approximately) were sorted completely into species. Most catches were larger; however, a sample of at least six boxes, and sometimes up to 12 boxes, was taken from both cod-end and cover and sorted into species. Subsamples were then taken from each species group and fish lengths measured. The size distributions of the measured subsamples of each species were then raised to the totals for the whole catches in cod-end and cover.

RESULTS

Catches were measured on all hauls in which the cod-end was undamaged and at least half a box of haddock or whiting was taken. It would not be practical to list the complete set of length-frequency distributions in this paper. Therefore, to illustrate the nature of the catches, some representative length frequencies are presented in Figures 2 and 3. The size of the catches varied widely. Haddock and/or whiting constituted the major part of the catch in almost all hauls. Figures 2 and 3 present data for haddock and whiting respectively, from cruise four (trawl, 1984, "Orkney Reiver") and from cruise seven (seine, 1984, "Boy Andrew"). These

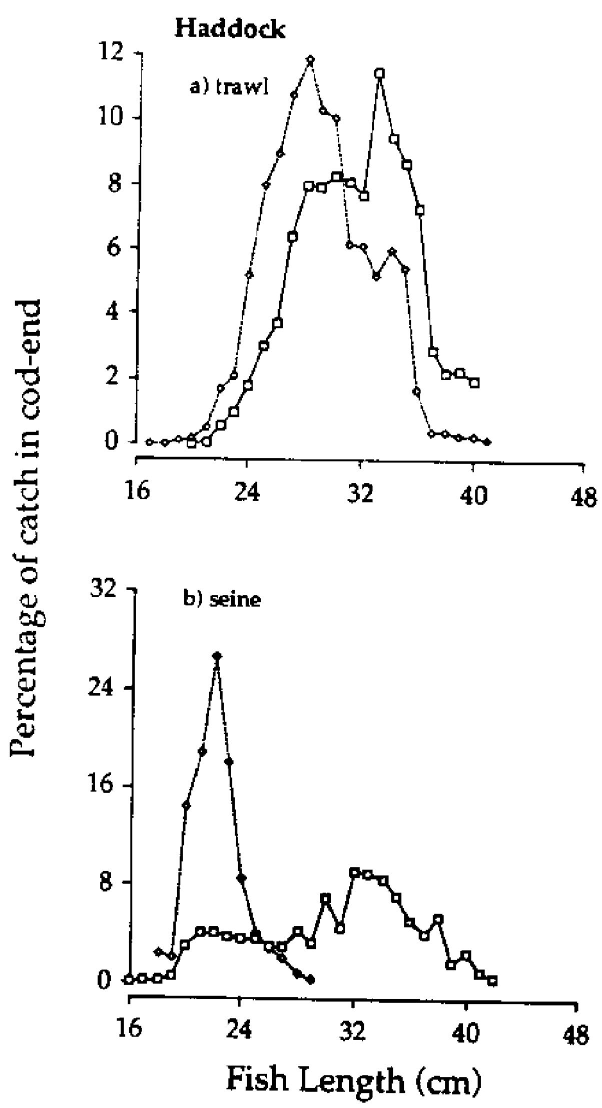

Figure 2. The length-frequency distributions of the total catches of haddock retained in diamond-mesh (◊) and square-mesh (□) cod-ends of 80-mm (nominal) mesh size; (a) in a trawl on cruise 4; (b) in a seine net on cruise 7.

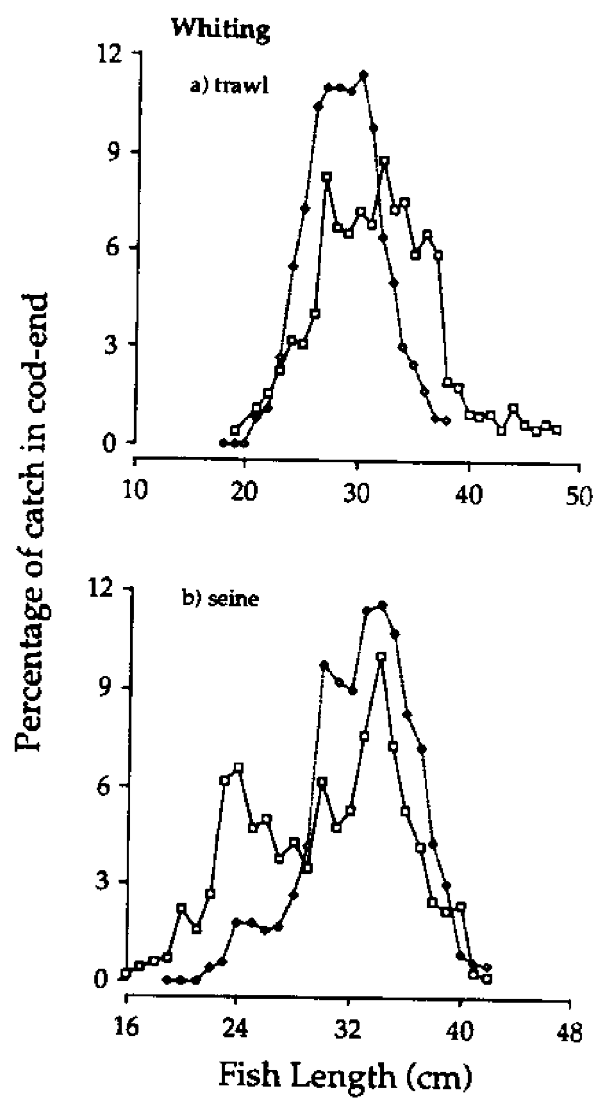

Figure 3. The length-frequency distributions of the total catches of whiting retained in diamond-mesh (◊) and square-mesh (□) cod-ends of 80-mm (nominal) mesh size; (a) in a trawl on cruise 4, (b) in a seine net on cruise 7.

figures give the combined length-frequency distributions for all hauls with diamond- and square-mesh cod-ends of the same nominal 80-mm mesh size. To aid comparison, the numbers at each length are expressed as percentages of the total catch of all sizes retained in each type of cod-end. On both cruises the two species sampled were found to have more than one year class in the length range of interest. The trawl and seine data in Figures 2 and 3 were collected in March and June 1984, respectively, on different grounds. By comparing the distributions with the market landing data, the year classes in each figure can be identified as follows: Figure 2(a), years 2 and 3; Figure 2(b), years 1, 2, and 3-plus; Figure 3(a), years 2 and 3; and Figure 3(b), years 1, 2, and 3-plus.

ANALYSIS

The catch data for each haul were treated separately. The percentage of the catch at each length retained by the cod-end was calculated and plotted against length. Initially, selection curves were fitted by eye, giving equal weight to each point. It was found that this produced a bias towards narrower selection ranges in square-mesh cod-ends, particularly for whiting. The catch numbers at each length vary widely and there is a relative scarcity of larger fish in the data. Thus the higher percentage points in many selection curves are relatively inaccurate compared with the lower points. This may in part explain the bias found. A systematic technique seemed to be required to avoid bias in estimating the selection parameters. The logistic function was chosen as a suitable symmetric curve to fit the data (Holden 1971). The method of fitting used maximum likelihood and thus the largest samples determined the positions of the curves. As an illustration of the technique, Figure 4(a) shows logistic curves fitted to the data from two hauls on cruise 5. These are for a square- and a diamond-mesh cod-end of the same nominal mesh size. The measured size ranges do not fully cover the selection curves, as was frequently found. The transformed values and the corresponding fitted straight lines are shown in Figure 4(b).

Using this method of analysis, the 50-percent retention length and the selection range for each haul were estimated. (The 50-percent retention length of a cod-end for a particular species is the fish length at which 50 percent of the species entering the cod-end is retained, and the selection range is the length difference between the 75-percent retention length and the 25-percent retention length.) Not all hauls produced enough of both species to justify measurement. At the larger mesh sizes, the relative scarcity of fish at the sizes around the 50-percent retention length reduced the accuracy with which the selection parameters could be estimated. In the trawl data, five haddock hauls and six whiting hauls were excluded from further analysis. Similarly, in the seine-net data, four haddock hauls and three whiting hauls were excluded. In three of the excluded haddock trawl hauls the 50-percent retention length was below 15 cm with an 87-mm mesh size, and in the remainder of the excluded hauls the selection parameters had extreme values since the 50-percent retention length was outside the measured length range of fish.

Trawl

In Figures 5 and 6 the 50-percent retention lengths and selection ranges for haddock and whiting caught in each trawl haul are plotted against mesh size. As the data are scattered, regression lines have been fitted to indicate the trend in the dependence of the parameters on mesh size. The regression lines were compared by an analysis of variance method which examines differences between the slopes and intercepts. For both haddock and whiting, the 50-percent retention lengths are higher for square than for diamond mesh of the same measured mesh size. The differences are significant at the level of $p < .001$. In the case of haddock, the

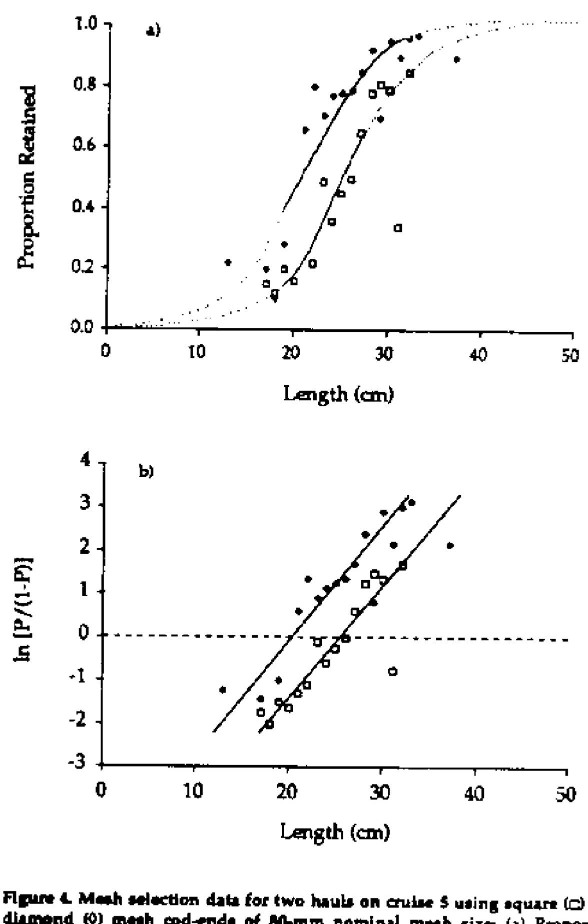

Figure 4. Mesh selection data for two hauls on cruise 5 using square (□) and diamond (◊) mesh cod-ends of 80-mm nominal mesh size: (a) Proportion retained (P) plotted against fish length with logistic curves fitted. (b) ln [P/(1-P)] plotted against fish length with lines fitted by maximum likelihood.

selection range was significantly smaller ($p < .01$) for square than for diamond mesh. For whiting there did not appear to be a difference in selection range between mesh types. Removing the outliers from the data and recalculating the regression lines made no significant difference to their positions.

