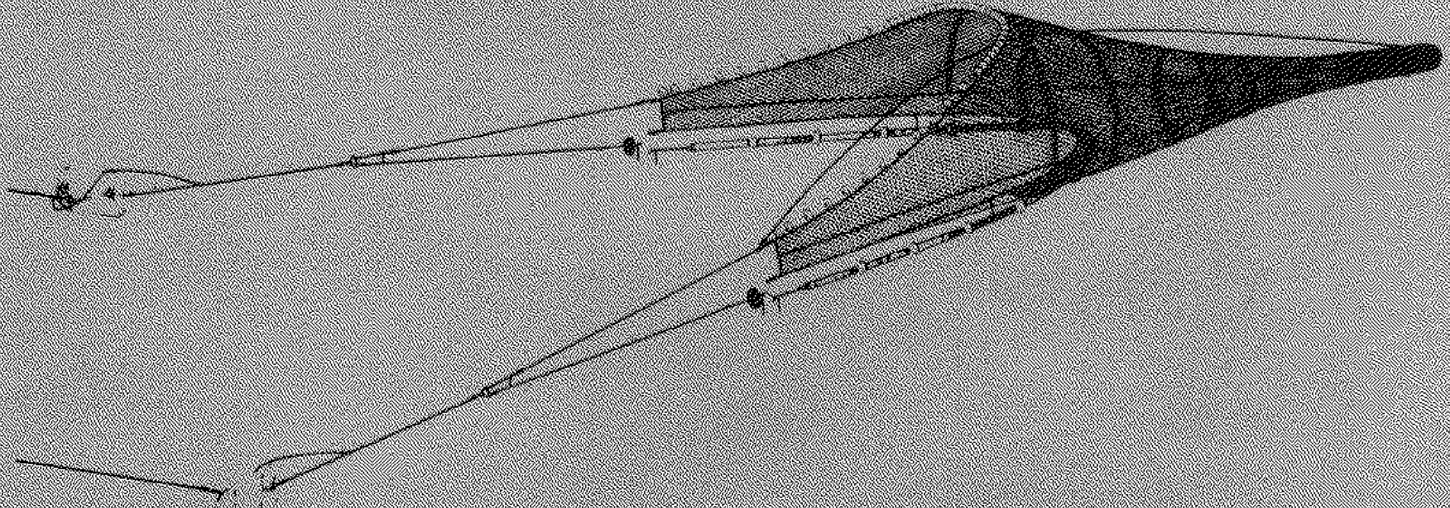
Proceedings of the Fisheries Conservation Engineering Workshop

Narragansett, Rhode Island, April 4-5, 1990



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Proceedings of the Fisheries Conservation Engineering Workshop

Held at The University of Rhode Island Bay Campus
Narragansett, Rhode Island, April 4-5, 1990

EDITED BY
Joseph T. DeAlteris and
Mary Grady, Rhode Island Sea Grant

LAYOUT BY
LaVie McDonald

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Introduction

Joseph T. DeAlteris

Department of Fisheries, Animal and Veterinary Science
The University of Rhode Island
Kingston, RI 02881

Marine fishery resources in the United States are experiencing record levels of exploitation. As a result, many fish stocks are depressed to record low levels. Resource managers face a difficult task: rebuilding the fish stocks while maintaining a viable commercial fishery. To allow the stocks to rebuild, fish mortality must be reduced, and this can only be achieved with a reduction in fishing effort and an improvement in the species- and size-selectivity of fishing gear. In addition, bycatch of nontarget marine resources must be reduced. Conservation engineering—the design of fishing gear that minimizes the negative impact of the harvesting process on the marine ecosystem—has the potential of realizing some reduction in fishing mortality without requiring a reduction in fishing effort.

These proceedings are the result of a workshop held at The University of Rhode Island on April 4 and 5, 1990. Fisheries biologists and fishing gear technologists met to review recent progress in various aspects of their research related to conservation engineering. Dr. Clem Wardle, from the Marine Laboratory in Aberdeen, Scotland, was invited to lecture on his ten years of research on fish behavior in the vicinity of fishing gear. Twelve papers were presented during the two-day meeting, and nine were submitted for publication in these proceedings.

The workshop was cosponsored by Rhode Island Sea Grant, the New England Fishery Management Council, the National Marine Fisheries Service, and the Massachusetts Division of Marine Fisheries. The workshop was organized by Joseph DeAlteris of The University of Rhode Island, Alan Blott of the National Marine Fisheries Service, and Arnold Carr of the Massachusetts Division of Marine Fisheries.

A Study of Ghost Gillnets in the Inshore Waters of Southern New England

H. Arnold Carr[1] and Alan Blott[2]

[1]Massachusetts Division of Marine Fisheries
Sandwich, MA 02563

[2]Fisheries Engineering Group
NOAA Fisheries
Narragansett, RI 02882

INTRODUCTION

Synthetic fibers revolutionized the fishing industry and have a wide application in gillnet construction. The nondegradable quality of the nylon is attractive to the fishing industry, but is also a serious threat to living marine resources when a net made of it becomes derelict. The controversy over gillnet losses and their continued fishing as derelict (ghost) gillnets has been an issue in this region for more than a decade, since the use of bottom-tending gillnets greatly expanded. Bottom-tending gillnets are used to fish for benthic species year round in inshore waters in the northeastern United States. These demersal nets are stationary and anchored to the bottom. Unlike pelagic (surface-tending) gillnets, the demersal net is not readily moved by tidal currents or storms.

The concern about ghost gillnet gear spurred the National Marine Fisheries Service (NMFS), the Massachusetts Division of Marine Fisheries (MDMF), and the National Undersea Research Program (NURP) to undertake a three-year study that determined the magnitude and impact of ghost gillnets in two traditional gillnet areas located in the Gulf of Maine. This study concluded in 1986 (Carr et al 1985). The research entered a second phase when one net that was found in 1984 was surveyed in the winter and spring of 1985 with a submersible, and again in 1986 with the use of a remotely operated underwater TV vehicle (ROV). This enabled scientists to observe the net when many important groundfish and marine animals were present. The results of these surveys indicate that a lost net may maintain its vertical profile due to the positive buoyancy of the floatline and floats and that the rate of continued fishing of the ghost net is primarily a function of the maintained vertical profile and the net's visibility to the fish (Cooper et al 1988).

Concern is still expressed by many, including the New England Fishery Management Council and the NOAA Entanglement Program, about gillnetting and the impact of lost demersal gillnets, which is inevitable when fishing. The question remaining is what level of gillnet losses are acceptable and what means are available to mitigate the impact of lost nets. The aforementioned studies suggested that gillnets lost in the two study areas in the Gulf of Maine were probably a result of a sharp increase in gillnetting by inexperienced people. More recently, losses appear to be more often a result of gear conflict between mobile and fixed fishing gear.

If gillnetting is continued without prohibition, two of the possible means of reducing the impact of lost gillnets on marine resources are:

1. Require gillnet fishermen to stand by any actively fishing gillnet gear.
2. Modify the gear to limit its active fishing life.

This project addressed the second of these possible solutions.

Last year, NMFS and MDMF started investigating the use of degradable products to limit the active fishing life of the gear. Our focus was on the eventual elimination of net buoyancy of a lost net. Without the buoyancy of the floats and floatline, the gillnet would lose much or all of its vertical profile, become overgrown, and blend into the bottom. The limitation of this potential solution is that the remaining webbing and leadline will not degrade and will remain in the marine environment.

The specific objective of this study was to determine if degradable float systems reduce the active fishing life of a bottom-tending derelict gillnet.

MATERIALS AND METHODS

Two 50 fa commercial gillnets with 10.5 cm mesh were set in four different configurations to compare floatation and resulting vertical profile. The control section was a typical commercial fishing arrangement. Section 2 had a neutrally buoyant polyester floatline. Section 3 had the floats connected to the floatline by 18-thread cotton string. The fourth section had the floats connected with biodegradable plastic panels provided by the Polymer Processing Institute at Stevens Institute of Technology.

Three different types of degradable plastics were used. Two types had different shapes but were both composites of polyethylene and 15 percent starch with aluminum stearate and a copper acetylacetoneate catalyst. The other was a blend of a low density polyethylene (80 percent) and polycaprolactone (20 percent), (Gonsalves et al 1989). Twenty floats were attached over a 48 m section of netting with these plastic panels (Fig. 1).

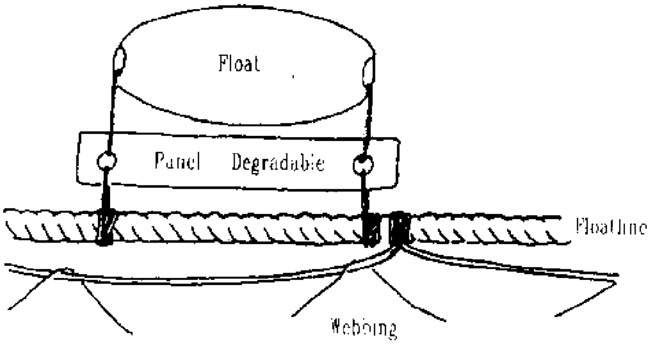

Figure 1. *Diagram of a degradable float.*

The site selected for this work was in 20 m of water at the entrance to Buzzards Bay (Fig. 2). The site was chosen because it was logistically convenient and not subject to impact by the trawl fishery.

The R/V *Gloria Michelle* served as the primary support vessel. Diving activities were conducted off an inflatable vessel.

The nets were set June 19, 1989. A series of lines connected the ends of the nets to each other. This arrangement permitted the divers to survey both nets during one dive. Each net was marked along the floatline at 9.7 m intervals with numbered tags and weighted along the leadline in five places with steamboat chain.

Dive surveys were scheduled every month between June and October, and bimonthly thereafter. The survey routine just after the nets were set and during the initial months was to dive over a two or three day period each month to permit a thorough evaluation of the entanglement rate. During this time the sites were expected to be heavily populated with a variety of vertebrate and invertebrate species. Surveys during the winter months would normally require one day. Data on vertical profile, float attachment and condition, and the catch of each section were recorded by the divers on waterproof paper and with underwater video cameras.

RESULTS AND DISCUSSION

Seven dive surveys were conducted between June 1989 and January 1990 (Table 1). The bottom type at the site was cobble with scattered boulders. A thin layer of silt covered the bottom, and the area was subject to surge. This may have contributed to the periodic poor underwater visibility in the

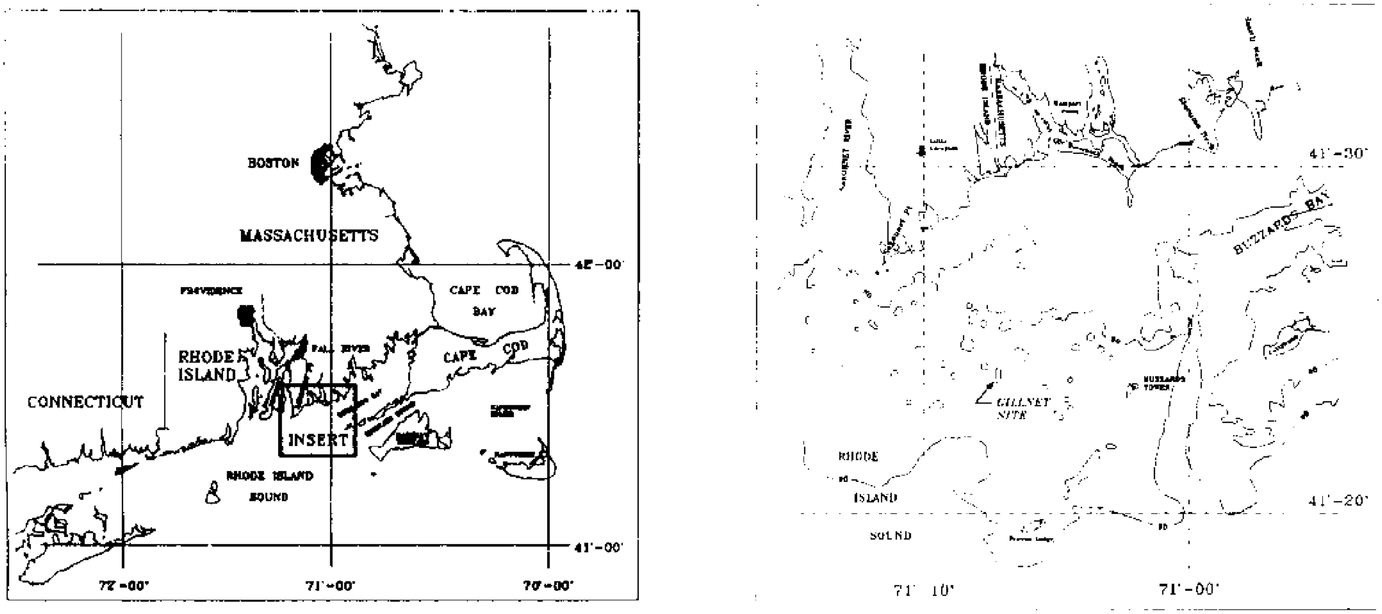

Figure 2. *Map of the study location in Buzzards Bay, off southeastern Massachusetts.*

Table 1: *Dive survey and activity schedule*

19 June 1989 to 31 January 1990

Date	Total days set	Activity
19 June	0	Set nets, preliminary dive survey
20 June	1	Dive survey
21 June	2	Dive survey
6 July	18	Abort dive, poor U/W visibility
19 July	31	Dive survey
20 July	32	Dive survey
28 August	71	Dive survey
30 August	73	Dive survey
23 October	124	Bouys gone, net not found
26 October	128	Recover high flyer, poor visibility
2 November	134	Aborted dive, poor U/W visibility
25 January	219	Survey, one net only, other lost

water, especially 2 to 3 m off the bottom. The poor visibility in the area resulted in reduced observations during the fall and spring.

One net made up of two sections, one with the neutrally buoyant floatline and one with the floats attached by cotton twine, was lost from August 1989 to July 1990. We believe this net was dragged offstation by a fishing vessel or a tug with a barge in tow.

The normal vertical profile of these demersal gillnets is about 2 m from the floatline to the leadline which is normally on the sea bottom. During the first dive survey, the nets had a vertical profile of 2 m off the bottom. Two exceptions were observed. One part of one of the nets was set over a 1.8 m high boulder; this piece of netting therefore rose to a height of about 3.5 m off the bottom. The other exception was the section with the neutrally buoyant floatline which had a maximum height of 0.3 m off the bottom.

On the second and third days after the initial setting of the nets, the vertical profile of the buoyant sections diminished as fish became gilled or entangled and twisted the webbing, which reduced the height in specific locations. The vertical profile observed thereafter was between 0.3 to 1.6 m in the sections with floats and more than 80 percent of these sections had a vertical height of less than or equal to 1 m. The section without floats remained less than 0.3 m in vertical profile throughout the experiment.

The experimental floatation arrangements were intact through August 30, 1989, 73 days after the gear was set. By this time, the monofilament webbing was becoming fouled with bryozoans. This fouling increased the visibility of the webbing (Fig. 3). Along certain locations of the net, the webbing was clean with no bryozoans. This was usually the result of entangled fish cleaning the immediate webbing while struggling to escape.

The next successful survey, when underwater visibility again permitted observations, was on January 25, 1990; 219 days after the gear was set. Two of 20 degradable plastic connectors had failed. The floats remained attached to one of the two points (Fig. 4).

Figure 3. *Float attached to the gillnet. The gillnet is overgrown with bryozoans.*

Figure 4. *Float with one of two twine attachments disintegrated.*

The gillnets immediately entangled animals. Skates (*Rala* sp.) were the most prevalent species and were caught almost equally in all sections of the net. Dogfish (*Squalus* sp.) were next most frequently caught, but only in the three sections with floatation. Other species caught, in descending abundance, were bluefish (*Pomatomus saltatrix*), tautog (*Tautoqis onitus*), scup (*Stenotomus chrysops*), winter flounder (*Pseudopleuronectes americanus*), summer flounder (*Paralichthys dentatus*), and sea robins (*Prionotus carolinus*). The bluefish catch was initially high, 22 fish, but quickly decreased as the net became fouled with bryozoans.

We did observe and record on video finfish escaping from the net. One of the most notable incidents was a bluefish which was entangled about the jaw. When divers approached the site where the bluefish was entangled, the fish twisted and managed to free itself.

Finfish were also observed feeding on entangled fish and invertebrates. The cunner (*Tautogalabrus adspersus*) was most numerous near the nets and was the most aggressive feeder. One event observed and recorded on video was a school of cunner feeding on a dogfish carcass.

The predominant invertebrate caught in the nets was the American Lobster. On July 6 the total catch was 18 lobsters; on July 19 the total catch was 37 lobsters; and on August 28 the catch was 36 lobsters. On January 25 the lobster catch was five, four alive and one dead. The catch of lobsters was about equally dispersed throughout the sections.

We presume that most, if not all, of the lobsters caught in the gillnet die. Dead lobsters were seen in the net with their exoskeletons intact. Exoskeletal parts were not found on the bottom near the net. These parts were probably devoured by other invertebrates or bacteria.

These nets were set in waters that are considered inshore. The previous studies were done on gillnets in offshore waters. The catch in the nets set inshore in this study differed considerably from the catch in the nets found offshore. Inshore there is more species variety and abundance. This difference was reflected in our observational data; the catch rates and species diversity were higher than those of the offshore study.

This study is ongoing and comprehensive results will be reported upon completion.

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Shrimp Separator Trawl Experiments in the Gulf of Maine Shrimp Fishery

John Kenney[1], Alan Blott[1], and Joseph T. DeAlteris[2]

[1]National Marine Fisheries Service Fisheries Engineering Group
Narragansett, RI 02882

[2]DeAlteris Associates, Inc.
Jamestown, RI 02835

INTRODUCTION

Statement of the Problem

The discard of finfish bycatch in the Gulf of Maine northern shrimp trawl fishery is considered a serious problem.The species-specific discard rate varied from 17 percent for winter flounder to 95 percent for silver hake in 50 tows made by commercial trawlers during the period 1985-1989 (Howell and Langran 1990). Studies by Jean (1963) and Howell and Langran (1987) suggest a very high mortality for discarded finfish in the western North Atlantic fisheries. The discard problem has two major facets: direct wastage in throwing fish back into the sea and loss of future catches of larger animals through the mortality of small individuals (Saila 1983).

Rationale and Objectives

Given the perceived problem of discarded bycatch in the Gulf of Maine shrimp fishery, the objective of this project was to experiment with several design modifications to existing traditional trawls that would reduce the juvenile finfish bycatch. The concept of selective shrimp trawls is not new. Trawl design modifications have been evaluated in shrimp fisheries for separating finfish from shrimp, with varying degrees of success (West et al 1984, Averill 1988, Watson 1989, Watson and Taylor 1990). The techniques utilize behavioral and size differences between shrimp and finfish, and include horizontal separator twine panels, large mesh escape panels, deflecting grids, accelerator funnels, and others. Northern-style shrimp trawls were the control nets in these experiments. The basic modifications to the nets evaluated in this project were: large mesh in the belly area and a funnel accelerator ahead of the trawl cod end.

METHODS

Study Area, Fishing Vessels, and Experimental Trawls

The trawl comparison experiments were conducted in the offshore waters of the Gulf of Maine. Water depths in the area range from 90 m to 120 m. The fishing vessels participating in the trawl comparison experiments were the F/V *Miss Paula* (MP), operated by Captain Terry Alexander, the F/V *Mary Ellen* (ME), operated by Captain Charles Saunders, and the R/V *Gloria Michelle* (GM), a NOAA research vessel operated by Lt. Kenneth Barton. Two of the vessels were southern shrimp trawlers converted to northern stern draggers, and all were about 23 m in length and powered by 365 HP diesel engines. The F/Vs *Miss Paula* and *Mary Ellen* were home ported in Cundys Harbor, Maine, and the captains were experienced in the local waters and local fishing methods, including the use of sonar to navigate a trawl through the rough bottom areas. The R/V *Gloria Michelle* was home ported in Narragansett, R.I., and the captain was not experienced with the specific area, nor did he have the use of sonar.

Northern-style shrimp trawls served as the control nets in the experiments and as the basic nets that would be modified with either large mesh in the belly section or the use of a funnel accelerator.

The Control Tobey (CT) was a net designed and built by Andrew Tobey. The trawl had a 23.4 m (76 ft) hanging line, a 16.3 m (53 ft) headrope, and a fishing circle of 800 meshes, each with a 5 cm (2 in) stretched mesh length (Fig. 1). The net was rigged with 28 m (15 fa) legs attaching the wing ends to the trawl doors.

The Control *Miss Paula* (CMP) was the net usually used on board the F/V *Miss Paula* in the shrimp fishery. This trawl had a 24.6 m (80 ft) hanging line, a 19.4 m (63 ft) headrope, and a fishing circle of 822 meshes, each with a 5 cm (2 in) stretched mesh length (Fig. 2). The net was rigged with 28 m (15 fa) legs attaching the wing ends to the trawl doors.

The Control *Mary Ellen* (CME) was the net usually used on board the F/V *Mary Ellen* in the shrimp fishery. This trawl had a 28 m (91 ft) hanging line, a 23.4 m (76 ft) headrope, and a fishing circle of 820 meshes, each with a 5 cm (2 in) stretched mesh length (Fig. 3). This net was rigged with 28 m (15 fa) legs attaching the wing ends to the trawl doors.

As noted previously, the experimental shrimp trawls were modifications of the three control nets. Experimental trawl No. X1 was a modification of the Control Tobey (CT) trawl. A rectangular section of square mesh webbing, 15 cm (6 in) on the straight bar, measuring 3.4 m (11 ft) by 3.4 m (11 ft) was located in the center of the belly extending back from the hanging line. The net included a poly flapper on the upper panel of the extension section. The net was rigged with 9.2 m (5 fa) legs connecting the net wing ends to the trawl doors.

Experimental trawl No. X2 was another modification of the Control Tobey (CT) trawl. A triangular section of diamond mesh webbing, 30 cm (12 in) stretched mesh length, measuring 3.4 m (11 ft) along the base and cut on the bar to an apex (22 meshes wide by 11 1/2 meshes deep) was located in the center of the lower belly extending back from the hanging line. The net included a poly flapper on the upper panel of the extension section. The trawl was rigged with 9.2 m (5 fa) legs connecting the net wing ends to the trawl doors.

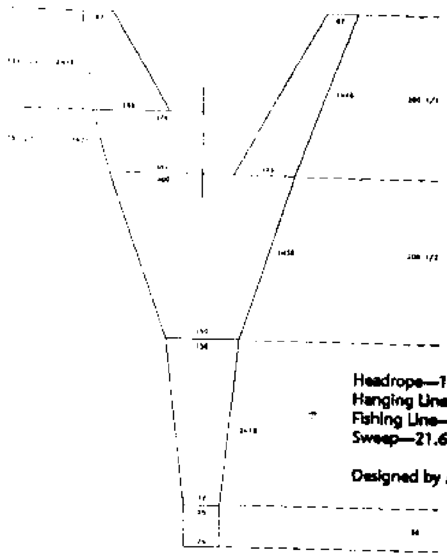
Experimental trawl No. X3 was a modification of the Control *Miss Paula* trawl (CMP). A diamond mesh section of webbing 20 cm (8 in) stretched mesh length was located at the wide end of the lower belly. In addition a poly flapper was installed in the upper panel of the extension section.

Experimental trawl No. X4a was another modification of the Control *Miss Paula* trawl (CMP). An accelerator funnel was constructed of 3.5 cm (1 3/8 in) stretched mesh length poly webbing that had undergone a depth stretch/heat setting process. This funnel was installed in the extension section of the net and two diamond-shaped holes were cut in the extension to provide a means of escape.

Experimental trawl No. X4b was a modification of the Control *Miss Paula* (CMP) and identical to X4a except that the escape means was provided by a diamond mesh section of webbing 30 cm (12 in) stretched mesh length in place of the diamond-shaped holes.

Experimental trawl No. X6 was a modification of the Control *Mary Ellen* (CME). A triangular section of large diamond-mesh webbing, 30 cm (12 in) stretched mesh length, measuring 3.4 m (12 ft) along the base and cut along the bar to an apex (24 meshes wide by 12 meshes deep), was installed in the center of the lower belly extending from the hanging line behind 5 rows of 15.4 cm (6 in) stretched mesh length reinforcing twine.

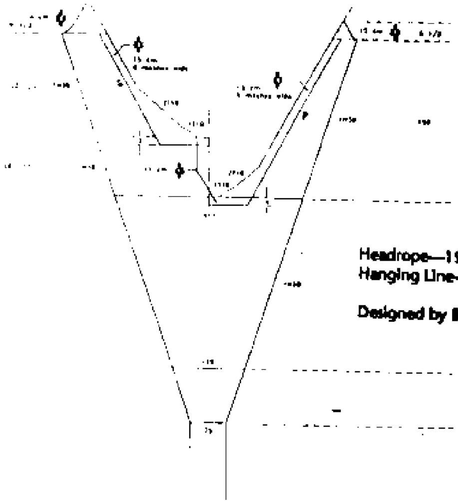
Experimental trawl No. X7 was another modification of the Control *Mary Ellen*. A trapezoidal section of large diamond mesh, 30 cm (12 in), was installed in the lower belly. The wide end of this section was 48 meshes, the narrow end was 38 meshes, and the depth was 6 meshes.



Headrope—16.15 (53')
Hanging Line—23.16 (76')
Fishing Line—22.86 (75')
Sweep—21.64-22.86 (71'-75')

Designed by Andrew Tobey

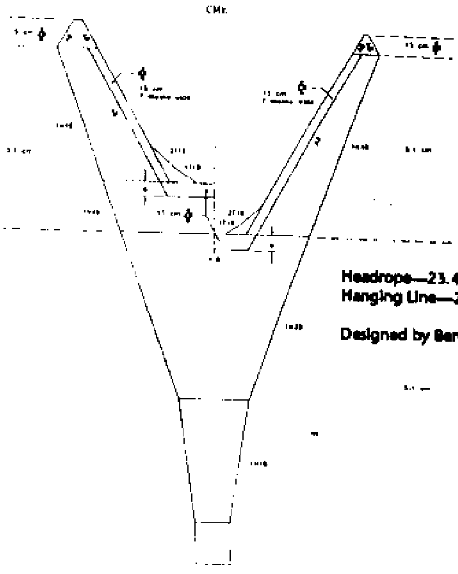
Fig. 1. *Net Plan: CT*



Headrope—19.2 (63')
Hanging Line—24.4 (80')

Designed by Benjamin Wallace

Fig. 2. *Net Plan: CMP*



Headrope—23.4 (76')
Hanging Line—28 (91')

Designed by Benjamin Wallace

Fig. 3. *Net Plan: CME*

Field Experiments

The field experimental design used was alternate paired tows. Tows were 60 minutes in duration at a towing speed of 2.5 knots. The experimental and control gear were alternated routinely by disabling (or covering) the experimental portion, or escape route, created by the experimental net. In addition, some of the configurations required changing the length of the legs.

In all comparisons, the control gear, including doors, frame, sweep, set-backs, etc., was identical to the experimental gear with the exception of the experimental modifications. This allowed for a direct evaluation of the design modification based on the catch data.

Catches were sorted by species and weighed. Selected species (or a subsample for large catches) were measured. Station selection was based on information from the commercial vessel captains with respect to locations of shrimp and bycatch. A ScanMar hydroacoustic trawl mensuration system was used periodically to determine trawl mouth geometry in order to confirm proper trawl performance.

The following paired alternate comparisons were made:

X1-MP vs. CT-MP
X1-GM vs. CT-GM
X2 vs. CT
X3 vs. CMP
X6 vs. CME
X7 vs. CME
X4a vs. CMP
X4b vs. CMP

Data Analysis

The final data were compiled by tow pairs for each comparison. The parameters evaluated for this comparison were number and weight of dabs, *Hippoglossoides platessoides*, the number and weight of cod, *Gadus morhua*, and the weight of shrimp, *Pandalus borealis*, captured per tow. A Wilcox signed ranks test was applied to each set of comparison data to test the null hypothesis that the catches of the experimental and control trawls were similar for the variables noted previously (i.e., testing the effectiveness of the modifications). If a significant difference was observed between the two trawls in the numbers of finfish bycatch retained, then a Kolmogorov-Smirnov two-sample test was applied to the length-frequency distributions of the catches of the two trawls to test for similarities in the proportions of the distributions (Sokal and Rohlf 1981). The purpose of this test was to investigate potential size-specific effects of the various modifications on the finfish bycatch.

RESULTS

Geometric Performance

The results of the ScanMar observation of trawl mouth geometry are presented in Table 1. Door spread of the various trawls was determined by leg length. The door spread of X1 trawl with the 9.2 m leg was only 24 m, while the other trawls with the 28 m legs experienced approximately a 34 m door spread. Wing spread of all trawls averaged about 12 m irrespective of door spread or leg length. Vertical opening of the trawl mouth was only 2.2 m on the Tobey trawl with the 5 m leg length, and reached about 4 m on the CME and CMP trawls.

Catch Performance

X1-MP vs. CT-MP

The results of the shrimp separator trawl comparison X1-MP vs. CT-MP are summarized in Table 2. Eleven paired tow comparisons were available for analysis. There was no significant difference in catch of dabs (number and weight) between the experimental and control trawls. There was a significant reduction in the number of cod with the experimental trawl, but no corresponding difference in the catch weight of cod. The length-frequency distributions of cod for the two trawls were compared. There was a significant difference in the proportions of the two curves, indicating that the experimental trawl captured less small cod. The legal minimum size of the cod is 48.3 cm (19 in), and 78 percent of the cod catch was undersize with the experimental trawl as compared to 87 percent with the control trawl.

The ratio of shrimp catch (kg) to the total bycatch of cod (kg) and dab (kg) was 2.3:1 for the experimental trawl, and 1.9:1 for the control trawl. Approximately 98 percent of the dabs were undersize (< 14 in, 35.6 cm) and discarded, and approximately 83 percent of the cod were undersize (< 19 in, 48.3 cm) and discarded.

X1-GM vs. CT-GM

The results of the shrimp separator trawl comparison X1-GM vs. CT-GM are summarized in Table 3. Eight paired tow comparisons were available for analysis. No significant difference was found in the weight or number captured of cod or dab between the experimental and the control trawls.

The ratio of shrimp catch (kg) to bycatch of dab (kg) plus cod (kg) was 1.3:1 for the experimental trawl and 1.3:1 for the control trawl.

X2 vs. CT

The results of the shrimp separator trawl comparison X2 vs. CT are summarized in Table 4. Seven paired tow comparisons were available for analysis. There was a significant

Table 1. *Shrimp Trawl Geometric Performance.*

Trawl	Leg Length (m)	Leg Length (fa)	Door Spread (m)	Door Spread (ft)	Wing Spread (m)	Wing Spread (ft)	Vertical Opening (m)	Vertical Opening (ft)
CT	28	15	35.1	115.1	11.2	36.7	2.6	5.8
X1	92	5	24.0	78.7	11.7	38.4	2.2	7.2
X3	28	15	34.4	112.8	12.2	40.0	3.2	10.5
CMP	28	15	33.5	110.1	12.6	41.4	3.8	12.5
CME	28	15	31.4	103.0	12.6	41.4	4.1	13.3

Table 2. *Shrimp Separator Trawl Comparison: X1-MP vs. CT-MP, based on 11 paired tows. Tabulated values are average per tow, ± a standard deviation. Statistical comparison is based on a Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X1-MP	Net CT-MP	Statistical Comparison
Number of Dab	280 ± 72	331 ± 74	0.14
Weight of Dab (kg)	27 ± 6	31 ± 8	0.08
Number of Cod	17 ± 10	23 ± 14	0.04*
Weight of Cod (kg)	14 ± 6	17 ± 10	0.08
Weight of Shrimp (kg)	94 ± 39	91 ± 40	0.48

Table 3. *Shrimp Separator Trawl Comparison: X1GM vs. CT-GM, based on 8 paired tows. Tabulated values are average per tow ± a standard deviation. Statistical comparison is based on a Wilcox signed ranks test; a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X1-GM	Net CT-GM	Statistical Comparison
Number of Dab	242 ± 90	258 ± 89	0.26
Weight of Dab (kg)	32 ± 10	37 ± 11	0.13
Number of Cod	5 ± 4	5 ± 5	0.58
Weight of Cod (kg)	11 ± 12	10 ± 7	0.99
Weight of Shrimp (kg)	58 ± 38	61 ± 53	0.99

Table 4. *Shrimp Separator Trawl Comparison: X2 vs. CT, based on 7 paired tows. Tabulated values are average per tow, ± a standard deviation. Statistical comparison is based on a Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X2	Net CT	Statistical Comparison
Number of Dab	210 ± 44	278 ± 70	0.02*
Weight of Dab (kg)	23 ± 4	33 ± 9	0.04*
Number of Cod	17 ± 9	28 ± 19	0.06
Weight of Cod (kg)	15 ± 7	27 ± 14	0.04*
Weight ofShrimp (kg)	83 ± 44	84 ± 21	0.87

reduction in both the catch number and weight of dab in the experimental trawl. The length-frequency distribution of dab for the two trawls were compared. There was no significant difference in the proportions of the two distribution curves, indicating no size-dependent characteristic in the reduced dab catch of the experimental trawl. Approximately 97 percent of the dab catch was undersize for both trawls. The number of cod captured was not significantly different for the two trawls, but the weight of cod captured was different, with the experimental trawl retaining less cod by weight.

