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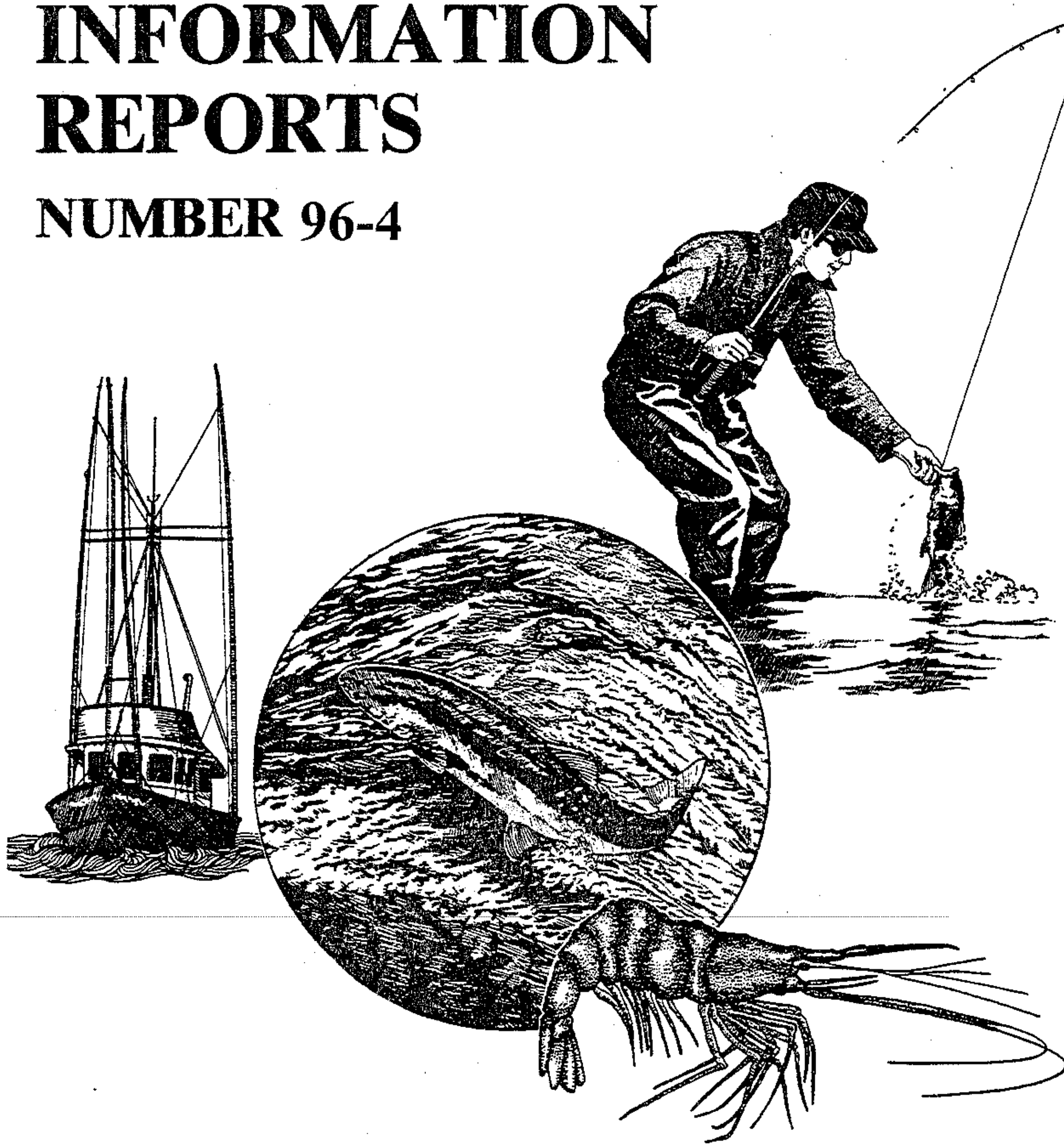

FISH DIVISION

Oregon Department of Fish and Wildlife

Evaluation of Fish Excluder Technology to
Reduce Finfish Bycatch in the Ocean
Shrimp Trawl Fishery