Seine

Fewer mesh sizes were tested on seine nets than on trawls. The 50-percent retention lengths and selection ranges for each haul are plotted against mesh size in Figures 7 and 8 respectively. Regression lines are fitted only as a crude aid to interpretation. The 50-percent retention lengths are again significantly higher ($p < .05$ for haddock and $p < .001$ for whiting) for square than for diamond mesh. In the case of whiting, the selection range appears to be significantly larger for square than for diamond mesh ($p < .001$) but not significantly different for haddock.

Comparison between Square and Diamond Mesh

The 50-percent retention lengths found in square-mesh cod-ends were higher than those in diamond mesh, in both trawls and seines. To catch the same size range of fish, smaller mesh sizes must be used in square- than in diamond-mesh cod-ends. In Figures 5 to 8 the square-mesh results cover a lower and smaller range of values of mesh size than the

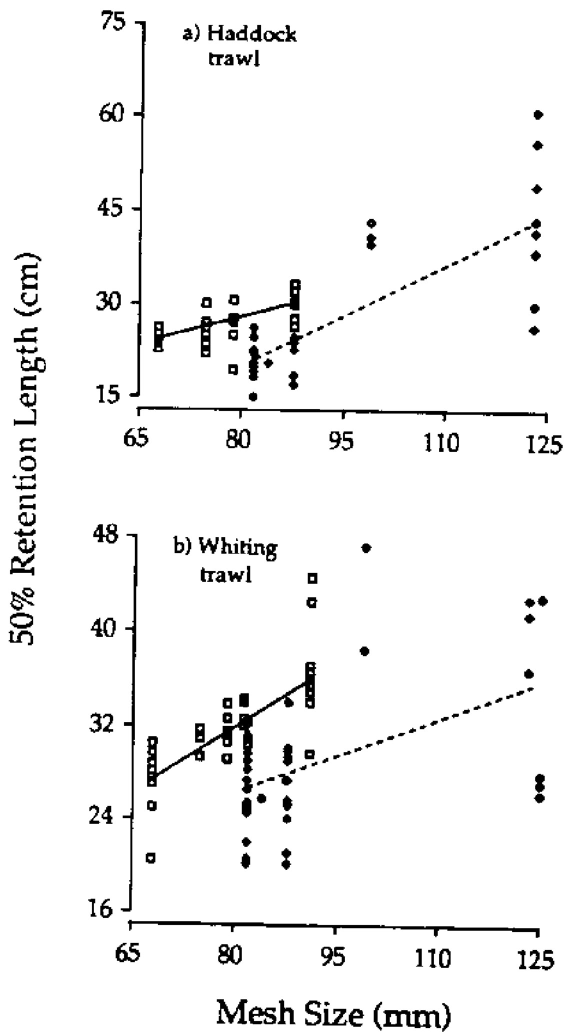

Figure 5. The measured 50% retention lengths (cm) plotted against measured mesh size (mm) for (a) haddock and (b) whiting caught in each trawl haul with diamond (◊) and square (□) mesh cod-ends. The lines were fitted by least-squares regression.

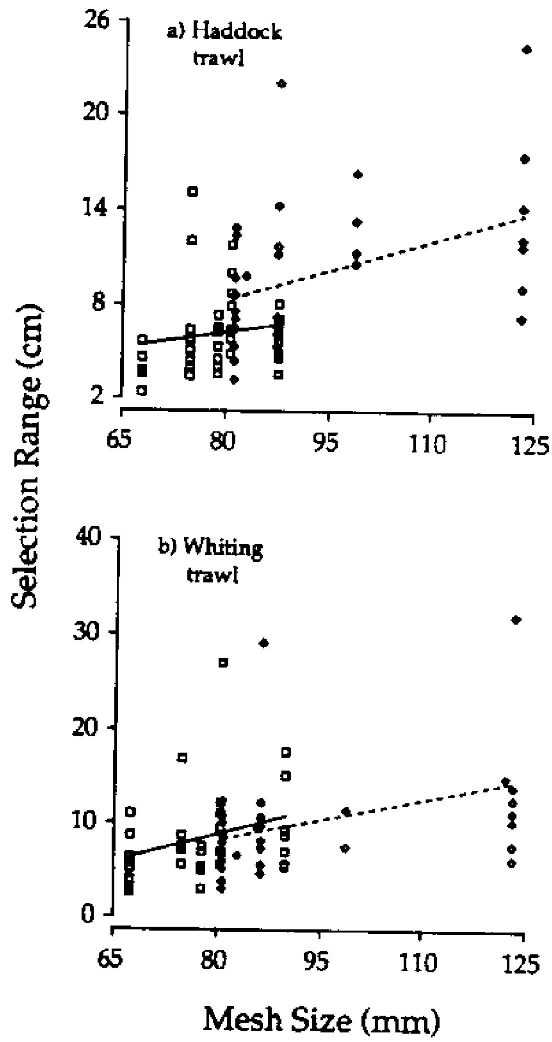

Figure 6. The measured selection ranges (cm) plotted against measured mesh size (mm) for (a) haddock and (b) whiting caught in each trawl haul with diamond (◊) and square (□) mesh cod-ends. The lines were fitted by least-squares regression.

diamond-mesh results. It was not practicable to test sizes of square-mesh netting larger than 90 mm as the catch retained would have been negligible, particularly of whiting.

Effect of Catch Size

The dependence of 50-percent retention lengths and selection ranges on catch size was examined. Catch in the cod-end, catch in the cover, total catch, and cod-end/cover catch ratio were considered, but no evidence was found to suggest that the selection parameters were dependent on catch size.

DISCUSSION

The catch data were highly variable, which complicates comparison of the square- and diamond-mesh selection parameters. The parameters found for diamond-mesh cod-ends on trawls are broadly the same as those reported by Holden (1971), which are also very variable. This would seem to be a characteristic of data from mesh selection experiments. More hauls to increase the numbers of estimated selection parameters would have been useful, particularly with mesh sizes above 90 mm. However, catch rates of haddock above 35 cm and whiting above 30 cm in length were low compared to those of smaller fish. Consequently, it would have required a very large number of hauls to amass enough data

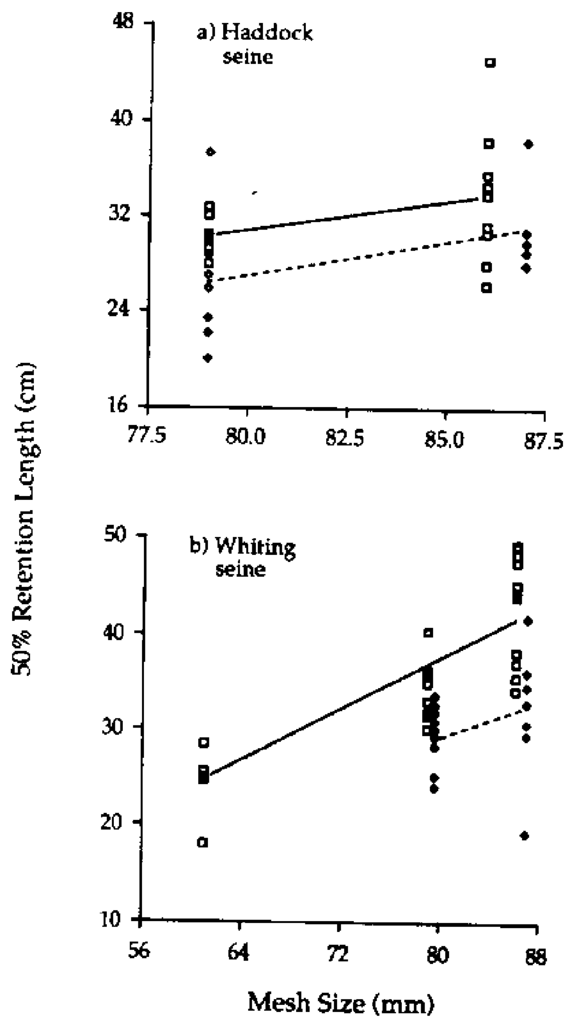

Figure 7. The measured 50% retention lengths (cm) plotted against measured mesh size (mm) for (a) haddock and (b) whiting caught in each seine haul with diamond (◊) and square (□) mesh cod-ends. The lines were fitted by least-squares regression.

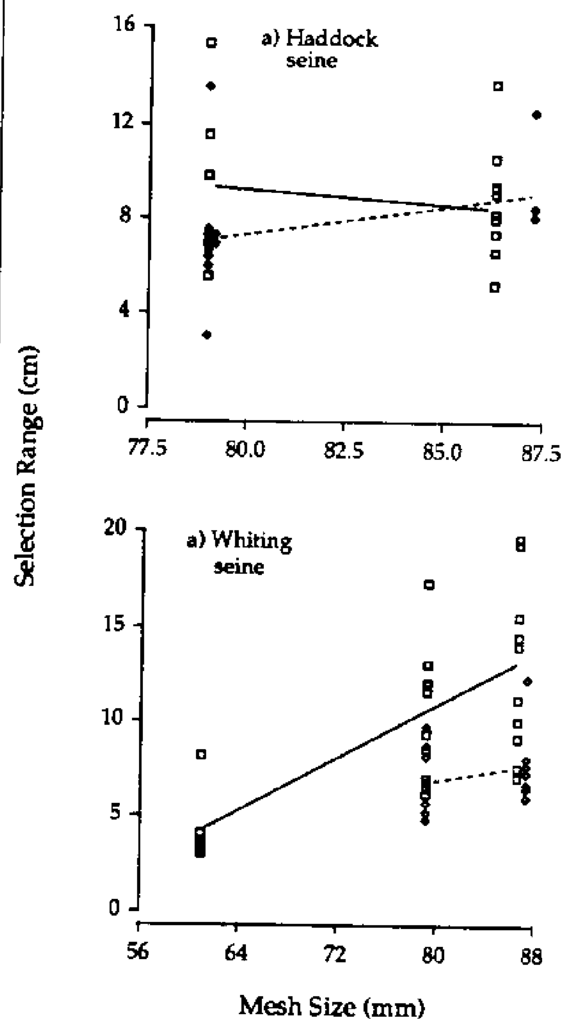

Figure 8. The measured selection ranges (cm) plotted against measured mesh size (mm) for (a) haddock and (b) whiting caught in each seine haul with diamond (◊) and square (□) mesh cod-ends. The lines were fitted by least-squares regression.

to estimate 50-percent retention lengths in these ranges with a high level of confidence. Although every effort was made to maintain constant conditions during the cruises, there was often significant variation in the selection parameters between consecutive hauls with the same cod-end. Changes in environmental conditions (e.g., light intensity) or in gear performance (e.g., towing speed and net height) may affect gear efficiency and selectivity (Wardle 1983). It should be noted, however, that only those hauls producing extreme values of 50-percent retention length and selection range have been excluded from the analysis. It is possible that in some of the hauls producing very low 50-percent retention lengths, masking of the cod-end meshes was taking place and hindering fish escape despite the efforts made to have a non-obstructive cover.