The ratio of shrimp catch (kg) to bycatch of dab (kg) and cod (kg) was 2.2:1 for the experimental trawl, and 1.4:1 for the control trawl.

X3 vs. CMP

The results of the shrimp separator trawl comparison X3 vs. CMP are summarized in Table 5. Five paired tow comparisons were available for analysis. No significant differences were found in either the weight or number captured of cod or dab between the experimental and control trawls.

The ratio of shrimp catch (kg) to bycatch of dab (kg) and cod (kg) was 2.1:1 for the experimental trawl and 0.75:1 for the control trawl. The reason this data set is uniquely high with regard to its cod bycatch is that on one tow the cod catch exceeded all others by 10 times.

X6 vs. CME

The results of the shrimp separator trawl comparison X6 vs. CME are summarized in Table 6. Six paired tows were available for analysis. No significant differences were found in either the weight or number captured of cod or dab between the experimental and control trawls.

The ratio of shrimp catch (kg) to bycatch of dab (kg) and cod (kg) was 7.1:1 for the experimental trawl and 6.6:1 for the control trawl.

X7 vs. CME

The results of the shrimp separator trawl comparison X7 vs. CME are summarized in Table 7. Ten paired tow comparisons were available for analysis. There was a highly significant reduction in the catch weight and number of dab with the experimental trawl as compared to the standard trawl. The length-frequency distributions of dab for the two trawls were compared. There was a significant difference in the relative proportions of the two curves, indicating the experimental trawl retained less small dab.

The ratio of the shrimp catch (kg) to bycatch of dab (kg) and cod (kg) was 4.0:1 for the experimental trawl and 3.4:1 for the control trawl.

X4a vs. CMP

The results of the shrimp separator trawl comparison X4a

Table 5. *Shrimp Separator Trawl Comparison: X3 vs. CMP, based on 5 paired tows. Tabulated values are average per tow, ± a standard deviation Statistical comparison is based on a Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X3	Net CMP	Statistical Comparison
Number of Dab	285 ± 109	224 ± 40	0.22
Weight of Dab(kg)	26 ± 4	24 ± 3	0.28
Number of Cod	34 ± 6	99 ± 148	0.69
Weight of Cod (kg)	22 ± 11	74 ± 124	0.89
Weight of Shrimp (kg)	101 ± 64	72 ± 51	0.22

Table 6. *Shrimp Separator Trawl Comparison: X6 vs. CME, based on 6 paired tows. Tabulated values are average per tow, ± a standard deviation. Statistical comparison is based on a Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X6	Net CME	Statistical Comparison
Number of Dab	112 ± 59	105 ± 71	0.92
Weight of Dab (kg)	14 ± 6	15 ± 12	0.92
Number of Cod	3 ± 2	4 ± 7	0.50
Weight of Cod (kg)	3 ± 2	3 ± 6	0.50
Weight of Shrimp (kg)	120 ± 54	119 ± 78	0.78

Table 7. *Shrimp Separator Trawl Comparison: X7 vs. CME, based on 10 paired tows. Tabulated values are average per tow, ± a standard deviation. Statistical comparison is based on Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X7	Net CME	Statistical Comparison
Number of Dab	42 ± 17	64 ± 32	0.01**
Weightof Dab (kg)	7 ± 2	9 ± 4	0.01**
Number of Cod	7 ± 6	9 ± 6	0.11
Weight of Cod (kg)	7 ± 6	11 ± 6	0.07
Weight of Shrimp (kg)	63 ± 36	67 ± 35	0.84

Table 8. *Shrimp Separator Trawl Comparison: X4a vs. CMP, based on 11 paired tows. Tabulated values are average per tow, ± a standard deviation. Statistical comparison is based on a Wilcox signed ranks test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X4a	Net CMP	Statistical Comparison
Number of Dab	169 ± 70	170 ± 77	0.86
Weight of Dab (kg)	18 ± 5	21 ± 6	0.07
Number of Cod	18 ± 20	30 ± 21	0.04*
Weight of Cod (kg)	17 ± 12	33 ± 42	0.06
Weight of Shrimp (kg)	66 ± 21	70 ± 23	0.72

Table 9. *Shrimp Separator Trawl Comparison: X4b vs. CMP, based on 6 paired tows. Tabulated values are average per tow, ± a single standard deviation. Statistical comparison is based on a Wilcox signed ratio test, a non-parametric test for paired samples. The tabulated value is a two tailed probability, * indicates a significant difference, ** indicates a highly significant difference.*

	Net X4b	Net CMP	Statistical Comparison
Number of Dab	197 ± 50	211 ± 70	0.75
Weight of Dab (kg)	25 ± 3	26 ± 6	0.75
Number of Cod	17 ± 11	19 ± 15	0.68
Weight of Cod (kg)	20 ± 13	23 ± 14	0.72
Weight of Shrimp (kg)	82 ± 55	91 ± 53	0.92

vs. CMP are summarized in Table 8. Eleven paired tow comparisons were available for analysis. There was no significant difference in the catch of dabs (number and weight) between the experimental and control trawls. There was a significant reduction in the catch number of cod with the experimental trawl, but no corresponding difference in the catch weight of cod. The length-frequency distributions of cod for the two trawls were compared. There was no significant difference in the relative proportions of the two curves, indicating that both trawls performed similarly with respect to size selectivity.

The ratio of the shrimp catch (kg) to the bycatch of dab (kg) and cod (kg) for the experimental trawl was 1.9:1 and 1.3:1 for the control trawl.

X4b vs. CMP

The results of the shrimp separator trawl comparisons X4b-CMP are summarized in Table 9. Six paired tow comparisons were available for analysis. No significant differences were found in the weight or number captured of cod or dab between the experimental and the control trawls.

The ratio of shrimp catch (kg) to bycatch of dab (kg) and cod (kg) was 1.8:1 for the experimental trawl and 1.9:1 for the control trawl.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Three northern-style basic shrimp trawls were compared to seven experimental trawls that were modifications of the three basic trawls. Eight paired comparisons were made.

The reduction in leg length from 28 m (15 fa) to 9.2 m (5 fa) resulted in approximately a 30 percent reduction in trawl door spread, which presumably should reduce herding effects on juvenile ground fish. Trawl wing spread was unaffected by leg length. Trawl vertical opening appeared to be a function of trawl design rather than modifications made. In this case control trawls of the F/Vs *Mary Ellen* and *Miss Paula* opened vertically almost twice as much as the control Tobey trawl. The apparent reason for this is that the control Tobey trawl had only 25 floats, whereas the control *Miss Paula* and *Mary Ellen* trawls had about 50 floats.

The bycatch issue in the Gulf of Maine shrimp fishery has attracted considerable interest in the last several years. However, compared to the tropical shrimp fisheries where 10 kg of finfish bycatch is captured and discarded for each 1 kg of shrimp captured, the Gulf of Maine shrimp fishery is not nearly as wasteful. The results of this project indicate that an average finfish bycatch for the control trawls is 0.43 kg of cod and dab per 1 kg of shrimp, and for the experimental trawls, 0.35 kg of cod and dab per 1 kg of shrimp. For the composite catches of all control trawl tows, approximately 73 percent of the cod catch was undersize (<19 in, 48.3 cm) and discarded; additionally, 98 percent of the dab catch was undersize (<14 in, 35.6 cm) and discarded.

With respect to the modifications of the basic northern-style trawls, it appears that large mesh (30 cm) in the lower belly, shorter legs (9 m vice 28 m), and an accelerator funnel can result in significantly reduced catches of either cod or dab. However, the results are not definitive for indicating whether reduced leg length alone, an accelerator funnel alone, or large mesh alone will reduce catches of both cod and dab. Trawl X2, with short legs and large diamond mesh, captured less cod and dab. Trawl X7, with only large diamond mesh, captured less dab; and trawl X4a with the accelerator funnel and diamond-shaped exits captured less cod.

The experimental results are not clear because the experimental design and the resulting data confound too many variables into single experiments, with insufficient data to definitively answer any questions. For example, an appropriate question may be: Does shorter leg length result in reduced catches of cod or dab due to reduced herding? The only variable tested should be reduced leg length, and the evaluation should be exhaustive, comparing several different net styles using 9 m and 28 m leg lengths in alternate paired tows with each net style.

Another issue might be to confirm that large diamond mesh in the lower belly reduces catches of cod and dab. Again the only variable tested should be the large mesh in the lower belly, and it should be evaluated on several net styles so as to confirm its usefulness on an industry-wide basis.

Future studies should emphasize experiments with single variables, and adequate replicate samples.

ACKNOWLEDGMENTS

This project was truly a cooperative effort between management agencies, scientists, engineers, and the fishing industry. The Atlantic States Marine Fisheries Commission initially addressed the issue of finfish discards in the Gulf of Maine shrimp fishery, and sought a technological solution to the perceived problems. The New England Fishery Management Council (NEFMC) funded this project to evaluate potential shrimp separator trawl design concepts. The Fisheries Engineering Group of the National Marine Fisheries Service was given the task of undertaking this project for the NEFMC, and they developed a team of interested parties within the region to assist with the project.

The Rhode Island Sea Grant Advisory Service provided assistance with the experimental design, and provided the ScanMar trawl mensuration system for the field work. The Massachusetts Division of Marine Fisheries and the Maine Department of Marine Resources provided assistance in the field, along with the New Hampshire Fish and Game Department, and personnel from the Northeast Region of NMFS and NEFMC. DeAlteris Associates Inc. assisted in the data analysis and report preparation. The shrimp fishing industry provided two vessels to assist with the experiments, the F/V *Mary Ellen*, operated by Captain Charles Saunders, and the F/V *Miss Paula*, operated by Captain Terry Alexander. Many others too numerous to mention also provided assistance and the authors of this report wish to recognize all involved.

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Effect of Mesh Size in the Body of a Bottom Trawl on the Catch Retained in the Cod End

Joseph T. DeAlteris[1], Kathleen Castro[1], and Salvatore A. Testaverde[2]

[1]Department of Fisheries, Animal and Veterinary Science
University of Rhode Island
Kingston, RI 02852

[2]National Marine Fisheries Service
One Blackburn Drive
Gloucester, MA 01930

ABSTRACT

Two experiments were conducted to investigate the effect of mesh size in the body of a bottom trawl on the catch retained in the cod end. The purpose of the experiments was to evaluate the potential impact on the catches of the trawl fishing industry of minimum mesh size regulations throughout the entire trawl rather than only in the cod end. Catches of small-mesh trawls with large-mesh regulation cod ends (standard trawls) were compared to catches of trawls with mesh sizes equal to or larger than the regulation cod end mesh size (experimental trawls). The target species were Atlantic cod, haddock, and yellowtail flounder.

The results of the experiments indicated no significant differences in the catches of the standard trawls compared to the experimental trawls with respect to both the numbers of fish captured and length-frequency distribution of the catches. This result confirms observations of previous investigators that the size-selection process occurs in the cod end and that mesh size in the body of the trawl does not affect catches. Therefore, regulations affecting mesh sizes in the body of the trawl will have no effect on the catches of the trawl fishing industry, and may improve compliance with minimum mesh size regulations because of the absence of webbing with a mesh size smaller than the regulation mesh size on board the fishing vessel.

INTRODUCTION

The New England Fishery Management Council (NEFMC) introduced the multispecies fishery management plan during the mid-1980s. The purpose of the plan was to effectively conserve the fishery resources through a management regime that maintained operational flexibility with maximum efficiency and minimum regulatory burden (NEFMC 1985). Two important changes that updated the initial plan were: (1) the establishment of regulations on landings of minimum fish length size for seven major commercial species, and (2) the increase of the minimum mesh size in mobile trawl nets. The required minimum mesh size in the cod end was increased to 140 mm in diamond-mesh or square-mesh configuration.

The revised 1987 regulations maintained the requirement that mobile trawl vessels continue the minimum 140 mm cod end; however, cod end length increased. New regulations stated that the cod end must extend for at least 75 meshes forward of the terminus of the net. The increase in cod end length was in response to fishermen's complaints that some vessels were fishing with cod ends 20 meshes in length. The 20 meshes reflected the initial mesh regulation which stated that the average mesh size for enforcement standards was determined from a series of 20 consecutive meshes.

After implementation of the 1987 regulations, further complaints indicated that some vessels were circumventing the minimum mesh size regulations via a technique called "tying off." Since the minimum mesh size regulations only pertained to the cod end, the body and extension piece of trawl net were permitted to have mesh sizes smaller than 140 mm.

Hence, "tying off" refers to the choking of the net at the junction of a smaller mesh size extension piece and the beginning of the regulated 140 mm mesh size cod end. During the fishing tow, captured fish are collected within the smaller mesh extension piece instead of the regulated cod end. The "tie-off" rope used to constrict the junction point consists of a material that breaks during the haul back. Fish then collect in the regulated cod end and are unloaded on the fishing vessel's deck.

Numerous complaints during NEFMC and public meetings indicated widespread use of liners, smaller mesh webbing placed within the regulated cod end. In effect, liners and "tie-offs" defeat the size selectivity of the cod end of the trawl nets.

An extensive discussion of selectivity of cod end mesh is provided by Smolowitz (1983). In essence, a particular mesh size retains a particular size fish length. As a result of continuing complaints from the fishing community regarding the circumventing of existing regulations pertaining to cod end mesh sizes, the NEFMC decided to explore alternative management tools that would improve mesh size regulation compliance. In particular, the NEFMC proposed a management measure that a trawl net be constructed entirely of the minimum mesh size of 140 mm or greater. Coupled with a regulation requiring minimum mesh size on board the fishing vessel, compliance with minimum mesh size would increase due to the difficulty in circumventing the regulation.

The purpose of this project was to determine and document the harvesting efficiency and potential size selectivity of groundfish with various fishing ports' standard multispecies trawl nets, versus a trawl with a minimum 140 mm mesh throughout the net. To date there exist no data to determine the catchability of legal size fish with the various non-regulated size trawls. Thus, the performance of alternate trawl net designs are evaluated in this report based on the relative size distribution and total numbers captured of three target fish species: cod, haddock, and yellowtail flounder (Motte and Iitaka, 1975).

METHODS

Two experiments were conducted. The first experiment was by two New Bedford, Mass., commercial fishing vessels fishing alternate paired hauls. The second experiment was by one commercial fishing vessel from Pt. Judith, R.I., conducting alternate fishing hauls.

Mesh Measurements

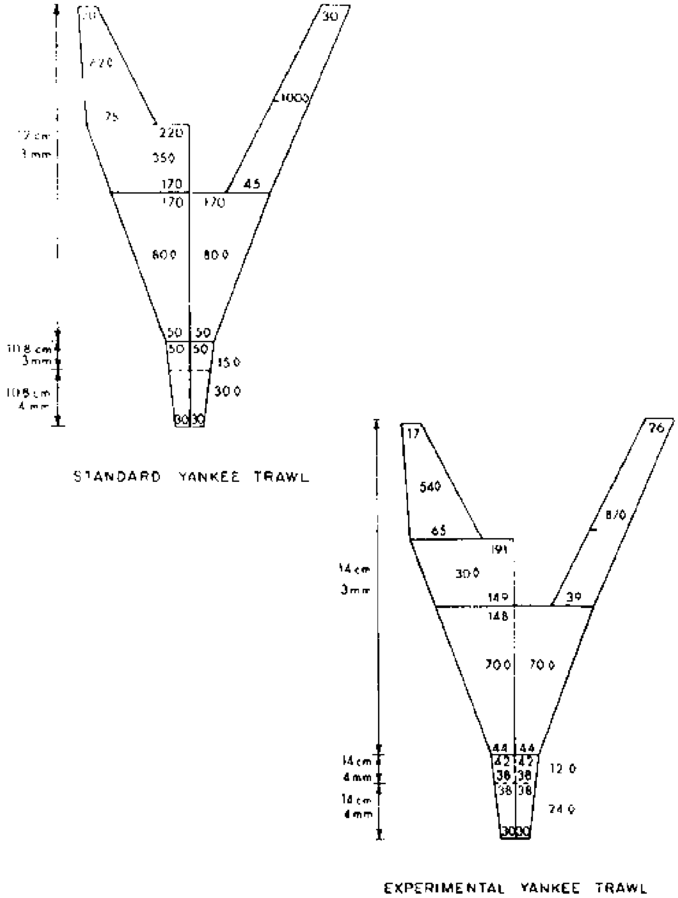
Mesh measurements were taken along the entire net from the square to the cod end. The average mesh was determined from a series of 20 consecutive meshes. All mesh measurements were taken by an ICES mesh gauge set at 5 kilograms. Measurements were recorded serially to enable any fore-aft trend to be detected. While steaming to the fishing grounds, mesh measurements were taken for each of the dry trawls. Thereafter, measurements of the standard and experimental trawl nets were collected and reported as the number of days fished.

Experiment One

The F/V *Lucisaura* and F/V *Calypso*, from the port of New Bedford, Mass., conducted a 10-day (May 17-26, 1988) experiment on Georges Bank. The alternate paired trawl hauls were conducted to obtain catch data on commercially important finfish species: haddock, cod, and yellowtail flounder.

Experimental trawl nets were built entirely from 140 mm mesh, while the standard trawl net consisted of 120 mm mesh in the upper and lower wings, top square, and belly, a 108 mm mesh extension piece, and the regulated 140 mm mesh cod end (Fig. 1). Each cod end had its underside sections matted with polyethylene strands. This standard trawl net is typical of the type that many members of New Bedford Offshore Mariners Association use, a Yankee-style net with an 18.3 m long headrope and a 24.4 m long sweep.

Twine size and type consisted of light-tone, green polyethylenes in diameters 3 mm, 4 mm, and 5 mm. Twine diameter size was adjusted during construction of the 140 mm mesh experimental trawl to equal the twine surface area of the standard trawl. The twine surface area of the two trawl nets was 41.3 m² for the standard net and 41.3 m² for the experimental net. Both trawls' headropes were 18.3 m of 22 mm combination rope equipped with 24 200 mm diameter plastic floats; the footropes were 24.4 m of 16 mm diameter chain with 12.5 mm rubber cookies. An additional 15 m of 16 mm diameter chain was attached from the center point of the footrope and twisted around the rubber cookies outwards toward each wing.



STANDARD YANKEE TRAWL

EXPERIMENTAL YANKEE TRAWL

Figure 1. *Net plans for the standard and experimental Yankee trawls. Stretched mesh size is expressed in cm and twine diameter is in mm.*

The trawls were fished with Euronete steel doors; each door weighed approximately 450 kg. These were rigged to the trawl net with 65 m of 22 mm diameter steel wire groundcables, 21 m upper legs of 16 mm diameter steel wire, and 21 m lower legs of 16 mm diameter steel chain.

The two medium-sized stern trawlers (F/V *Lucisaura* and F/V *Calypso*) were each outfitted with standard and experimental trawls. While maintaining close communication and interaction, each of the paired vessels followed normal commercial fishing practices. All experimental tows were conducted at normal towing speeds. Each vessel had dual net reels, and each vessel had an identical standard trawl net and an identical experimental trawl net. The trawl nets were alternated tow by tow on each vessel. Duration of tows were two hours or more during the experimental fishing activities. Both vessels set out and hauled back at approximately the same time, providing tows of about equal duration.

On both vessels, catch per effort and biological data were collected and recorded by technical observers during a 12-hour period per day. The total catch weight of each tow was estimated by the captain, crew, and observers. Length-frequency measurements of all groundfish, especially haddock, cod, and yellowtail flounder, were recorded during each experimental 12-hour period.

The catch data from 32 paired tows conducted from the F/V *Lucisaura* and F/V *Calypso* in May of 1988 were analyzed. Tow durations ranged from 135 to 195 minutes. All tow data was initially adjusted to a duration of 150 minutes to allow for a comparison between vessels, and grouping for the gear comparison. The adjustment was made by proportioning the data based on a ratio of the actual tow duration to the common time of 150 minutes.

The raw length-frequency distribution data for each of the target species and tows were initially loaded into a LOTUS spreadsheet. The data were sorted to provide summary length-frequency distributions for each target species, comparing the experimental trawl on the F/V *Lucisaura* to the experimental trawl on the F/V *Calypso* (n=6), and the standard trawl on the F/V *Lucisaura* to the standard trawl on the F/V *Calypso* (n=6). The relative proportions of the length-frequency distributions were compared using a two-way contingency table and chi-square test statistic (Hintze 1983, Sokal and Rohlf 1981). Similarities between the proportions of the distribution were evaluated at $\alpha=0.05$.

A comparison of the total number of fish captured per tow in the length-frequency comparison was conducted using a Mann-Whitney two-sample test (Hintze 1983, Sokal and Rohlf 1981). This non-parametric procedure compares the medians of two populations using independent samples. In this case, the null hypothesis is that the populations of total catch (numbers) per tow of a particular target species were similar for each of the previously noted comparisons. This hypothesis was evaluated at $\alpha=0.05$.

Experiment Two

The F/V *Yankee Lady*, out of Point Judith, R.I., conducted a nine-day (April 9-17, 1989) experiment on Georges Bank. Twelve alternate hauls were conducted between the experimental and standard trawl nets. The alternate trawl hauls were conducted to obtain catch data on commercially important finfish: haddock, cod, and yellowtail flounder.

The F/V *Yankee Lady*, a steel stern trawler, was outfitted with a typical "multi-purpose" (380-by-14 cm mesh) four-seam trawl net (Fig. 2). The standard trawl net was constructed of braided polyethylene 203 mm mesh in the upper and lower wings, 140 mm mesh in the square and first bellies, 121 mm mesh in the second upper and lower bellies, and 76 mm extension piece extending to the regulated 140 mm mesh cod end. The length of the headrope and footrope were 31 m and 34.2 m, respectively. The trawl was hung on 16 mm stainless steel combination ropes with a rubber and lead cookie, adjustable sweep, and 40 200 mm plastic floats. This type of trawl net is used in many fisheries found along the Southern New England coast, for example, silver hake, squid, butterfish, etc.

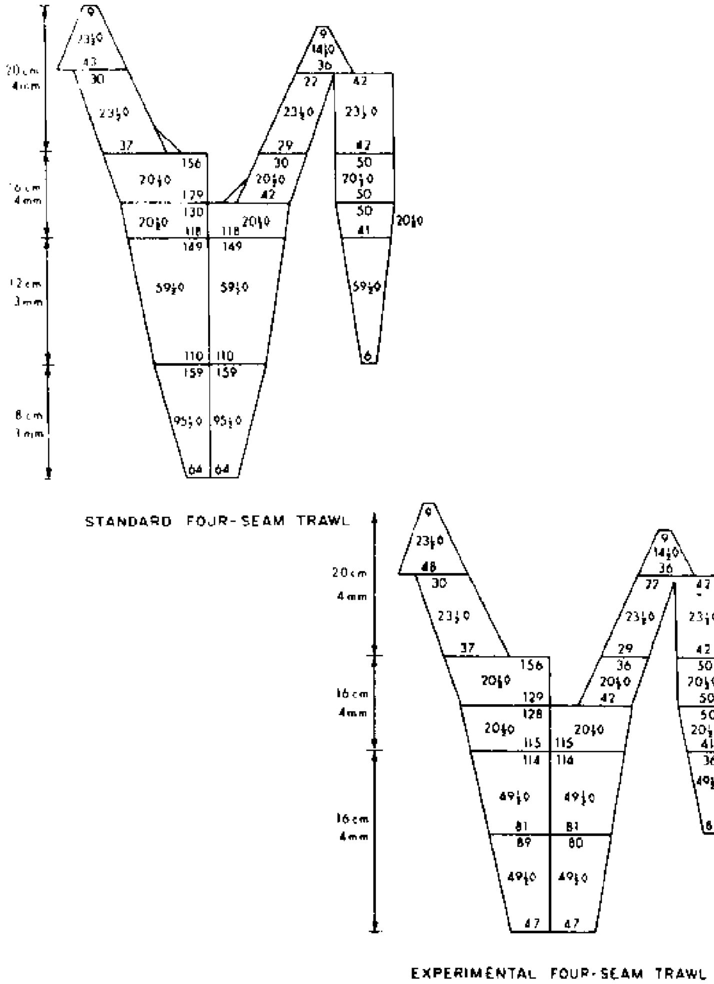


Figure 2. *Net plans for the standard and experimental four-seam trawls. Stretched mesh size is expressed in cm and twine diameter is expressed in mm.*

The experimental trawl was built entirely from 203 mm to 160 mm mesh, continuous to the regulated 140 mm cod end. All trawl net dimensions were similar to the standard trawl. The cod end was a double 6 mm polyethylene, with a 40-mesh wide 140 mm nylon mat of polyethylene strands. The twine surface area of the two trawl nets was similar, with a standard net of 48.3 m^2 and an experimental net of 49.0 m^2.

The trawl nets were fished with steel Thyvoron Slot V-Doors; each door weighed approximately 377 kilograms. These were rigged to the trawl net with a 19 mm diameter, 109 m steel wire cookie, covered groundcables, and 19 m diameter, 36.5 m steel wire upper and lower legs.

The F/V *Yankee Lady* was outfitted with the two multipurpose trawl nets. The vessel followed normal commercial fishing practices. All experimental tows were conducted at normal towing speeds. As the vessel had only one net reel, the trawls were alternated. Duration of tows were 90 minutes or more during the experimental fishing activities.

The catch per effort and biological data were collected and recorded by technical observers during a 12-hour period each day. The total catch of each tow was placed within plastic tubs and recorded. Two random subsamples were collected with all species in each sample being weighed and recorded. Length-frequency measurements of all groundfish, especially haddock, cod, and yellowtail flounders, were recorded during each experimental 12-hour period.

The catch data from 24 trawl net tows conducted aboard the F/V *Yankee Lady* in April of 1989 were available for analysis. Tow durations ranged from 60 to 240 minutes; however, most of the trawl net tow data were from paired sets of equal duration. Unequal sets were adjusted to a common time by proportioning the catch data accordingly.

The raw length-frequency distribution data for each of the target species and tows were initially loaded into a LOTUS spreadsheet. The data were sorted to provide summary length-frequency distributions for each target species comparing the standard net to the experimental net (12 paired tows; N=12). The relative proportions of the length-frequency relationships for the standard and experimental trawls were compared using a two-way contingency table and chi-square test statistic (Hintze 1983, Sokal and Rohlf 1981). Similarities between the proportions of the distributions were evaluated at α=0.05.

A comparison of the total numbers of fish captured for each of the target species for the standard and experimental net designs was conducted using a Mann-Whitney two sample test (Hintze 1983, Sokal and Rohlf 1981). This non-parametric procedure compares the medians of two populations using independent samples. In this case, the null hypothesis was that the populations of total catch (numbers) per tow (n=12) of a particular target species were similar for both the standard and experimental trawls. This hypothesis was evaluated at α=0.05.

RESULTS

Mesh Measurements

The means and standard deviations of the mesh size measurements taken from each trawl net's body and cod end are given in Table 1. The data indicate considerable variability in the measured mean mesh size within a single net as a function of time and space. Yet there are no apparent trends in mesh size variation, suggesting either random measurement error or an inherent high degree of variability in mesh size.

Experiment One

The length-frequency distributions of the cod catches for the F/V *Lucisaura* and F/V *Calypso* standard and experimental trawls were compared using a chi-square analysis that indicated no significant difference in the relative proportions of the curves. A Mann-Whitney test indicated no significant difference in the total number of cod captured per tow for the two nets on the two vessels.

The length-frequency distributions for the grouped vessel catches for the standard and experimental trawls are presented in Figure 3. The chi-square analysis indicated no significant difference between the two nets with respect to the relative proportions of the distribution curves. The Mann-Whitney test indicated no significant difference in the total number of cod captured per tow in this comparison.

The length-frequency distributions of the haddock catches for the F/V *Lucisaura* and the F/V *Calypso* for the standard and experimental trawls were compared using a chi-square analysis that indicated a significant difference between the relative proportions of the curves. A Mann-Whitney test indicated a significant difference in the total number of haddock captured per tow for the two nets and the two vessels. Careful examinations of the data indicated that on two of the tows the F/V *Calypso* caught many more haddock than the F/V *Lucisaura*. These larger catches included proportionately more small fish and this accounts for significant difference in the length-frequency distributions.

The length-frequency distributions for the grouped vessel catches for the standard and experimental trawls are presented in Figure 4. The chi-square analysis indicated no significant difference between the two nets with respect to the relative proportions of the distribution curves. The Mann-Whitney test indicated no difference in the total number of haddock captured per tow in this comparison.