Evaluation of Fish Excluder Technology to Reduce Finfish Bycatch in The Ocean Shrimp Trawl Fishery

by

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II. Abstract

This project evaluated the effectiveness of four different types of fish excluders in the ocean shrimp (*Pandalus jordani*) trawl fishery. Assessment techniques included underwater video equipment and comparative fishing experiments employing side-by-side comparisons on double-rigged shrimp vessels. Data are presented on fish exclusion efficiency by fish type and length, as well as data on shrimp loss caused by the devices and effects on shrimp size composition. Recommendations for further development and testing of fish excluders for this fishery are also provided.

III. Executive Summary

Four fish excluders were evaluated in the ocean shrimp trawl fishery, under actual fishing conditions. Three of the excluders were simple "soft-panel" devices employing either 3, 5 or 8 inch mesh to guide fish out an escape port on the top of the trawl. The fourth design tested was the Nordmore grate system. The 5 and 8 inch excluders, and the Nordmore grate, were first evaluated using an underwater video camera. Subsequently, all four excluders were evaluated by fishing them against a control net on a double-rigged shrimp vessel. Our findings were as follows:

1. All four devices worked well at excluding large fish, reducing fish catch 70% to 100%, by weight.

2. The Nordmore grate and 3 inch mesh excluders were clearly better at excluding adult hake (*Merluccius productus*), excluding nearly 100%. The other excluders eliminated roughly 70% of the adult hake.

3. All four of the devices performed similarly at excluding small fish. Exclusion rates were highly variable, ranging from 30% to 70%.

4. Shrimp loss caused by the excluders was highly variable, even between cruises testing the same excluder device.

5. The Nordmore grate and 3 inch soft-panel excluder caused shrimp losses of from 0 to 10%. The other devices caused higher losses, sometimes as high as 15% to 31%.

6. Shrimp loss data for the Nordmore grate indicated that a grate with larger bar spacing may perform better in this fishery, especially in the southern fishing areas where shrimp are larger.

7. Since only one cruise tested the 3 inch excluder, it's unclear that this device can consistently deliver performance comparable to the Nordmore grate. The 3 inch mesh excluder used a different escape port design than the other devices, and was much easier to handle on-deck than the grate.

8. In some tests, the excluder devices caused statistically significant increases in average count-per-pound of shrimp captured, although this effect was not consistent between trials.

9. Additional study of the 3 inch mesh device is recommended. Follow-up research should include an assessment of this device using underwater video equipment to determine how escape port design influences shrimp loss, and also some additional comparative fishing experiments. Testing of a Nordmore grate with larger bar spacing is also recommended.

IV. Purpose

A. Description of the Problem

Discard rates in the Pacific northwest trawl fishery for ocean shrimp (*Pandalus jordani*) are low in comparison to other shrimp fisheries throughout the world (Alverson et al. 1994). However, in some years and in certain areas discard can still represent a large proportion of the total catch in this fishery (Demory et al. 1980). Sometimes the unmarketable bycatch is so large that entire tows are dumped, wasting shrimp as well as fish. Occasionally, large portions of the shrimp grounds are avoided by shrimpers because the unwanted bycatch is too abundant.

Since 1989, the abundance of Pacific hake (*Merluccius productus*) on the shrimp grounds off of California, Oregon and Washington has been particularly high, causing shrimpers to dump tows and avoid more areas. In an effort to reduce waste, gain access to more of the productive grounds and reduce the time spent sorting the catch, fishermen began experimenting with home-made, soft-panel, fish excluder devices. These devices, made from 3 to 8 inch groundfish mesh (Figures 1 and 2), were built to be readily enabled or disabled by simply removing a zipper in the excluder panel.