These results indicate that square-mesh cod-ends constructed from the same sheet netting as diamond-mesh cod-ends are likely to have higher 50-percent retention lengths for both haddock and whiting caught in trawls and seines. For the 50-percent retention lengths for each species to be the same in square and diamond mesh, it appears that the mesh size of the square-mesh cod-end would have to be reduced by approximately 10 to 15 mm in the 75- to 95-mm range. The selection ranges found for haddock in trawls were narrower in square than in diamond mesh, whereas those for whiting were no different. In seines it was found that the selection ranges for haddock in square and diamond mesh did not differ, whereas those for whiting appeared to be wider in square mesh. As fewer mesh sizes were used and fewer hauls made with seine net, the results are less certain than those found for the trawl. Thus only in the case of haddock in trawls do the results suggest that a square-mesh cod-end will have a sharper selectivity and retain fewer undersize fish than a conventional cod-end with the same 50-percent retention length.

A fish can escape through a mesh if its body section can be squeezed through the available mesh opening. The variation in fish girth at each length (partly related to stomach fullness) ensures that not all the fish of a given length will escape. Consequently, the selection curve will not be knife-edged but sloping, and the girth-to-length relationship will impose an upper limit on the slope of the curve (Beverton and Holt 1957). The increase in 50-percent retention length found in square-mesh cod-ends may arise because the average mesh opening in the escape zone of a diamond-mesh cod-end is less than in a square-mesh cod-end.

The different effects of square mesh on the selection ranges for haddock and whiting are difficult to explain. Both species encountered the same conditions in the cod-ends. If the difference is real, it may arise from different behavior patterns in the two species. The greater area of open meshes in square-mesh cod-ends will only result in improved selection if the fish try to escape at many places and particularly if they make repeated attempts. Possibly the species differ in their level of escape activity, which might account for the difference. Also, the body shapes of haddock and whiting are different, whiting being smaller and rounder in section. This is reflected in the higher 50-percent retention lengths for whiting. The more open shape of the square meshes may present less of an advantage to whiting than to haddock.

It is noted that the seine net selection parameters differed from those obtained on trawls. In the 80- to 90-mm range of mesh size, the 50-percent retention lengths found in the seine catches were higher than those in the trawl catches by about 6 cm for haddock and 4 cm for whiting. This may arise from the different capture processes involved. In the trawl, fish are herded continuously in front of the gear. As they become exhausted, fish of all sizes turn into the net and pass to the cod-end. Thus, in moderate fishing conditions there is a steady flow of fish into the cod-end. In the seine, however, fish do not enter the net and cod-end until a late stage in the haul. Many small fish tire, are overtaken by the ropes, and do not reach the front of the net. Further, a seine net is usually towed more slowly than a trawl, allowing the cod-end meshes to be less stretched and more open. The likelihood is, therefore, that fewer small fish are caught and that there is more opportunity for escape if they do reach the cod-end.

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Scale Damage and Survival of Young Gadoid Fish Escaping from the Cod-end of a Demersal Trawl

J. Main and G. I. Sangster

INTRODUCTION

WHEN FISH ENTER A COD-END, some are retained while others escape. The escape of a particular fish will depend on its ability to get through the open meshes of the cod-end and is thus dependent on its size and girth. Therefore, if a fish is very large relative to the cod-end mesh size it will be caught, and if it is very small relative to the mesh size it should escape. However, in practice, as opposed to theory, it is well established from cod-end selection ogives that many small fish do not escape from cod-ends. This is due, for example, to (a) fatigue caused by the enforced swimming activity created by the trawl stimulus, (b) the meshes being partially closed or even blocked by other fish present in the cod-end or (c) cod-end design, which can limit the area of open meshes (Robertson and Ferro, 1988).

Direct observations have shown that the shape of a cod-end changes during the duration of a haul. At the start, when the cod-end is empty, the meshes have an open diamond shape with little strain on the material (Plate 1). As the catch builds up at the rear of the cod-end, the increasing drag resulting from the accumulated bulk draws out the cod-end netting into a pear shape The meshes in the forward zone become more elongated and closed (Plate 2), reducing fish escapes in this area. In this situation, small fish have to find unblocked meshes near the rear of the cod-end in order to escape (Plate 3). This may prolong their time spent in the cod-end and increase the likelihood of superficial damage by abrasion, either with the meshes or by contact with crustaceans (e.g., *Nephrops*) or rough-skinned species (e.g., dogfish and gurnards).

Other direct television observations of fish in cod-ends (Main and Sangster, unpublished data) have demonstrated many examples of young roundfish either being permanently trapped halfway through these elongated meshes or being temporarily restricted before eventual escape. Those of the latter category were seen to squeeze themselves through the meshes, resulting in scale removal and damage to their flank regions. Fish scales are often seen billowing around the cod-end. Furthermore, after escaping, some roundfish swam away while others did not swim normally but were tossed around bodily in the wake of the cod-end.

How badly damaged are the fish that manage to escape from a cod-end? Do the scale-damaged ones recover or die? These are questions that have never been answered. Fishery management by mesh size regulation is based on the assumption that escaping fish survive. An investigation to assess and quantify this topic would obviously have some bearing when minimum cod-end mesh size regulations are reviewed.

This report describes the experiments and preliminary results of an investigation to study the scale damage and survival of young gadoid fish escaping from the cod-end of a demersal trawl.

METHODS

Fishing and Diving Procedures

Experiments were conducted during the summers of 1985 to 1987 in waters near Gairloch, Scotland, using the commercial trawler "Aries" BCK 126 (230 hp, 20 m). This vessel also towed the Marine Laboratory's diver-operated towed underwater vehicle, TUV II. Conventional compressed air diving techniques were used and they, together with safety and operational procedures, are described in greater detail by Main and Sangster (1983). Fishing was usually conducted at a towing speed of 1.5 m/sec (3 knots), in depths between 25 and 40 m on the "Melvaig Tow," where the desired sizes and species of fish are normally found. Greater working depths would severely restrict the frequency and duration of dives for decompression reasons. The duration of each haul was never more than one hour. The net used was a "Jackson" rockhopper trawl with an 80-mm (single twine) cod-end. Three other cod-ends, with mesh sizes of 70 mm (single), 80 mm (double) and 80 mm (square mesh) were substituted periodically (Robertson 1982). Details of these cod-ends are presented in Table 1.

Table 1. Details of the four cod-ends used in the experiments.

Mesh	Size	Twine	Meshes on round	Cod-end length
Diamond	70 mm	Single polyethylene	120	4.2 m
Diamond	80 mm	Single polyethylene	120	4.2 m
Diamond	80 mm	Double braid polyethylene	120	4.2 m
Square	80 mm	Double braid polyethylene	120	4.2 m

The trawler towed the fishing gear from the deep end of the tow into shallower water, during which time (approximately 30 min) the diver controlling the TUV II and monitoring depth on an echo sounder would carefully choose his moment to submerge the vehicle and be in the correct position alongside the cod-end for the proposed work when sufficient numbers of fish should be present in the net and in a convenient depth. On completion of this, the pilot/diver of the TUV II maintained the vehicle's position so that the observer/diver could watch for and describe (via the communication link to the ship) the behavior of individual fish escaping through the cod-end meshes.

Collection of Fish for Scale Loss Assessment

To investigate scale damage, single fish seen passing through a mesh were caught in a suitable-sized transparent polyethylene bag and immediately killed by the addition of a strong solution of benzocaine. This anesthetic was administered to the fish in its water-filled bag, from a syringe-type reservoir flask housed inside the TUV II. This rapid method of killing each specimen ensured that no further scale damage occurred during captivity in the bag. Each pre-numbered bag containing a single fish was then sealed by a cable tie and stored carefully within the TUV II. This method was repeated until sufficient numbers for convenience of handling were caught or the dive was terminated due to the "no decompression" time limit. On completion of each dive, the collected specimens were quickly and carefully returned to the towing vessel to be immediately examined, measured, and/or photographed.

On subsequent fishing hauls, a small-mesh cover (40-mm stretched mesh) was fitted over the cod-end. After the cod-end had been taken on board on completion of each haul, samples were taken from the cod-end and cover for length and girth measurements and from the cod-end for scale damage assessment. These latter were categorized "deck sampled" and could be compared to the samples caught *in situ*.

Analysis of the Scale Loss

Each dead specimen was removed carefully from its water-filled polyethylene bag and held firmly, by inserting the index finger of one hand into the fish's mouth while holding the extreme tip of its tail between the forefinger and thumb of the other hand. In this way, no part of the flank regions sustained further damage. No scales were evident or recovered from the bag's seawater contents Both sides of the fish were visually subdivided as shown in the illustration in Figure 1, and an indicator of scale loss in each of the five zones per flank was assessed on the following scale:

0 - no damage

1 - small amount of scales missing (approximately 10 percent)

2 - medium-sized area of scales missing (approximately 20 percent)

5 - large amount of scales missing (approximately 50 percent)

10 - no scales present in the zone.

The mean value of these 10 percentage scale losses (five per flank) was then calculated, giving an overall scale loss indicator of each fish. This indicator tends to be an overestimate of actual percentage scale loss for the fish since the longitudinal sections are not equal in areas and in general the smaller areas have greater scale loss.

Each specimen was also measured for length and maximum girth, and some were photographed to demonstrate different examples of damage. Scale loss, species, length, girth, and sample category could then be compared against mesh size and any specific pre-recorded escape behavior.

Experimental Procedures for Measuring Survival

The fish-survival part of this work was carried out by studying and assessing the relative survival in separate groups of captive fish held in seabed cages. These categories were:

a) fish that had successfully passed through the cod-end meshes (diamond-mesh escapes);

b) fish that had been retained in the cod-end (diamond-mesh captures);

c) fish caught by hook and line (control fish);

d) fish caught and damaged by hook and line (hand-line-damaged fish);

e) fish that had escaped through a square-mesh cod-end (square-mesh escapes).

The experimental method was designed to try to ensure that:

1) no fish experience a pressure change;
2) no tags be used to identify individuals;
3) all fish be kept at the same depth in large sea cages;
4) all fish be offered food at regular intervals;
5) daily counts of fish in each cage be carried out to estimate survival.

In these circumstances, the main difference between control and experimental fish would be the experience of being in and escaping from a trawl. The degree of fatigue and stress for each fish on entry to the cage might vary, however, for both classes of fish.

Description of the Sea Cages

Figure 2(a) describes the shape and dimensions of the seabed cages. The design consists of a 17-cubic-meter tailored net cage suspended inside a partly demountable metal structure. This arrangement ensured that no metal surface would abrade the captive fish. Furthermore, the cages had no netting floor but a loose skirt was attached all around the side wall netting and weighted down by stones and chain. The absence of a netting floor ensured that fish were in contact only with the natural substrate. The end-walls were made of small-mesh (10 mm) white nylon netting. This enabled the fish to see the extremities of the enclosure and to minimize contact with the netting. The small mesh would also reduce any strong tidal water flow through the cage, providing some shelter. The main body netting of the cage was constructed in soft nylon (50-mm stretched mesh), rather than in hard polyethylene-type twine, to minimize abrasion.