The length-frequency distribution of the yellowtail flounder catches for the F/V *Lucisaura* and F/V *Calypso* for the standard and experimental trawls were compared using a chi-square analysis that indicated no significant difference in the relative proportions of the distribution curves. A Mann-Whitney test indicated no significant difference in the total number of yellowtail flounder captured per tow for the two

Table 1. *Mesh size measurements (mm) for each trawl body and cod end. Measurements were taken daily with an ICES gauge set at 5 kgs force (n=20).*

FISHING DAYS

	0		1		2		3		4		5		6	
Net section	Body	Cod end	Body	Cod end	Body	Cod end	Body	Cod end	Body	Cod end	Body	Cod end	Body	Cod end
F/V Ludsaura - Standard trawl - 120 mm body, 140 mm cod end														
Mean	127	157	132	141	137	151	133	142	131	149	136	140	137	139
std. dev.	5	5	2	5	3	2	2	6	7	7	3	5	4	7
F/V Ludsaura - Experimental trawl - 140 mm body, 140 mm cod end														
Mean	147	150	148	148	148	147	148	147	147	147	150	147	-	-
std. dev	4	2	3	2	2	4	2	4	0	4	3	2		
F/V Calypso - Standard trawl - 120 mm body, 140 mm cod end														
Mean	125	135	127	135	127	134	125	143	127	132	127	135	128	138
std. dev.	1	4	2	4	2	3	4	2	2	1	3	4	2	1
F/V Calypso - Experimental trawl - 140mm body, 140 mm cod end														
Mean	142	138	145	142	144	143	146	143	145	143	144	142	145	143
std. dev.	3	3	2	3	3	4	3	3	2	3	3	3	2	3
F/V Yankee Lady - Standard trawl - 140 mm body, 140 mm cod end														
Mean	147	149	-	-	-	-	148	139	-	-	148	-	-	-
std. dev	3	10					3	5			2			
F/V Yankee Lady -Experimental trawl - 160mm body, 140mm cod end														
Mean	146	141	144	143	144	138	-	-	-	-	146	-	-	-
std. dev.	3	3	3	3	4	4					3			

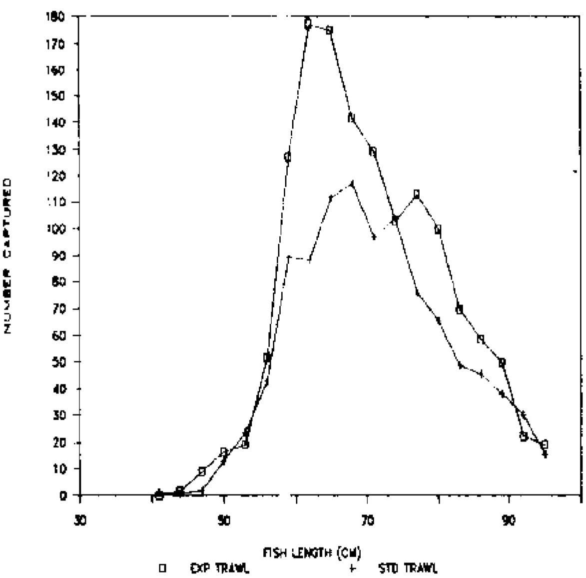


Figure 3. *Experiment One: length-frequency distributions of the Atlantic cod catches of the grouped standard and experimental trawls.*

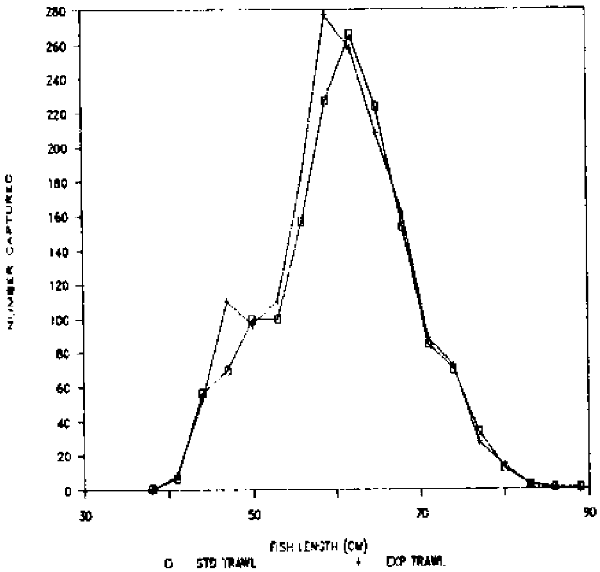


Figure 4. *Experiment One: length-frequency distributions of the haddock catches of the grouped standard and experimental trawls.*

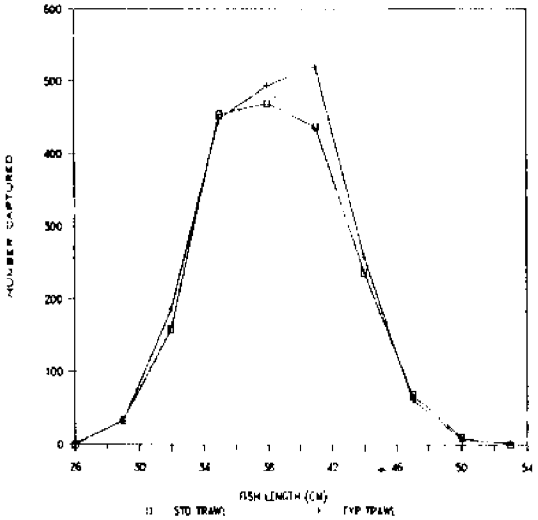


Figure 5. *Experiment One: length-frequency distributions of the yellowtail flounder catches of the grouped standard and experimental trawls.*

nets on the two vessels.

The length-frequency distributions for the grouped vessel catches for the standard and experimental trawls are presented in Figure 5. The chi-square analysis indicated no significant difference between the two nets with respect to the relative proportions of the distribution curves. The Mann-Whitney test indicated no significant difference in the total number of yellowtail flounder captured per tow in the comparisons.

Experiment Two

The length-frequency distributions of the cod catches for the standard and experimental nets are shown in Figure 6. Chi-square analysis of the relative proportions of these distributions indicated no significant difference. The comparison of the total number of cod captured per tow for the standard and experimental trawls (Mann-Whitney test) indicated no significant difference.

The length-frequency distribution of the haddock catches for the standard and experimental nets are shown in Figure 7. Chi-square analysis of the relative proportions of these distributions indicate a significant difference in the catch curves, with the experimental trawl retaining proportionally more fish in the 50-70 cm range. In contrast, the results of the Mann-Whitney test comparing the numbers of haddock captured per tow by the standard and experimental trawls indicated no significant difference in the medians of the two populations.

The length-frequency distributions of the yellowtail flounder catch for the standard net and experimental trawls are shown in Figure 8. Chi-square analysis of the relative proportions of these distributions indicated no significant difference. The comparison of the total number of yellowtail flounder captured per tow for the standard and experimental trawl

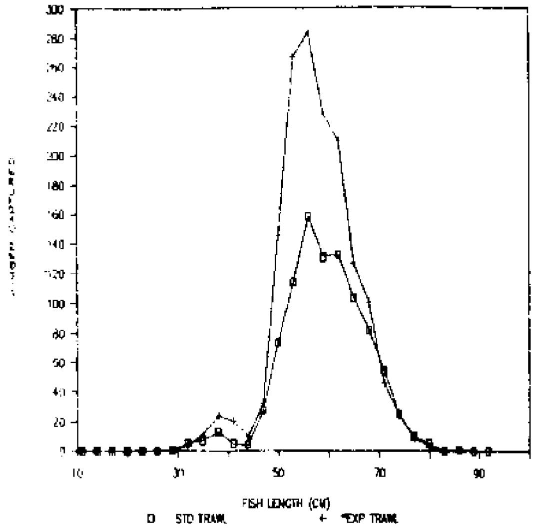


Figure 6. *Experiment Two: length-frequency distributions of the Atlantic cod catches with the experimental and standard trawls.*

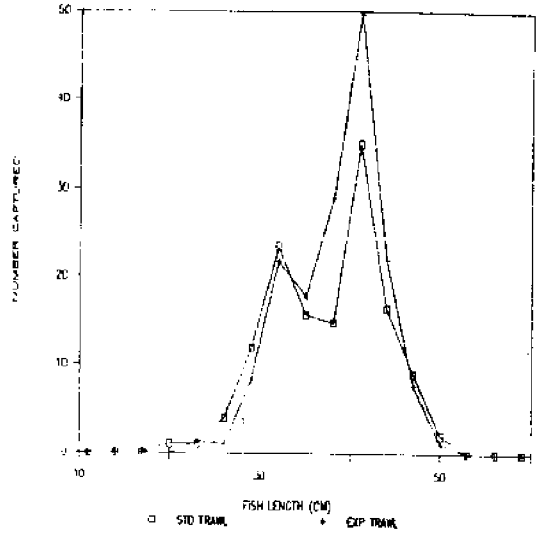


Figure 7. *Experiment Two: length-frequency distributions of the haddock catches of the experimental and standard trawls.*

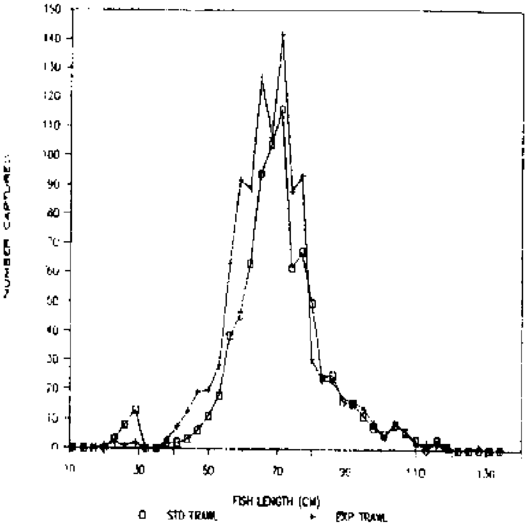


Figure 8. *Experiment Two: length-frequency distributions of the yellowtail flounder catches of the experimental and standard trawls.*

designs indicated no significant difference in the medians of the catches using the Mann-Whitney test statistic.

DISCUSSION

The primary purpose of these two experiments was to investigate the effect of the mesh size in the body of a trawl net on the catch retained in the cod end. The standard net had a small mesh body and the regulation large-mesh cod end. The experimental trawl had no webbing with a mesh size smaller than the regulation large mesh cod end. In experiment one, the experimental trawl was constructed of uniform mesh size equal in mesh size to the regulation cod end. In experiment two, the experimental trawl was constructed of larger mesh size in the trawl body than in the regulation cod end. It is notable that mesh size measured with the ICES gauge was variable, and may present management problems in the future.

The three target species were Atlantic cod, haddock, and yellowtail flounder. The results of these experiments clearly indicate that both the standard and the experimental trawls had reasonably similar catch performance on the target species, with respect to both the relative proportions of the length-frequency distributions of the cumulative catches and the numbers per tow of target species captured. These results confirm the observations of previous investigators that almost all selection occurs in the rear section of the cod end (Beverton 1963, Margetts 1963), and therefore that the mesh size in the mouth and body of the net does not affect catch performance.

In conclusion, the results of these experiments clearly indicate that regulations affecting mesh sizes in the body of the trawl will have no effect on the catches of the trawl fishing industry. It is speculated that these regulations may improve compliance with minimum mesh size regulations because of the absence of webbing with a mesh size smaller than the regulation mesh size on board the fishing vessel.

Postscript

Regulations based on this research were implemented on January 1, 1990, for the large-mesh management areas of the New England region.

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Improved Trawl Selectivity through Strategic Use of Colored Twine

Phillip H. Averill

Fisheries Technology Service
Maine Department of Marine Resources
Augusta, ME 04333

ABSTRACT

As efforts to develop more selective groundfish and shrimp trawls have increased, it has become necessary to find ways to direct a fish's behavior so the fish will go toward or away from certain parts of the net. Fish have been shown to respond to color or contrast differences in a net. This project was intended to be a field study on the exploitation of this phenomenon. Only the first of two phases of the work was completed. The results show little impact of color on fish escapement by the method chosen here. Still, we believe that this subject area deserves more study as our results were not conclusive.

INTRODUCTION

Improved size and species selectivity of trawl gear has become a fertile area of investigation by gear technologists all over the world. Separator trawls, square mesh cod ends, roped cod ends, radial escape sections, and skylight trawls are all being used to provide "holes" for fish of certain sizes or species to leave a net while desired sizes or species are retained. This has created a need to understand marine fish behavior, an area of study that has received very little attention to date.

Work by a few researchers and observations by commercial fishermen have indicated that fish can sense and react to parts of a net that they can see. A variety of experiments have been carried out at the Marine Laboratory in Aberdeen, Scotland, showing how fish can be made to go toward or away from twine areas of certain contrast (Wardle 1986, Wardle and Main, pers. com.). Our intent in this project was to combine this information with our need to have fish find the "holes" we provide for them in our various selective trawl designs by making those "holes" a contrasting color.

As a first step in the direction of improving the selective performance of trawls through strategic use of contrast, we proposed to demonstrate the "color effect" in conventional groundfish trawls. After defining which colors were effective in altering fish behavior, we intended to move on to specific applications of those colors to various fish escapement systems with square mesh being the first candidate.

MATERIALS AND METHODS

To observe the effects of twine color variations, the trouser trawl method was chosen. It was felt that the effects we were looking for might be small at this point, and much reduction in control variability was needed to define fish behavior changes. The trawl had a dividing panel splitting the net in two from the headrope back to two cod ends (Fig. 1). The catch was split equally on each side by this panel. The plan was to build a mono-color trouser trawl, in this case, light blue, and fish it with a matching (light blue) cod end on one side as a control. The cod end on the other side would be of different colors to try to maximize and minimize its appearance to the fish. All cod ends were made from the same bale of 10 cm white braided nylon twine. Colors were achieved by dying. White was achieved by dying in clear dye so twine smell, stiffness, and movement were the same for all colors.

Tows were made as similar as possible to a commercial fishing operation and data were recorded on fish size, number, and weight. All work was performed off the FTS vessel R/V *Paul Derocher*, a 13 m fiberglass dragger. Experimental and control cod ends were swapped side to side daily in case the trouser trawl was not fishing evenly on both sides. Tows were of two-hour duration. Ninety-six tows were made at 30 to 50 fathoms off Pemaquid Point and Damariscove Island.

RESULTS

Initial tows were made with two light-blue cod ends to confirm that the trouser trawl fished evenly on both sides. As in the total project, catches of fish in these control tows were low, especially catches of cod, our main species of concern. These low catches forced us to group fish types together into flatfish, cod, skates, dogfish, and others in order to obtain numbers of sufficient size to analyze statistically. Our assumption (not based on any particular scientific findings) was that most flatfish species behaved similarly and could be treated as one group.

We found that flatfish were divided quite evenly between the two cod ends on the control tows while cod seemed to slightly favor the port side of the net. All other species divided fairly evenly (Table 1). The control tows were also used to tune up the net. ScanMar net mensuration gear was made available by The University of Rhode Island Sea Grant Marine Advisory Service and was used to document door spread, wing spread, and headrope height at various speeds.

The first experiment was white vs. blue control cod ends. Underwater observations confirmed the results from Scotland that light blue and white appeared similar underwater. The catch data in Table 1 confirm this and these tows can be combined with the control tows to broaden the control baseline, if need be. Again, no differences were noted in the catch of the two sides for any of the species groupings.

Table 1
Catch Results

NUMBER

color	# tows	blue side	flatfish		cod		skate & dogfish		others	
			treatment	control	treatment	control	treatment	control	treatment	control
blue v blue	21	21S	200	190	57	31	19	26	112	109
white v blue	19	9S 10P	198	196	47	40	39	33	149	108
$\frac{\text{black}}{\text{white}}$ v blue	13	5S 8P	108	94	26	20	88	108	78	44
$\frac{\text{white}}{\text{black}}$ v blue	12	4S 8P	73	62	4	7	99	116	105	46
window v blue	13	7S 6P	157	173	21	16	134	155	342	201
WEIGHT (KG)										
blue v blue	21	21S	107	95	84	46	60	40	104	79
white v blue	19	9S 10P	98	95	70	64	185	145	188	240
$\frac{\text{black}}{\text{white}}$ v blue	13	5S 8P	50	55	68	41	284	277	94	85
$\frac{\text{white}}{\text{black}}$ v blue	12	4S 8P	41	30	20	14	387	472	78	30
window v blue	13	7S 6P	64	71	92	55	611	682	219	201

The next two colors studied were black top/white bottom and white top/black bottom. As with the control tows, no significant differences were noted (using standard t-test) in any species groupings. As can be seen in Table 1, the blue control cod end caught consistently fewer fish than the experimental side but not enough fewer to be called significant.

In an attempt to maximize the "color effect," since we had not seen one yet, a "window" cod end was made. This was a black cod end with white "windows" at 10 o'clock and 2 o'clock on the circumference of the net. Two "windows," each about 30 by 60 cm, were on each side (Fig. 2). The hope was that fish would view these as large holes in the net and attempt escape. While the data did change somewhat with this arrangement by having higher retention of flatfish on the blue side, no significant differences were discerned for the four species groups examined.

Length-frequency data were collected on cod, hake, whiting, and flatfish. Length-frequency plots are given in Figure 3 and show no differences in retention by length for any color. However, upon sorting the catch, it was quite noticeable that there was a major difference in the whiting catch (Table 2). While the whiting catch was quite low, fish were only occasionally found in the blue control side while being found frequently in the window side. While this difference was seen in the other colors as well, it was much more pronounced in the window trawl.

At this point, a number of events ranging from lack of fish to winch motor replacement brought the vessel operations to an end. Four tows were made with the square mesh cod end in a "window" color but catch was too low to be of value.

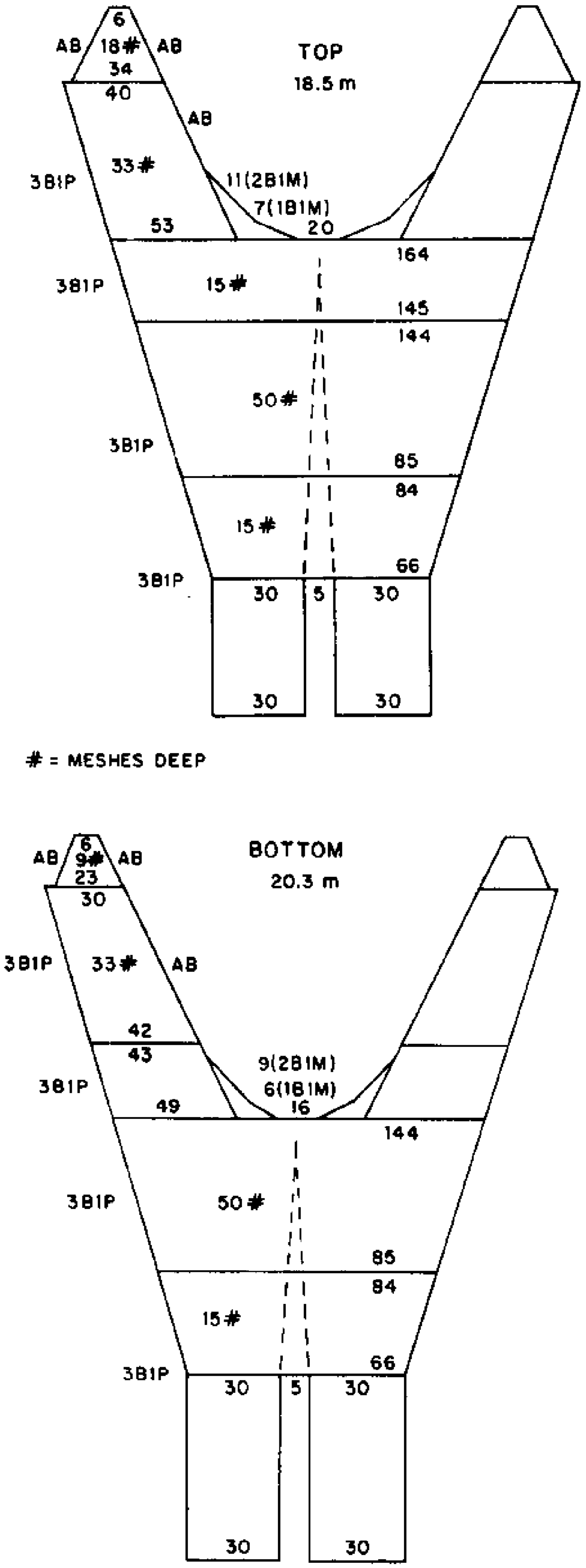


Figure 1. *DMR Trouser Trawl, based on C. Goudey's 3-in-1 net. Hanging ratio 0.5, headrope and footrope hung 5% tight, rigged with rollers. 3 mm, 14 cm mesh throughout. The vertical dividing panel is made from any available shrimp twine (mesh size not important).*

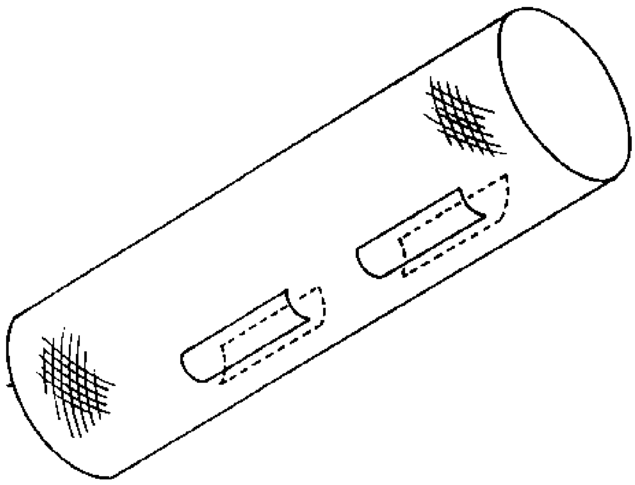
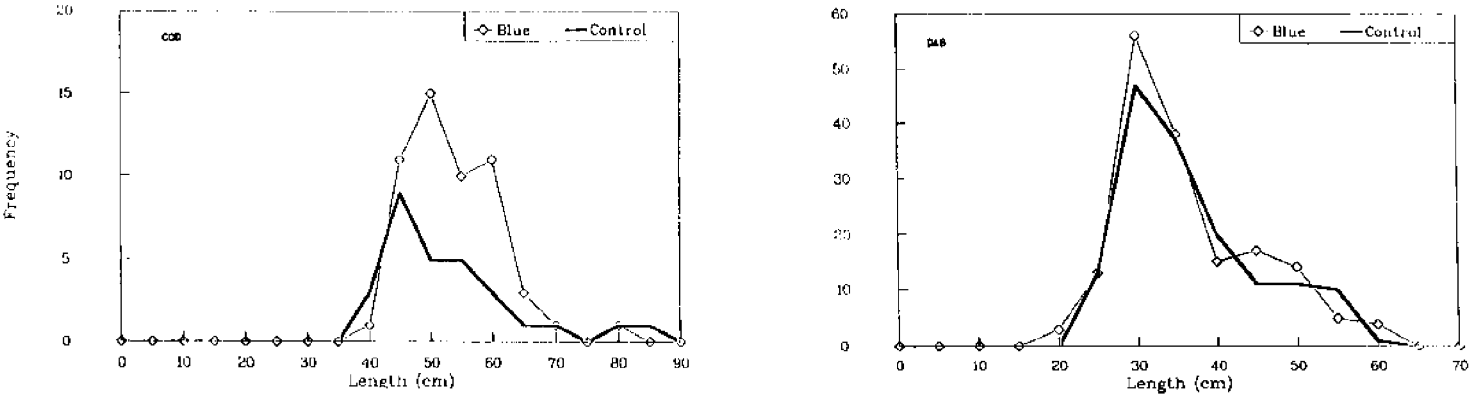
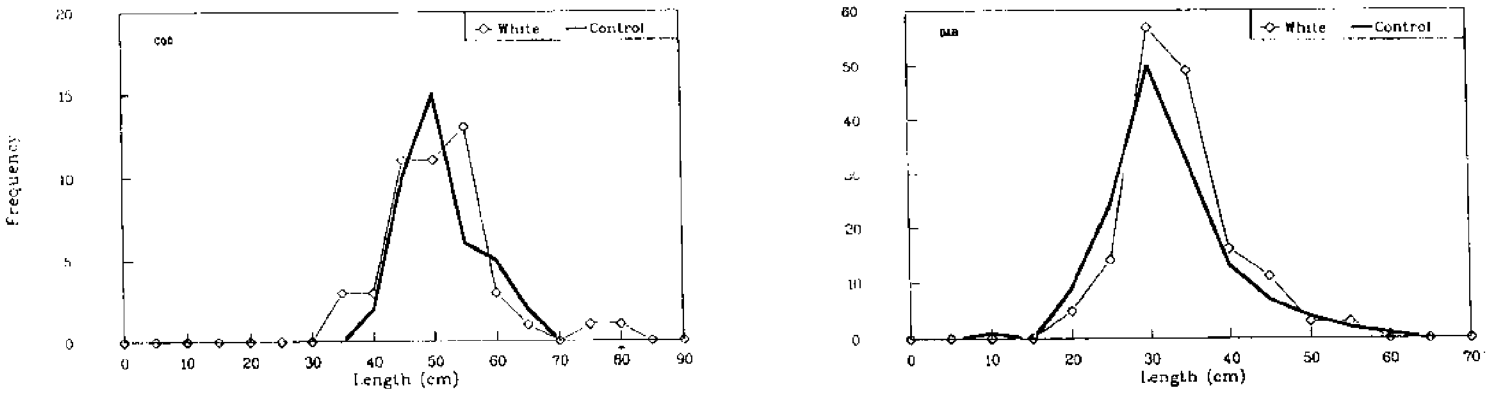


Figure 2. *Arrangement of white "windows" in black cod end at 10 o'clock and 2 o'clock.*

a. Blue Diamond Mesh vs Control (Blue)



b. White Diamond Mesh vs. Control (Blue)



c. Black Over White Diamond Mesh vs. Control (Blue)

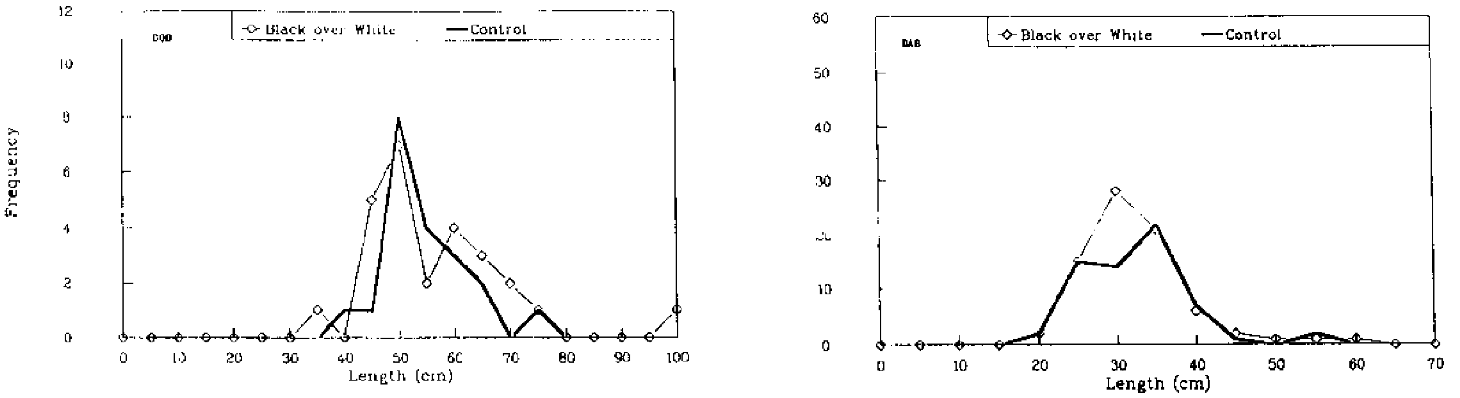
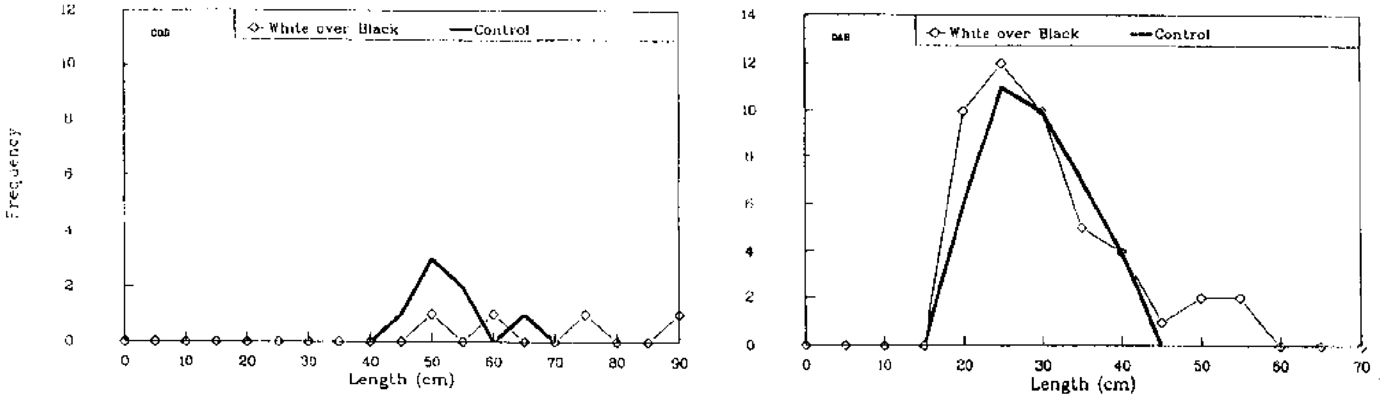


Figure 3. *Length-frequency plots for cod and dab captured during the colored-twine experiments.*
a. blue vs. control; b. white vs. control; c. black over white vs. control; d. white over black vs. control; e. window vs. control

d. White Over Black Diamond Mesh vs Control (Blue)



e. Windows Diamond Mesh vs Control (Blue)

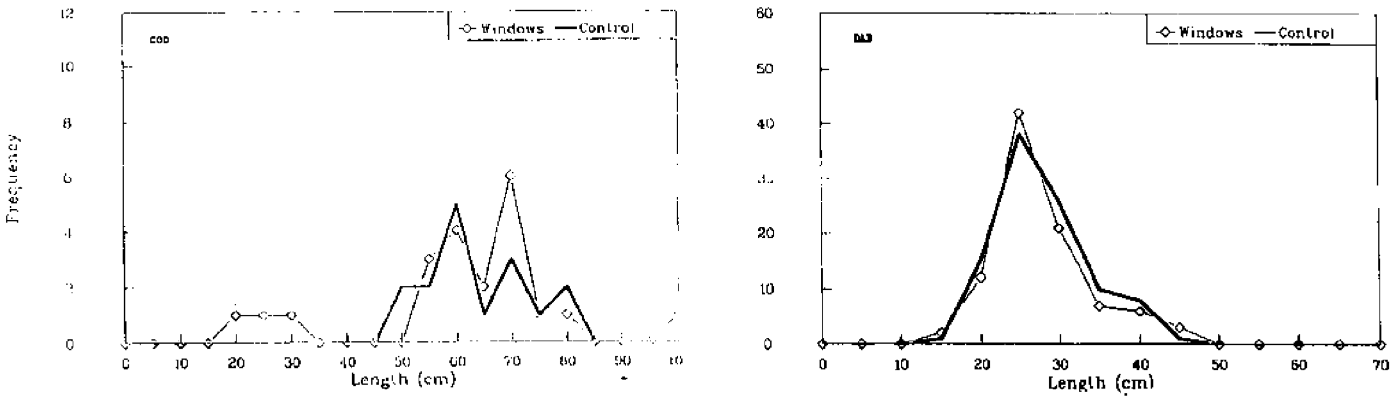


Table 2
Whiting and Hake
NUMBERS CAUGHT

	Whiting		Hake	
	Color	Blue	Color	Blue
Blue v Blue	6	4		8
White v Blue	43	27	27	11
Black v blue White	20	8	5	3
White v Blue Black	10	17	2	2
Window v Blue	120	26	40	10

DISCUSSION

The original goal of the project was to demonstrate the use of twine color in directing fish behavior to improve trawl selectivity. The plan was to start with conventional diamond-mesh cod ends to learn how color changes affect catch and then move on to square-mesh cod ends to see if the color effects could be enhanced.

The diamond-mesh trials were completed but few effects were seen. Square-mesh trials were not undertaken. The results with the few whiting we caught indicated some sort of color reaction for at least that species. Still, the color effect has been demonstrated in research trials and we are led to conclude that our experimental design may have been faulty. One possibility is that by having the colors in the cod end, the fish were too exhausted by this time to respond to the opportunities presented, that is, attempt escape more vigorously.

The second possibility is that the low catches did not close up the diamond meshes and the resulting open meshes allowed excellent selectivity. With everything getting out both sides that could get out, no differences would be seen. Fish may have reacted to the colored sections but nonreacting fish escaped later in the tows through the slack meshes.

The third possibility is that providing colored escape opportunities is not enough. Some form of physical stimulation may be needed to get fish to utilize these opportunities.

We hope to investigate these possibilities by a variety of methods, from moving the colored sections up into the bellies, to providing simulated catch in the cod ends with water-filled garbage bags. With requirements for separator trawls now in the regulations in the shrimp fishery, and increased calls for improved selectivity of regulated species, we believe that color of twine may play a large role in improving net performance and thereby avoiding more onerous regulations and restrictions.

ACKNOWLEDGEMENTS

This work was supported by Saltonstall-Kennedy funds from National Marine Fisheries Service. Special thanks go to SERVE/Maine volunteer Olian Small who provided the extra manpower needed to carry out the on-board catch measurements. Thanks also to Joe DeAlteris and Dan Reifsteck of The University of Rhode Island for use of Rhode Island Sea Grant's ScanMar net mensuration system.

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A Methodology for Investigating the Behavior and Survival of Bottom-Trawl Cod End Escapees and Some Preliminary Results

Daniel M. Reifsteck and Joseph T. DeAlteris

Department of Fisheries, Animal and Veterinary Science
The University of Rhode Island
Kingston, RI 02881

ABSTRACT

The physical validity of an experimental methodology for investigating the behavior and survival of bottom-trawl cod end escapees is described. The physical characteristics of the methodology are critically evaluated. Flume tank tests were conducted to evaluate the flow within a towed cod end simulation apparatus (TCESA). There was no significant effect ($P>0.05$) on flow velocity due to mesh shape or the presence of a cod end cover. A small but significant difference ($P<0.001$) in flow velocity was detected between the TCESA and a cod end attached to a box trawl tested in the flume tank. Results based on two years of data collection on scup and one year on winter flounder are reviewed. Field trials resulted in high survival of control fish and variable survival of treated fish. Data collected from this methodology include accurate measurement of escapement time for individual fish, general behavior patterns within the cod end for different fish species, and the survival probability of fish relative to species, size, mesh shape, and escapement time.