Since local fishermen began experimenting with excluder devices, trip limits for

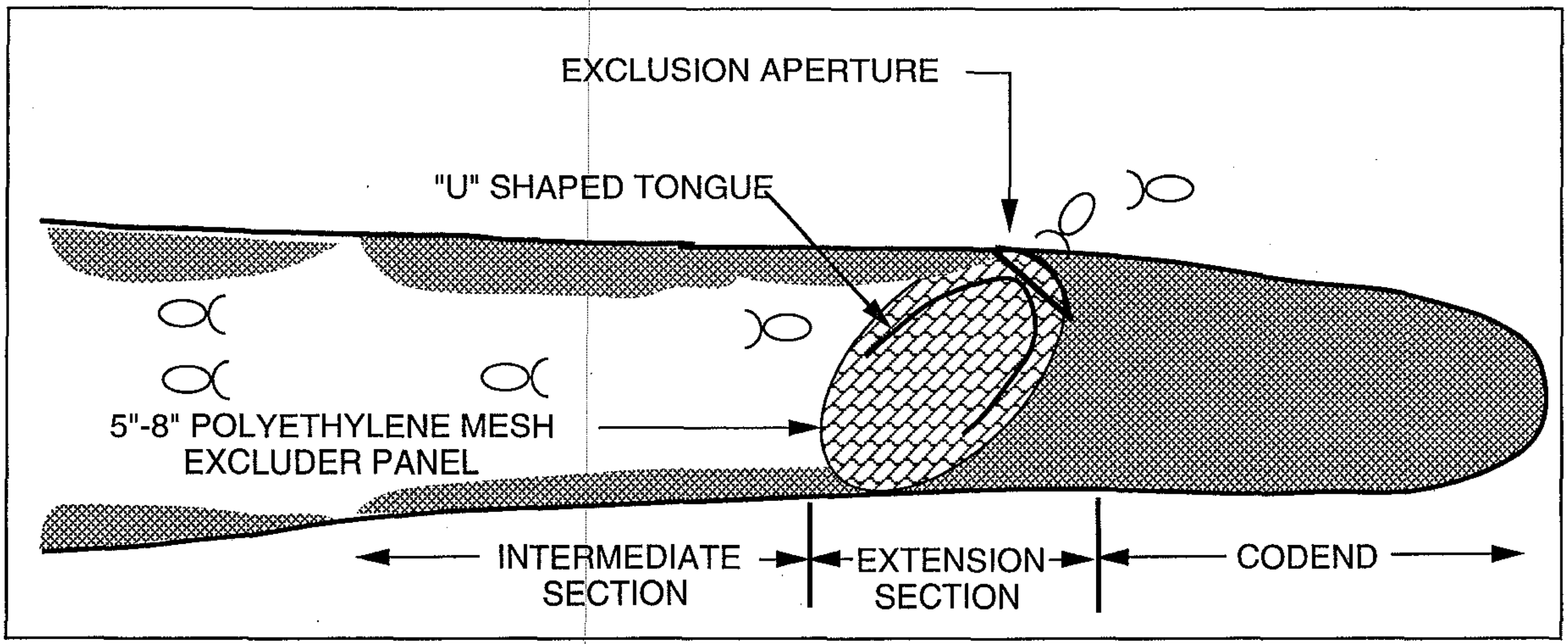


Figure 1. The design of the 5 and 8 inch soft-panel excluders.