After assembly and rigging on land, each complete cage was partially collapsed, by slackening the locking bars as in Figure 2(b), ready for transportation by a Zodiac inflatable boat to the seabed site. The choice of site was as near to the fishing area as was practically possible (approximately 2 km). On arrival at the site, the cages were lowered to the seabed, erected, anchored, and marked by buoys. As a precautionary measure, two small floats were attached to the top of each cage to prevent the weight of the roof netting from sagging (Plate 4).

Collection of Fish for Cage Experiments – 1985

To collect a suitable number of fish for the cage experiments (i.e., "escapes" and "captures"), the above diving procedures were repeated by a second team of divers. The "escapes" were manually caught, as previously described, but held in black polyethylene bags without the addition of anesthetic. In the past, it has been found that the use of black polyethylene bags, rather than transparent ones, will keep captive fish in a docile state during handling or transportation. Otherwise, individuals will tend to become agitated and may thrash around in the confinement of a transparent bag, possibly causing additional superficial damage. Once suitable numbers were collected from the cod-end, they were transported in their black bags, at depth, to a pre-determined sea cage. The "captive" specimens were obtained by removing the cod-end under water (the cod-end was attached to the net by rings and drawline), attaching a suitable length of surface-to-bottom marker line, and slowly towing it, just off the seabed, to the cage site using a Zodiac motor-powered rubber boat. Divers then carefully transferred the required numbers of fish from the cod-end to the pre-determined sea cage. Meanwhile, suitable numbers of the same size and species were line-caught at a similar depth, using barbless hooks, then placed in black bags by divers and similarly moved at depth to the "control" cage.

Collection of Fish for Cage Experiments – 1986

The experiments carried out in 1985 were repeated in 1986, with the addition of a fourth cage containing hand-

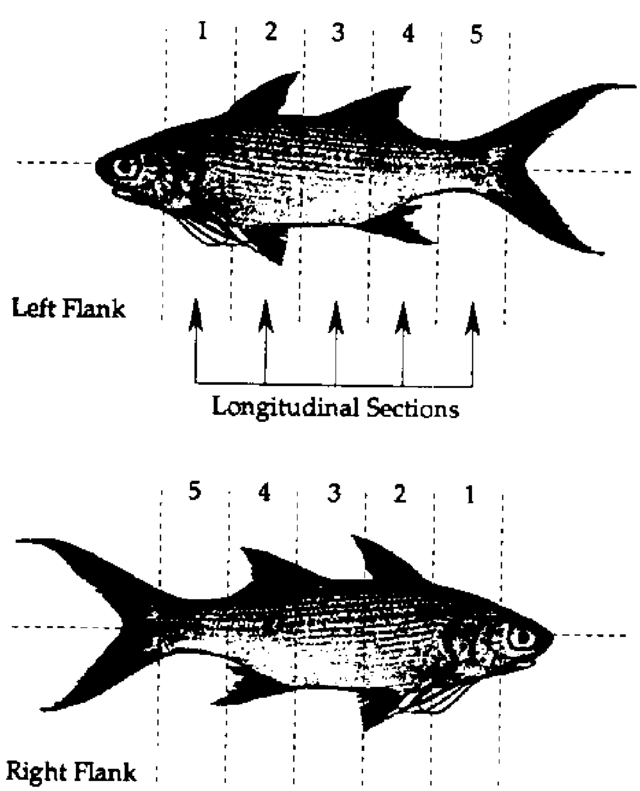


Figure 1. Scale loss indicator sections.

Figure 2(a): Cage fully erected

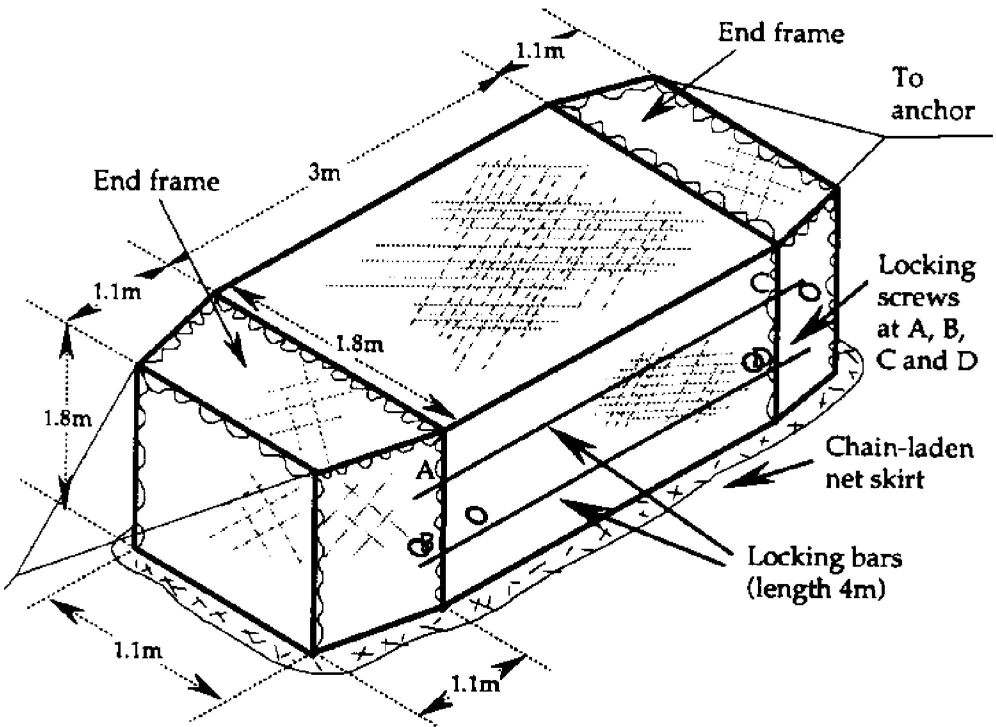
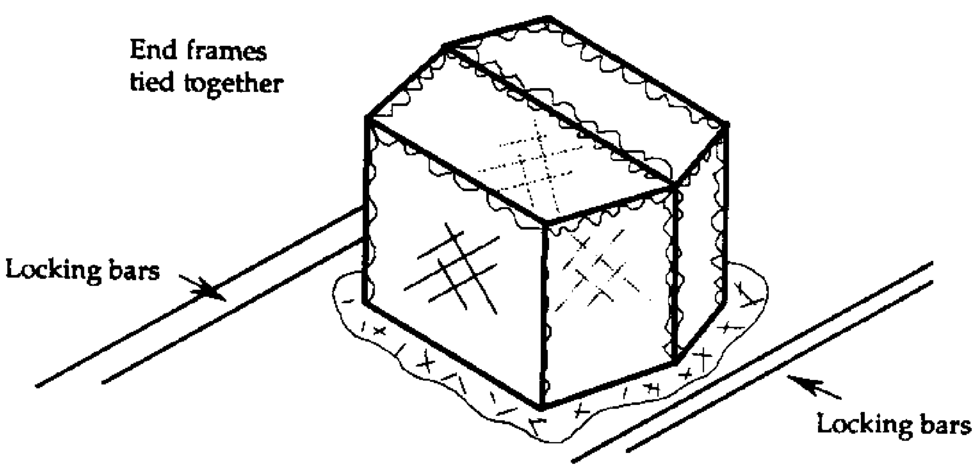


Figure 2(b): Cage collapsed (main bag of netting gathered inside framework)



line-damaged fish. These were collected in the following manner: Individual specimens of haddock, whiting, and cod that had become slightly abraded on the hook-and-line tackle after capture were subdivided into three categories (X, Y, and Z), "X" being those showing a single area (approximately 4 cm^2) of scale damage below the lateral line; "Y," those similarly scaled *only* around the tail area; and "Z," fish having small areas of scales missing along the length of one flank. These groups of fish were transferred, as previously described, into a single cage and labelled "hand-line-damaged fish." These methods were repeated, so that by the end of the first day, the cages under comparative investigation contained the required numbers of fish. On completion of stocking the cages, the survival experiments began. Visits were made by divers and accurate fish counts obtained from all cages as frequently as time and weather conditions allowed. One complete series of fish counts was obtained at least every 24 hours. Food, in the form of mussels (*Mytilus* sp.), small sand eels (*Ammodytidae*), and finely chopped squid (*Loligo* sp.) was offered to the fish during each visit.

Collection of Fish for Cage Experiments – 1987

The experiments of 1986 were repeated, with the addition of a cage to investigate fish damage in a cod-end made of square-mesh netting.

RESULTS

Table 2 shows the numbers of species examined to date from each particular cod-end mesh size. Although 221 fish were examined, two (numbers 182 and 192) were *Trisopterus esmarki* and are not included in this study.

Scale Loss

Table 3 presents percentage scale losses in the five longitudinal sections of the 219 fish. Analysis of fish length and total body scale-loss damage indicated no clear relationship between scale damage and fish length. However, it was apparent that the greatest damage is not necessarily caused to the widest part of the fish girth. The damage increases progressively back towards the tail in nearly all species examined. Plates 5 and 6 demonstrate different examples of haddock scale damage from the head back along the left flank towards the tail.

Figures 3–5 show the length-to-girth relationship for haddock, whiting, and cod obtained using a small-mesh cover over an 80-mm (single twine) diamond cod-end. These data present the size ranges of these three species present on the fishing grounds in the experimental area worked and hence show the lengths of fish that escaped, and those that were retained, in the various cod-ends used.

Cod-end Observations and Effect on Fish Behavior

Direct observations showed that the diamond-mesh cod-ends took on a bulbous shape as the increased drag of the catch pulled on the rear of the net (Plate 7). The meshes were tight on all four bars and widest open just ahead of the accumulated fish mass where most of the roundfish were seen to escape. At the narrow entrance to the cod-end, the meshes were almost closed, thus minimizing the possibility of fish escape.

The square-mesh cod-end observations showed that all the meshes remained open throughout the haul (Plates 8 and 9). The shape of this type of cod-end remained parallel as

Table 2. Numbers and species of fish examined from each cod-end mesh size (diamond mesh unless noted to be square).

Type of cod-end	Haddock	Whiting	Cod	Hake	Total
80 mm (single) (underwater sample)	56	39	2	0	97
80 mm (double) (underwater sample)	27	12	0	0	39
80 mm (double square) (underwater sample)	23	8	2	0	33
70 mm (single) (underwater sample)	9	14	0	16	39
80 mm (single) (deck samples)	11	0	0	0	11
Totals	**126**	**73**	**4**	**16**	**219**

the catch increased, thus creating a long, open, uniform cylindrical shape; and many small haddock, whiting, and cod (visually assessed at between 25 and 30 cm) were seen to escape with relative ease. The strain on the netting was taken on the two side bars of the mesh, which run fore and aft, whereas the cross bars to the water flow were bent and slack, with little or no apparent tension. If the size of the catch was large, all four bars were seen under tension.