INTRODUCTION

Minimum mesh size regulation is the primary method of regulating trawl fishing mortality on juveniles in a fish stock. The basic principle in minimum mesh size regulations is that undersized fish escape from the cod end and survive, becoming part of the future spawning biomass of the population. This assumption has never been thoroughly tested. Sound scientific evidence is needed to prove that undersize fish that do escape actually survive.

Research has shown that otter trawl gear has the potential to have a devastating effect on fish stocks (Alexander et al 1915, Herrington 1932 and 1935, and Main and Sangster 1981). The process of fish capture and escape from a trawl net presumably induces an acute stress and has been associated with mortality (Dando 1969, Miles et al 1974, and Lockwood et al 1983). The potential mortality of escapees may be related to the physical damage such as abrasions, lacerations, and contusions that a fish may acquire within the net or during escape. Mortality may also occur because of physiological stress associated with hyperactivity and the resulting conditions.

Hydrodynamic forces within the net may play a critical role in fish retention. The selectivity of a trawl depends partially on the flow regime through the net, especially in the cod end (Ferro 1988). In experiments conducted in a circulating water channel, water velocity inside the net body was higher than that at the net mouth or at the outer surface of the net. This was related to the ratio of twine diameter to mesh size (Higo 1964, Higo et al 1973, Higo et al 1974, Higo and Mouri 1975). These results are supported by recent Polish research using towed model nets (Ziembo 1974, 1987, 1988) that indicate increases in velocity of the flow within small- and medium-mesh nets, but no increase in a large-mesh net when compared to the velocity of the towing platform. High (1967) noted diminished flow in the rear of a trawl cod end when captured fish slowly drifted out of an opened cod end, yet the same work indicated that flow inside the webbing exceeded adjacent water flow outside the tapered body of the trawl. These observations suggest that when a small-mesh trawl net is towed through still water the tapered body of the net acts as a funnel, accelerating water into the cod end. Eventually the flow reverses as water becomes entrained by the cod end, providing a zero flow velocity relative to the trawl net in the rear of the cod end.

The setting angle of the netting may contribute significantly to the water flow in the cod end (setting angle is defined as the angle of the individual bars relative to the direction of travel). The setting angle of diamond-mesh webbing is relatively acute and is variable with the amount of load applied to the twine. Increasing load will cause individual meshes to elongate in the direction of travel and to close in the direction perpendicular to travel. Bars of square-mesh webbing maintain a parallel and perpendicular relationship to the direction of travel, which is independent of load provided there is no degeneration in the integrity of the twine and/or knots. Ferro (1988) found that a square-mesh cod end did not entrain water to the same extent as in the diamond-mesh cod end. The setting angle then, affects the porosity of a net section and may inhibit or enhance the flow of water through the meshes of the twine depending on that angle. Less porous nets may filter less water than more porous nets (Tranter and Smith 1968).

A scientific method was designed to investigate escapement of fish from bottom-trawl cod ends and the survival of escapees. The experimental design is described herein and critically evaluated in terms of its physical and biological performance.

Experimental Methodology

A towed cod end simulation apparatus (TCESA) was designed to duplicate the cod end environment (Fig. 1). This device consisted of a swimming chamber tapering to a cod end section, which is enveloped in a cover, all of which was attached to a towing sled. The sled was made from 5 cm ID plastic pipe. Front and top sections were at right angles with support braces on either side. Water surface planing devices were attached to each side of the top section.

Extending 5.5 m from the sled was a cylindrical panel of 3.0 cm bar length square-mesh webbing. Three plastic hoops, 126 cm in diameter, were fixed to the inside of the small mesh cylinder to maintain the diameter of the webbing. A tapered section of 6.0 cm diamond mesh, 30 cm in depth, tapered back to the cod end. Different experimental cod ends were easily exchanged with a zipper line. Mesh shape and the setting angle of the experimental cod ends were maintained by securing small hoops to the webbing. A plastic plate 30 cm in diameter was attached to the terminus of each cod end to simulate fish catch and provide tension on webbing in tow.

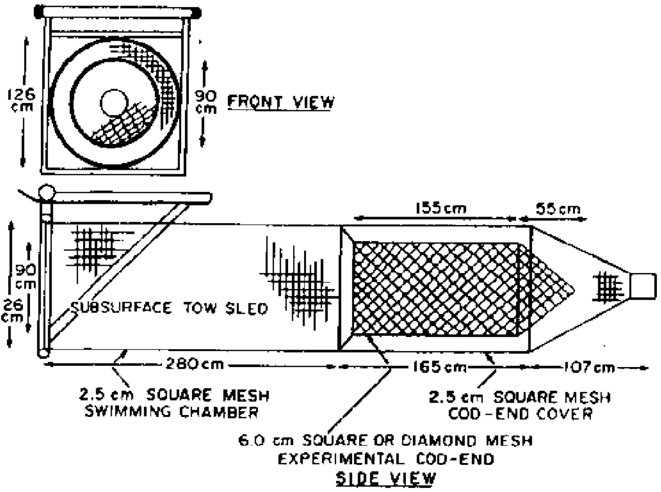


Figure 1. *Front and side view of a towed cod end simulation apparatus (TCESA) designed to duplicate the cod end environment of a fishing net. The subsurface tow sled, swimming chamber, removable cod ends, and cod end cover are illustrated. Mesh length of various components is described (bar length of the mesh is expressed in cm).*

Cod end webbing was double twine polyethylene, 4.0 mm in diameter with a 6.0 cm bar length. Tests were conducted with the cod end webbing hung on a square and diamond shape. The square-mesh cod end was 48 bars around a circular hoop frame 90 cm in diameter and 35 bars in total length. The open area of the square-mesh cod end was 4.15 m^2. The diamond-mesh cod end was 48 meshes around a circular hoop frame 90 cm in diameter, and 20 meshes in length. The open area of the diamond-mesh cod end was 3.96 m^2.

Size range of fish to be treated was determined by conducting selectivity experiments. Selectivity work was carried out with a conventional bottom trawl net. Cod ends were of identical material and design as those described previously but were two times longer. The square-mesh and diamond-mesh cod ends were switched with alternate tows. Catches retained in the cod end and in the cover were sorted and measurements on individual fish included total length, standard height, and maximum width. These data were used to develop selectivity curves for each species and for each mesh shape (Pope et al 1975). Based on these curves, fish sizes between 5 and 30 percent retention were selected for the survival/behavior experiments.

In the survival/behavior experiments one or two small research vessels (6 m) equipped with live tanks were utilized. Three live tanks were used (control, capture, and treatment). Both experimental and control treatments were applied during a single day. Experimental fish were captured with techniques that varied with species. Scup (*Stenotomus chrysops*) were easily captured with barbless hooks on hand lines. Winter flounder (*Pseudopleuronectes americanus*) were captured during a 5 min. tow with a small scientific trawl net. Plastic zip-lock bags were used for all fish transfers.

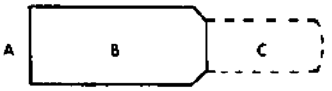
Fish were placed in a capture holding tank and measurements of total length and depth were estimated. After a brief acclimation period of at least one hour, the treatment was applied. Half of the captured fish were used as controls and half were treated.

Each trial consisted of two actions. From the capture tank one individual was transferred to a control tank and another individual was introduced into the mouth of the TCESA by a diver. Towing speed was maintained at 128 cm/s. Tow duration was as long as the fish required to escape or a maximum of 30 minutes. At that time the trial was terminated, the towing vessel stopped, and the fish were allowed to escape through the slack cod end webbing. The escapee was immediately removed from the cover and carefully deposited into the treatment tank of the towing vessel. Observations of fish behavior in relation to the webbing were recorded. Behavioral characteristics were noted and recorded chronologically at the end of each trial. At the culmination of the experiments, the treated and control fish were placed in separate cages on the seabed to begin a 10-day monitoring period.

Quantitative data collected in the survival experiments included total swimming time and escapement time for each treatment fish and percent survival for each treatment group. Analysis of variance was used to determine if significant differences exist between the escapement time and survival as a function of mesh shape.

The objectives of this paper are to assess the physical validity of the previously described experimental methodology, and to present preliminary biological results on the two species. The physical evaluation is based on a comparison of flow conditions inside a bottom trawl net with attached cod end, and inside the TCESA. The effect of the cod end cover on flow conditions is also considered. Parrish and Pope (1963) and Pope et al (1975) indicate that the masking effect of small mesh covers over the cod end may affect flow or hinder escapement in selectivity experiments. The biological evaluation is based on a comparison of the survival of control and treatment fish in terms of experimental handling stress, and the usefulness of the fish behavior data collected in terms of the escapement process and the associated stress.

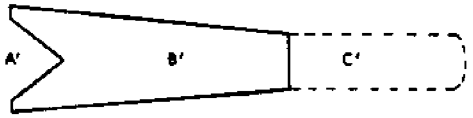
SURVIVAL CONFIGURATIONS



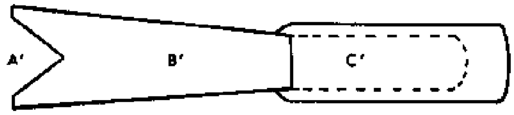
Swimming chamber and cod-end

Swimming chamber, cod-end and cover

SELECTIVITY CONFIGURATIONS



Four-seam net and cod-end



Four-seam net, cod end and cover

Figure 2. *Four net configurations representing the various gear types used. Square-mesh and diamond-mesh cod ends were tested with each configuration for a total of eight treatments tested in the flume tank. Interchangeable cod ends are represented by dashed lines. Refer to Table 1 for details of the individual components.*

Table 1. *Design details of each component used to make up the various configurations. Details include the total area, the twine surface area, and the open area of each panel. The open area (m^2) of the webbing panel is obtained by subtracting the twine surface area (m^2) from the total area (m^2) of the panel.*

Component Type	Total area of Panel (m^2)	Twine surface of panel (m^2)	Open area of panel (m^2)
Square mesh Selectivity Cod end	8.92	2.76	6.16
Square mesh Survival Cod end	6.00	1.85	4.15
Diamond mesh Selectivity Cod end	9.77	3.34	5.81
Diamond mesh Survival Cod end	6.03	2.07	3.96
Selectivity Cod end Cover	21.10	3.29	17.71
Survival Cod end Cover	10.42	1.60	8.82
Survival Swimming Chamber	10.68	2.29	8.89
Four-seam Trawl		4.80	

METHODS

Full-scale tests were conducted in a flume tank to measure the water flow regime in the previously described net configurations. The purpose was to detect and quantify differences in water flow within the webbing as affected by mesh shape and cod end cover.

The circulating water channel at the David Taylor Naval Ship Research and Development Center in Bethesda, Md. (USA), was employed. Two vertical struts were positioned at the upstream end of the test section for attachment of net configurations. A single velocity of 103 cm/s was used for all experiments. Higher flume velocity was impossible because of the extreme drag associated with the test configurations, and the limited structural capacity of the struts.

Flow measurements were obtained with a Marsh-McBirney Model 523 laboratory-quality electromagnetic current meter with a 1.2 cm diameter spherical sensor. Flow measurements were made at stations along the longitudinal axis of the gear. Individual readings were recorded along a cross section of each station at various depths. In addition to these eulerian measurements of the flow, injections of dye from a single point source were used to investigate the flow distribution ahead of and within the net. The pattern of the dye streams was photographed and used to qualitatively assess spatial variability in the flow.

Four net configurations representing the various gear types were studied (Fig. 2). The measurement locations were divided into three regions. For the survival configurations, measurement locations were in front of the net mouth (A), in the body of the net or swimming chamber (B), and in the cod end (C). For the selectivity configurations the locations were in front of the net mouth (A'), in the body of the four-seam net (B'), and in the cod end (C'). Square-mesh and diamond-mesh cod ends were tested with each configuration for a total of eight treatments. The design details of each component are described in Table 1. Square-mesh and diamond-mesh selectivity cod ends were tested behind a four-seam trawl. The four-seam trawl was constructed of single polyethylene twine with a stretched mesh size of 14 cm and a diameter of 3.5 mm. The effect of a cod end cover on water flow in the different selectivity cod ends was examined. The survival configuration from the TCESA was tested with square-mesh and diamond-mesh cod ends, and the effect of the cover on water flow in the different cod ends was also examined. A plastic plate 30 cm in diameter was secured to the back end of each of the cod ends to simulate catch and induce adequate tension of the webbing.

Velocity was expressed as a ratio of flow inside the net to the free stream velocity and was transformed for statistical analysis (Dowdy and Wearden 1983). Using transformed velocity data as the dependent variable, the General Linear Models Procedure (SAS 1987) was applied to detect significant statistical differences due to cover effects, mesh type, net type, and location within the net. The interaction of important variables was tested (Saila 1964).

RESULTS

The results of the velocity profile experiments for the selectivity and survival net configurations are shown in Tables 2 and 3, respectively. The relationship between the velocity measured within the net to the free stream velocity at the same depth is described by a dimensionless ratio. Velocity ratios of each configuration were averaged and grouped by area for comparison.

There was no significant effect (P>0.05) on the flow due to different mesh shape or due to the cover. Flow within the entire net configuration was significantly different (P<0.001) between the selectivity and the survival configurations, with mean flow 9.5 percent less in the latter. However, it must be noted that mean flow in both configurations diminished no more than 10.8 percent of free stream velocity. There was a

Table 2. *Means and standard deviations of velocity ratios for the area in front of the net mouth, in the body of the net, and in the cod end of each selectivity configuration. The mean is the average of ratios that describe the relationship between the velocity measured within the net to the free stream velocity at different points in the same area of the net. Mean is represented by v and standard deviation is represented by σ.*

	Front of net mouth n = 7		Body of net (four seam net) n = 10		Cod end of net n = 8	
	v	σ	v	σ	v	σ
With cover and square mesh cod end	0.953	0.035	0.968	0.082	1.000	0.032
No cover and square mesh cod end	0.951	0.036	0.991	0.055	0.960	0.051
With cover and diamond mesh cod end	0.949	0.018	0.970	0.060	0.988	0.036
No cover and diamond mesh cod end	0.966	0.016	0.982	0.073	0.950	0.092

Table 3. *Means and standard deviations of velocity ratios for the area in front of the net mouth, in the body of the net, and in the cod end of each survival configuration. The mean is the average of ratios that describe the relationship between the velocity measured within the net to the free stream velocity at different points in the same area of the net. Mean is represented by v and standard deviation is represented by σ.*

	Front of net mouth n = 4		Body of net (swimming chamber) n = 9		Cod end of net n = 9	
	v	σ	v	σ	v	σ
With cover and square mesh cod end	0.968	0.025	0.906	0.057	0.812	0.073
No cover and square mesh cod end	0.983	0.015	0.901	0.072	0.787	0.087
With cover and diamond mesh cod end	0.925	0.037	0.910	0.094	0.764	0.090
No cover and diamond mesh cod end	0.963	0.026	0.895	0.072	0.813	0.056

significant two-way interaction ($P<0.001$) of the configuration type and the location. In the selectivity configurations there is a significant ($P<0.05$) increase in velocity ratio from the net mouth (A') to the body of the net (B'), and no significant difference ($P>0.05$) between the net body (B') and the cod end (C'). In the survival configurations there is no significant difference ($P>0.05$) in velocity ratio between the net mouth (A) and the net body (B). However, there was a significant decrease ($P<0.05$) in the flow ratio from the net body (B) to the cod end (C). Between the two configurations there is significantly less ($P<0.01$) flow (18 percent) in the cod end of the survival configuration.

Field experiments have been conducted on two species of fish to date. Results have been obtained from experiments with scup (*S. chrysops*) and winter flounder (*P. americanus*). Two seasons of data have been collected on scup and one season on flounder. It is planned to conduct a third season of experiments on scup and a second season on winter flounder. Therefore the results reported herein are preliminary.

The analysis of the selectivity data was performed on each species to establish selection ogives. The L_{50}'s for square-mesh and diamond-mesh cod ends on scup (*S. chrysops*) were similar at 21.5 cm and 21.1 cm respectively. The L_{50}'s for square-mesh and diamond-mesh cod ends on winter flounder (*P. americanus*) were 20.8 cm and 23.6 cm respectively. The lengths of the fish used in the survival experiments were all substantially less than the L_{50} determined in the selectivity experiments.

Statistical analyses were conducted to determine the effect of mesh shape on survival probability. In 1988 there was no significant difference ($\alpha=0.05$) between scup treated with square mesh and the control fish after four trials (Table 4). However, there was a significant difference ($\alpha=0.05$) between scup treated with diamond mesh and the control fish after six trials (Table 4). A one-way analysis of variance determined that there was also a significant difference ($\alpha=0.05$) between the survival means of square-mesh treated scup, diamond-mesh treated scup, and pooled controls. When diamond mesh survival was compared to square mesh survival in 1988 there was also a significant difference ($\alpha=0.05$).

To determine if bottom water temperature was associated with mortality observed for the diamond mesh escapees, a simple linear regression was performed. Significant correlation was found between decreasing water temperature and increasing survival ($r=0.86$).

In 1989 there was no significant difference ($\alpha=0.05$) between the survival of scup treated with square mesh and the control fish after seven trials (Table 4). There was also no significant difference ($\alpha=0.05$) between scup treated with diamond mesh and the control fish after seven trials (Table 4). When diamond mesh survival was compared to square mesh survival in 1989 there was no significant difference ($\alpha=0.05$).

Statistical analyses were conducted to determine the

Table 4. *Results from square mesh and diamond mesh trials of juvenile scup* (Stenotomus chrysops) *in Narragansett Bay, Rhode Island. Results include average total length, average swimming time, average escape time, percent survival of treated fish, and percent survival of control fish.*

	number of fish	average total length (cm)	average swimming time (min)	average escape time (min)	percent survival
1988					
control	36	-	-	-	100
square mesh trmts.	34	17.5	9.1	11.5	94
1988					
control	37	-	-	-	89
diamond mesh trmts.	32	17.4	17.8	19.7	50
1989					
control	38	-	-	-	100
square mesh trmts.	38	16.9	5.3	9.6	100
control	35	-	-	-	100
diamond mesh trmts.	35	16.5	6.2	13.6	97

Table 5. *Results from square mesh and diamond mesh trials of juvenile winter flounder* (Pseudopleronectes americanus) *in Narragansett Bay, Rhode Island. Results include average total length, average swimming time, average escape time, percent survival of treated fish, and percent survival of control fish.*

	number of fish	average total length (cm)	average swimming time (min)	average escape time (min)	percent survival
1988					
control	38	-	-	-	100
square mesh trmts.	38	16.4	0	11.3	100
1988					
control	29	-	-	-	100
diamond mesh trmts.	28	16.4	0	17.1	96

effect of mesh shape on survival probability for winter flounder in 1989. There was no significant difference (α=0.05) between fish treated with square mesh and the control fish after seven trials (Table 5). There was no significant difference (α=0.05) between fish treated with diamond mesh and the control fish after seven trials (Table 5). There was also no significant difference (α=0.05) in the survival between square-mesh and diamond-mesh treated fish.

Total swimming time and total time to escape for individual fish were easily measured by the observer in close proximity to the fish. Swimming and escapement normally occurred in the rear of the cod end section, although the design of the apparatus made it easy to track and observe fish in all areas of the TCESA. Although many fish remained in the cod end for the maximum time period, all fish easily swam through the slack meshes of the cod end when the trial was terminated.

Information from scup trials was more general because measurement of total length was impossible until after the monitoring period. For each treatment group only mean total length, mean swimming time, and mean escapement time could be recorded. Flounder could easily be measured prior to treatment and provided a comparison between length and escapement time for each fish. Flounder exhibited no swimming ability within the TCESA.

In 1988, the time to escape from the cod end for scup was significantly longer (α=0.01) in diamond mesh than square mesh. Total swimming time inside the cod end for scup was significantly longer (α=0.05) in diamond mesh than square mesh. In 1989 time to escape from the cod end for scup was significantly longer (α=0.05) in diamond mesh than square mesh. There was no significant difference (α=0.05) in total swimming time inside the cod end for scup in 1989 between square and diamond mesh.

In 1989, time to escape from the cod end for winter flounder was not significantly different (α=0.05) between diamond mesh and square mesh. Winter flounder exhibited no swimming behavior, therefore no swimming time was recorded.

DISCUSSION

The experimental methodology provided a unique view of fish behavior within a simulated cod end (TCESA). The observer had the ability to initiate the capture process, follow activity, and monitor subsequent trauma to individuals. The TCESA proved to be a reasonable simulation of a trawl cod end under actual fishing conditions. The sled was a suitable working platform with adequate strength and rigidity, although a lighter collapsible welded aluminium sled has replaced the plastic sled. The surface planing devices provided rotational stability and prevented the sled from diving below the surface during tow. The swimming chamber provided treated fish an opportunity to orient to water flow before entering the cod end and for active swimming behavior prior to fatigue.

The covered cod end allowed for fish escape, and subsequent retention of escapees. The square-mesh cover streamed with maximum cross-sectional area (Stewart and Robertson 1985). The cover was not distorted by water pressure, so meshes were fully opened and the netting retained a cylindrical shape while in tow. An additional advantage of a square mesh cover was a greater degree of visibility for observation of fish during trials. For the selectivity and survival net configurations, the total mesh opening of the cover was designed to be at least two times that of the cod end so as not to inhibit water flow through the cod end. Comparison of the velocity ratios within the net configurations indicates that the covers were not responsible for any significant differences in flow regimes among net configurations. This has important implications with regard to the validity of covered cod end selectivity experiments.

The effect of setting angle of the webbing on flow is insignificant in these results and in disagreement with Ferro (1988). Square-mesh and diamond-mesh webbing in cylindrical sections of similar general dimensions have only slight differences in porosity. At the experimental towing speed of 103 cm/s, with double 4 mm polyethylene webbing of 6 cm bar length, no significant difference can be detected in flow between square and diamond mesh webbing. Significant difference in flow within a cod end between selectivity and survival configurations may be explained by the effect of webbing that covers the mouth of the swimming chamber in the TCESA, and the lack of a funnel effect in the TCESA as compared to the four-seam trawl. The TCESA is basically of cylindrical shape whereas the selectivity configuration is a funnel section that tapers to a cylinder. The velocity measurements indicate that flow tends to decelerate into the cod end of the TCESA. In the selectivity configuration, evidence suggests that acceleration of water does occur in the funnel of the net. The fact that no deceleration occurs in the cod end suggests that the funnelling effect may still be present but is masked by a deceleration factor as represented in the survival cod end. To simulate conditions of specific towing speeds and counteract the diminished flow in the cod end, calibration trials are recommended for the TCESA.

Observation of swimming and escapement were useful to make generalizations about typical fish behavior in the two types of cod ends. This controlled situation allowed for an excellent opportunity to document behavior with video equipment. Relative swimming speed could be determined by measuring tail beats per unit time and used to compare fish swimming in different cod ends.

Total time to escape of individual fish was easily measured by the observer in close proximity to the fish. Swimming and escapement normally occurred in the rear of the cod end section, although the design of the apparatus made it easy to track and observe fish in all areas of the system. Total swimming time of individual fish was easily calculated by the summation of all time periods spent swimming prior to escapement or termination of the trial.

Slight modifications to the general procedure have been incorporated for the various species tested. Juvenile scup were an easy fish to capture because of their aggregating behavior and voracious appetite. This species' normally active swimming behavior required that circular tanks 1 m in diameter be used to prevent overcrowding and damage. Tanks of this size required the use of two vessels for successful trials. Juvenile winter flounder could be successfully captured in feasible numbers only by use of a small sampling trawl. Short tows of 5 minutes allowed for low impact and high survival. The sessile behavior of this benthic fish permitted the use of small 50 liter containers for holding tanks. All three holding tanks were easily secured in one vessel, thus simplifying logistics.

Survival probability as a function of mesh shape was determined by observing mortality over time. Comparison of diamond-mesh and square-mesh survival was conducted with analysis of variance statistics to determine if significant differences existed. The seabed cage system proved to be an excellent technique, allowing for a high survival rate of control fish. Water temperature was recorded every two days to determine if trends in water temperature had an impact on survival. Water visibility was measured on trial days to determine if turbidity impacted escapement time.

The nature of this experimental design eliminates the impact of other animals and rubbish on escapement and on the probability of survival. This allows for the unique investigation of escapement and hyperactivity and how these factors relate to survival. Use of individual experimental fish allowed easy tracking and successful recording of behavior over time. Relating survival with specific behavior was difficult because individuals were not distinctively marked.

This procedure could be improved significantly if marking techniques could be implemented without impacting survival. In some cases gross observations about size-related escape could be recorded but not accurately used for analysis. The more sessile nature of winter flounder allowed for fairly accurate measurement of total length by coaxing the individual over a grid marked on the bottom of the tank. The grid technique was moderately successful for distinguishing fish through the monitoring phase. The experimental procedure disregards the importance of schooling relations in fish behavior during stressful situations. This, however, could be overcome by group introduction.

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Trawl Width Variation during Bottom-Trawl Surveys: Causes and Consequences

Craig S. Rose and Gary E. Walters

Alaska Fisheries Science Center
7600 Sand Point Way East
Seattle, WA 98115

ABSTRACT

Crab/groundfish surveys of the eastern Bering Sea were conducted from 1982 to 1989 by scientists of the Alaska Fisheries Science Center (AFSC). Operating widths of otter trawls used have varied between stations and cruises. These differences in gear performance can cause biases and increased variability in survey results. Regression analysis was used to explore factors that might be used to predict these width differences. Much of the variation between trawl tows was related to changes in the length of towing cable (scope) required to fish at different depths. The effects of this variation on survey results were assessed by recalculating results from a set of stations having measured widths, using three methods for estimating width. Population abundance estimates were compared, using calculations from measured widths as a standard. A method accounting for effects due to vessel and scope produced results closely matching those generated using measured trawl widths. Customary methods, which did not consider the scope effect, produced biased results.

INTRODUCTION

A primary function of the Resource Assessment and Conservation Engineering (RACE) Division of the AFSC is to provide fishery-independent estimates of abundance and biological condition of fish stocks to the Pacific and North Pacific Fishery Management Councils. These estimates are derived from bottom-trawl and hydroacoustic surveys. Bottom-trawl survey estimates are calculated by dividing the catch of each sampling tow by the area of bottom that it swept. The mean of these catch rates is then multiplied by the ratio of the total survey area to the area swept during a trawl tow. To estimate the area swept, it is critical to know the fishing width of the trawl as it samples the bottom. Historically, area swept abundance estimates have not used information on trawl width variability. Initially, it was not possible to collect enough trawl width measurements to estimate anything more than a mean width value for each trawl type. Therefore, a single width estimate was used for all stations in a survey, often from width data collected in previous years.

Observations with prototype gear mensuration systems showed that trawl widths did vary and were affected by a number of factors, including depth, rigging, and currents (West 1981). These observations motivated the effort to measure trawl dimensions during all survey tows. Prototype mensuration systems, developed under contract for the RACE Division, were used to monitor trawl behavior between 1975 and 1983. The last of these systems was successfully used during survey work in 1981-83, though it required a specialist to operate it. When components of that system were destroyed in 1983, a newly available commercial system was selected to replace it. This new system was first used in 1985. Experience with its use, acquisition of more units, and improved training of survey personnel in its use have resulted in progressively better coverage of survey tows. The 1988 Bering Sea survey was the first where operating widths were measured at most of the stations for both of the participating vessels. While a substantial amount of data was collected in previous years, there are numerous gaps in the coverage of survey vessels. Only recently have sufficient data been available to analyze gear performance on a tow-by-tow basis.

Bottom-trawl surveys have been conducted annually on the eastern Bering Sea continental shelf since 1971. The surveys have varied in range, with large-scale surveys occurring in 1975 and annually since 1979. They monitor the abundance, distributions, and population structures of eastern Bering Sea demersal fish and crab stocks including the major gadid stocks of walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*). In addition to the information provided to the North Pacific Fishery Management Council and the International North Pacific Fisheries Commission, the surveys also provide abundance and distribution information to the fishing industry. This paper will examine some of the factors affecting gear performance during the Bering Sea surveys and how different methods for estimating trawl width can affect survey results. Calculations using measured widths for each tow will be used as a standard to evaluate effects of previous and other alternative methods.

MATERIALS AND METHODS

Sampling Methodology and Gear

The sampling regime for the Bering Sea surveys consists of a 20 nm square grid with one 30 minute tow at 3 knots performed in the middle of each square (Fig. 1). In areas around the Pribilof Islands and St. Matthew Island, tows are also performed at the corners of the grid to increase precision of estimates for blue king crab (*Paralithodes platypus*). Two vessels are used, operating on alternate columns of stations, and working from inner Bristol Bay to the continental shelf edge. The sampling area has been stratified based on depth and latitude into six major areas. The standard survey trawl for these surveys is the 83/112 Eastern trawl, a low opening two-seam trawl, with a 26.5 m (83 ft) headrope and a 34.1 m (112 ft) hose-wrapped cable footrope with no roller gear. This trawl is towed behind 2 m-by-3 m steel V-doors with two 55 m bridles on each side with 0.6 m extensions on the lower bridles to improve bottom contact. Total catch weight and numbers are determined for each species in each haul, and length-frequency samples are taken for selected species. The distance fished is calculated from Loran readings taken at the start and finish of each haul. Net width information has been gathered whenever possible using mensuration equipment.

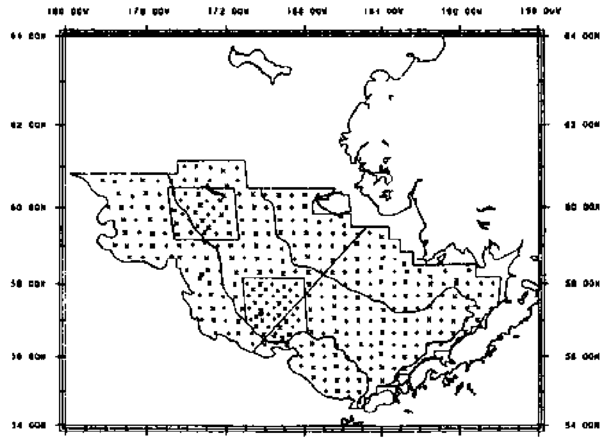

Fig. 1. *1988 Bering Sea sampling stations (+ =* Alaska, *x =* Ocean Hope 3*).*

Area Swept Biomass Analysis

The methods for biomass analysis are given in detail by Wakabayashi et al (1985). Briefly, biomass estimates are made for each species using the "area swept" methods of Alverson and Pereyra (1969). The formula for catch per unit area swept by the trawl for each species k in haul j within stratum i ($CPUE_{ijk}$) is

$$CPUE_{ijk} = \frac{W_{ijk}}{(D_{ij} \times T_{ij}) \times C_{jk}}$$

where W_{ijk} is the weight of each species in haul j, D_{ij} is the distance trawled during haul j, T_{ij} is the trawl width and C_{jk} is the catchability of species k. While catchability probably varies considerably between species and stations, there is no practical method for measuring this parameter. Lacking this information, catchability is arbitrarily set at 1.0. The area swept by the trawl is the product of the distance fished and trawl width. The mean CPUE for a strata with n_i stations is then:

$$\overline{CPUE_{ik}} = \frac{\sum_{j=1}^{n_i} CPUE_{ijk}}{n_i}$$

and the biomass estimate, $\hat{B}_{ik}$ is:

$$\hat{B}_{ik} = Area_i \times \overline{CPUE_{ik}}$$

where $Area_i$ is the total area of stratum i.

Population size compositions are estimated by combining the length-frequency samples weighted by the CPUE in the haul and stratum they were taken from.

Description of Mensuration Equipment

Trawl dimensions are monitored with acoustic measurement systems. The spread of the net is measured by two acoustic units that are attached to the upper wings. An electronic transponder/processor on one wing sends an acoustic pulse that is received and echoed by a transponder on the other wing. The time difference between the initial pulse and receipt of the echo is converted to a distance measurement by the processor, which acoustically sends this data to receiving instruments on the towing vessel. Net height is measured by a similar unit on the headrope of the trawl by echoing acoustic pulses off the sea floor. Measurements of the width and height of the trawl opening are automatically recorded at 10-second intervals throughout each tow, giving a maximum of 180 readings for a standard 30-minute tow. Actual samples are usually smaller due to the loss of signals from acoustic interference. The mean of the valid measurements represented the path width for each tow.