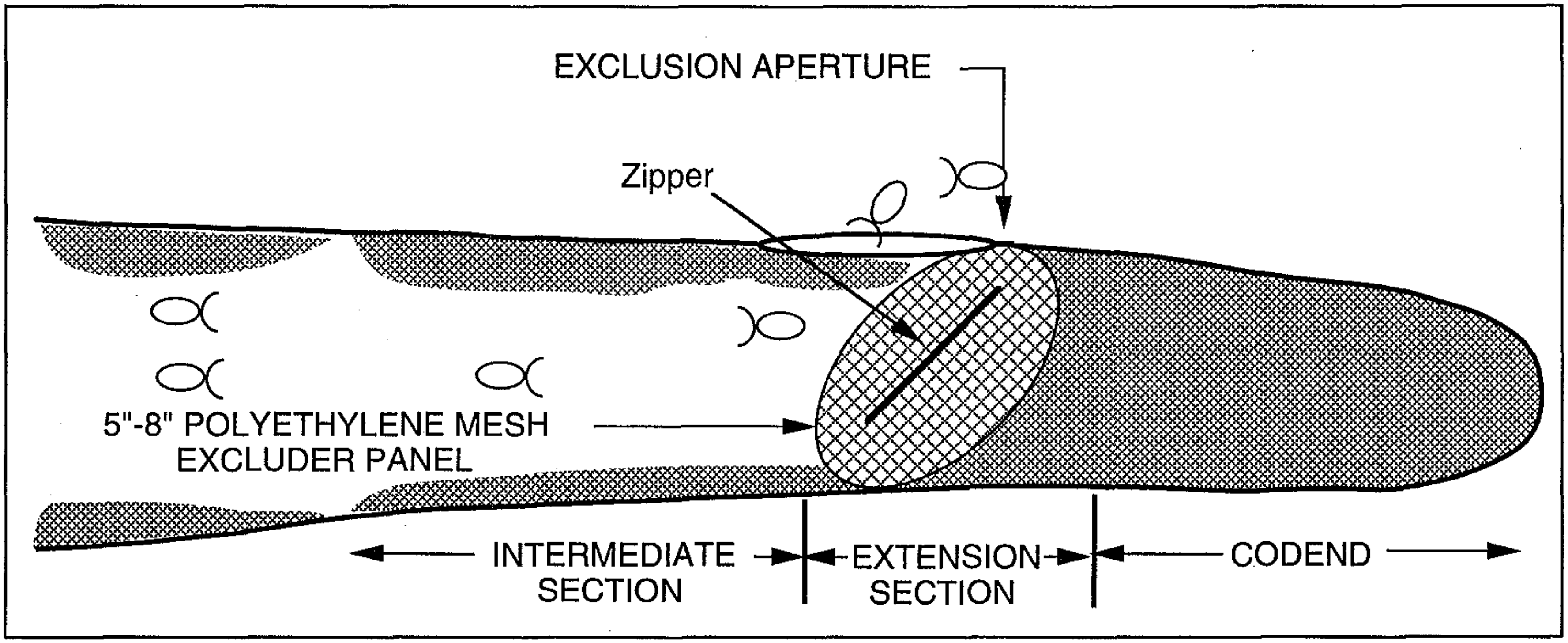


Figure 2. The design of the 3 inch soft-panel excluders.

many groundfish species have been reduced by the Pacific Fishery Management Council. Since implementation of limited entry for the Pacific coast groundfish fishery, federal groundfish trip limits now apply to shrimpers (PFMC 1992). In the future, finfish excluders may become a necessary tool in managing the shrimp fishery to prevent significant wastage of marketable fish which are under reduced trip limits. A thorough understanding of the efficiency of the available excluder designs, and the operational problems they create for fishermen, is needed prior to any consideration of using excluders as a management tool. Additionally, to encourage fishermen to choose excluders as an alternative to on-deck sorting of the catch, information on the effectiveness of various designs is needed. Basic information on the performance of excluders now in use can also assist in the development of more effective devices for this fishery.

B. Objectives

The principal objective of this study was to evaluate the efficiency of four readily available fish excluder designs, under actual fishing conditions, in the ocean shrimp fishery. The designs we tested were the soft-panel excluders (Figures 1 and 2) in 3, 5 and 8 inch mesh versions (note: metric units are used throughout this report, with the exception of the excluder designations, 3 inch, 5 inch etc. where we employed the designations used by the shrimp industry) and the Nordmore grate excluder with 25.4 mm bar spacing (Figure 3). The Nordmore grate has been proven to be effective in other shrimp fisheries (Isaksen et al. 1992, Kenney et al. 1992, Larsen et al. 1991, Ryan and Cooper 1991). Specifically, we wanted to determine the following.

1. What level of shrimp catch reduction can be expected with the excluders?

2. How does the level of bycatch reduction vary by fish species, and fish size for each of the excluders tested?

3. How is the size frequency of the shrimp catch changed by the Nordmore grate and by the soft excluders?

One secondary objective of this study was to gather information on operational problems associated with the use of excluders to better understand how fishermen feel about using the devices. Another secondary objective was to obtain some additional information on general levels of bycatch in the shrimp fishery.