Haddock, whiting, and codling swimming ahead of the diamond-mesh cod-end were seen to tire, drop back to the rear of the cod-end, and lie, pressed flat against the meshes. Some of these individuals succeeded in forcing their heads into open unblocked meshes and squeezed and wriggled in an attempt to pass out through the meshes. Depending on their girth size, some were unsuccessful in escaping and remained enmeshed. Others that were successful, at the last moment before escape, gave a few rapid tail beats to ensure freedom. It was visually evident from this latter escape movement that most of these fish incurred varying degrees of scale removal on both flanks, which was seen to be quite severe in many individuals, especially around the area of the caudal peduncle. After escape, these particular fish were seen to be tossed around in the swirling water eddies behind the cod-end. However, not all escaping fish were seen being subjected to such harsh treatment. Other direct observations in diamond-mesh cod-ends demonstrated that many haddock, whiting, and codling managed to strike upwards at an open mesh and escape with relative ease. On these occasions, however, due to the relative speed of the fish escape sequences, the extent of their scale losses was not obvious.

Water Flow in the Cod-end and Its Effect on the Catch

As the catch increased at the rear of the diamond-mesh cod-end, it formed a solid barrier to the water flow passing back through the net. A circular motion of flow occurred just ahead of the fish mass, affecting the escape behavior of fish towards the end of the cod-end. This circulation of water threw all sizes and species of fish forward by approximately 2 m along the top sheet, then downwards and backwards along the bottom sheet towards the main fish mass at the rear of the cod-end. During this movement, fish were seen to be tossed around, often striking the meshes and colliding with other fish and abrasive debris. Depending on their shape and girth, many fish were either forced out through the meshes by the turbulence to escape either head- or tail-first (Plate 10), or caught halfway through the meshes. Fish that managed to swim ahead of the turbulence (by approximately 2 to 2.5 m) were seen to hold position in the fore part of the cod-end. Here, haddock, whiting, and codling (visually assessed size range 25 to 35 cm) remained low down, swimming near the belly sheet, where weaker eddies were evident. After 1 to 2 minutes at a towing speed of 1.5 m/sec,

Table 3. Percent scale loss data by species.

	Mean % scale loss for each section									
	Right flank					Left flank				
Species	1	2	3	4	5	1	2	3	4	5
Haddock[1]	22	29	51	60	62	26	36	48	62	65
Haddock[2]	25	28	47	48	51	26	29	42	44	41
Haddock[3]	25	38	46	53	57	23	30	52	62	67
Haddock[4]	69	87	92	95	92	74	82	87	82	82
Haddock[5]	7	8	14	15	12	5	15	29	31	22
Whiting[6]	18	38	55	53	56	27	42	52	70	70
Whiting[7]	8	21	28	22	17	18	19	26	33	31
Whiting[8]	15	25	37	36	28	18	23	42	35	29
Whiting[9]	64	89	98	100	96	68	80	86	93	91
Hake[10]	51	75	77	71	67	53	61	86	81	71

[1]data from 56 escapees from 80-mm diamond-mesh cod-end (single twine)
[2]data from 27 escapees from 80-mm diamond-mesh cod-end (double twine)
[3]data from 23 escapees from 80-mm square-mesh cod-end
[4]data from 9 escapees from 70-mm diamond-mesh cod-end (single twine)
[5]data from 11 deck-sampled specimens from 80-mm diamond-mesh cod-end (single twine)
[6]data from 39 escapees from 80-mm diamond-mesh cod-end (single twine)
[7]data from 12 escapees from 80-mm diamond-mesh cod-end (double twine)
[8]data from 8 escapees from 80-mm square-mesh cod-end
[9]data from 14 escapees from 70-mm diamond-mesh cod-end (single twine)
[10]data from 16 escapees from 70-mm diamond-mesh cod-end (single twine)

these sizes of fish would become exhausted (Wardle 1977), and indeed after this period of time they eventually tired and dropped back to the rear of the cod-end.

Direct observations with the square-mesh cod-end showed that as haddock and whiting dropped back, they almost always struck upwards to escape through the open top meshes along the length of the cylindrically shaped cod-end. Furthermore, with this type of cod-end, the water circulation was again evident when the rear zone of the cod-end was blocked with fish, especially flatfish. These direct observations allowed us to conclude that slightly larger haddock and whiting escaped, or were thrown, through the square meshes than was seen with the diamond-mesh cod-end. Although visual scale damage was still evident to both haddock and whiting, the permanently open meshes in this type of cod-end seemed to provide the fish with an easier and more distinct exit to freedom.

In 1985, the collection and handling of both the scale-damaged specimens and cage fish from the trawl were somewhat hampered by the presence of an abundance of jellyfish, *Cyanea* sp., in the trawling area. These scyphomedusae were unavoidably captured in the net while towing and some drifted back to the cod-end, blocking several mesh areas and therefore restricting fish escapes. Pieces of jellyfish tentacles inevitably broke away from these animals in the swirling water vortex inside the cod-end and eventually adhered to numbers of both captive and escaping fish. Only those fish which visibly showed no sign of *Cyanea* presence on their bodies were chosen for the cage experiments.

Fish Behavior in the Sea Cages – 1985

The "control" and "escaped" categories of fish showed no fright, panic, or escape activity while being transported by divers in polyethylene bags to the sea cage sites. The "retained" fish that were slowly (less than 0.5 knots) moved along the seabed, inside the detached cod-end, swam gently in the direction of towing, without nosing against the meshes or attempting to escape. Once inside the cages, all categories swam calmly back and forth around the total area of the cage. No agitated or panic swimming activity was apparent during this presumed initial exploration period of their confinement. Only those fish from cages A and B (Table 4) that were visibly scale-damaged swam with some degree of awkward behavior. Observations on these showed that a scaled individual would sink occasionally to the seabed, before again swimming off around the cage. Some fish, irrespective of category, accepted food immediately; others required a day or so to commence feeding. The line-caught "control" fish revealed various degrees of mouth injuries due to hook damage; otherwise, these fish visually appeared to be in excellent condition. Edible crabs (*Cancer* sp.) congregated around the perimeters of the cages, but were unable to enter, even though some attempted to excavate under the

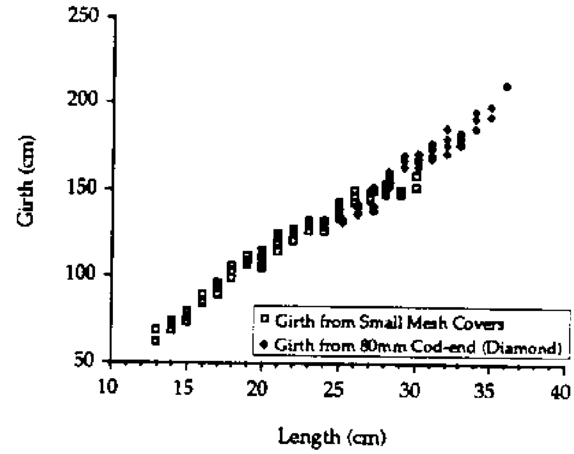


Figure 3. Length to girth relationship for the range of haddock sizes caught in the area fished during the experiments.

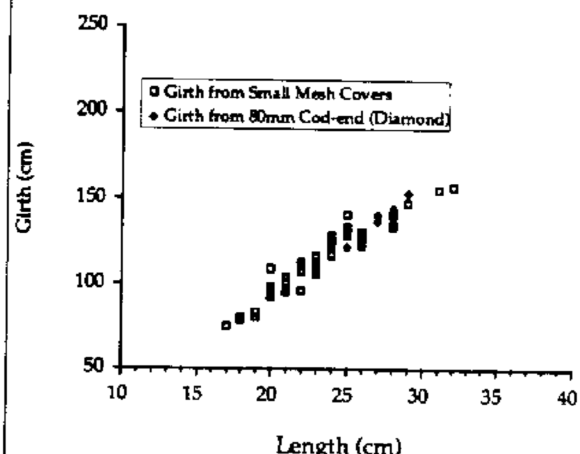


Figure 4. Length to girth relationship for the range of whiting sizes caught in the area fished during the experiments.

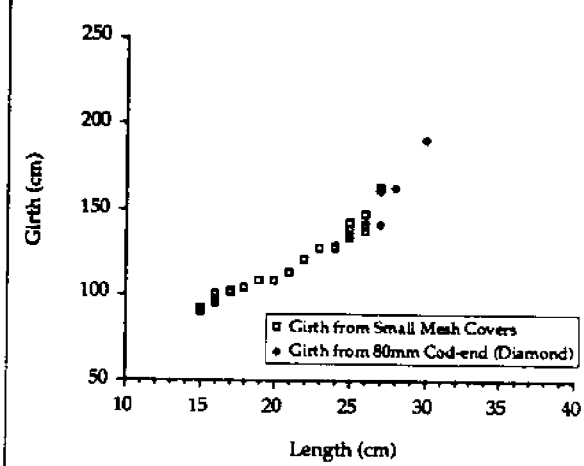


Figure 5. Length to girth relationship for the range of cod sizes caught in the area fished during the experiments.

Table 4. 1985 Cage survival experiments (numbers of haddock, whiting, and cod counted from day one through to the termination of the experiments).

	Cage A (diamond-mesh escaped)			Cage B (diamond-mesh retained)		Cage C (control)
Day	Haddock	Whiting	Cod	Haddock	Cod	Haddock
1	56	2	1	28	3	14
2	53	-	-	26	3	14
3	52	-	-	26	3	14
4	50	-	-	26	3	14
5	47	-	-	25	3	14
6	46	-	-	25	3	14
7	44	-	-	25	3	14
8	44	-	-	25	3	14
9	42	-	-	25	3	14
10	40	-	-	25	3	14
11	38	-	-	24	3	14
12	bad weather; no counts					
13	Cage lost			Cage lost		14*
|						
35	-			-		14 (fish released)
Haddock % survival	67%			86%		100%

*cage survived the bad weather

chain-laden netting skirts. As a precautionary measure, these crustaceans were daily removed by divers to prevent any further hindrance to the experiments. Daily counts of death and survival in each cage during the 1985 experiment provided the data presented in Table 4. The numbers of live fish counted on successive days in each cage are shown from day one onwards until the termination of the study. Unfortunately, in 1985 cages A and B were lost in a storm and these experiments were unavoidably and prematurely terminated after 11 days. However, the initial results from the 11-day period showed that fish in cage A (those that had escaped through the cod-end meshes) were suffering a form of body lesion in the scale-damaged areas around the adipose and anal fins. This type of damage was not seen in the damaged fish in cage B, 86 percent of which survived. After 35 days, the "line-caught" control fish in cage C remained in excellent condition, feeding regularly and showing no visible hook injuries around their mouths.