Factors Affecting Trawl Width

Measurements from Bering Sea surveys were used to determine the best predictors of trawl width. Trawl width was regressed against depth, length of towing cable (scope), speed, and trawl height, both by cruise and for all cruises combined. Stepwise regressions were used to select the best combination of predictors for each data set. Predictors entered the model when the F statistic for adding them to the regression was the largest available and exceeded 4.0. A predictor was removed from the equation when the associated F statistic dropped below 3.9.

Previous studies had indicated that width could be affected by the scope. To explore the form of that relationship, two transformations of scope were also used in the regressions. One factor that could affect the scope-width relationship is the inward lateral force exerted on the doors by the towing warps. This component of the total towing force (F_T) is determined by the equation:

$$F_I = F_T \ X \ (L_D - L_B) / S,$$

where F_T is the force of the towing cables pulling the doors, L_D is the distance between the doors, L_B is the distance between the towing blocks on the vessel, and S is the scope. As scope increases, this inward component would be expected to decrease, allowing the doors and the trawl itself to spread wider. Although this relationship between scope and trawl width would also be influenced by drag of the trawl and the change in door spread itself, the inverse of the scope was chosen to represent this effect in the regressions. This inverse transformation fit the data to a family of scope-width curves that increase to an asymptote, a characteristic seen in data from earlier studies.

Another possible factor is that the upward pull of the towing warps decreases the force with which the doors press into the sea floor. This would reduce the shearing action of the doors and thus their spreading force. To represent this effect, the amount of scope needed to just contact the bottom at 3 knots was determined by experiment and the amount of scope in excess of that value was used in the regressions.

Effects of Width Estimation

During the 1988 Bering Sea survey, trawl width measurements were made for 211 of the 354 trawl hauls. These measurements were distributed throughout the survey area and were taken from both participating vessels. This set of known widths provided data that could be used to model different methods of estimating trawl width.

The biomass estimation procedure was conducted four times, using only tows with valid width measurements. Each time, a different method was used to estimate the trawl widths for area swept calculations. These methods represent alternative uses of trawl widths, requiring progressively more data. The different degrees of error between these sets of survey results reflect the costs of not collecting additional trawl performance information. Comparisons were made on estimates of biomass, distribution, size composition, and the coefficient of variation of the biomass estimate.

In the first method, a single estimate (16.41 m), the mean of measurements from the 1983 Alaska cruise, was used for all tows. This number was used from 1983 to 1988 because of the lack of additional measurements from that vessel. Having no relationship to measurements from the current survey, this method includes error due to trawl width differences between vessels and from year to year.

In the second method, a mean width was calculated for each vessel and applied to all of that vessel's tows. While all of the measurements were used to generate these means, this method could be accomplished with relatively few data from each vessel. While this method adjusts for between-vessel differences, it does not account for any of the haul-to-haul variation, particularly that associated with depth and scope changes.

The third method, which required more measurements from the full range of depths surveyed, fits a regression function to the relationship between inverse scope and trawl width. The scope selected for use at any station is a nonlinear, increasing function of the depth. The scope-to-depth ratio is as high as 5 in shallow water and decreases to below 2 in deeper water. Therefore, the scope/width relationship implies a depth/width relationship. This method adjusts for both depth and vessel differences.

On the fourth run, the calculations were done with the actual trawl width measurement for each haul. Because all trawl width variation was accounted for, this was used as a standard set of survey results against which those from the estimation methods could be compared.

The three estimation methods were chosen to represent three possible strategies for collecting and using net width information. The first represents using the same width value for every trawl tow in all years and cruises, requiring no new measurements. The second represents using a single value for all tows within each cruise. This could be accomplished by making a few test tows at a standard site before or after each cruise year. The third represents estimating a scope-width function for each cruise. This could be accomplished by taking measurements during tows at a variety of depths. The fourth method, used as the standard, represents measuring widths during every trawl tow.

Because the full data set was used in estimating the means and functions for the second and third methods, they depict the best possible case. Actual estimates from such experiments would also be vulnerable to sampling variability and nonrepresentative conditions.

RESULTS

Factors Affecting Trawl Width

Trawl width measurements were available from 11 Bering Sea survey cruises (Table 1). Width measurement coverage of both survey vessels occurred in 1983, 1988, and 1989, while the other years received lighter coverage. The 1985 *Argosy* measurements were limited to waters deeper than 90 m and the 1988 *Miller Freeman* observations were taken from a northern extension of the survey into an area with mostly shallower depths (<50 m).

A stepwise regression of the combined width data found trawl height, inverse of the scope, excess scope, and towing speed to be significantly related to trawl width in that order (Table 1). Height was the best predictor, explaining 24 percent of the variation alone. Inverse scope accounted for 23 percent of the variation alone and added 15 percent after the height effect. The other two factors contributed 2 percent each.

Examining the data by cruise showed considerable variation from this pattern (Table 1). Height and inverse scope were again the dominant factors, though in four cruises the scope-width relationship was linear enough that scope itself replaced inverse scope in the equation. Because the 1985 *Argosy* measurements included only deepwater tows, where the scope/width relationship approaches an asymptote, none of the scope functions were significant.

In comparing the scope/width functions, the 1988 Alaska cruise had substantially lower widths than all other cruises (Fig. 2). A short study done in February 1989 verified this difference and indicated that the doors used on that cruise were the most likely cause of the narrow widths. These doors, while nominally the correct size, were actually 10 percent lighter and had 10 percent less surface area than the doors used on the other cruises.

Repeating the combined regression after removing this cruise produced different results. The fit was greatly improved, explaining 50 percent of the variation. Also, inverse scope replaced height as the best predictor, explaining 43 percent of the variation by itself. Height explained only 14 percent by itself and explained only an additional 5 percent when added to the inverse scope regression. Speed contributed an additional 3 percent and excess scope was not selected by the stepwise procedure.

Fitting separate stepwise regressions for each cruise, which required the estimation of 40 parameters (11 intercepts and 29 slopes for the selected predictors), explained 75 percent of the total variation. The regressions fitting only inverse scope to each cruise required only 22 parameters (11 intercepts and 11 slopes) and accounted for 65 percent of the trawl width variation. Forcing those regressions to have a common intercept (17.9 m) decreased the R^2 to 60 percent. While the intercepts were significantly different between cruises (F test, $p<0.001$), this small reduction in R^2 after eliminating 10 of 22 parameters indicates a great deal of similarity between the intercepts.

Effects of Width Estimation

Results of the 1988 Bering Sea survey were calculated four times, each using a different means of determining trawl width. Results based on three estimation methods were compared with those using actual width measurements to calculate errors resulting from width estimation. The functions for estimating width and the raw measurements are represented in Figure 3.

A measure of abundance, usually biomass, is the principal estimate derived from AFSC bottom-trawl surveys. Calculations based on the prior width estimate underestimated biomass for all species because the widths were

Table 1. *Results of regressions on trawl width for the 83/112 Eastern trawl used in groundfish surveys of the eastern Bering Sea, 1982-89, by cruise and combined (All regressions significant $p<0.001$, F-test).*

Cruise	N	Factors*	All factors stepwise		Inverse scope only	
			R^2	Intercept	Slope	R^2
Pat San Marie 1982	41	IS,SP,HT	0.76	18.3	-511	0.44
Alaska 1983	20	SC,SP	0.78	19.4	-715	0.69
Chapman 1983	37	SC,HT	0.91	18.4	-537	0.73
Argosy 1985	16	HT	0.31	17.9	-92	0.02
Morning Star 1986	23	IS,HT	0.69	17.8	-320	0.60
Pat San Marie 1987	99	SC,HT	0.62	18.9	-474	0.23
Alaska 1988	102	IS,HT	0.54	15.8	-517	0.49
Ocean Hope 1988	109	IS	0.57	17.8	-519	0.57
Miller Freeman 1988	77	SC	0.63	18.1	-446	0.48
Alaska 1989	141	HT,IS,DP	0.47	18.1	-341	0.31
Ocean Hope 1989	107	HT,IS,SC	0.49	18.9	-594	0.34
ALL Cruises	772	HT,IS,SP,EX	0.42	17.7	-406	0.23
ALL, except Alaska 1988	670	IS,HT,SP	0.50	18.4	-478	0.43

*Factor abbreviations: IS-Inverse Scope, HT-Height, SC-Scope, SP-Speed, EX-Excess Scope, DP-Depth.

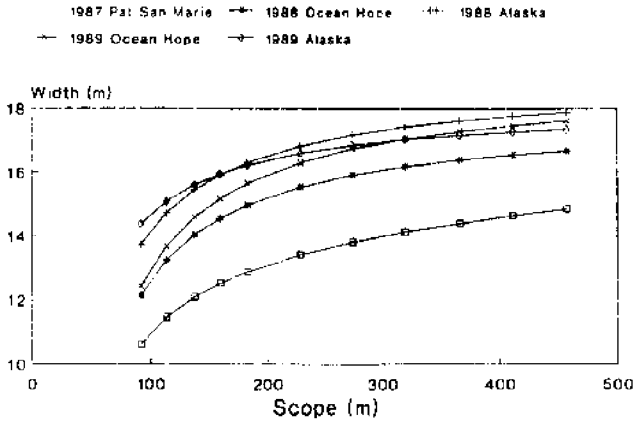

Fig. 2. *Comparison of scope/trawl width function from the 1988 bottom trawl survey of the eastern Bering Sea aboard the* Alaska *with those from other cruises.*

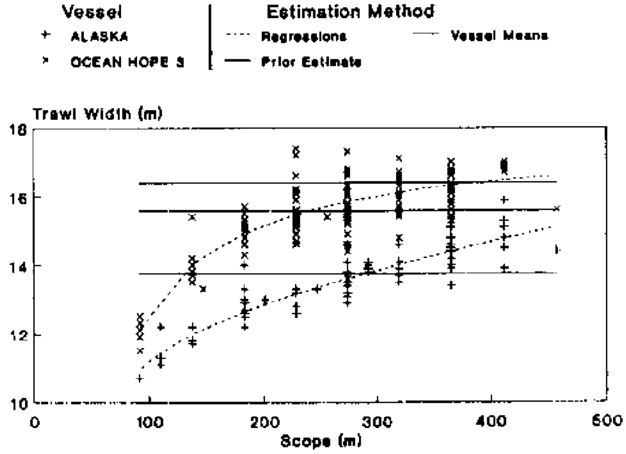

Fig. 3. *Scope/trawl width data from both vessels used in the 1988 bottom trawl survey of the eastern Bering Sea with a comparison of three methods used to estimate trawl width.*

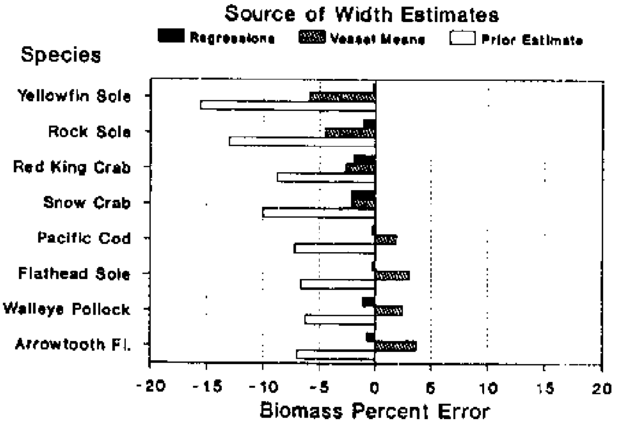

Fig. 4. *Errors in biomass estimates from the 1988 bottom trawl survey of the eastern Bering Sea using three methods for estimating trawl width.*

consistently estimated to be wider than they actually were (Fig. 4). If the prior estimate had been narrower than the average for these cruises, biomasses would generally have been overestimated.

The effect of the vessel means method varied by species. Yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta bilineata*), and the crab species *Paralithodes camtschatica* and *Chionoecetes* spp. were underestimated, while Pacific cod, flathead sole (*Hippoglossoides elassodon*), walleye pollock, and arrowtooth flounder (*Atheresthes stomias*) were overestimated. The differences between these two groups followed their depth distributions (Fig. 5). The first group was found primarily in shallower waters where the vessel means method overestimated width, thus underestimating biomass; the second group had more biomass in the deeper waters where the width estimates were too low, causing overestimates of biomass.

The biomass estimates generated using the scope regressions matched those from actual measurements within 1 or 2 percent for all species with a very small negative bias. This close agreement is expected, since both vessel- and depth-related variability are accounted for.

The effects seen in the biomass estimates—overall negative bias when the prior estimate was used, bias varying with depth for both the prior estimate and means methods, and low bias results with the scope regressions—carried over to the distribution and size composition results. For individual species that occurred over a range of depths, such as walleye pollock (Fig. 6), the means method underestimated the proportion occurring in shallower strata and overestimated it in deeper waters. Biases in the population size composition of a species were observed where fish size varied with depth. This occurred most strongly with yellowfin sole (Fig. 7), where smaller individuals were found in shallower water.

Part of the rationale for making trawl width measurements was the hope of increasing the precision of trawl survey results. A comparison of the coefficient of variation (CV) of the biomass estimates generally showed lower variability as more of the trawl width variation was accounted for (Fig. 8). The prior estimate method, which used none of the width variability, had higher CVs than the vessel means method, which accounted for the considerable difference between vessels. The means method, in turn, had higher CVs than the regressions method, which also adjusted for the depth variability. Unfortunately, the CV reductions were relatively minor, all at or below 5 percent. Two anomalous results occurred, with yellowfin sole and arrowtooth flounder, where the variability showed a trend opposite to that expected.

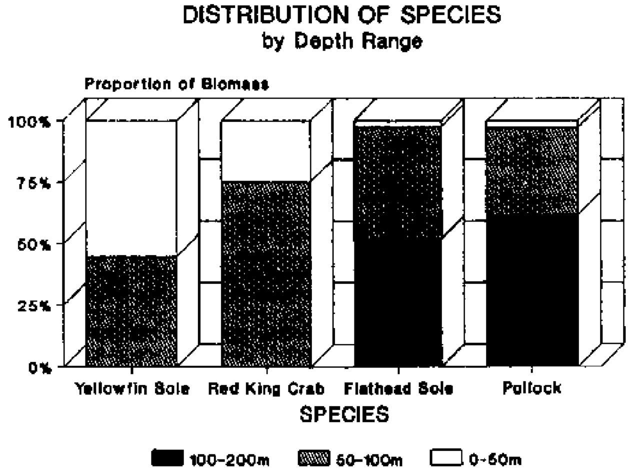

Fig. 5. *Depth distribution of four species from the 1988 bottom trawl survey of the eastern Bering Sea.*

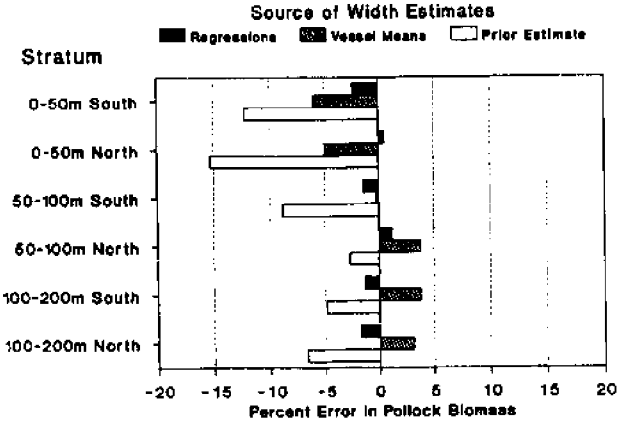

Fig. 6. *Percent error in walleye pollock biomass by strata from the 1988 bottom trawl survey of the eastern Bering Sea using three methods for estimating trawl width.*

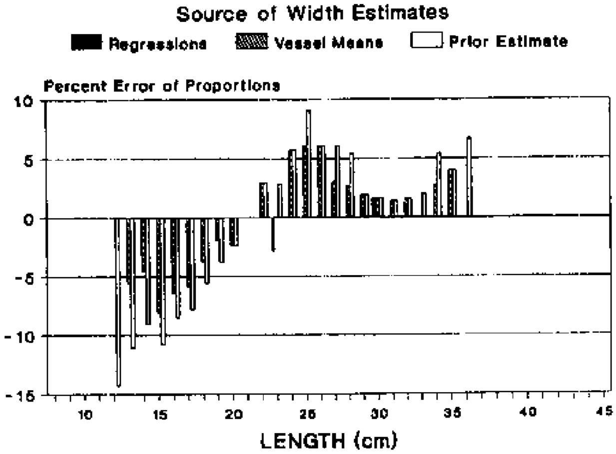

Fig. 7. *Percent error in proportions of length groups of yellowfin sole from the 1988 bottom trawl survey of the eastern Bering Sea using three methods for estimating trawl width. No bar indicates negligible error.*

DISCUSSION

The opening widths of otter trawls can vary during assessment surveys of groundfish stocks. Failure to account for this variation can cause biased results with lower precision.The inverse of the scope was the best predictor of trawl width. The next best factor, trawl height, was actually another indicator of the shape of the trawl that necessarily covaries with width due to the trawl's structure. In the inverse scope relationship, width will change rapidly with increasing scope (deeper water depth) at first, then level off to an asymptote in deep water. The intercept of the regression determines that asymptote, and should represent the average spread of the trawl when the towing cables are so long that they do not pull the doors toward each other.

Since these results were derived from survey tows instead of a designed experiment, there are some limits to their general applicability. The results were influenced by the range and distribution of the factors considered. For example, while scope varied over a wide range, the excess scope and speed parameters were limited by survey standardization. Also, the depth distribution of valid width measurements varied between the cruises. This variation between cruises influenced which part of the scope/width curve was weighted most heavily, and could have created artificial differences between the resulting regression parameters.

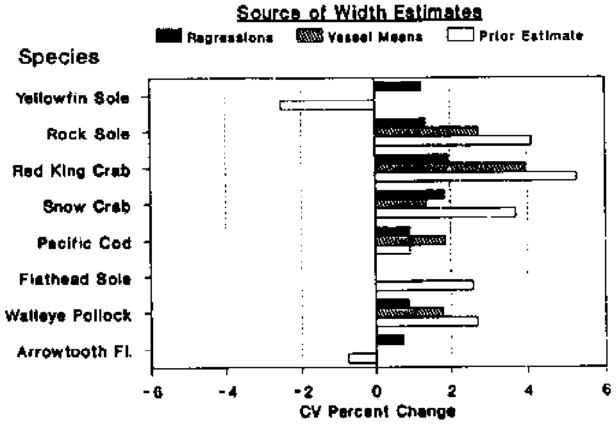

Fig. 8. *Percent change in the coefficient of variation (CV) of biomass estimates from the 1988 bottom trawl survey of the eastern Bering Sea using three methods for estimating trawl width. No bar indicates negligible error.*

There was a considerable amount of width variability that was not explained by the factors considered here. Two factors that could have caused some of that additional variation are currents on the bottom and bottom type. Practical methods for measuring these factors need to be developed to determine their effects on trawl shape. These effects could be particularly important in deep water where the influence of changes in scope is small.

Two causes of survey result bias due to trawl width estimation have been demonstrated. First, if the width estimates are biased, the resulting abundance estimates also will be biased. The best example of this was the prior estimate method, which did not reflect current survey data. The second cause results when fish density is correlated to something that also affects trawl width, and that factor is not adjusted for in the width estimate. The vessel means width estimates were not biased over the whole survey, but they did not account for the effects of depth on width caused by the necessary changes in scope. Since fish density is also a function of depth, biased abundance estimates resulted.

This last kind of bias could easily occur in other situations. Both current speed and bottom type could be correlated with fish density. If they also strongly affected trawl width during a survey, biases would result.

The magnitudes of the biases and variation increases demonstrated here are important to consider. For the 1988 Bering Sea survey, many of these were quite small relative to the total variability and biases in survey results. A 2 percent decrease in variability may not be worth pursuing if the confidence intervals of the estimates are plus or minus 50 percent. Likewise, a relatively small bias may be quite acceptable, especially if the results are used primarily as indices instead of absolute values.

Some of these problems can be dealt with by means other than measurement. One result of the RACE trawl mensuration program has been an increased emphasis on standardization. Depth/scope relationships and trawl rigging have both received additional attention. Another approach is to modify the trawl or change to a different gear to achieve constant operation at all sites. Unfortunately, beam trawls, which maintain a constant width, do not fish well for some species on some grounds; and gear changes can destroy the comparability of long-term time series.

Although practical methods have not been developed to measure the catchability of an otter trawl, ways in which catchability could be affected by width variability should be considered. Observations of interactions between fish and trawls indicate several ways in which catchability could be affected by trawl operating width (Main and Sangster 1981, Foster et al 1981). When fish are being herded by the trawl bridles, the angle of the bridles to the direction of motion determine how fast the fish must swim to stay in front of the bridles. High bridle angles should result in more fish, particularly slower swimmers, being overtaken by the bridles and not being herded into the path of the net. For a given trawl system, wider net spreads are caused by higher bridle angles and could thus be associated with lower catchabilities. Very wide spreads can also increase the tension in the footrope to the point that portions of the footrope are pulled off of the bottom during the tow. This would provide another potential escape path. Finally, wider net spreads are associated with lower headrope heights. Fish that are swimming off of the bottom would more easily escape over the net when it is fishing in this wide, low configuration. All three of these hypothetical effects would reduce catchability when the trawl is spread wider, causing smaller catches than those expected from the increased area swept.

Variability in trawl width and its resulting biases present some difficult questions regarding standardization of the time series of Bering Sea trawl surveys. A variety of methods have been used for estimating trawl width, including the three described here and some combinations (depending on the best information available). The variable biases from these methods could easily have clouded interpretation of the series. It may be possible to correct some of the past biases in the series. Even though there was significant variation between cruises, the scope/width relationships are certainly similar. Use of the combined scope/width equation for those cruises where data are not available would at least adjust for the depth-related biases. Unfortunately, there is no way to know if the widths from any of those cruises diverged from the normal pattern, as occurred on the 1988 Alaska cruise.

This study highlights the usefulness of trawl mensuration for bottom trawl surveys. The assumption of constant widths does not hold for otter trawls as they are now used. In addition to allowing adjustment for varying widths, trawl monitors also make it possible to detect any number of gear malfunctions that prevent a tow from adequately measuring fish density. Some of these include crossed doors, separation of the footrope from the seabed, hang-ups, tangling of various parts of the trawl, and incorrect estimation of bottom tow starting and ending locations. Without trawl monitors, many such malfunctions would remain unaccounted for in the data base, adding to the already considerable variation associated with trawl survey data.

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Fish Behavior in Bottom Trawls and the Use of Video for Behavior Observations

Clem S. Wardle[1]

Department of Agriculture and Fisheries
Marine Laboratory
Victoria Road
Aberdeen, Scotland
AB98DB, United Kingdom

[1] edited by J. T. DeAlteris, from notes provided by C. S. Wardle for a talk presented to the Conservation Engineering Working Group at Narragansett, R.I.

REACTIONS OF FISH TO VISUAL STIMULI

The silicon-intensified video camera tube (SIT) is used in underwater cameras by a number of companies. At present we are using Osprey cameras made in Wick, Scotland. The RCA tube is about as sensitive as human vision but gives a very much brighter, contrast-enhanced view. A diver sees a view with much lower contrast than we see on the video screen. No artificial light is used. Video cameras are either deployed by scuba divers using a piloted vehicle or operated remotely from the Magnus rotor vehicle. Both vehicle systems were developed in 1975 to 1980. Wardle (1987) provides a complete description of the development of these observation techniques.

Water visibility is the most important variable in the underwater environment with respect to video observations. Figure 1 relates the scale plan of the gear to distance seen by a fish. The fish can be considered to be in the center of a sphere, with the sphere's surface representing maximum visibility range. The visibility range determines the visual reaction distance. Visibility range determines the distance at which the fish can react to the visual stimulus of the gear.

The trawl otter board as a visual stimulus has properties of high contrast, but is not easily seen. It first becomes visible to the fish's visibility sphere when coming out of the darkness. Before it is seen, it has probably been heard. Its sound varies according to the substrate but will attract attention to its approach. The fish's directional hearing will have indicated the approach direction of the sound. Like other vertebrates, the fish has its attention drawn to the approach of a threat that is identified as soon as possible by vision. Fish have the ability to hear in a frequency range similar to humans, with low frequency sounds more important. Some pelagic fish may be sensitive to higher frequencies. Note when the otter board is first noticed it is least visible, but the fish's attention is attracted by the sound and it may be looking out for it. Sound provides a warning function.

Swimming performance needed to avoid the gear is determined by the combined approach speed of the gear and the visibility range, and is summarized in Figures 2 and 3.

Fish eyes have a slightly better ability to detect low-contrast images than human eyes. Once the otter board has passed, a spreading mud cloud is thrown up in the vortex wake. The fish's reaction to the otter board wake is the observed zigzag movement of the fish ("fountain effect") ahead of a single following stimulus. This reaction as a performance limit is relevant here. The fish avoids a fast escape reaction by maintaining a safe distance while watching and avoiding the moving stimulus. A fast escape reaction would involve a burst of swimming, using the anaerobic white muscle at full power, and would lead to rapid exhaustion as well as loss of visual contact with the threat. Reacting slowly by maintaining a "safe" distance from the approaching threat conserves the escape reaction potential and maintains visual contact with the threat. The fountain effect appears to be a result of the blind zone, an area behind the fish in which objects cannot be seen by the two eyes of the fish (Figs. 4, 5, and 6). If the fish is to keep its eye on the threat while swimming away, it cannot swim directly ahead but must swim with the stimulus at an angle that will maintain the threat as an image in the rearmost zone of the visual field of one of its eyes.

The diagram of the eye visual fields and the results of the black ball approach experiment illustrate these points. The ball was dragged on an invisible line through a group of small whiting. Although all the fish are visible through the surface

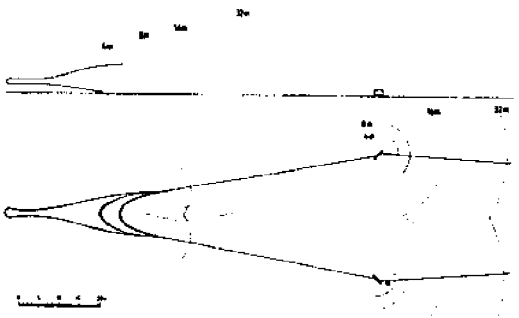

Figure 1: *A scale plan (lower part of figure) and elevation (upper part of figure) of a trawl that can be towed by a 600 HP vessel. The dotted lines indicate the various ranges of visibility discussed in the text in relation to the reaction behavior of fish. (From Wardle 1986).*

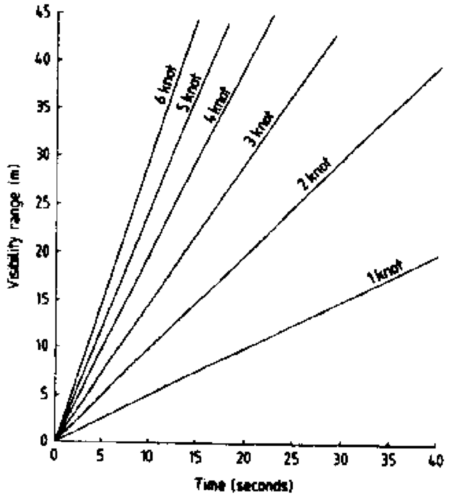

Figure 2: *Time to collision with an object first seen at visible range, approaching at the speeds indicated on the firm lines. One knot is approximately 0.52 meters per second. (From Wardle 1986).*

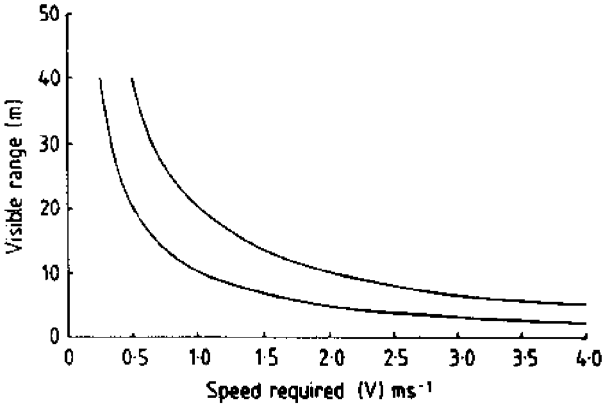

Figure 3: *Swimming speed required to clear the headline of a trawl approaching at 2ms¹ (4 knots). The headline heights drawn are 5 m (lower line) and 10 m (upper line). The fish starts to swim upwards from the sea bed at the different visible ranges indicated. (From Wardle 1986).*

of the tank, the fish can see no more than 1 meter through the water. Only the fish within this range of the ball react directly to the ball. It is not certain that each fish reacts individually to the ball according to the limit of the angle of the rear edge of the field of vision. However, the detailed measurements of range of reaction and angle of fish body as the ball passes suggest that they do react as individuals (Hall, Wardle et al 1986).

With respect to a moving bottom trawl, a summary plan of the reactions and swimming directions is shown in Figure 7. Once encompassed by the trawl doors, the fish swim toward the net mouth and then turn and swim forward in the trawl mouth at the same speed as the towed gear. This illustrates the optomotor response that can be mimicked in laboratory conditions (e.g., stripes in flume walls, moving light pattern in the gantry tank, the Bainbridge wheel) and occurs in station-keeping in streams, etc. Note that there are strong visual clues in the netting patterns when seen in natural light. Original papers on optomotor response by Lyon (1904) and reviews by Arnold (1974) and Harden Jones (1963) are discussed in Wardle (1983).

Humans experience the optomotor response when in a stationary train alongside another train. When one of the trains starts to move, the movement is perceived immediately but it may not be evident which train is moving. A contextual view of the rest of the world is needed to be certain.

The effect of the optomotor-induced behavior in the trawl is to maintain the fish in a stable position relative to the surrounding bits of fishing gear. The trawl maintains a very stable deployment for long periods. This may be interrupted by snagging on hard ground or by strong tidal effects, distorting the ideal gear shape and displacing the sand cloud. The optomotor response depends on visual contact between the swimming fish and some part of the gear. The effect disappears at extremely low light levels and in poor water visibility. If we consider the visibility range and the visual fields of the two eyes, it can be concluded that the fish will only see those parts of the gear that intrude visually within these limits (Fig. 8).

The parts of the gear must have properties of high or low contrast in order to be definitely visible or least visible within these limits. Gear characteristics are determined by the gear designer. The type of gear makes little difference. Hemmings noted in 1973 that even without a back part to the net the fish will still swim for long periods in the mouth area. Wardle (1986) demonstrated this with his rope experiments. Sand eels were forced to swim near their maximum speeds in the presence of ropes spaced 1 m apart instead of the net. When made to swim at this high speed, the small sand eels eventually succumb to exhaustion. Their shyness to the ropes is shown by the way they appear to flow through the spaces, avoiding the zones near the rope.