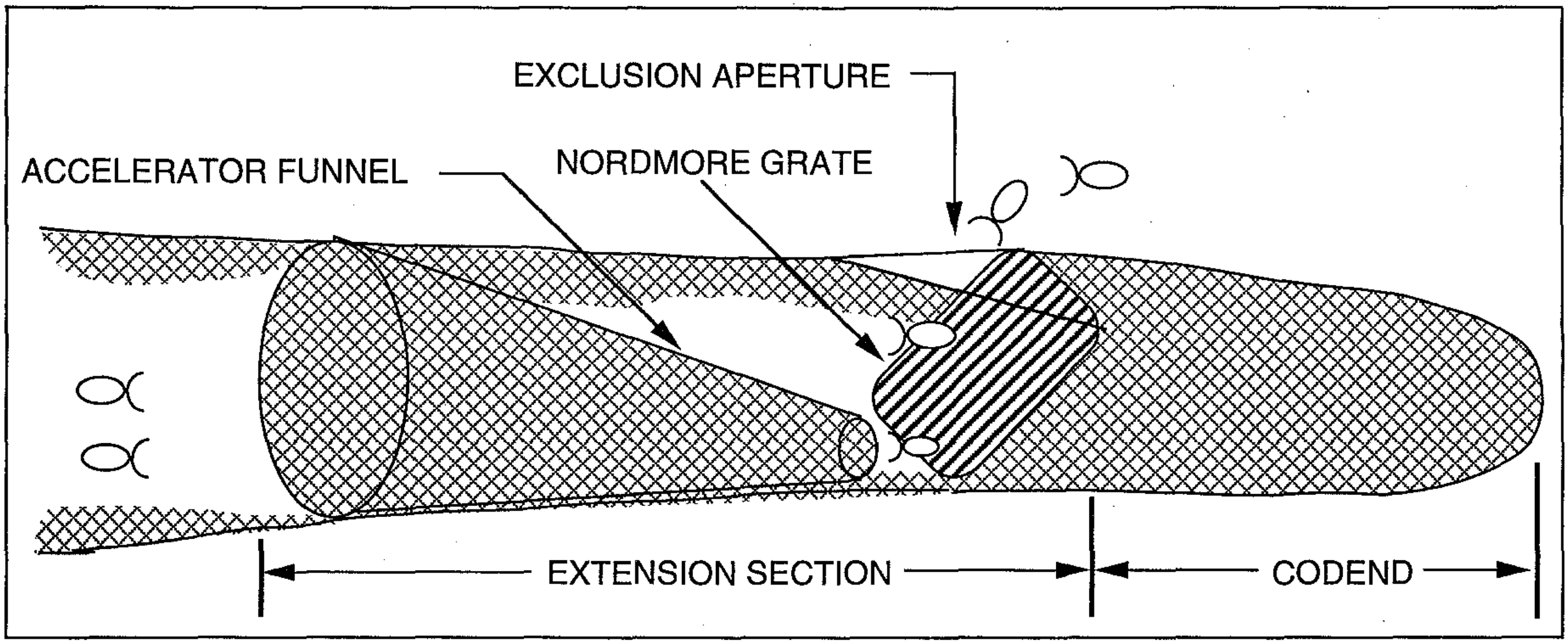


Figure 3. Schematic of the Nordmore grate fish excluder.

V. Approach

A. Description of the Work Performed

1. Study Design

The original intent of this project was to test three devices; the 5 and 8 inch soft-panel excluders and the Nordmore grate. The 3 inch soft-panel excluder came into use in the shrimp fishery after our original study plan had been submitted. Consequently, evaluation of this device was conducted only after the original study plan to test three devices had been completed.