Fish Behavior in the Sea Cages -1986

The 1986 experiments continued along similar lines to those of the previous year, with one exception. One extra cage was introduced to provide another fish category, i.e., line-caught damaged fish. These allowed observations to be made of scale-damaged fish that had not been subjected to the trawling process of herding, capture, and/or escape and the associated physiological stress and fatigue. Daily counts of survival in each category are presented in Table 5.

Observations similar to those of the previous year were obtained, showing that most fish, with the exception of approximately 10 haddock in cage C, swam calmly around their cages in loose shoals and displayed no sign of agitation or panic behavior in captivity. The 10 damaged individuals in cage C (Table 5) did not shoal, but remained apart from the others and either swam lethargically with repeated rests on the seabed or slowly swam high up near the roof of the cage. Healthy-looking fish fed regularly and greedily, whereas the damaged ones fed intermittently. The survival rate of "diamond-mesh-escaped" fish in cage C (Table 5) was very low and it is very noticeable from the data that most haddock in this category failed to survive the first four days of the experiment, whereas the control haddock (cage A) survived totally to the thirty-eighth day. It is interesting to note that in cage C, after the initial mortality, only one haddock died between day four and day 108, and that during that period all the cod survived. The "hand-line-damaged" fish in cage B survived very well with the exception of four haddock losses in the first week. Initially, it was easy to distinguish individual haddock by the degree of damage (i.e., either X, Y, or Z category). By the seventh day, however, discrimination was becoming virtually impossible, as the scale-damage areas had been masked by body mucus. It was

Table 5. 1986 cage survival experiments (numbers of haddock, whiting and cod in each cage from day one through to the termination of the experiment).

Day	Cage A (control) Haddock	Cage A Whiting	Cage A Cod	Cage B (hand-line damaged) Haddock* X	Haddock* Y	Haddock* Z	Whiting X	Cod Z
1	26	1	5	9	10	10	1	2
2	26	1	5	9	10	10	1	2
3	26	1	2	9	10	10	1	2
4	26	1	2	9	10	10	1	2
5	— no count - bad weather —			9	9	10	1	2
6	26	1	2	9	9	7	1	2
7	26	1	2	25**	1	2		
8	26	1	2	25	1	2		
9	26	1	2	25	1	2		
10	26	1	2	25	1	2		
11	26	1	2	25	1	2		
12	26	1	2	25	1	2		
13	26	1	2	25	1	2		
14	26	1	2	25	1	2		
38	26	1	2	25	1	1		
108	— cage turned over - no fish —			— cage turned over - no fish —				
Haddock % survival	100%			86%				

Day	Cage C (diamond-mesh escaped) Haddock	Cage C Whiting	Cage C Cod	Cage D (diamond-mesh retained) Haddock	Cage D Whiting	Cage D Cod
1	28	2	5	10	1	-
2	18	0	5	10	1	-
3	10	-	5	9	1	-
4	6	-	5	8	1	-
5	— no count - bad weather —			— no count - bad weather —		
6	6	-	5	7	1	-
7	6	-	5	7	1	-
8	6	-	5	7	1	-
9	6	-	5	7	1	-
10	6	-	5	7	1	-
11	6	-	5	7	1	-
12	6	-	5	7	1	-
13	6	-	5	7	1	-
14	6	-	5	7	1	-
38	5	-	5	7	0	-
108	5	-	5	7	0	-
Haddock % survival	18%			70%		

*X = 4 cm^2 damage below lateral line; Y = tail slightly scaled; Z = small areas of scales removed above lateral line
** after day six only total haddock counts were made because it became impossible to distinguish x, y, and z categories

therefore decided to revert to a total count of surviving haddock irrespective of category. In cage D ("diamond-mesh retained"), the haddock, after a small initial mortality of three fish during the first six days, survived until counts ceased on day 38. As a final experiment, all the cages and fish were left untouched until the area was revisited on day 108 to clear the site and to make final counts. Unfortunately, cages A and B were found overturned, presumably due to commercial fishing activity in the area rather than adverse weather conditions. Cages C and D, situated close by, survived without any damage. Table 5 presents the final counts obtained on day 108. No further deaths occurred between days 38 and 108 in cages C and D.

Fish Behavior in the Sea Cages – 1987

Experiments continued in 1987, maintaining the same protocol as in the two previous years. The "hand-line-damaged" fish category was omitted from this year's experiments as the divers had found discrimination between the X, Y, and Z types to be difficult, and, furthermore, the final haddock survival figures (X, Y, and Z pooled) to be as good as the "control" fish. The introduction, for the first time, of a group of haddock which had escaped through a square-mesh cod-end allowed survival comparisons to be made against haddock from "control" and diamond-mesh cod-end categories. Table 6 presents the data accumulated from the 1987 experiments. All but the badly scaled haddock (cages B, C, and D) commenced feeding after day three and, in all the cages, fish were seen competing for food. Badly damaged fish were seen either swimming in a head-raised attitude near the seabed, obviously distressed, or as visually distressed individuals (well away from the main loosely-shoaling group) swimming slowly near the top of the cage (Plates 18 and 19). After two to three days, the injured areas of these fish where scales were visibly missing eventually turned a white color, similar to the start of a type of fungus (Plate 20). Furthermore, three haddock in cage C that had abrasive wounds on their flanks and tails eventually developed ugly dark sores after day five. These three fish showed progressive deterioration, refused to accept food, and eventually died between day six and day nine. Most deaths in cages B and D occurred in the first three or four days, whereas

Table 6. 1987 Cage survival experiments (numbers of haddock in each cage from day one through to day 52).

Day	Cage A (control)	Cage B (diamond-mesh retained)	Cage C (diamond-mesh escaped)	Cage D (square-mesh escaped)
1	23	60	46	53
2	23	50	38	52
3	23	48	24	46
4	23	47	20	46
5	23	41	16	46
6	23	41	15	44
7	23	41	14	44
8	23	41	14	41
9	23	41	13	41
10	23	41	9	41
11	23	41	9	40
12	23	41	9	40
13	23	41	9	40
14	23	41	9	40
15	23	41	8	40
16	23	41	8	40
17	23	41	8	40
18	23	41	8	40
|				
52	23	40	0 (assumed)	40
% survival (at day 18)	**100%**	**68%**	**17%**	**75%**
% survival (at day 52)	**100%**	**67%**	**0%**	**75%**

in the control cage (A) all fish survived until the termination of the experiment at day 52. Fish in cage C, although having a heavy mortality in the first three days (similar to cages B and D), continued to die off steadily during the next seven days (unlike those in cages B and D). Divers carefully removed the carcasses daily using a long hooked pole.

Although the experiments were basically finished on day 18, the complete set-up was left unattended until day 52, when the divers revisited the site for further counts. Between days 18 and 52, one fish died in cage B and none in cage D, whereas no fish survived in cage C. Divers found no carcasses inside cage C and discovered no evidence of a possible escape route, so it was assumed that these last eight individuals (see Table 6, "cage C") died and were devoured by invertebrates. Final observations and counts during day 52 showed that all surviving fish accepted food (finely chopped squid) greedily, and only one haddock (cage B) showed any form of visible damage. This individual had an open sore below its left side lateral line; however, during this observation period, the injury did not seem to impair either its appetite or its swimming ability. All other fish appeared healthy and in excellent condition.

After fish counts were completed, the fish were set free as was the normal annual procedure at the end of the experimental work.

DISCUSSION

Although, at present, the number and species of fish which have been investigated for scale damage are still relatively small (see Table 1), the results do not show a relationship between the size of the individual fish and the amount of scale loss damage for any given mesh size. Further scale damage data for haddock, whiting, and especially codling are required before any firm conclusions can be drawn. The percentage scale loss for fish escaping through 70- and 80-mm meshes are fairly high figures for most species for both diamond- and square-mesh cod-ends, which initially looks potentially serious. It must be pointed out, however, that these data are based on only those fish which were successfully caught escaping from the cod-ends by the divers. Many other fish escaped, but were not caught by the polyethylene bag method. Furthermore, it could be that many fish escaped more easily than others through the meshes, with less superficial damage to their bodies. What the data may actually be showing are the *highest* percentages of fish scale damage sustained by the most lethargic fish during the escape sequence. More data will clarify these points. It is clear, however, that most fish sustain scale removal during escape and that the damage to a particular size of fish has no *one* single cause. As already discussed, factors affecting a fish's physiology and behavior before it even reaches the stage of escape from a cod-end include various degrees of fatigue from herding by the trawl; collisions with other fish, crustaceans, and trash; and abrasion from the netting both before and after entering the cod-end. It is obviously desirable to determine some of these parameters, and such a study must eventually involve a detailed investigation of the physiological condition of a fish at various stages of the trawling process. For example, what are its lactic acid levels before, during, and after confinement in a cod-end towing at a certain towing speed? If this were known, we might have a better idea as to what "fuel" or energy resources (if any) a fish still possessed inside the cod-end and whether or not it was capable of escape through a particular shape of mesh.

The results from the cage experiments are encouraging, but not conclusive. They showed that the control fish and the "square-mesh escapes" survived well in confinement. The "diamond-mesh escapes" did not endure as well in captivity, but it is difficult to draw a concrete conclusion from these experiments. Fish in confinement are affected by stress to an unknown degree. This factor is impossible to quantify and could have biased the results for the latter group. We have tried to minimize the differences in treatment of the various groups of fish by our experimental protocol, described in the "Methods" section, and by always using "control" fish. To improve the experimental procedure we intend to continue these cage experiments by introducing seabed-tagged control fish into all the sea cage categories *including* the control cage itself, which will also contain untagged control fish as in previous experiments. This should eliminate any variables in habitat, water flow, food and feeding, and bottom substrate, so that more realistic and accurate comparisons of fish survival can be made between all cages. Hislop and Hemmings (1971) performed cage experiments on seabed-tagged haddock with a survival rate of between 78 and 100 percent. Further work by these authors on seabed-tagged haddock from a seine net cod-end produced tagged fish returns from the wild of between 90 and 95 percent. These results are very encouraging for our future cage experimentation proposals.

The next phase of the research will include three categories of fish (diamond-mesh escapes, square-mesh escapes, and control fish). The detailed proposals are discussed below:

1. Number of fish per cage

From a statistical point of view, as many fish as possible should be used; however, in practice 30 fish per cage would be suitable. With fewer — i.e., 20 — fish, each individual contributes ±5 percent to the survival estimate, which means that differences in survival of 10 percent or possibly more are not going to be detectable. With 30 fish per cage per treatment, the margin is reduced to around 7 percent, which is more satisfactory.

2. Replication of the experiments

Each treatment (escapes from diamond mesh, escapes from square mesh, and control fish) should be replicated at least three times. This would provide a degree of residual variation which would permit analysis of the resulting data by a simple one-way analysis of variance. In addition, a randomized, Latin-square layout of the cages should remove any additional biases resulting from the position of the cages on the seabed. Such replication leaves open the option of pooling all the data to give a single estimate of survival under each treatment, whereas using the same number of fish without replication does not permit estimation of residual variation. Thus, even if it is possible to catch only low numbers of fish, the few that are caught should still be distributed among three cages rather than put into one.