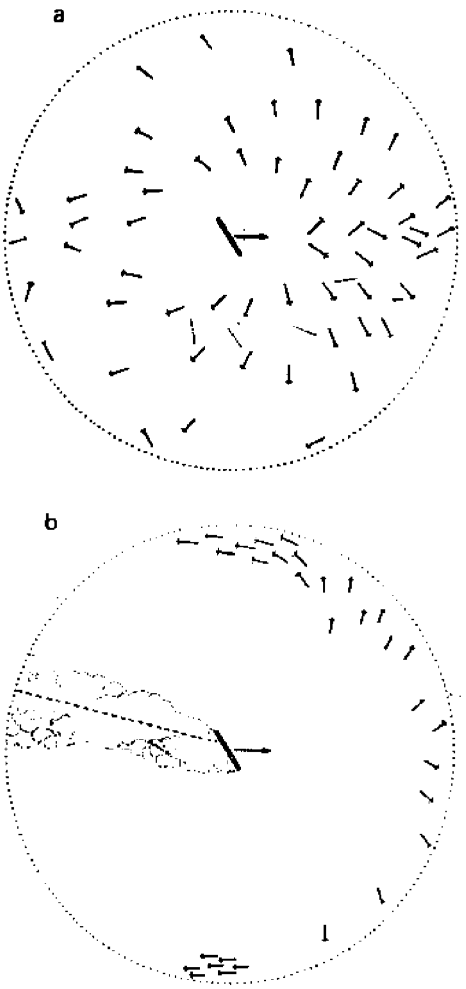

Figure 4: *Plan view of the predicted reaction of fish due to visual stimulus from (a) an isolated moving object like an otter board or human swimmer; and (b) an otter board with its trailing wall of sand cloud and sweep wire. The dotted circle indicates a maximum visible range of 8 m. (From Wardle 1986).*

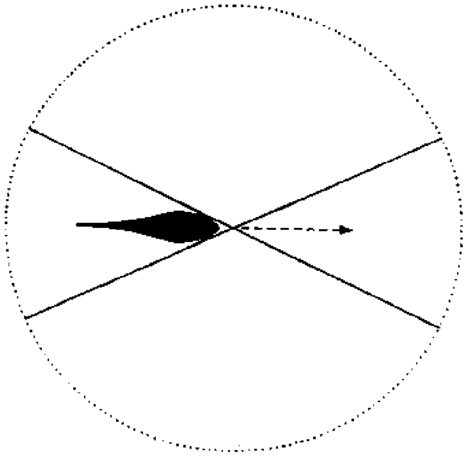

Figure 5: *Plan showing the two hemispherical fields of vision of a roundfish like a cod. The line forming a tangent to each eye delimits the outer edge of the field of view of each eye as the fish passes through the center of the circle. The sector immediately behind the fish is the blind zone and the sector ahead of the fish is a zone of binocular vision. The dotted circle represents a limit to range of visibility. (From Wardle 1986).*

The behavioral interpretation of maintaining station with the gear is to some extent a common-sense reaction. If the animal can maintain a constant position relative to the threat or the predator it is safe from interaction with the threat. In a similar way, a man running steadily ahead of a bull is safe as long as his endurance matches the bull's. If his endurance is exhausted, the danger increases when dodging in an attempt to pass the bull. The running and the dodging are two distinct reactions or behavioral responses to the same stimulus, caused by physiological change related to performance thresholds. Can we predict these speeds, their thresholds, and the expected endurance?

ESCAPE BEHAVIOR

A diver swimming alongside a net has little effect on the observed fish behavior. But if he reaches out to grab one of the larger saithe or haddock swimming in the gear, the fish will swim rapidly away and is easily able to clear the gear using its escape-burst swimming speed. Mackerel have been observed swimming gradually ahead and out of the vicinity of the gear mouth. Direct observations show that mackerel have a superior sustained swimming speed compared with the similar-sized saithe, but it is not clear what makes them move forward, released from the optomotor response. At higher towing speeds, mackerel are trapped by the optomotor response. There may be a performance range for ideal optomotor response.

The period for which fish are prepared to swim appears to relate closely to their swimming endurance. It is clear that the whole swimming physiology of fish must be understood to interpret the behaviors seen in trawls. A single saithe was seen swimming at exactly the same speed as the gear. At that speed it could probably swim for several hours. The saithe were then seen at a higher towing speed, unable to quite keep up, and they show occasional catch-up kicks forward. Individual fish give up and turn into the net funnel. At this speed, these fish are swimming at a limited endurance level.

The gantry tank drives fish through a circular track in still water to determine swimming endurance (Fig. 9). Graphs comparing endurance of different sizes of the same species and those comparing different species of the same size illustrate species and cite specific differences in swimming performance. For example, He and Wardle (1988) gantry tank endurance curves for mackerel, saithe, and herring (Figs. 10, 11, and 12). Note the positions and significance of the steep slope of the endurance curves in relation to towing speeds of fishing gears. The change in behavior of fish due to exhaustion is caused by the white muscles' conversion of the anaerobic muscle fuel glycogen to lactic acid.

Extremes of size, with fish lengths varying from 3 cm to 30 cm to 300 cm, may affect limits to speeds. For mackerel (length about 30 cm) all the interesting speed limits have now

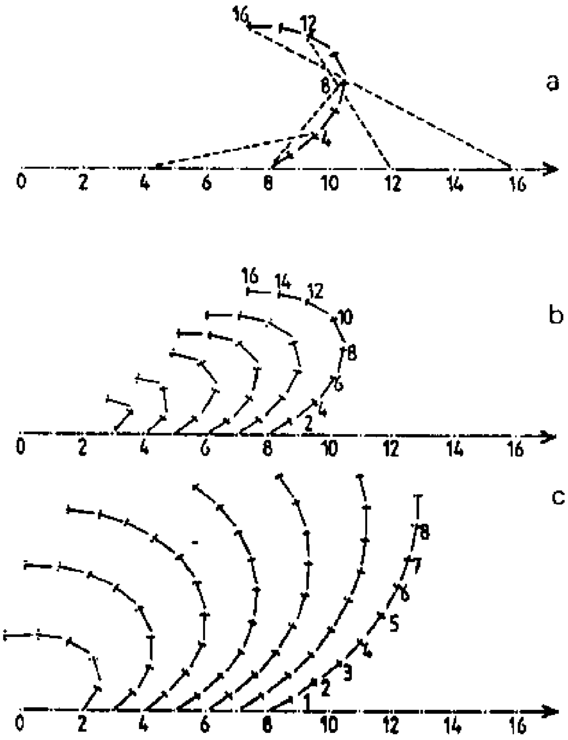

Figure 6: *The predicted tracks of a roundfish reacting to an approaching object such as an otter board. The horizontal line is the track of the otter board where the numbers indicate time in seconds. The curve of the fish track is set by keeping the otter board at each position just at the edge of the visual field (dashed lines shown in figure a).(a) shows how the track is determined; (b) shows the swimming speed of the fish set at half the approach speed of the otter board (the fish tracks shown start from points 3 to 8 m ahead of the otter board); (c) shows a similar set of tracks when swimming speed is equal to the otter board approach speed. The numbers marked on the curves identify coincident positions of fish and otter board. (From Wardle 1986).*

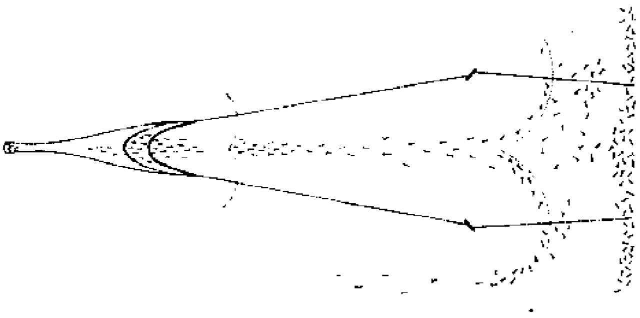

Figure 7: *Plan showing the reaction of fish predicted by visual reaction with a visual range of 16 m (dotted lines). (From Wardle 1986).*

been defined (see Fig. 13). Measurements from bluefin tuna (length 300 cm) provide an indication of the effect of large size (Figs. 14 and 15). The studies of swimming performance of tiny fish entering power station water intakes provide speed measurements of 3 cm fish.

The change in behavior from running to dodging and its physiological explanation were first recognized in the various hauling stages of the Danish seine net while observing flat fish (see the film, *Divers observe seine nets fishing*, Wardle 1977). In the trawl films, the change in behavior is first seen in haddock, then cod and saithe. The distinct behavior change from the optomotor response to taking the risk of position-changing (and possibly encountering the unknown threat), is forced on the fish by progressive exhaustion, leading to the inability to continue swimming forward. The net assumes a new function when the fish changes its behavior. The fish seeks out a clear path through the threatening array of ropes and net surrounding it. Visual clues are important in guiding the fish. Visual range, for example, makes it appear as if the sides of the net lead into a route through or along the center of the trawl funnel. In most common visibility ranges, the cod end is too far away for the fish to see it from the net mouth. Colored panels used in rear parts of nets can change the appearance or perception of this passage through the gear. The size of a trawl net in relation to visibility range of the water can alter the balance between fish and visual stimulus. Different sized nets may suit different water visibility conditions.

Due to the optomotor response, all sizes and species of fish swim at the same speed as the towing speed of the gear. The distance moved forward for each complete tail beat during steady velocity swimming will vary with fish length, resulting in an individual fish stride length. Two fish swimming side-by-side at 3 knots—one 10 cm and one 100 cm in length—will require different numbers of tail beats to move 1.5 m in one second. Tail beat rates vary from 3 tail beats per second for the larger fish to 30 for the smaller fish (Figs. 16 and 17). Frames from a film were analyzed, showing the fast tail beat of a sand eel completing a left right sweep in one frame (20 ms) or nearly 25 tail beats per sec. The tail of the larger sea trout hardly moves between the frames.

At trawl gear towing speeds of 1.5 ms^{-1}, huge numbers of small fish swim only briefly in the mouth and then drop back and break out through the net. In contrast, a group of larger fish can swim easily at the same speed as the gear for long periods. Swimming in the mouth, they fill the space between the wings, showing little or no turnover and effectively blocking further accumulation of fish. This can lead to other fish passing over the net headline. Larger fish in this situation may be present, swimming between the wings for the duration of a tow but then escaping.

Flatfish can be herded by sweeps or seine net ropes. This may consist of either one- or two-point herding using the eye

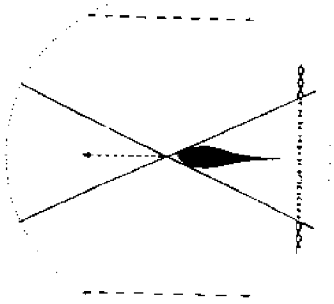

Figure 8: *Plan suggesting the contents of the visual fields of the left and right eyes of a roundfish swimming forward at the same speed as the net inside the mouth of a trawl. Note the chain in the blind zone (shown dotted) is not seen by the fish. The net panels on the opposite sides of the gear disappear outside the visible range indicated by the dotted circle. (From Wardle 1986).*

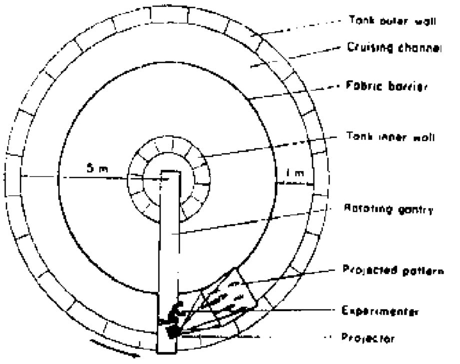

Figure 9: *A plan diagram of the experimental set-up in the 10 m diameter gantry tank (not to scale). The mean diameter of the swimming channel is 9 m and circumference 28 m.*

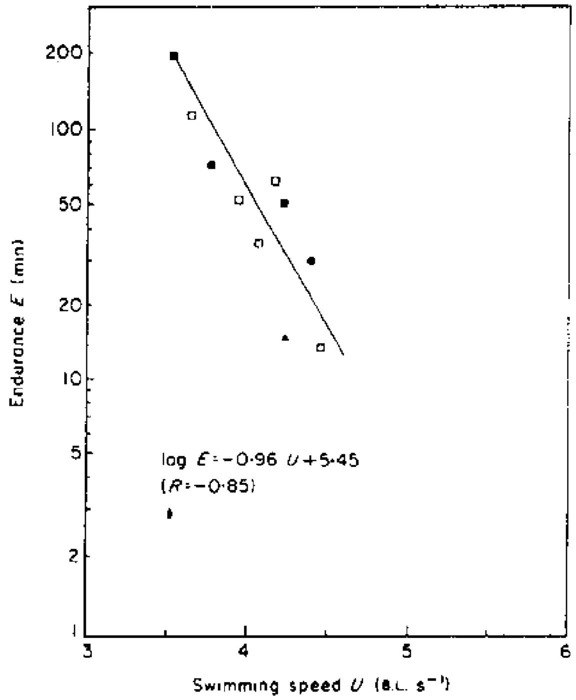

Figure 10: *Swimming speed and endurance (note log scale) of Atlantic mackerel, 29-33 cm F.L, at 11.7°C. The line and the formula are from the least square regression. Symbols for each specimen are:* ■, *33 cm;* □, *29 cm;* ▲, *30 cm;* ●, *32 cm.*

field diagram (Fig. 8). One-point herding is more strongly linked to the optomotor response, and seems to occur if visible patterns show details of the actual forward motion of the rope. In two-point herding, the rope is seen by both eyes, but because it is angled and moving along, its length is not perceived. In this case, the fish moves away at right angles and the rope "appears" to follow. Due to the angled motion, it catches up with the fish at a point much nearer the mouth of the net. Figure 18 helps to explain these two reactions. Roundfish like saithe and haddock have been seen by divers herded in this way, but so far no film of this process has been made.

The effect of simple herding devices on small and large fish, and the responses at different angles of the rope, are important considerations in the size selectivity of Danish seine ropes and pair trawl sweeps and warps. Forward-moving sections allow escape of all the small fish herded too quickly, as described in the previous example of sand eels in parallel ropes. In contrast, at very small angles to the forward motion at the same towing speed, the ropes creep slowly inwards and herd even tiny fish into the region of the wings. If used effectively these devices could be used for successful size selection and probably are used this way in some rigs. There are many observations of round and flat fish herded in by sweeps across the seabed toward the track of the mouth of the trawl. Two out of every three skate captured are herded by the action of the sweeps; the otter boards are 30 m apart whereas the mouth area is only 10 m wide.

VISION AND SOUND

The role of vision and sound has been described, but not their use and control. The variable nature of all the physical factors determines the intensities of the various stimuli presented by a towed gear to a fish. In a film made at 300 ft (50 fathoms) depth with natural light, the netting is not visible unless quite close to the camera. But the ribs, the patches, and the seaweed caught in the meshes of the net form the main visual clue of the net's more distant presence and of its motion. The light, coming mainly from above, glints in the steel bobbin and forms marked shadows under the fish. The headline and net ribs are silhouetted clearly against the light from above. A mackerel school was visible in quite low light levels and the gloomy pictures are interrupted by flashes of the remote 35mm camera. These pictures are much clearer than the video images and confirm the mackerels' identity.

The very clear conditions were exceptional and it appears that the haddock seen in the film swim ahead of the wings near the seabed and then slowly rise from a point some 10 to 15 m ahead of the net mouth and pass over the headline 6 to 8 m above the sea bed. No haddock were caught in the net. Fishermen do not catch haddock in the daytime, they capture them only at night.

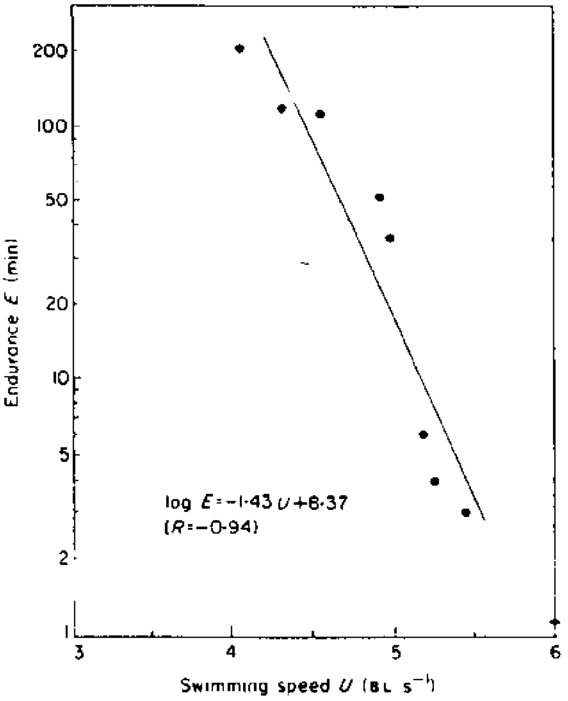

Figure 11: *Swimming speed and endurance (note log scale) of Atlantic herring, 25.3 cm mean F.L., at 13.5°C. The line and the formula are from the least square regression.*

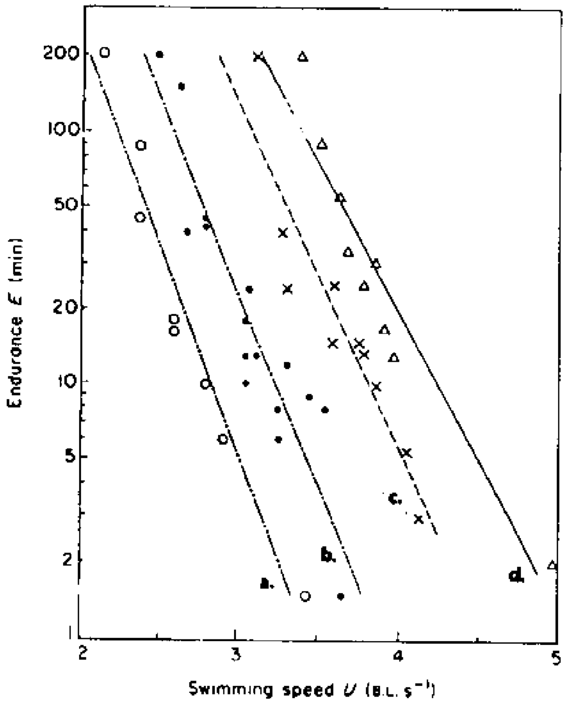

Figure 12: *Swimming speed and endurance (note log scale) of saithe, 25.5 to 50 cm F.L., at 14.4°C. The lines, from the least square regression for each group of fish, are: Group A, 50 cm,* n=*1; Group B, 41 to 44 cm,* n=*4; Group C, 33.5 to 36 cm,* n=*4; Group D, 25.5 cm, range 23 to 29 cm, S.E. 1.5 cm,* n=*31.*

In clear-water fisheries a number of devices have been found successful for haddock and herring. Elaborate high kite rigs, as shown in the United Nations Food and Agriculture Organization's catalog of gears, are one device used to drive these fish back into the net mouth (Fig. 19). The frontal view of the approaching net might be made less visible to be more useful in clear water conditions.

The other occasions when fish have been seen to pass out of gears in large numbers are when the sand cloud is displaced through the mouth. The tow may be displaced by cross currents or a turn or when the net mouth is filled with larger fish with low turnover blocking all swimming space in the net mouth. In the last case, fish rise up over the fish already there and swim away when they find themselves above the wings. The latter was also seen when the wings of the Danish seine net close up just before the fast haul.

BEHAVIOR IN THE COD END

A final consideration is the behavior of fish in the cod end of a trawl. Most of the fish escapement from a trawl occurs in the cod end. The concept of escape is a human concept, and is probably not appreciated by the fish in the cod end.

The cod end should be interpreted as a flume or water flow channel in which the fish are swimming with the main aim of keeping clear of the walls. The fish must be able to cope with the flow, or if unable to continue, they are swept down against the webbing.

We need to consider what stimuli are present in the cod end to cause the passage of fish from inside to outside the cod end. The obvious stimulus is being squeezed or trapped, for example, against a mesh by the flow or by other fish. Crowding from too many fish trying to swim within the restricted space suggests space might be important. Other factors might be the arrival of predatory species, etc. Do some cod ends have a built-in stimulus and can we identify it? Loose netting, color changes, flapping devices, etc., have been considered. Can we design and incorporate into cod ends a reliable device that would stimulate small fish to attempt to leave?

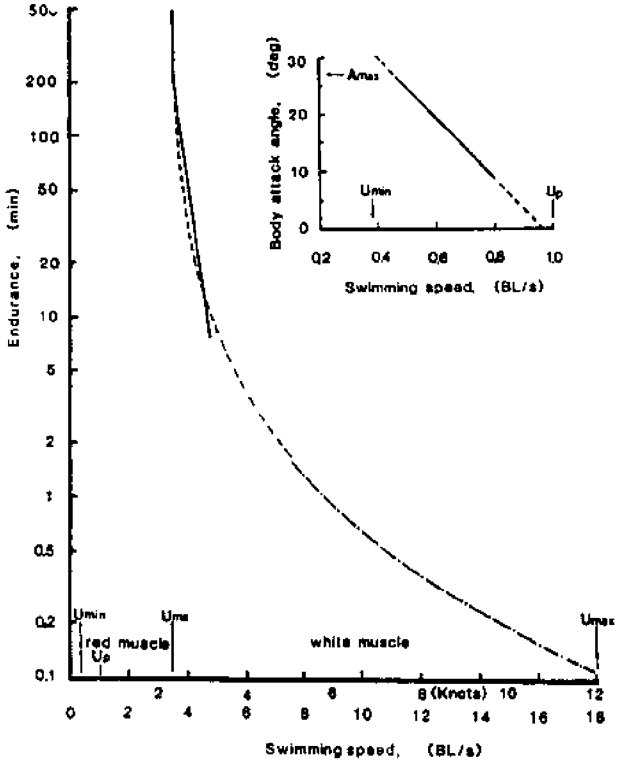

Figure 13: *A summary of the swimming endurance of the 30 cm mackerel,* Scomber scombrus. *Note speed is indicated in meters per second and knots.*

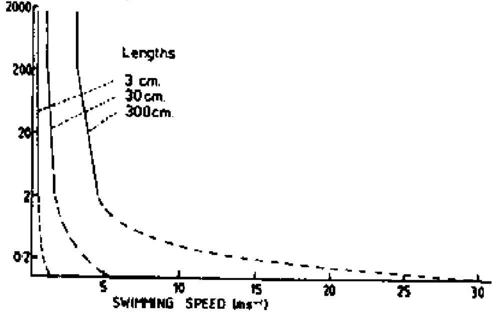

Figure 14: *A summary of the effect of size on swimming speed and endurance. One meter per second equals about two knots.*

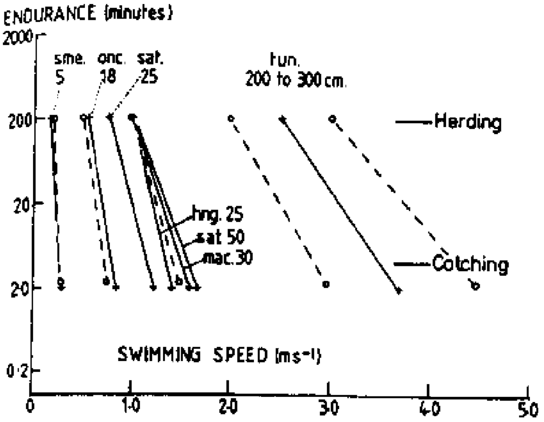

Figure 15: *The endurance of different species and sizes of fish. Dashed lines show the endurance change for 50 percent speed increase. From left to right, the abbreviations stand for smelt,* Oncorhynchus, *saithe, herring, mackerel, and tuna.*

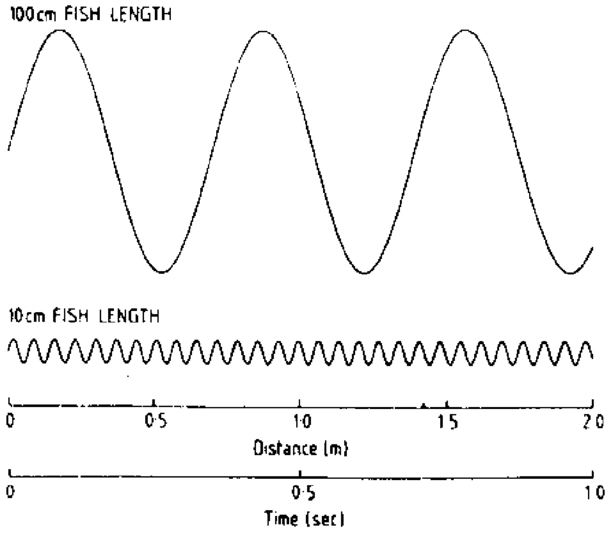

Figure 16: *Tracks of the tail tip of a 100 cm and a 10 cm fish. These tracks illustrate why a different frequency of tailbeat is required of a 10 cm and a 100 cm fish swimming at 2 ms⁻¹ (4 knots). (From Wardle 1986).*

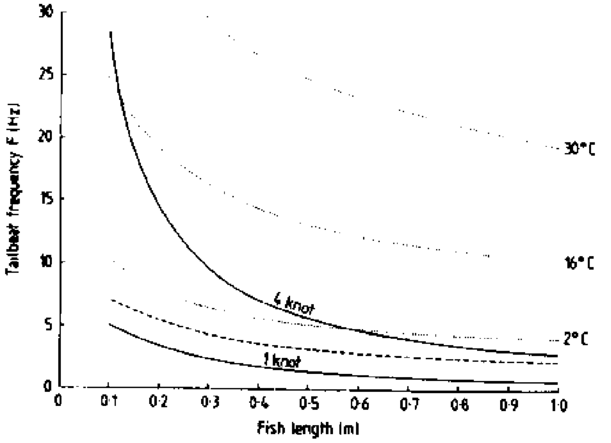

Figure 17: *Tail beat frequency of fish of different sizes swimming at 0.5 and 2 ms⁻¹ (1 knot and 4 knots, firm lines). Dotted lines show the maximum tail beat frequencies of fish at the indicated temperatures. Dashed line shows the tail beat frequencies at maximum aerobic cruising speed. (From Wardle 1986).*

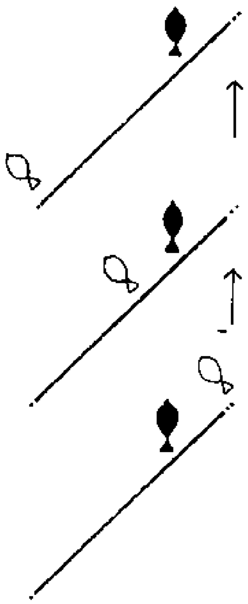

Figure 18: *In this plan view, the herding rope (firm line) on the seabed is moving vertically up the page. Three positions are shown. The black fish swims in the towing direction ahead of the rope and is eventually lost. The white fish swims at 90° to the rope and progresses toward the net mouth off to the left. Based on a video recording from 1976.*

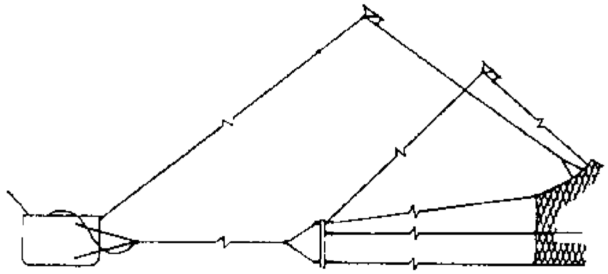

Figure 19: *A rig diagram of kites used in a Dutch herring trawl (from Figure 117B FAO Fishing Gear Catalogue, 1965).*

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Research on Selective Shrimp Trawl Designs for Penaeid Shrimp in the United States

A Review of Selective Shrimp Trawl Research in the United States since 1973

John W. Watson and Charles W. Taylor

Department of Commerce
National Marine Fisheries Service
Mississippi Laboratories
Pascagoula Facility
P.O. Drawer 1207
Pascagoula, MS 39568-1207

ABSTRACT

The incidental catch of finfish by shrimp trawling gear is a significant source of mortality affecting the conservation, utilization, and management of finfish stocks in the southeastern United States. The National Marine Fisheries Service (NMFS) Southeast Fisheries Center has investigated techniques to reduce finfish bycatch in shrimp trawl gear. In the early 1970s separator designs using webbing separator panels developed in Europe and the northwestern United States were tested in the Gulf of Mexico, but were not effective due to gilling and clogging of the separator panels by small fish and debris common in the fishery.

In 1977 a new panel design was developed by NMFS to optimize separation of finfish from shrimp by taking advantage of the difference in behavior of these animals observed in the catching process of shrimp trawl gears. Six different mesh size panels were evaluated, with resulting finfish separation rates of 60 to 80 percent compared to standard trawl gear. Shrimp production loss varied between 10 percent for short tows in light fish concentrations to 50 to 60 percent in heavy fish conditions or when small fish gilled the panels.

In 1978, NMFS researchers proposed an electrical separator trawl design based on research on the reactions of shrimp and fish to electrical fields. Pulsed DC current causes an involuntary jumping response in shrimp while causing a fright reaction in fish. Electricity is a positive stimulus that can be used effectively to separate fish and shrimp, and a prototype trawl design was proposed using this technology. Evaluation of the prototype design demonstrated that the technique was technically feasible, but the system was never tested in commercial operations.

In 1980 a unique separator trawl design was introduced by NMFS. The system, called the turtle excluder device (TED), was developed by NMFS to reduce the incidental capture of endangered sea turtles by shrimp trawls as a technical option to mitigate Endangered Species Act violations by the shrimp industry. Research during the development of the TED led to new finfish separator designs based on modification of water-flow characteristics in the trawl. The design uses webbing funnels to accelerate water in the cod end of the trawl, and leading panels and openings to exclude finfish. The separation technique utilizes the differences in swimming ability and behavior between shrimp and finfish to reduce the finfish catch. Separation rates of as much as 78 percent during daytime fishing and 50 percent during nighttime fishing, with no significant difference in shrimp catch rates, were achieved during evaluation of the technique.

INTRODUCTION

The major shrimp fisheries in the United States are the penaeid shrimp fishery in the southeastern United States and the pandalid fisheries in the northwestern and northeastern United States. The incidental catch of finfish in these fisheries is a source of finfish mortality affecting conservation, utilization, and management of fishery resources. In the northwestern and northeastern United States pandalid fisheries, interest in shrimp separator trawls was generated by the difficulty in sorting fish from the relatively large catches of shrimp. When the bycatch component of these catches was too large, the fishing vessels could not operate. More recently, the increased fishing pressure on finfish stocks in the Northeast has caused concern for the finfish caught and discarded by the shrimp fishing fleet, particularly the juvenile stocks of commercially important species. In the southeastern United States increased competition between recreational and commercial fishermen for fisheries resources, and potential markets for groundfish stocks in the Gulf of Mexico, have focused attention on the incidental catch and mortality of finfish by the penaeid shrimp fishery. This problem has become more critical because the high value of shrimp has provided economic incentive for shrimping in areas with high finfish density.

The need for selective shrimp trawling gear in the Gulf of Mexico was first discussed by Seidel (1975). Investigators have reported finfish catch rates between 2.8 and 18.0 kg for each kilogram of shrimp caught (Blomo and Nichols 1974, Chittenden and McEachran 1976, Bryan 1980, and Juhl et al 1976). The most recent study by Pellegrin et al (1985) estimated fish bycatch for the northern Gulf of Mexico penaeid shrimp fleet at more than 510,000 mt annually.

The development and use of improved trawling technology to reduce finfish bycatch mortality by shrimp trawling gear is a possible technical management option. Shrimp trawls designed to separate shrimp from fish were first developed in Europe in the early 1960s. Selective trawls were used in France, the Netherlands, Belgium, Norway, and Iceland. The development of shrimp separator trawls in the United States was initiated in 1968 at the National Marine Fisheries Service (NMFS) Northwest Fisheries Center in Seattle, Wash. A summary of this work was presented at a conference sponsored by the Food and Agriculture Organization of the United Nations in 1973. Since 1973, research on separator trawls has been conducted in the southeastern United States by the NMFS Southeast Fisheries Center, the North Carolina Department of Natural Resources, and in the northeastern United States by the Maine Department of Marine Resources.

Separator trawl designs developed in Europe and in the Northwest Fisheries Center were evaluated in the Gulf of Mexico penaeid shrimp fishery in the late 1960s and early 1970s. These separator designs all used panels of webbing placed in the mouth, throat, or along the wings of the trawl to lead fish toward escape openings, allowing shrimp to pass through relatively large panel meshes into the cod ends. Other designs divided the trawl into upper and lower halves with separate cod ends, or used a trawl-within-a-trawl design concept. Mechanical separation of fish and shrimp with webbing panels has been successful in fisheries where the difference between sizes of shrimp and fish is significant. Panel-type separator trawls tested in the Gulf of Mexico, however, were not very successful. The European horizontal panel trawl separated finfish adequately but produced poor shrimp catches. The Northwest Fisheries Center's vertical panel trawl produced similar results and the vertical separator panel placed across the trawl mouth clogged easily, decreasing separating efficiency.

The problems encountered with the introduction of these trawl designs to the southeastern United States penaeid shrimp grounds stem from the similar size of fish and shrimp characteristic to this region, and are intensified by the abundance of fish in the catches. In the crangonid and pandalid fisheries, shrimp total lengths range between 30 mm and 70 mm and may compose up to 90 percent of the total catch. The penaeid shrimp are larger (100-230 mm total length) and may compose only 10 percent of the total catch. Fish species diversity and size range associated with the penaeid shrimp fishery make separation extremely difficult. The panel meshes become clogged and gilled with fish, thus reducing separation efficiency to an unacceptable level.