In the first phase of the project, we used underwater video equipment to verify that each set of excluder gear was fishing correctly. National Marine Fisheries Service's Conservation Engineering Division provided the video equipment (Figure 4) and expertise necessary to complete this phase of the project, which was completed in roughly four days of vessel charter time, aboard the F/V Prospector out of Astoria, Oregon. We positioned the video equipment in a variety of locations within the excluder sections and in the codend to answer the following questions about the 5 inch, 8 inch and Nordmore grate excluders.

1. Was the excluder panel, as installed, hanging at the proper angle?

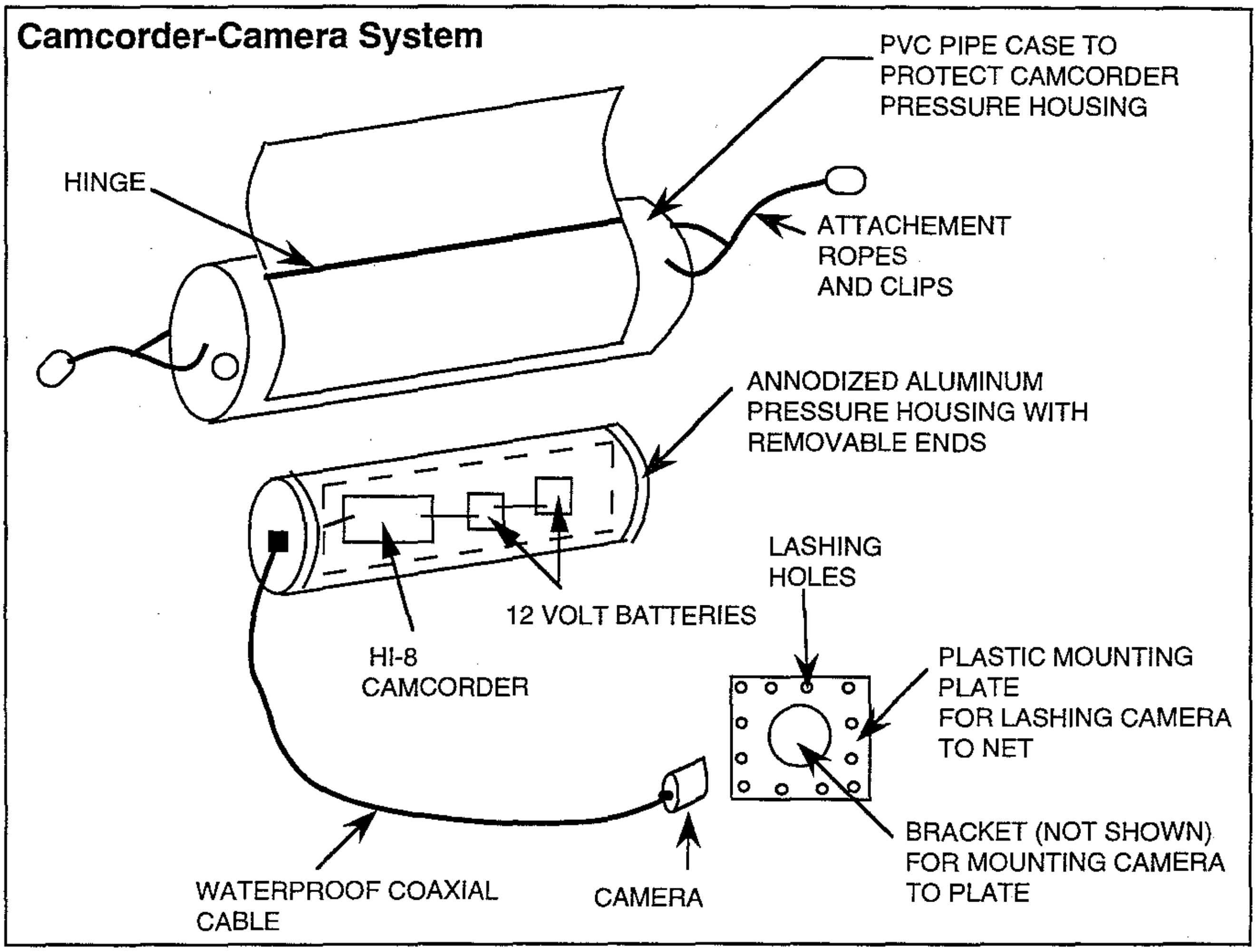
2. Was the water flow out the exit hole, and/or the quantity of shrimp observed escaping, excessive?