3. Tagging

Similar numbers of tagged control fish should be put in the cages with the "escaped fish" as in the cage with the untagged "control fish." This would provide a more solid basis for interpreting mortalities as it would ensure that conditions would be as identical as possible in all cages and it should indicate whether the presence of tags has any deleterious effect on survival.

Since this whole study began in 1985, the minimum mesh size stipulated by regulations has steadily increased from 70 mm, through 80 and 85 mm, to a proposed mesh size of 90 mm. Future experimentation in this work will include an investigation into fish scale damage and survival of 90-mm diamond-mesh and square-mesh cod-ends.

ACKNOWLEDGEMENTS

We are most grateful for suggestions and constructive criticism on the manuscript from Dr. P. A. M. Stewart and Mr. R. S. T. Ferro. The authors also express thanks to our colleague, Mr. Stuart Reeves, for his suggestions and recommendations to the future work program from an analytical point of view and to Mr. W. R. Mojsiewicz for his technical help and expertise during this whole scientific study. Thanks also go to Skipper J. Slater and the crew of the commercial trawler "ARIES" BCK 126 for their willing help, patience, and enthusiasm during many aspects of the work.

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Robertson, J.H.B. and Ferro, R.S.T. 1988. Long and short, narrow and wide codend selection. Scottish Fisheries Research Report (in press).

Wardle, C.S. 1977. Effects of size on swimming speeds of fish. *In:* Scale effects in animal locomotion, ed. T.J. Pedley. New York Academic Press; pp. 299-313.

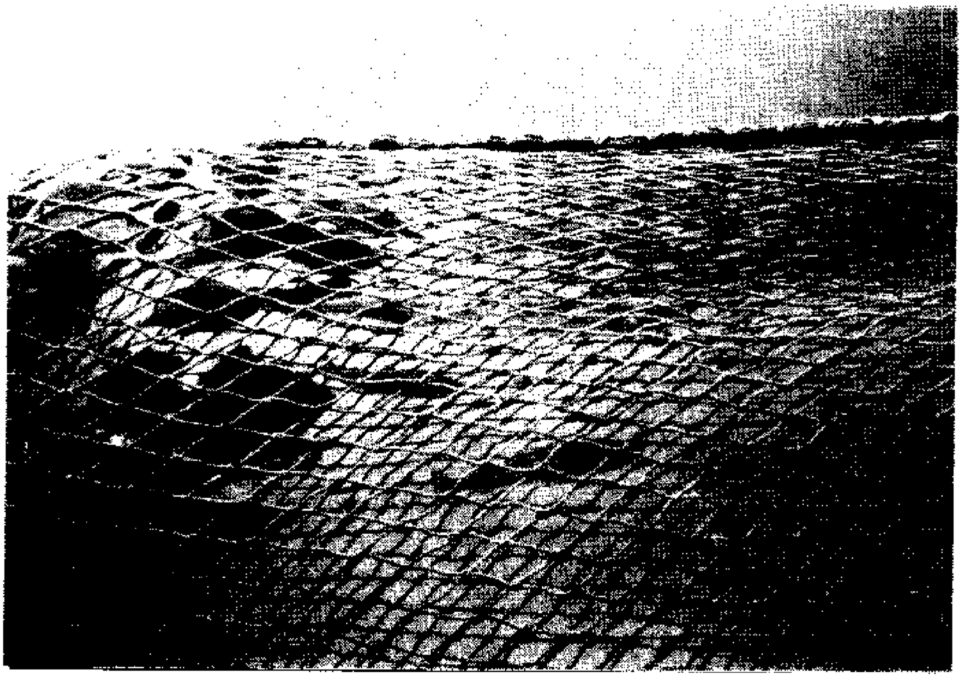

Plate 1. Nearly empty cod-end showing the slack and open shape of the meshes.

Plate 2. Cod-end, partially full, showing the elongated shaped meshes in the fore part and its overall bulbous shape.

Plate 3. Fish trapped halfway through the elongated cod-end meshes.

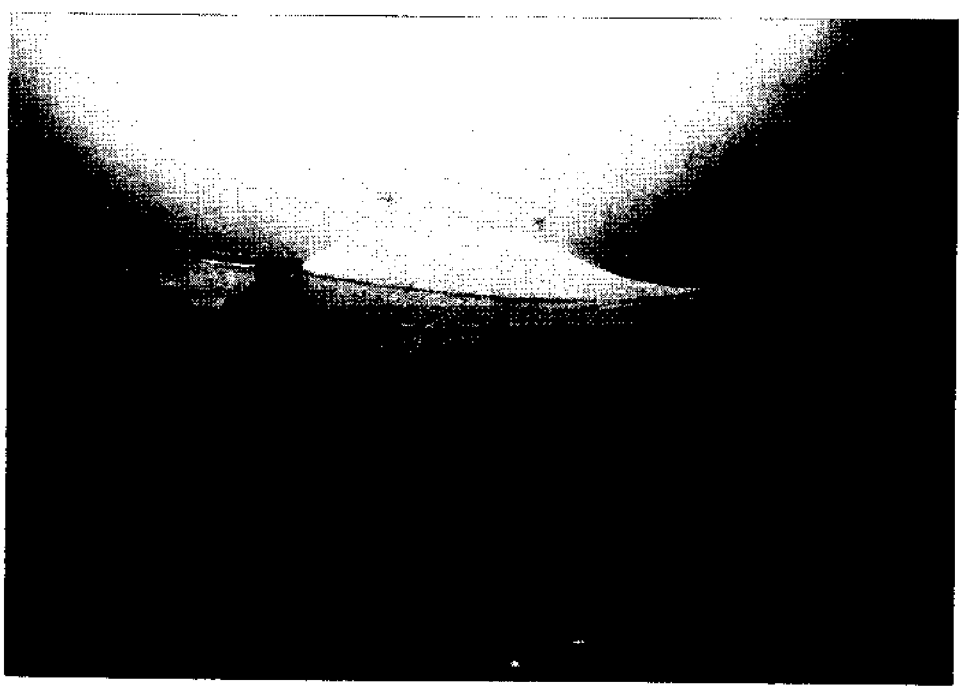

Plate 4. Fully erected cage on the seabed.

Plate 5. Cod-end mesh damage around the dorsal fin.

Plate 6. Large areas of scales missing.

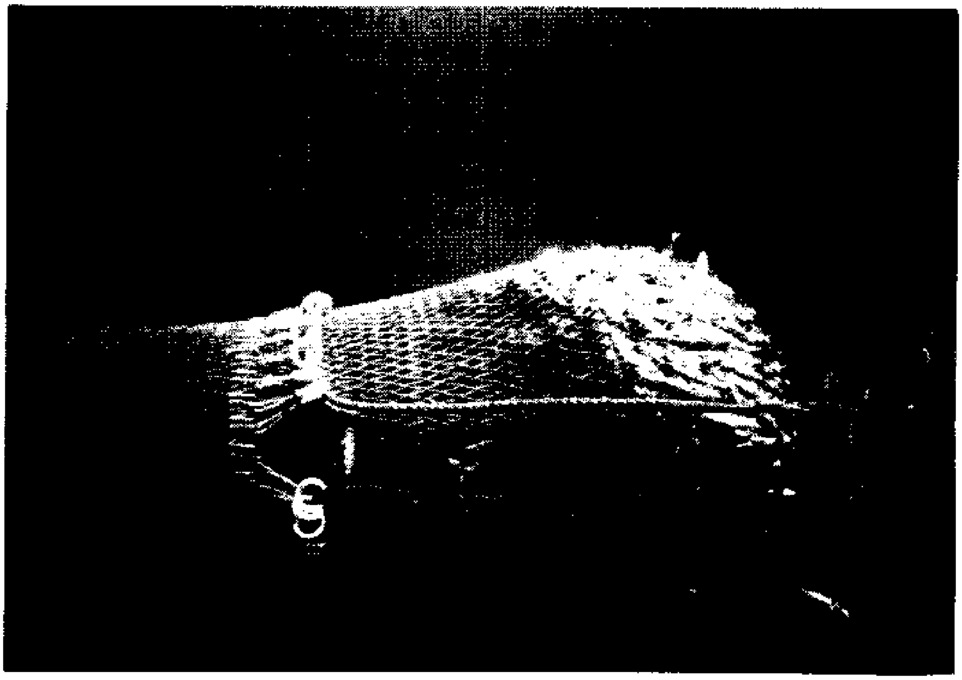

Plate 7. The meshes just ahead of the fish mass are open, but meshes are more closed further up towards the cod-end entrance.

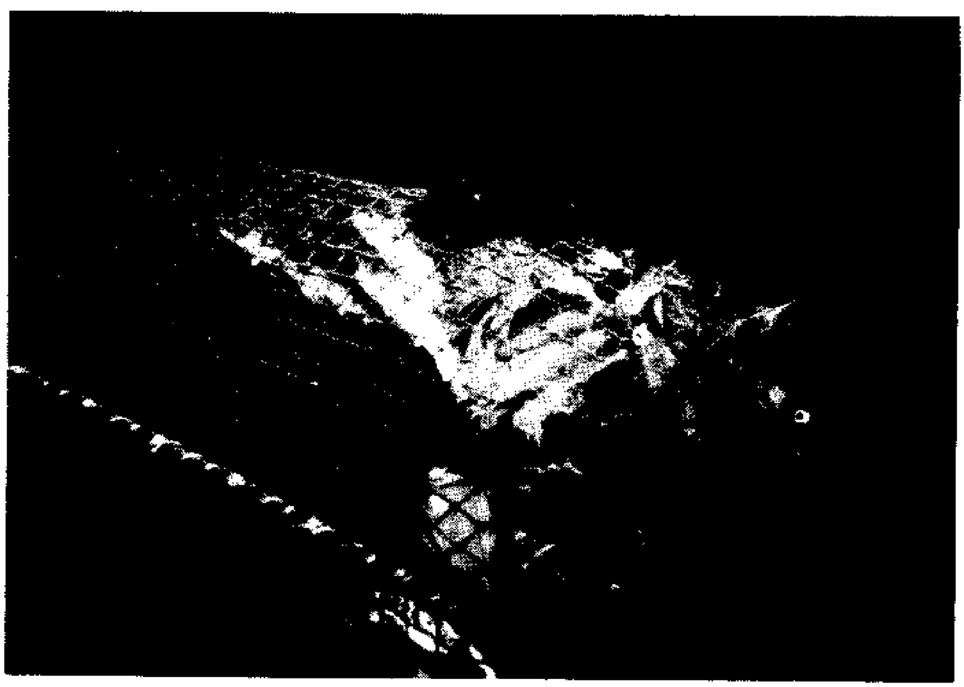

Plate 8. Rear section of a square-mesh cod-end, showing the open meshes.