Additionally, some panel designs were found to be too complex in design or too fragile for production fishing. Another problem was the complexity of fitting panels to the

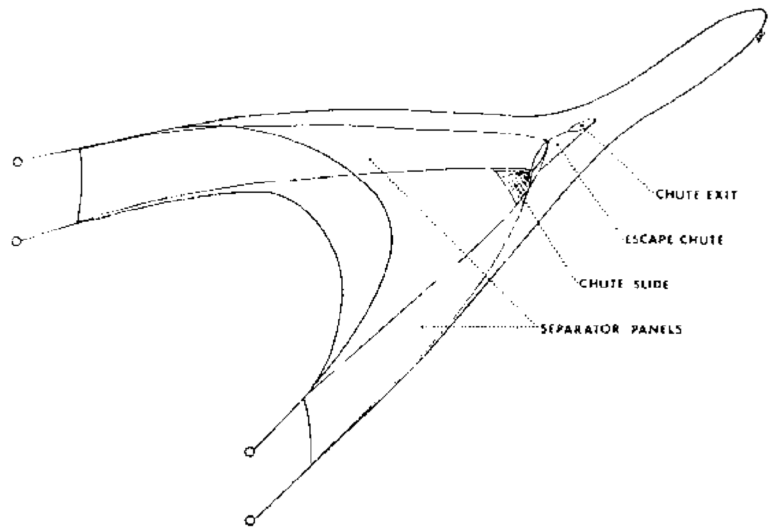

Figure 1. *A "V" design separator panel installed in a four-seam semiballoon shrimp trawl.*

many diverse trawl types in use by the penaeid shrimp fishery, and the restriction of trawl configuration flexibility imposed by the separator panels.

The NMFS Southeast Fisheries Center Mississippi Laboratories began a separator trawl development project in 1974 (Seidel 1975). This work resulted in the development of the "V" design vertical separator panel (Watson and McVea 1977). In 1978 Seidel and Watson introduced a selective trawl design concept employing electricity to separate shrimp from fish. In 1980, a new separator design was introduced by the NMFS. The separator, initially called the Turtle Excluder Device (TED), was developed in response to a critical conservation problem involving the incidental capture and mortality of endangered sea turtles. The TED was designed to allow turtles to escape from shrimp trawling gear through a trap door positioned in the throat of the trawl (Watson and Seidel 1980). During development of the TED, scuba observation of fish and shrimp in the experimental devices indicated a marked behavioral difference in fish and shrimp responses that could allow effective separation. Design modifications proved to be effective at eliminating finfish, jellyfish, sharks, rays, and other bycatch (Watson 1983a). The concept employed in the TED has been incorporated in other prototype separator designs that are currently being tested in the Northwest, Northeast, and Southeast shrimp fisheries.

"V" DESIGN VERTICAL SEPARATOR PANEL

The "V" vertical separator panel was designed to optimize separation of finfish from shrimp by taking advantage of the difference in behavior of these animals observed in the catching process of shrimp trawl gears. Scuba observations by NMFS Harvesting Systems Branch personnel (Watson 1976) indicated that penaeid shrimp exhibited specific escape reactions when encountering shrimp trawl gear. The escape reactions observed were similar to the behavior described by Lockhead (1961). Upon the reception of a strong external stimulus, the abdomen is strongly flexed ventrally and the shrimp is propelled rapidly backward. The response is coordinated through the giant fibers in the central nervous system. Impulses in the giant fibers lead only to symmetrical movements and thus to straight backward motion. Penaeid shrimp exhibit this reaction when being struck by the "tickler" chain and/or footrope of the shrimp trawl. This escape reaction is often repeated three to five times and can propel the shrimp several meters in random directions, but generally in a vertical direction.

Following the initial escape reaction, the shrimp reorient themselves to the bottom and begin swimming using their swimmerets. It was observed that penaeid shrimp species are generally weak swimmers and are unable to maneuver against the water flow generated by operational gear. As the trawl is fished, shrimp are impinged against the trawl webbing and tumble down the webbing into the cod end. Shrimp entering the center of the trawl are carried directly into the cod end. Because most fish species are stronger swimmers they swim ahead of or lead along the approaching trawl webbing and eventually maneuver to an area of less turbulent water in the cod end.

Utilizing observations and measurements of water flow patterns and fish/shrimp behavior, a panel was designed to separate the shrimp from the fish. The "V" design panel was a modification of the Northwest Fisheries Center vertical panel (Fig. 1). The panel was designed for and installed in a 12 m (headrope length) Gulf of Mexico four-seam semiballoon shrimp trawl. Correct placement and adjustment of the "V" panel required numerous modifications accomplished by gear technologists/divers using trawl evaluation techniques described by Wickham and Watson (1976). The trawl design specifications were presented by Watson and McVea (1977). The "V" panel was laced into the trawl in two sections

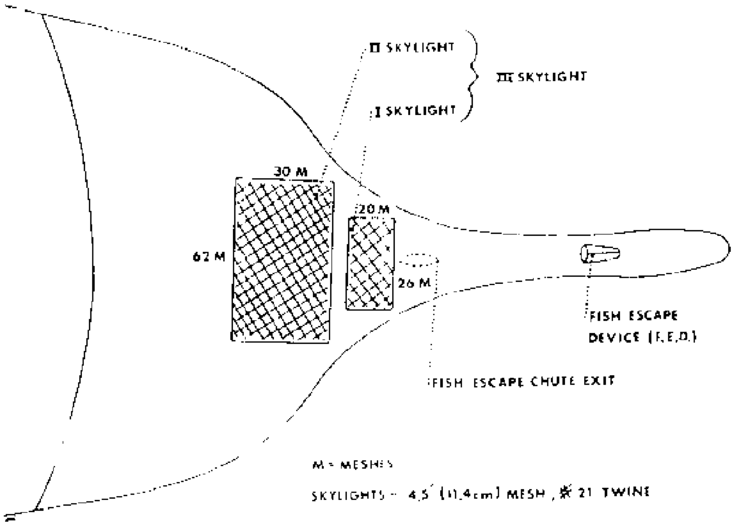

Figure 2. *Skylights installed in a shrimp trawl.*

beginning at the trawl wings and following the top seam of each wing 36 meshes. Panels were then laced to a straight line of meshes which intersected at the top center of the trawl, 166 meshes back from the center of the headrope. Panel sections were then joined to an escape chute that leads to an opening in the top of the trawl. The separator panel length, width, and placement were critical to the proper opening of meshes necessary for shrimp separation.

Six different mesh size panels were designed and used for field evaluations. Three panels were constructed of square-mesh webbing with 3.2 cm, 3.8 cm, and 4.4 cm bar lengths, the other three panels were constructed of square meshes with alternate bars removed, forming rectangular meshes. The rectangular mesh panels were 2.9-by-5.7 cm, 3.2-by-6.4 cm, and 2.5-by-7.6 cm. All separator panels were constructed from #18 nylon webbing. Two secondary fish separator techniques were also evaluated: 1) fish escape device, a small wire frame 39 cm long and 19 cm in diameter, sewn into the cod end creating a hole through which small fish can escape (Fig. 2); 2) "skylight," an 11.4 cm stretch mesh webbing panel placed in the top of the trawl to allow fish escape through the large meshes (Fig. 2).

The "V" panel designs and secondary fish escape techniques were tested in the Gulf of Mexico from the fishery research vessels *Oregon II* and *George M. Bowers* in 1975 and 1976. Each 12-meter experimental trawl was towed simultaneously against a control four-seam semiballoon shrimp trawl of the same size. Tows were of one-hour duration with the catches in both nets sampled to determine total bycatch weight, total shrimp weight, species composition, average weight, and shrimp length frequency. Differences in total bycatch weight and total shrimp weight between trawls were calculated to evaluate effectiveness of the panel designs and secondary escape techniques. The results of these experiments were presented by Watson and McVea (1977). Detailed analysis of the catch weights and bycatch separation rates by species, as well as the shrimp loss rates, were presented for the experimental separator and control trawls.

Comparisons of the three square-mesh separator panels indicated the best bycatch separation was obtained with the 3.2 cm mesh size. This mesh size also had the highest shrimp production loss (62 percent) because the mesh was too small for adequate shrimp separation. Large shrimp were not being retained as indicated by the mean shrimp length of 138 mm for the 3.2 cm mesh panel and 151 mm for the control trawl. These data indicated that the 3.2 cm mesh panel was too small for effective separation. Shrimp loss for the 3.8 and 4.4 cm mesh panels were 6 percent and 12 percent respectively, and mean shrimp lengths were nearly equivalent for both panels. The predominant finfish species caught in the control nets were Atlantic croaker (*Micropogon undulatus*) and longspine porgy (*Stenotomus caprinus*), composing 40 to 45 percent of the total catch. The 3.8 cm panel separated an average of 69 percent of the croaker and 82 percent of the porgy compared to 57 percent and 49 percent for the 4.4 cm mesh. Total bycatch separation was 45 percent for the 3.8 cm panel and 38 percent for the 4.4 cm panel. Shrimp loss rates with the rectangular mesh panels were 10 percent for the 2.5-by-7.6 cm panel, 14 percent for the 3.2-by-6.4 cm panel and 18 percent for the 2.9-by-5.7 cm panel. Shrimp mean length was consistent between the experimental trawls and the control trawls indicating no selectivity in the size of shrimp lost. Finfish separation rates were 48 percent for the 2.9-by-5.7 cm panel, 63 percent for the 3.2-by-6.4 cm panel and 39 percent for the 2.5-by-7.6 cm panel. The best overall separation rates combined with shrimp loss rates were obtained with the 3.2-by-6.4 cm rectangular mesh panel.

The fish escape device improved the finfish separation rates by as much as 20 percent; however, the shrimp loss rate with this device in combination with the 38 cm square panel was 30 percent. The large-mesh skylights did not significantly improve finfish separation. The results indicated that optimum "V" panel mesh size and shape for the penaeid shrimp fishery appeared to be between the 3.8 cm square mesh and the 3.2-by-6.4 cm rectangular mesh. The rectangular mesh webbing was produced by cutting alternate bars from a square-mesh panel. This technique was adequate for test purposes but is not realistic for production fishing. Based on this work, the NMFS Harvesting Systems Branch developed a prototype shrimp separator trawl to be tested in production fishing tests. The prototype trawl was an 18 m (headrope) four-seam semiballoon trawl. The 3.8 cm^2 separator panel and a rectangular mesh 3.2-by-7.6 cm panel constructed from #24 twine knotless webbing were tested.

The prototype trawls were tested using commercial production fishing techniques in 1978. These tests indicated that the "V" panel separator trawl was effective on offshore grounds where the fish size and shrimp size difference was the greatest. In these conditions finfish separation rates of between 60 to 80 percent were achieved. A major problem was loss in shrimp production, which varied greatly depending on the conditions encountered. On the offshore fishing grounds shrimp loss was as little as 10 percent during short tows in relatively light concentrations of fish. When heavy concentrations of fish were encountered (250 to 500 kg/h), or when fish were small in size, the shrimp loss reached 50 to 60 percent. Smaller fish gilled in the separator panel, blocking the panel and reducing the quantity of shrimp which could pass thorough the panel into the cod end. Large concentrations of fish passing out of the escape chute carried shrimp out of the exit without contacting the separator panel. There was a correlation between shrimp loss rates and towing time which appeared to be a function of the increasing gilling of fish in the panel with time. Clogging of the trash chute occurred on a frequent basis because of the trash encountered on the shrimp grounds in the Gulf of Mexico. Trash such as logs, tires, crab traps, etc., clogged the trash chute and significantly reduced the finfish separation rates.

The limitations of the panel-type separator trawls in the tropical and subtropical penaeid shrimp fisheries is a function of the finfish species diversity and size diversity associated with the shrimp fishing. Because of the inherent problems with this technique and the limited application and acceptance by the commercial shrimp fleet in the southeastern United States, research on separator panels was discontinued in 1978. An alternative technique employing electricity to selectively capture shrimp was proposed by Seidel and Watson (1978).

ELECTRIC SEPARATOR TRAWL

The NMFS Harvesting Systems Division in Pascagoula, Miss., began investigating electrical fishing techniques for applications in the southeastern United States penaeid shrimp fishery in the 1960s. This research resulted in the development of the electric shrimp trawl system (Seidel 1969). Although never widely used as a commercial technique due to the relatively high cost of the system and the recurrent problem of electrical conductor cable failure, the electric shrimp trawl system is an effective harvesting device that can increase shrimp production. Improvements to the electrical pulsar system and redesign of the electrode array design in the late 1970s significantly improved the performance of the system. Behavior studies of shrimp reactions to electrical stimulus and field experiments established the first accurately defined catch efficiency for a shrimp trawl system (Watson 1976). Studies of fish behavior to electrical fields made by Klima (1972) and Seidel and Klima (1974) resulted in technology to control fish behavior using electrotaxis. Based on this work, an electrical separator trawl design concept was proposed.

A diagrammatic view of the electric separator shrimp trawl is shown in Figure 3. The prominent feature of the concept is that the mouth of the trawl is completely closed with a small-mesh webbing panel, and 6 to 8 feet of set-back was designed into the trawl to give the mouth panel a pronounced slope. The fish barrier closing the mouth of the trawl allows water to flow into the trawl, prevents fish from entering, and provides lift to allow it to fish 30 to 60 cm above the substrate. A large-mesh (30 to 45 cm) bottom panel is installed in the forward section of the trawl. An electrode array is attached to the footrope of the trawl and trails back under the net to provide an electrical field. A capacitor discharge electrical pulsar, similar to that described by Seidel (1969), is used to create the electrical field that controls the behavior of the shrimp. Shrimp are forced to jump up through the large-mesh bottom panel, while fish stimulated by the field are herded ahead and off to the side of the oncoming trawl.

This concept is unique and differs from other separator trawl designs in that the fish never enter the trawl. The application of electricity to sort shrimp from fish is possible because of the different behavioral reactions of fish and shrimp to electrical fields. The slower pulse rates (4 to 5 pulses per second) required to control shrimp response do not induce electrotaxis in fish, but do produce a fright response. The reaction direction of shrimp to an electrical field is vertical while the fright reaction of fish is horizontal. These behavioral differences can be used to effectively select shrimp for capture at a rate approaching 100 percent. Field testing of the electrode array and shrimp behavioral studies conducted in 1978 and 1979, and evaluation of a prototype trawl design showed that the concept was technically feasible. The system

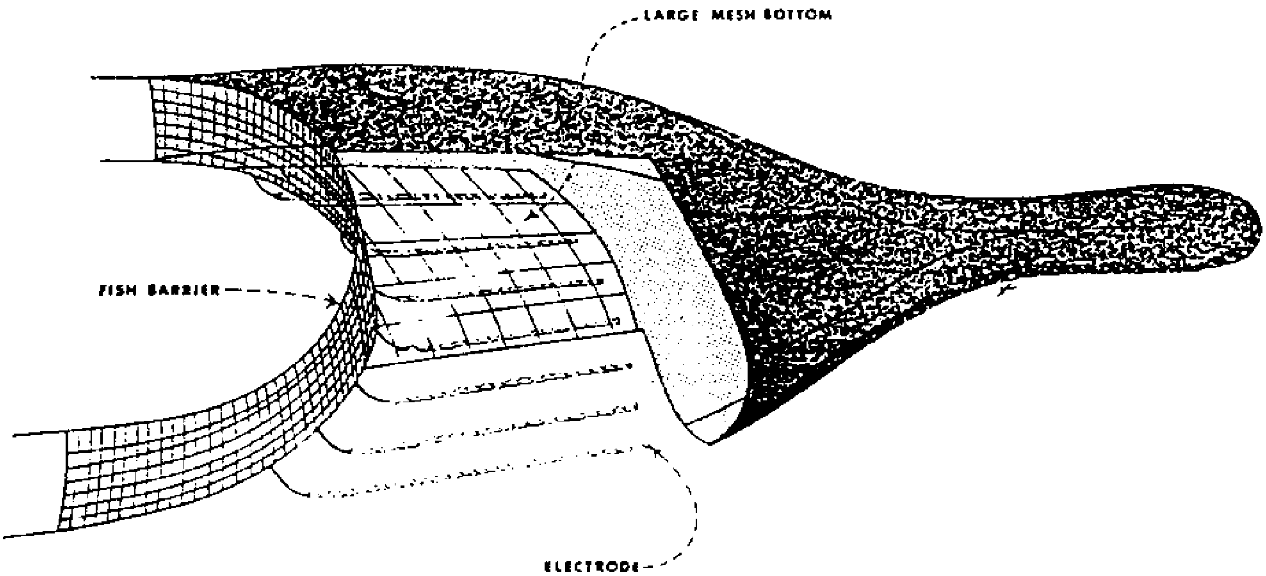

Figure 3. *Electric separator shrimp trawl.*

was never tested for commercial production fishing due to changes in program direction and funding.

The major obstacles to the acceptance of an electrical separator system are the high cost of the pulsar system and conductor cables, and the replacement costs of lost gear. Advancements in electrical technology since 1978 and future advancements may make such a system practically feasible. Improvements in battery technology may make it feasible to power the electrical field with batteries rather than a pulse generator. Provided the battery system is cost-effective, the major obstacle to developing a practical system would be overcome. Other possibilities might include water-driven electrical turbines or advancements in pulse generator technology that would lower costs and improve efficiency.

TRAWLING EFFICIENCY DEVICE

In 1980, a unique separator trawl design was introduced by the NMFS, Southeast Fisheries Center, Mississippi Laboratories in Pascagoula, Miss. The turtle excluder device (TED) was developed by the Mississippi Laboratories Harvesting Systems Division in cooperation with the commercial shrimping industry. The TED was designed to allow turtles to escape from shrimp trawling gear through a trap door positioned in the throat of the trawl (Watson and Seidel 1980). During development of the TED, scuba observations of fish and shrimp in the experimental devices indicated a marked behavioral difference in fish and shrimp responses that could allow effective separation. Design modifications based on behavioral observations proved to be effective in eliminating finfish, certain species of jellyfish, and other bycatch (Watson 1983). Several commercial TED designs have been developed and introduced into the fishing industry in response to regulatory measures requiring the use of selective trawling gear for the protection of sea turtles on some shrimping grounds in the southeastern United States.

The NMFS TED design consists of frames constructed of 9.5 mm and 6.3 mm (I.D.) galvanized pipe (Fig. 4). The TED is constructed in two sizes depending on the size of the trawl employed. The large size for trawls with headrope lengths of 12 m or larger is 91 cm long, 114 cm wide, and 76 cm high. The smaller size for trawls with headrope lengths less than 12 m is 80 cm long, 86 cm wide, and 51 cm high. Inside the frame are deflector bars angled at 41° for the large TED and 35° for the small TED. The deflector bars are spaced 7.5 cm to 15 cm apart depending on the composition of the bycatch. The large TED has a 76-by-76 cm door and the small TED has a 66-by-66 cm door at the top of the deflector bars. Objects that cannot pass through the deflector bars are forced through the door. The door opens on hinges, allowing objects to pass out of the trawl, and then close as the object is released. Smaller objects (fish, shrimp, etc.) pass through the angled bars into the cod end.

The water flow is accelerated in the TED through the use of webbing funnels or panels. The deflector bar spacing is

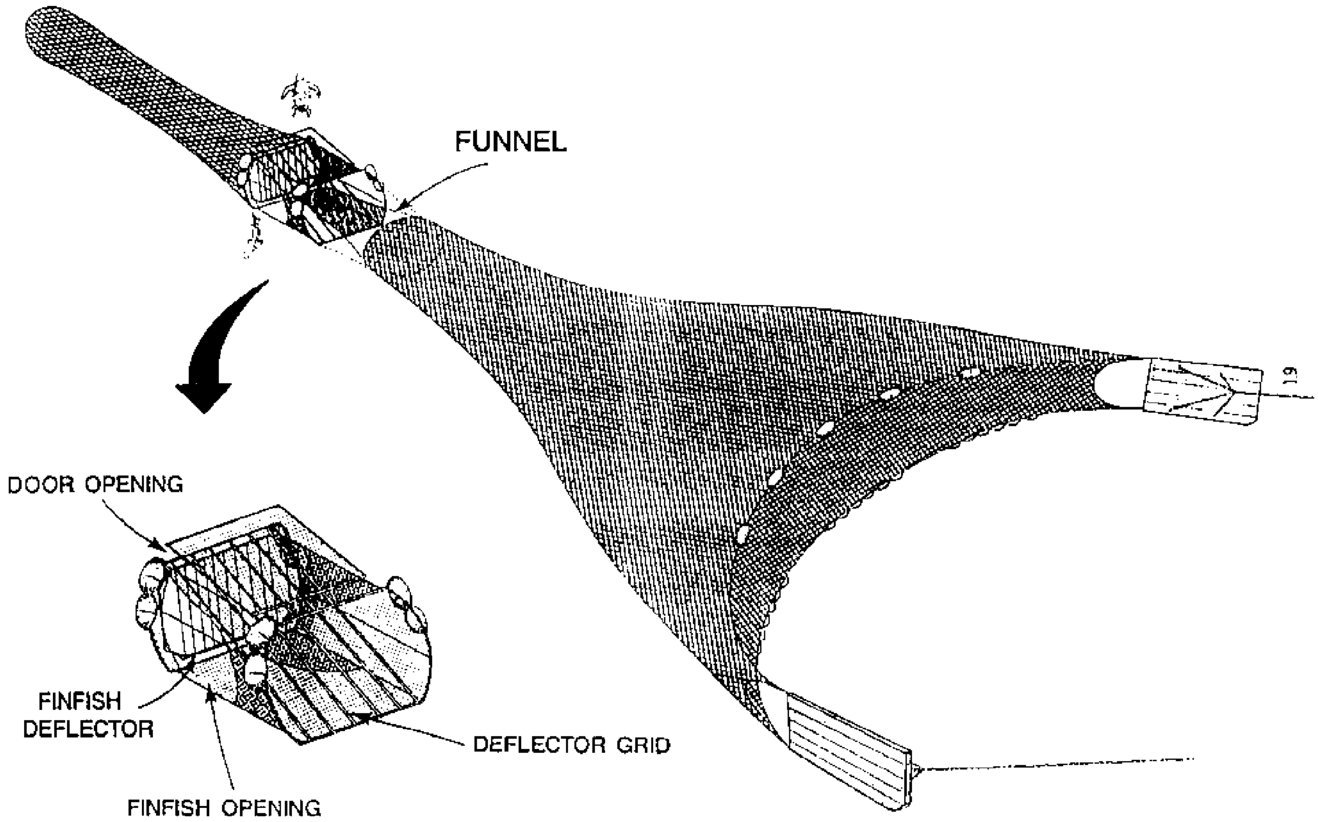

Figure 4. *NMFS TED installed in a shrimp trawl.*

adjusted to exclude different components of the bycatch. Finfish separation is accomplished by employing a smaller finfish deflector grid and openings with leading panels to guide fish out of the trawl (Fig. 5). The TED is installed between the trawl body and the beginning of the cod end in the extension of the trawl.

The original TED design was constructed with a rigid frame and was large, bulky, and hard to handle. The refined designs are smaller, lighter, and are collapsible for easier handling and storage (Fig. 6). TEDs were extensively tested by NMFS and commercial shrimp fishermen between 1980 and 1984. Comparative tows were conducted from double-rigged commercial shrimp vessels. A trawl with a TED installed was towed simultaneously with an identically rigged trawl without a TED. Catches from each trawl were weighed and bycatch samples taken. Data were collected on shrimp catch rates, finfish catch rates, and total catch rates. The test results were presented by Watson (1983) and Watson et al, (1986). The TED was shown to be effective in reducing finfish catches by as much as 85 percent during daytime fishing and 54 percent during nighttime fishing with no significant difference in shrimp catch rates.

The trawling efficiency device represents a new concept in selective fishing gear that employs a different mechanism to separate finfish and other bycatch from the shrimp catch. Historically, separator trawl designs have relied on webbing panels to sort bycatch by species or size from the rest of the catch. The TED uses a rigid frame placed in the zone of the trawl where the wings and body taper into the cod end. Finfish gilling is common in this section of a standard shrimp trawl, indicating that finfish escape reactions occur in this zone. The TED utilizes differences in the behavioral reaction of finfish and shrimp and the better swimming ability of the fish to separate and exclude fish from the catch. A funnel of webbing (or panels of webbing angled toward the center of the trawl) accelerates water flow entering the cod end of the trawl. The accelerated water carries the shrimp, which are weak swimmers, into the cod end. Finfish actively swimming in the trawl also pass through the funnel or panels but are stimulated by the crowding of the webbing to escape the trawls. As the fish pass through the funnel, they either strike a finfish deflector or enter an area of reduced water flow to the side of the main water flow (Fig. 5). There, fish are guided by webbing panels and can exit the trawl through side exits. Shrimp do not have the swimming ability or behavior necessary to reach the exit openings and are carried into the cod end. Larger objects or organisms that cannot pass through the openings of the main deflector grid are ejected through the hinged door at the top of the TED.

The potential of the TED as a finfish separator was discovered by scuba divers observing turtles passing through the TED during tests of the device. They noticed that fish had a tendency to turn and swim out of the accelerated flow and then swim forward to an area inside the TED where the water flow was relatively slack. Other fish carried further into the cod end tended to swim forward along the bottom and side of the cod end until they reached the wall of webbing at the front frame of the TED. The finfish escape openings were designed to take advantage of the reaction of the fish within the trawl to allow them to escape without loss in shrimp production.

When the TED was introduced in 1980 it was used by shrimp fishermen because it was effective in reducing the incidental catch of cannonball jellyfish (*Stemolophus* sp.), sponges, and horseshoe crabs (*Timulus* sp.), which at times prevented shrimpers from shrimping in certain areas. In 1982, the finfish separator modifications were first introduced with limited success. Finfish separation rates up to 53 percent were achieved during the day compared to standard trawling gear, but only a 10 percent reduction was achieved during nighttime trawling (Watson 1983a).

Fish apparently have different nocturnal and diurnal behavior and several design modifications were tested to improve nocturnal finfish separation. These modifications included light, luminescent materials, and various types of deflectors. The most successful of the modifications was a small deflector grid placed behind the main deflector frame. The finfish deflector grid was introduced in 1983 and resulted

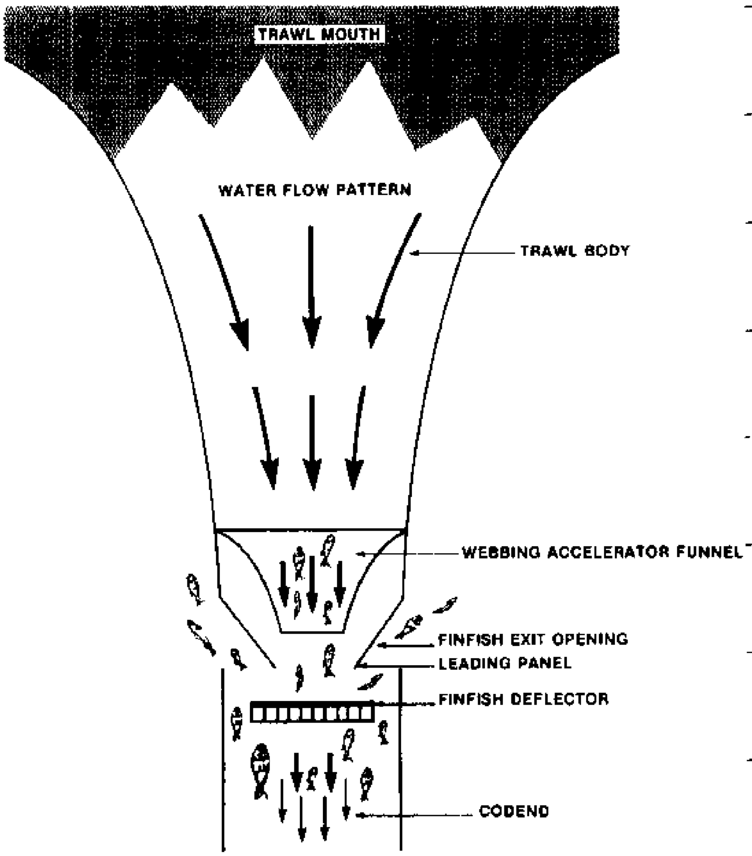

Figure 5. *Diagrammatic representation of the trawling efficiency device finfish separation technique.*

in improved finfish separation rates averaging 78 percent during the day (Watson 1983a) and 50 percent at night with no significant difference in shrimp catch rates (Watson et al 1986).

The finfish deflector grid acts as a mechanical stimulus and generates sound vibrations that induce escape responses in finfish. The effectiveness of the TED design in separating finfish varies with individual species and appears to be related to the swimming ability of the individual species and their behavior patterns. Total separation rates thus vary with the species composition of the catch and may also be related to the size of the individual as it relates to swimming ability.

The TED, although fairly simple in concept, has experienced setbacks in introduction into the industry. The size, weight, and cost of the device and the negative reaction of the industry to mandatory use have impeded the introduction of this technology into the industry. The TED must be adjusted to optimize its performance under different commercial fishing conditions and must be regularly checked and adjusted to prevent shrimp production loss. Critical adjustments include trap door tension, finfish deflector tensions, and proper functioning of the accelerator funnel and leading panels. In some fishing conditions the accelerator funnel used in the large TED can become clogged and it may be necessary to remove it. Recent testing has indicated that the side panels provide adequate water acceleration and the accelerator funnel may be removed without affecting finfish separation or shrimp production. It has also been determined that the installation of a TED and its webbing extension into shrimp trawls of different designs can alter the performance of the trawl, requiring tuning adjustments to the trawl gear to maximize production. In some trawl designs installation of the TED causes the trawl to tend bottom lightly, requiring additional footrope weight to maximize shrimp production. With other designs the TED may cause the trawl to fish heavier on the bottom, requiring the opposite adjustment. Each trawl should be tuned to maximize performance after the TED is installed.

The NMFS TED represents the most successful separator technique developed for the penaeid fisheries in the United States to date. The concept of using water flow patterns, behavioral differences between shrimp and fish, and the difference in the swimming abilities between shrimp and fish to selectively capture penaeid shrimp is a feasible technique. Several new TED designs have been developed since the NMFS TED was introduced in 1980. The new designs are less expensive and require less tuning and maintenance than the original TED design, but are not as effective in reducing finfish bycatch (Holland 1989; Pearce et al 1989).

FINFISH SEPARATOR DEVICE

The TED was designed primarily to reduce the incidental capture of sea turtles in shrimp trawls. The finfish separation techniques were developed as secondary objectives to make the device more acceptable to the industry. The concept

Figure 6. *TEDs installed in Gulf of Mexico shrimp trawls.*

employed to separate finfish was incorporated into an experimental finfish separator device (FSD) in 1982 (Fig. 7). The FSD consists of three fiberglass rings (91 cm in diameter) that are sewn into the cod end. The webbing is removed from between the forward and center ring and the cod end is held together with reinforced tongues of webbing and metal rings. This section can also be replaced with large-mesh webbing. A webbing funnel extends from the forward section of the cod end to halfway between the middle and last ring. The funnel is held in place by nylon-covered rubber shock cords attached to the last ring. A finfish deflector constructed of a smaller fiberglass ring and strung with stainless wire at 25 mm intervals is suspended in the last ring and is weighted at the bottom. The accelerator funnel carries the shrimp past the open area of the device into the cod end. The deflector simulates the fish exiting the funnel and they escape through the open area of the device.

The FSD operates on the same principle as the TED. The disadvantage of the design is that large objects can become lodged in the FSD and clog up the funnel, causing loss of separating efficiency. Clogging of the accelerator can also be a problem with the TED since the funnel is positioned ahead of the deflector grid. Finfish/shrimp separator designs employing accelerator funnels and large-mesh webbing escape panels are being evaluated in Norway (West et al 1984) and in the northwestern United States pandalid fishery. Similar experiments have been conducted in the northeastern United States by the Maine Department of Marine Resources.

An alternative approach that may have some merit for the penaeid shrimp fishery is to combine the TED deflector grid with a funnel-type device similar to the FSD or the Norway design. A simple deflector grid and exit opening would eject larger objects. The FSD would be placed behind the deflector grid so that the accelerator funnel is behind the deflector grid and would be protected. The combination of the TED grid and FSD may be more effective in finfish separation than either of the techniques alone.