3. Was the excluder panel hanging evenly, or were there areas in which the panel was stretched too tightly or bunched up?

4. Were the intermediate and codend sections expanded normally or collapsed?

In the second phase of the project, we conducted comparative fishing experiments to evaluate each excluder device. Double-rigged shrimp trawlers were chartered for these experiments. The budget was scaled to provide the vessel time needed to conduct the video work and comparative fishing experiments on the Nordmore grate and the 5 and 8 inch versions of the soft-panel excluder. Since the actual cost per vessel-day was lower than originally projected, we were able to accomplish some additional work. Specifically we completed an additional cruise evaluating the Nordmore grate, and an additional cruise assessing a 3 inch version of the soft-panel excluder.

The basic statistical design of the fishing experiments compared catches from either side of a double-rigged shrimp trawler (Figure 5), with one side of gear fishing the excluder device (Figures 1-3) and the other acting as a control. Each cruise tested only one type of excluder versus a control. In addition to requiring each charter



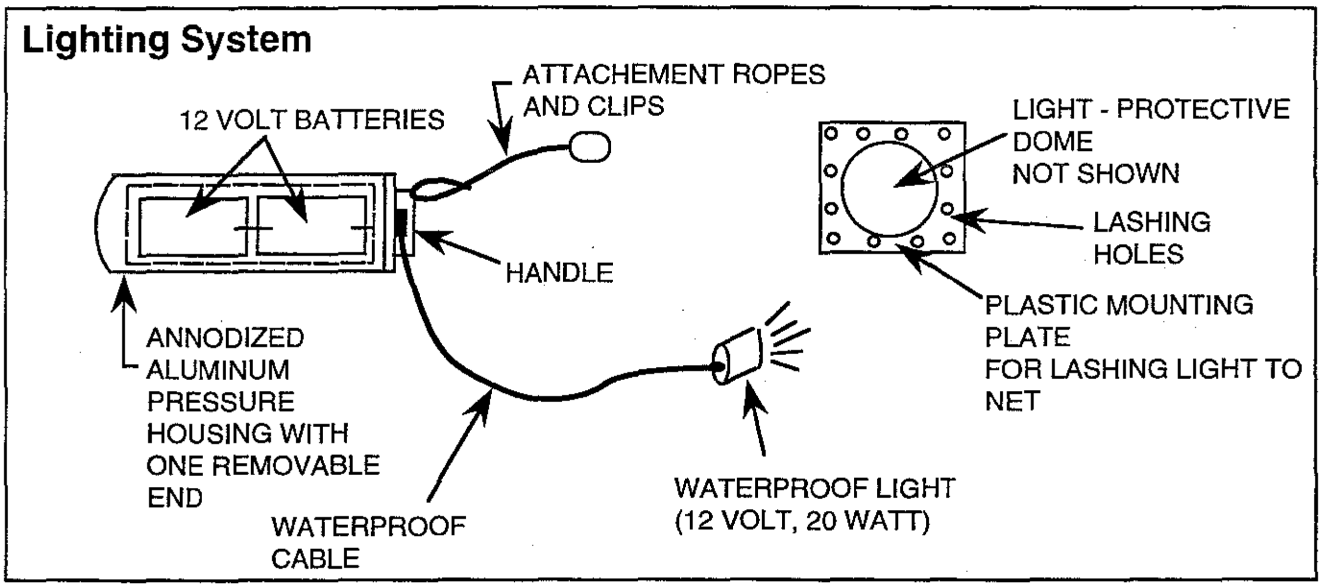


Figure 4. Schematic drawings of the NMFS underwater camera and lighting system used to observe finfish excluders while fishing.