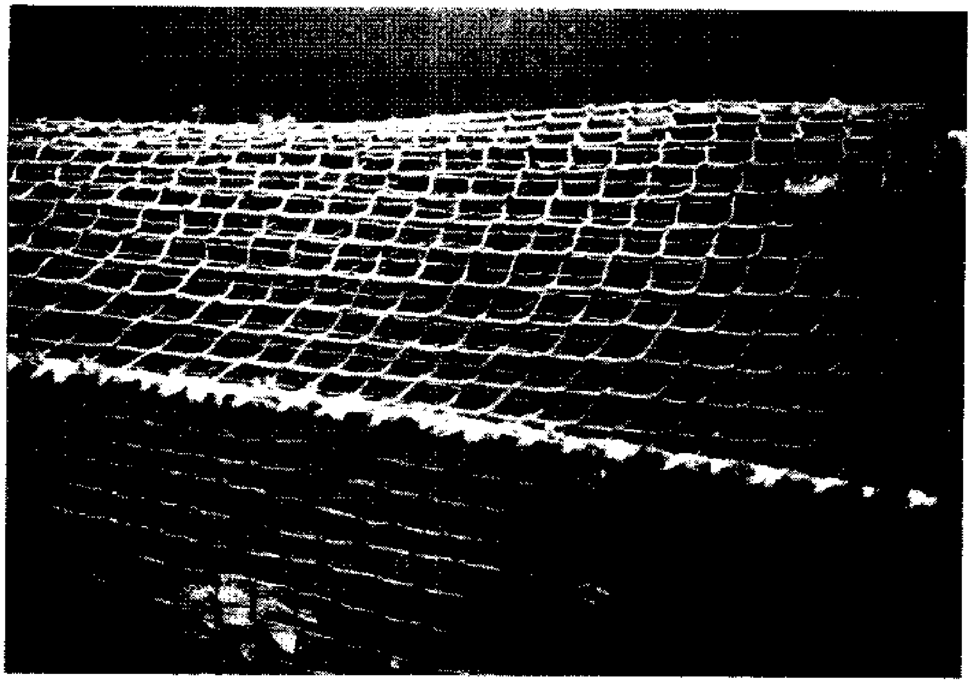

Plate 9. Near the front of the square-mesh cod-end. The meshes are still wide open.

Plate 10. Fish being tossed around in the water turbulence resulted in many individuals becoming trapped halfway through the meshes.

Further Reading
(Annotated Bibliography)

Averill, P.H., and Carr, H.A. 1987. Use of square mesh in New England's groundfishery. *In:* Oceans 87 Proceedings (volume 2), pages 649-651. Halifax: Marine Technology Society and IEEE Ocean Engineering Society.

The authors describe a limited study of square- and diamond-mesh trawl cod-end selectivity (alternative vessel method, 120-mm mesh size) and durability by the Massachusetts Division of Marine Fisheries and a larger study of square-mesh extensions placed forward of diamond-mesh cod-ends carried out by the Maine Department of Marine Resources (alternative tow method). The MDMF study provided results on yellowtail and grey sole, and indicated no difference in selectivity for these species.

Burd, A.C. 1986. Why increase mesh sizes? Laboratory Leaflet No. 58. Lowestoft (U.K.): Ministry of Agriculture Fisheries and Food Directorate of Fisheries Research. 20 pages.

The author traces the history of mesh regulations, explains how mesh selectivity is measured, describes some results of mesh selection experiments, and provides a method for using the results of mesh selection experiments to estimate short- and long-term effects of an increase in mesh size. Particular reference is made to estimating the effects of a proposed increase to 90 mm from 80 mm for the North Sea trawl fishery.

Cooper, C. G. and Hickey, W.M. 1989. 1988 Selectivity experiments with square mesh cod-ends of 135, 140, and 155 mm. Project Report No. 154. Fisheries Development and Fishermen's Services Division. Halifax: Department of Fisheries and Oceans.

The authors describe selectivity experiments for cod, haddock, pollock, and plaice using 135-, 140-, and 155-mm square mesh and 130-, 135-, 140-, and 155-mm diamond-mesh trawl cod-ends (trouser trawl method, knotted and knotless twine, small-mesh control on one side and experimental trawl on the other). The authors deployed both Atlantic western IIA and Nordsea 642 nova groundfish trouser trawls and found a trouser trawl with a vertical separator panel running the length of the trawl superior to either the alternative haul or covered cod-end method for producing selectivity curves. The authors recommend a goal of ten tows, half carried out in the opposite direction, and a sample of at least 400 fish in the experimental cod-end. Results indicated that for cod, haddock, and pollock, square-mesh cod-ends have higher 50-percent retention lengths, higher selection factors, and smaller selection ranges than equivalent-size diamond mesh cod-ends. In the 130- to 155-mm mesh range, a square-mesh cod-end performs similarly to a 10- to 15-mm larger diamond-mesh cod-end. For plaice, the square mesh had a *smaller* 50-percent retention length *and* a smaller selection range than equivalent-size diamond mesh.

________. 1987. Selectivity experiments with square mesh cod-ends on haddock and cod. *In:* Oceans 87 Proceedings (volume 2), pages 608-613. Halifax: Marine Technology Society and IEEE Ocean Engineering Society.

The authors describe selectivity experiments for haddock and cod using 121- and 130-mm square-mesh and 121-mm diamond-mesh trawl cod-ends (trouser trawl, square mesh on one side and diamond on the other). A remote-controlled TV vehicle was used to observe the trawl. Fifty-one sets were made and comparisons of equivalent-size square and diamond mesh indicated the square mesh reduces catch by 25 percent and yields larger 50-percent retention lengths and selection factors. The authors note that the differences between day and night retention lengths and selection factors can be equal to or greater than the differences between equivalent-size square and diamond meshes.

DeAlteris, J. and D.M. Reifsteck. (In press). Selectivity of cod-ends on scup, *Stenotomus chrysops*, and the survivability of cod-end escapees: a preliminary report. *In:* World Symposium on Fishing Gear and Fishing Vessel Design, St. Johns, Newfoundland, Canada, November 1988. 16 pages.

The authors describe selectivity experiments and monitor the survival of cod-end escapes for scup using 60-mm square- and diamond-mesh trawl cod-ends (cod-end cover method). The selectivity results indicate that the square- and diamond-mesh cod-ends produce equal 50-percent retention lengths although the square-mesh cod-end yields a smaller selection range. The authors also report significant differences in the survival of square- and diamond-mesh escapes (square-mesh survival higher), although sample size is quite small and the authors indicate that the survival of diamond-mesh escapes increased as the study progressed.

Fonteyne, R. and M'Rabet, R. (In press). Selectivity experiments with square mesh codends in the sole beam trawl fishery. *In:* World Symposium on Fishing Gear and Fishing Vessel Design, St. Johns, Newfoundland, Canada, November 1988. 10 pages.

The authors describe selectivity experiments for plaice using 75-mm square- and diamond-mesh beam-trawl cod-ends (covered cod-end method). The authors report no significant difference in the 50-percent retention lengths or the selection ranges of the square- and diamond-mesh cod-ends.

Isaksen, B. and Valdemarsen, J.W. (In press). Selectivity experiments with square mesh codends in bottom trawl, 1985-1987. *In:* World Symposium on Fishing Gear and Fishing Vessel Design, St. Johns, Newfoundland, Canada, November 1988. 9 pages.

________. 1986. Selectivity experiments with square mesh codends in bottom trawls. ICES, CM 1986/B:28.

The authors describe selectivity experiments for cod and haddock using 120- and 135-mm square- and diamond-mesh trawl cod-ends and a 135-mm mixed-mesh cod-end design (modified trouser trawl and cod-end cover methods). A remote-controlled TV vehicle was used to observe trawl shape and fish escape behavior. The authors report that the square-mesh cod-ends had higher 50-percent retention lengths for cod and haddock and a *larger* selection range for cod (no selection range reported for haddock). The authors note that differences in selection properties were more pronounced when the catches were relatively small and when they consisted mainly of cod and haddock.

Larsen, R.B. (In press). A review on the application and selectivity of square mesh netting in trawls and seines. *In:* World Symposium on Fishing Gear and Fishing Vessel Design, St. Johns, Newfoundland, Canada, November 1988. 22 pages.

The author describes selectivity experiments for shrimp using 35-mm square- and diamond-mesh trawls (alternate haul method) and for cod and haddock using 120-mm square-mesh and 125-mm diamond-mesh trawl cod-ends (alternate haul method) and 120-mm and 135-mm Danish seine cod-ends (twin cod-end method). Changing species composition, day-versus-night variability, and choice of the alternate haul method complicated comparisons of trawl-net selectivity, although the 120-mm square mesh retained fewer small fish than did the 125-mm diamond mesh. The Danish seine experiment indicated that a very high proportion of haddock larger than 39 cm in total length were lost by the 120-mm square-mesh cod-end compared to the 120-mm diamond-mesh cod-end. A larger 50-percent retention length and smaller selection range were obtained using the square-mesh cod-end compared to the diamond-mesh cod-end. The discussion emphasizes the important result that the square-mesh cod-end yields a steeper selection curve (smaller selection range) than the diamond-mesh cod-end.

Robertson, J.H.B. 1983. Square mesh cod-end selectivity experiments on whiting (*Merlangus merlangus* [L]) and haddock (*Melanogrammus aeglefinus* [L]). Int. Coun. Explor. Sea CM 1983/B:25. 13 pages.

The author describes selectivity experiments for whiting and haddock using 70- and 90-mm square-mesh and 90- and 130-mm diamond-mesh trawl cod-ends (covered cod-end method). Results indicate square-mesh cod-ends yield larger 50-percent retention lengths and smaller selection ranges for whiting and haddock when equivalent size square- and diamond-mesh cod-ends are compared. However, the author notes that direct comparison of square- and diamond-mesh cod-ends requires that the selectivity curves coincide at the 50-percent retention length. The author also notes a dramatic drop in the number of whiting retained by the square-mesh cod-end and indicates that a possible reason for this may be the significantly thinner body shape of whiting compared to haddock.

Thorsteinsson, G. (In press). Icelandic investigations on the selectivity of square mesh codend in bottom trawls. *In:* World Symposium on Fishing Gear and Fishing Vessel Design, St. Johns, Newfoundland, Canada, November 1988. 17 pages.

The author describes selectivity experiments for cod and haddock using 155-mm square- and diamond-mesh trawl cod-ends (trouser trawl, covered cod-end and alternative haul methods). Experiments were carried out aboard commercial trawlers and research vessels. The author reports superior selectivity (reduced mortality of undersize fish without any marked loss of fish over 60 cm) of square-mesh cod-ends on cod when catch rates are not higher than 2 tons per hour. Although not many haddock were retained in the 155-mm mesh, the limited data suggest that it is not worth considering using the square-mesh cod-end for haddock. The author notes that square-mesh cod-end selectivity on cod may be influenced by the cod's feeding habits and that square-mesh shrinkage may pose problems for enforcement.