The NMFS Mississippi Laboratories is currently developing new prototype finfish separator designs. The designs utilize funnels and/or small-mesh panels to accelerate water past openings designed to allow finfish to escape. The designs are based on the use of a deflector grid to eliminate large objects that can clog accelerator funnels. A proposed research project will test the efficiency of the prototype designs in combination with changes in operational tactics to enhance trawl-produced stimuli. New video camera and ROV technology will be used to investigate fish behavior in trawls and effectiveness of separation techniques.

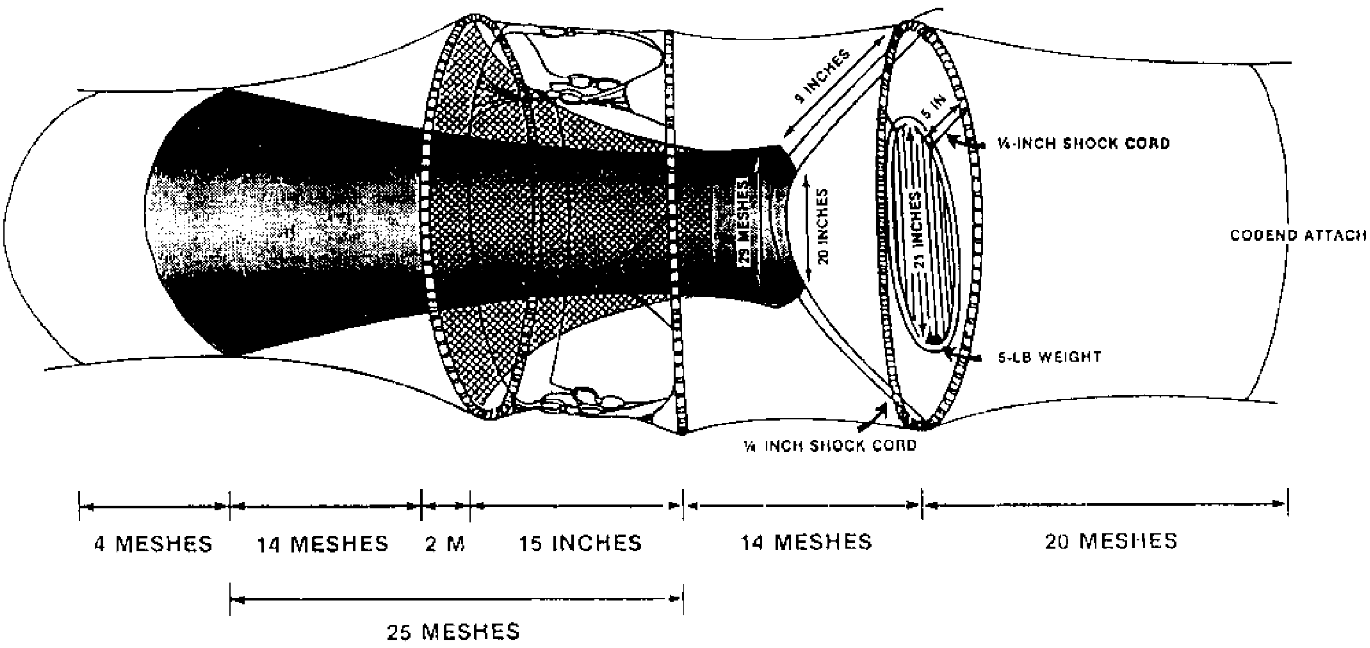

Figure 7. *Finfish separator device.*

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Experimental Designs and Data Analysis Methodologies for the Evaluation of Bottom Trawl Performance Based on Catch Comparisons

Joseph T. DeAlteris and Kathleen Castro

Department of Fisheries, Animal and Veterinary Science
The University of Rhode Island
Kingston, RI 02881

INTRODUCTION

The fundamental question in the comparative evaluation of bottom trawl performance is: How does an experimental trawl "catch" compare to a standard trawl "catch"? The primary variable is the design features of the various trawls. The secondary variables are towing vessel and captain, time of day, season, rigging, and operation. The measured response is the catch retained in the cod end of each trawl.

Some characteristics of the measured response for each trawl that can be determined are:

1. mean numbers or weights of total catch per tow,
2. mean numbers or weights of target species per tow,
3. mean numbers or weights of bycatch (nonmarketable species and sizes) per tow,
4. length-frequency distributions of target species captured per tow.

The standard trawl can be compared to one or more experimental trawls using paired, alternate, or random tows. The secondary variables should be held constant, or at least any variability in the catches due to the secondary variables should be minimized and evenly distributed between all trawls. Another issue that must be considered initially is the number of replicate samples that will be required to demonstrate a significant difference in the trawl catches, if it exists.

Potential working hypotheses for the trawl comparison are:

1. mean total catch numbers and weights for all trawls are similar,
2. mean catch numbers and weights for a target species for all trawls are similar,
3. effects of other factors such as towing speed, rigging, etc., on the catch for all trawls are similar,
4. length-frequencies of target species are similar for all trawls.

Using standard statistical methods these working hypotheses can be tested, and decisions made about the results of the comparisons. The two potential hypotheses are:

1. Null Hypothesis (H0) - indicates no difference in two or more groups of samples.
2. Alternative Hypothesis (H1) - rejection of the null hypothesis implies a real and replicable difference exists between two or more groups of samples.

The two hypotheses can be evaluated at specified levels of significance or degrees of confidence, $\alpha = 0.10, 0.05, 0.01$.

Depending on the complexity of the experimental design, question, or hypothesis being tested, and the assumptions about the data being made, various statistical methods are available to analyze the data. These are summarized in Table 1. For the sake of brevity, not all the analysis methods listed in Table 1 will be presented in these notes. Only two sample comparisons will be described: the comparison of a standard trawl to an experimental trawl. The reader is referred to a standard statistical text book (Sokal and Rohlf 1981) for a more complete description of all the methods quoted herein.

DESCRIPTIVE STATISTICS

Before describing some statistical methods currently used in trawl performance evaluation, it is necessary to define some basic descriptive statistical terminologies and the notations that will be employed later.

1. The mean $\overline{X}$ of set $X_1, X_2, \ldots, X_n$ is the sum of the values divided by the number of items, i.e.:

$$\overline{x} = \Sigma x_i / n$$

2. Deviation is referred to as the difference between an individual value and the mean of a set of values, notated as:

$$(x_i - \bar{x})$$

3. Variance is the sum of the squared deviations divided by the number of observations, expressed as S^2.

$$S^2 = \Sigma (x_i - x)^2/n - 1$$

4. Standard deviation is an important concept in statistics. As with the variance, it describes the dispersion of a set of observations from the mean. The greater the dispersion of the observations around their mean, the larger the standard deviation. If there is no dispersion, i.e., if all values are equal, the standard deviation is equal to zero. The standard deviation is the square root of the variance.

$$S = \sqrt{S^2}$$

5. Coefficient of variation is the standard deviation expressed as a percentage of the mean.

$$CV = \frac{(S)\ (100)}{\bar{X}}$$

6. Standard error is expressed as:

$$SE = S/\sqrt{n}$$

and measures the dispersion of sample mean from an expected value. The standard error is used in calculating the critical value for the t-test, f-test, or other tests.

7. Level of significance (α level) is a chance or probability factor. For example, if the conclusion drawn is that the difference in catch between two trawl gears is significant at the 5 percent level, that implies that if the experiment is repeated, 95 out of 100 times the result of the experiment will be the same. In practice, the proper level of significance is decided according to the situation. As an alternative, statistical software packages provide an exact probability (p) value that is equivalent to the α level, but expresses the probability that a decision is correct.

8. Confidence Interval about the mean provides an interval estimate for the mean based on a specified level of significance or probability.

$$CI = \frac{\bar{X} \pm (t_{df,\ 1-\alpha})\ (S)}{\sqrt{n}}$$

where $t_{df,\ 1-\alpha}$ is the t-value for a given df and a given α (Table 12, Rohlf and Sokal 1981). The df is one less than the sample size (df = N - 1) and is called the degrees of freedom for the t value. The confidence level for the interval is $1 - \alpha$, that is, for a 95 percent confidence level, $\alpha = 0.05$. For large N and $\alpha = 0.05$, t = 1.96.

APPLICATIONS OF BASIC DESCRIPTIVE STATISTICS IN ASSESSING FISHING GEAR PERFORMANCE

Consider a series of ten tows of a standard trawl net, if the catch numbers of cod are as follows:

76
84
98
78
86
93
78
84
96
98

$$\Sigma X_n = 871$$

The mean catch number of cod is:

$$\bar{X} = \Sigma X_n/N = 871/10 = 87.1.$$

The deviation, variance, and standard deviations are all calculated simultaneously.

X	$\bar{X}$	$(X-\bar{X})$	$(X-\bar{X})^2$
76	87	-11	121
84	87	-3	9
98	87	+11	121
70	87	-9	81
86	87	-1	1
93	87	+6	36
78	87	-9	81
84	87	-3	9
96	87	+9	81
98	87	+11	121
			$661 = \Sigma (X_i - \bar{X})^2$

$$\text{Variance} = S^2 = \frac{\Sigma(X_i - \bar{X})^2}{n-1} = \frac{661}{10-1} = \frac{661}{9} = 73.4$$

$$\text{Standard Deviation} = S = \sqrt{S^2} = 8.6$$

$$\text{Coefficient of Variation} = \frac{8.6 \times 100}{87.1} = 9.8\%$$

$$\text{Standard Error} = SE = 8.6/\sqrt{10} = 2.7$$

Confidence Interval for the estimate of the mean:

$$CI = \bar{X} \pm \frac{(t\ df, 1-\alpha)(S)}{\sqrt{N}} = \bar{X} \pm (t)(S.E.)$$

for: $\alpha = 0.05$ $N = 10$, $t = 2.262$
$\alpha = 0.01$ $N = 10$, $t = 3.250$

so for 95% level of confidence, the mean is:

$$87 \pm \frac{(2.26)\ (8.6)}{\sqrt{10}} = 87 \pm 6.1$$

for 99% level of confidence the mean is:

$$87 \pm \frac{(3.25)\ (8.6)}{\sqrt{10}} = 87 \pm 9.0$$

Note: If one desires a greater degree of confidence that the estimate of the mean is the true population mean (number of cod per tow), then the confidence interval increases.

HYPOTHESIS TESTING

Hypotheses regarding catch data can be simply evaluated by comparing the confidence intervals about the means of the data in simple cases, or can be tested using specific analysis methods presented in the following sections.

As a simple example consider the following catch data from two trawls, A and C, after 10 replicate tows of each net. ***Question 1:*** Are the catches of trawl A significantly different from trawl C? ***Question 2:*** Are the catches of trawl C 10 percent less than trawl A? Both tests are conducted at $\alpha = 0.05$.

Data:	A	C
N=10		
	91	76
	97	81
	96	63
	107	90
	115	87
	97	65
	93	67
	79	96
	85	84
	95	72
	$\bar{A} = 95.5$	$\bar{C} = 76.1$

Question 1:

$$CI(A) = \bar{X} \pm (t\ df, 1-\alpha)(S)/\sqrt{N}$$

$$= 95.5 \pm (2.26)(10.0)/\sqrt{10} = 95.5 \pm 7.4$$

$$= 102.9 \rightarrow 88.1$$

$$CI(C) = \bar{X} \pm (t\ df, 1-\alpha)(S)/\sqrt{N}$$

$$= 76.1 \pm (2.26)(9.4)/\sqrt{10} = 76.1 \pm 6.8$$

$$= 84.9 \rightarrow 69.3$$

Answer 1: Catches of trawl A are significantly different from trawl C at $\alpha = 0.05$ because there is no overlap in the confidence intervals, therefore; reject null hypothesis.

Question 2:

$$CI\ (A - 10\%) = (95.5 - 9.5) \pm 7.4$$

$$= 86.5 \pm 7.4$$

$$= 93.4 \rightarrow 78.6$$

$$CI\ (C) = 84.9 \rightarrow 69.3$$

Answer 2: Catches of trawl A less 10 percent are not significantly different from trawl C at $\alpha = 0.05$ because of the overlap in the confidence intervals, therefore; accept null hypothesis.

COMPARISON OF PAIRED SAMPLES OF CATCH NUMBERS AND WEIGHTS

Parametric Paired Comparison Assumptions

1. random sampling of individuals
2. paired samples
3. homogeneity of variance or homoscedasticity evaluated using a F-test for a two-sample analysis or comparison between two means
4. error terms distributed normally

Student T-test for Paired Comparisons

Experiment: numbers of cod captured in STD and EXP trawls in 10 paired tows:

Data:

STD	EXP	D = STD-EXP	D^2
91	106	-15	225
97	94	3	9
96	118	-22	484
107	109	-2	4
115	118	-3	9
97	95	2	4
93	99	-6	36
79	97	-18	324
85	109	-24	576
95	106	-11	121

$A = 95.5 \quad B = 105.1 \quad \Sigma D = -96 \quad \Sigma D^2 = 1392$

$$\bar{D} = \frac{\Sigma D}{N} = \frac{-96}{10} = -9.6$$

Standard deviation of the paired differences:

$$S = \sqrt{\frac{N(\Sigma D^2) - (\Sigma D)^2}{N(N-1)}} = \sqrt{\frac{10(1392) - (-96)^2}{10(9)}} = 9.8$$

Test Statistic $= \bar{D}/(S/\sqrt{N}) = -9.6/(9.8/\sqrt{10}) = -3.098$

Tabulated Values (from Table 12 Rohlf and Sokal 1981)

degrees of freedom = df = N-1= 10-1 = 9

$\alpha = 0.05, \quad t = 2.26$ * significant

$\alpha = 0.02, \quad t = 2.28$ * significant

$\alpha = 0.01, \quad t = 3.25$

Tcal > t table, $\alpha = 0.02$

Therefore: Difference between STD and EXP Trawls will be real or significant 98 times out of 100.

Non-Parametric Paired Comparisons

Advantages of non-parametric tests are that there are very limited assumptions, in particular homogeneity of variance and normality are excluded.

Assumptions

1. similar distributions
2. random sampling
3. paired samples

Wilcox Signed Ranks Test

For Paired Samples of Cod Catch Numbers
from Trawls A and B

Trawl A	Trawl B	D = A-B	Ranked Differences
91	94	-15	-7
97	95	3	3.5
96	97	-22	-9
107	99	-2	-1.5
115	106	-3	-3.5
97	106	2	1.5
93	109	-6	-5
79	109	-18	-8
85	118	-24	-10
95	118	-11	-6

Sum + Ranks = 5
Sum - Ranks = 50

Test statistic is the *smaller* of the value sums.

5 or 50, Ts = 5

Tabulated values (from Table 30, Rohlf and Sokal 1981)

$$N = 10, \quad \alpha = 0.05$$
$$Ts = 8 \text{ for } p = 0.048$$
$$9 \text{ for } p = 0.064$$

Because Ts < T table, $\alpha = 0.05$, two-tailed test.

$$(5) < (8\text{-}9)$$

Reject null hypothesis, accept alternative hypothesis that the difference between cod catch numbers of trawls A and B is significant or real at least 95 times out of 100.

Procedure for Wilcox Signed Ranks Test

1. Compute the differences between the N pairs of observations, referred to as D.
2. Rank these differences from smallest to largest without regard to sign.
3. Assign to the ranks the original signs of the differences.
4. Sum the positive and negative ranks separately. The test statistic Ts is the smaller absolute value.
5. If Ts < T tabulated, than reject null hypothesis.

COMPARISON OF INDEPENDENT, NON-PAIRED SAMPLES OF CATCH NUMBERS AND WEIGHTS

Parametric Comparisons

Independent T-Test for Two Groups of Independent Samples

The procedure in calculating the independent t value is the same as for the dependent t-test. It is given by:

$$t = [(\bar{x}_1 - \bar{x}_2) - (\bar{u}_1 - \bar{u}_2)](S_{\bar{x}_1\bar{x}_2})^{-1}$$

where $\bar{x}_1 - \bar{x}_2$ is the difference in mean between two groups and $\bar{u}_1 - \bar{u}_2$ is the difference in population mean, assumed to be equal to zero.

S_{x1x2} is standard error, given by:

$$S_{x1x2} = \sqrt{(SS_1+SS_2)/(n^2-n)}$$

where, $SS_1 = \Sigma x_1^2 - (\Sigma x_1)^2/n_1$

$$SS_2 = \Sigma x_2^2 - (\Sigma X_2)^2/n_2$$

As before, if the calculated independent t value is larger than the corresponding t value from the table, it indicates that the difference between the two groups is significant.

To test the difference in dab catch weights of two trawls, the gears are towed in the same fishing ground, keeping the towing speed, duration, and other conditions constant. The catch weight (kg) data per tow is as follows:

Tow No.	STD Net	EXP Net
1	4.39	3.18
2	0.4	3.19
3	6.08	16.85
4	10.33	19.99
5	10.13	8.45
6	1.92	24.42
7	4.23	3.70
8	3.61	2.73
9	5.66	2.56
10	4.74	2.77
11	0.61	2.42
12	0.32	2.64
13	0.43	1.11
14	0.18	2.24
$\bar{x}$:	3.79	6.81
Σx:	53.02	96.25
Σx^2:	355.52	1436.00

$$SS_1 = 355.52 - 53.02^2/14 = 154.73$$

$$SS_2 = 1436 - 96.25^2/14 = 774.28$$

$$t = (6.81-3.79)/\sqrt{(154.73 + 774.28)/182} = 1.34$$

$t_{0.05,26} = 2.060$ (from Table 12, Rohlf and Sokal 1981) is larger than 1.34.

A non-significant difference is found between the two gears according to the t-test. Despite the apparent difference in the means, the large variability masks the difference in the means.

Non-Parametric Comparisons

Mann-Whitney Test for Two Groups of Independent Samples

Given cod catch numbers for ten tows of two trawls, when the gears have been towed in the same fishing grounds, keeping the tow speeds, duration, and other conditions constant. The data can be evaluated as to the difference in cod catch numbers for the two trawls.

Procedure:

1. Rank the two columns of data.
2. For each observation in one column (it is convenient to use the smaller sample) count the numbers of observations in the other sample that are lower in value.
3. Sum of Counts = C
4. Mann-Whitney Statistic is the greater of C or (N_1N_2 - C)

Data Manipulation:

	STD	Ordered	Rank	EXP	Ordered	Rank	Count
Data:	91	79	1	106	94	5	0
	97	85	2	94	95	6.5	0
	96	91	3	118	97	10	0
	107	93	4	109	99	12	0
	115	95	6.5	118	106	13.5	1.5
	97	96	8	95	106	13.5	2
	93	97	10	99	109	16.5	2.5
	79	97	10	97	109	16.5	2.5
	85	107	15	109	118	19.5	6
	95	115	18	106	118	19.5	8
			77.5			132.5	22.5

Trawl Data

C = 22.5

C = (10) (10) - 22.5 = 77.5

From Table 29 (Rohlf and Sokal, 1981):

$N_1 = 10, \; N_2 = 10$

two-tailed test $U_{0.05} = 77$

$U_{0.02} = 81$

Significant difference at $\alpha = 0.05$ but *not* at $\alpha = 0.02$

REQUIRED SAMPLE SIZE TO TEST HYPOTHESES

Number of replications (N) required to detect a specified "true" difference between means, if it exists at all, with a specified level of probability.

$$N \geq 2 (\sigma/\delta)^2 [t_{(\alpha)(\upsilon)} + t_{2(1-P)(\upsilon)}]^2$$

N = Number of replications

σ = true standard deviation

δ= the smallest true difference that is desired to detect (Note: it is necessary only to know the ratio of σ to ø, not the actual values)

υ = degrees of freedom of the sample standard deviation within *a* groups and N replications per group, $\upsilon = a(N-1)$

α = significance level

P = desired probability that a difference will be found to be significant

$t\alpha(\upsilon)$ and $t\ 2(1-P)\ (\upsilon)$ = values from a two-tailed t-table with υ degrees of freedom and corresponding to probabilities α and 2(1-P), respectively.

For example, consider the following data for catches of trawls A and B:

A	B
91	106
97	94
96	118
107	109
115	118
97	95
93	99
79	97
85	109
95	106
$\bar{A}$ =95.5	$\bar{B}$ = 105.1

Standard deviation of the paired differences = 9.8 .

Problem 1:

Determine N required to show a difference of 20 percent greater catch efficiency with Trawl B than Trawl A, at the 5 percent level of significance, with an 80 percent probability of detecting the difference.

$\delta = (20\%)\ (95.5) = 19.1$

$(\sigma/\delta) = 9.8/19.1 = 0.51$

similarly, σ is about 10% of $\bar{A}$ and $\bar{B}$, and δ is 20% of $\bar{A}$, therefore $\sigma/\delta\ =\ 10/20 = 0.5$.

Initial estimate of N used to determine υ for N = 20 and 2 groups:

$\upsilon = (2)\ (20\text{-}1) = 38$

$t\ (0.05)\ (38) = 2.43$

$t\ 2(1\text{-}P)\ (\upsilon) = t\ \ (2)\ (1.0 - 0.8)\ (38) = t\ (.4)\ (38) =$ 0.851

$N \geq 2\ (0.5)^2\ \ (2.43 + 0.85)^2$

$2\ (.25)\ (10.76)$

$N \geq 5.4 - 6$

Iterative Solution:

for $N = 6$, $\upsilon = 2\ (6 - 1) = 10$

$t\ (0.05)\ (10) = 2.228$

$t = (.4)\ (140) = .879$

$N \geq 2(0.5)^2\ \ (2.288 + 0.819)^2$

$2(.25)\ (10.02)$

$N \leq 5$

Notes: 1. as this detectable difference δ increases, N decreases: for crude estimates, small value of N; for fine estimates, large value of N;

2. if σ is large, a large N is required to detect any differences.

Interpretation of Results of Problem 1:

Given the level of variability in the data ($\sigma = 9.8$), if one is seeking to show a 20 percent difference between trawls A and B with a 5 percent level of significance and an 80 percent probability of detecting it, 5 replicates will detect the difference if it exists.

Problem 2:

Given the same set of data, determine N required to show 5 percent greater catch efficiency with trawl B than trawl A at the 1.0 percent level of significance, with a 90 percent probability of detecting the difference if it exists.

$\delta = 5\%$ of $\bar{A}$ or $\bar{B}$

$\sigma = 10\%$ of $\bar{A}$

$\sigma/\delta = 10/5 = 2.0$

Initial estimate of N = 20

$\upsilon = (2)\ (20 - 1) = 38$

$t\ (0.01)\ (38)\ \ = 2.710$

$t\ (2)\ (1\text{-}P)\ (1) = t\ (2)\ (1 - 0.9)\ (38) = t\ (.2)\ (38) = 1.305$

$N = (2)\ (2)^2\ (2.710 + 1.305)^2$

$N = (2)\ (4)\ (16)$

N = 128 sample pairs or replicates

Iterative Solution:

$N = 128$

$\upsilon = (2)\ (128 - 1) = 264$

$t\ (0.01)\ (264) = 2.60$

$t\ (0.2)\ (264) = 1.28$

$N = (2)\ (2)^2\ (2.60 + 1.28)$

$N = (2)\ (4)\ (15) = 124$

Interpretation of Results of Problem 2:

Given the level of variability in the data ($\sigma = 9.8$), if one is seeking to show a 5 percent difference between trawls A and B at a 1 percent level of significance with a 90 percent probability of detecting the difference if it exists, then 124 replicates will detect the difference if it exists.

COMPARISON OF LENGTH-FREQUENCY DISTRIBUTIONS

Non-parametric tests can be utilized to examine differences between two relative distributions, for example, length-frequency distributions of the catches of a single fish species for two different trawls.

H0 - (null hypothesis) - No difference in the distributions for two samples, thus the test is sensitive to differences in location, dispersion, skewness, etc.

Hl - (alternative hypothesis) - A difference exists between the two samples.

Kolmogorov-Smirnov Two-Sample Test for Large Samples

Given length-frequency data for two sample catches, convert the individual frequencies (f) of each length group to individual percents of total ($\Sigma f/N$), cumulative frequencies (F), and cumulative percents ($\Sigma F/N$).

As an example, consider the following length-frequency distribution data for the catches of trawls A and B as illustrated in Figure 1. These distributions will be analyzed using the Kolmogorov-Smirnov Two-Sample Test. This statistical method compares the relative proportions of two percent-frequency distributions. The test statistic compares the maximum difference between the two cumulative percent distributions and a calculated value based on the sample sizes and the specified level of significance for the test.

Procedure:

1. Given the initial frequency data (fa and fb) for Trawls A and B at the central point in the length classes of the fishes, form cumulative frequency distributions (Σfa and Σfb) and relative cumulative frequency distributions ($\Sigma fa/Na$ and $\Sigma fb/Nb$) (Table 2).
2. Compute the absolute difference between the relative cumulative frequency distributions.

$$D = \left| \Sigma fa/Na - \Sigma fb/Nb \right|$$

3. Locate the largest unsigned difference D, in this case 0.94
4. Calculate the critical value of D_α from the expressions:

For a two-tailed test:

$$D_\alpha = K_\alpha \sqrt{\frac{N_1 \pm N_2}{N_1\ N_2}}$$

Where $K_\alpha = \sqrt{0.5\ [\ -\ln\ (\alpha/2)\ ]}$

Thus for $\alpha = 0.05$ $K_{.05} = 1.35810$

and for $\alpha = 0.01$ $K_{.01} = 1.62762$

For this example where $N_1 = 421$ and $N_2 = 349$

$$D_{.05} = 1.35810 \quad \frac{421 + 349}{\sqrt{421\ (3 \times 9)}}$$

$$= 0.098$$

$$D_{0.1} = 0.118$$

Therefore, because D observed (0.94) is greater than $D_{.05}$ and $D_{0.1}$, the difference in the length-frequency distributions of trawl catches is highly significant.

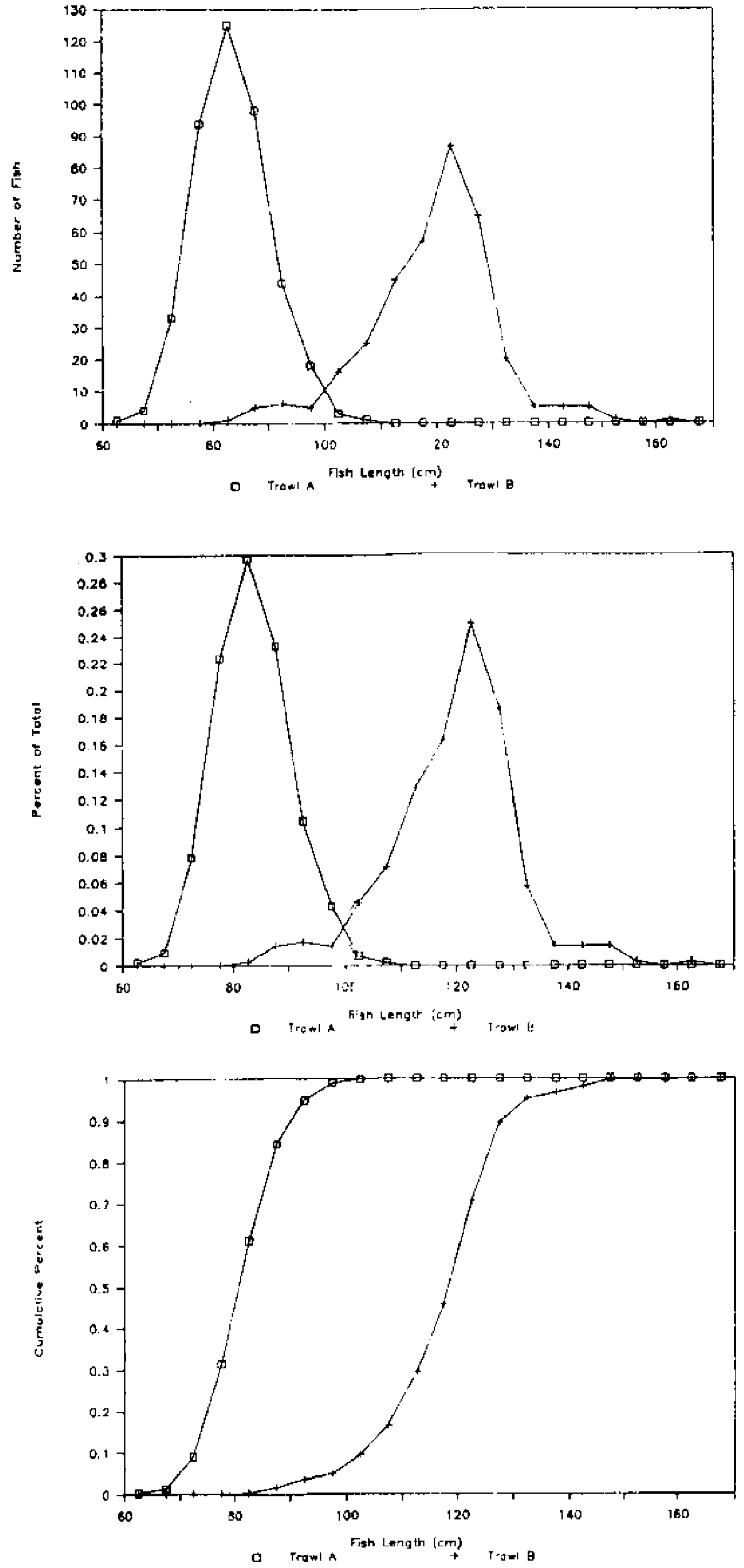

Figure 1. *Catch comparisons of trawls A and B, A. length-frequency, B. length-percent, C. length-cumulative percent.*

Table 1: *Simple experimental designs and data analysis strategies*

Single variable - only 2 groups of samples	
Paired samples	
T-test	P
Wilcox Signed Ranks Test	NP
Independent samples	
T-Test	P
Mann-Whitney Test	NP
Single variable - 2 or more groups of samples	
One way analysis of variance (ANOVA)	P
Kruskal-Wallis	NP
Two or more variables - 2 or more groups of samples	
Two or three way ANOVA	P
Friedman's Method	NP
Length-frequency distribution	
Contingency table and chi-square analysis	NP
Kolmogorov-Smirnov Test	NP

P = Parametric
NP = Non-parametric

Table 2: *Length-frequency Distributions for Cod Catches from Trawls A and B.*

Fish (L)	Trawl A				Trawl B				Difference
Length	**fa**	**fa/Na**	**Σfa**	**Σfa/Na**	**Fb**	**fb/Nb**	**Σfb**	**Σfb/Nb**	**Σfa/Na-Σfb/Nb**
62.5	1	0.002	1	0.002	0	0	0	0	0.002
67.5	4	0.009	5	0.012	0	0	0	0	0.012
72.5	33	0.078	38	0.090	0	0	0	0	0.090
77.5	94	0.223	132	0.314	0	0	0	0	0.314
82.5	125	0.296	257	0.610	1	0.002	1	0.003	0.607
87.5	98	0.232	355	0.843	5	0.014	6	0.017	0.826
92.5	44	0.104	399	0.948	6	0.017	12	0.034	0.914
97.5	18	0.048	417	0.990	5	0.014	17	0.049	*0.941
102.5	3	0.007	420	0.998	16	0.046	33	0.095	0.903
107.5	1	0.002	421	1.00	25	0.071	58	0.166	0.834
112.5	0	0	421	1.00	45	0.129	103	0.295	0.705
117.5	0	0	421	1.00	57	0.163	160	0.458	0.542
112.5	0	0	421	1.00	87	0.249	247	0.708	0.292
127.5	0	0	421	1.00	65	0.186	312	0.894	0.106
132.5	0	0	421	1.00	20	0.057	332	0.951	0.049
137.5	0	0	421	1.00	5	0.014	337	0.966	0.034
142.5	0	0	421	1.00	5	0.014	342	0.980	0.020
147.5	0	0	421	1.00	5	0.014	347	0.997	0.003
152.5	0	0	421	1.00	1	0.002	348	0.997	0.003
157.5	0	0	421	1.00	-	0	348	0.997	0.003
162.5	0	0	421	1.00	1	0.002	349	1.000	0
167.5	0	0	421	1.00	-	0	349	1.000	0
N	421				349				

REFERENCES

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