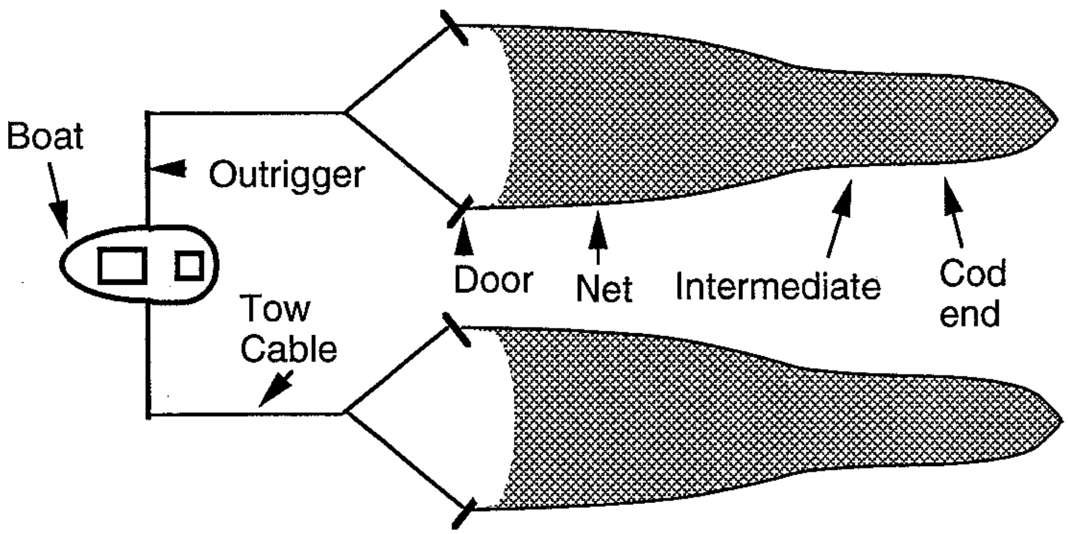


Figure 5. Schematic of a double-rigged shrimp vessel.

vessel to provide well-matched nets, we also attempted to eliminate the influence of differences in efficiency between the port and starboard nets via the statistical design. Prior to each cruise, the excluder devices to be tested were incorporated into the port and starboard nets of the charter vessel. Each excluder was designed to be rapidly enabled or disabled. The physical setup of the comparisons; the side of the vessel to fish the enabled excluder and the side with the excluder disabled (the control) was changed systematically every two tows.

The original study design called for randomization of the excluder effect with respect to the port and starboard sides of trawl gear. Early on, it became apparent that the F/V Ginger B's nets were not fishing evenly; the starboard net was consistently out-fishing the port net. While our statistical design was planned to compensate for just such a problem, some additional steps were taken to assure that we could get the most useful information from this data. Analysis we had completed in early May suggested that when the nets were poorly matched, a systematic statistical design (similar to a latin square) was more efficient than a randomized design. Thus, on the first cruise we switched to a systematic approach for varying the excluder effect between port and starboard sides of the boat. We also made sure to alter the pattern as needed to balance the number of tows with the excluder enabled between the port and starboard sides before the end of each cruise. In addition, we conducted four "calibration tows" where both excluders were disabled and the catch from each side was sorted and weighed. The calibration tows were conducted so that a correction factor could be calculated for the two nets, allowing an alternate approach to data analysis. Analysis of the data from the first cruise indicated that the statistical design was generally working as anticipated and calibration tows were probably not needed.

For the second and third sets of cruises we continued using the balanced statistical design, systematically varying the side with the excluder effect, and did not conduct calibration tows. On the second set of cruises, the F/V Lady Kaye's nets were fishing evenly, further obviating the need for calibration tows. For the third set of cruises, again on the F/V Ginger B, the skipper installed a different net on the port side in an effort to provide a better matched pair of nets. However, after the first few tows, it was clear the starboard net was still out-fishing the port net. Prior to the last cruise, the skipper added some additional chain to the footrope of the port net. Subsequently, the nets fished much more evenly.

In another minor departure from the original study design, on one cruise we conducted several tows with the escape port on the 8 inch mesh excluder reduced in size. This was done because it appeared that shrimp loss caused by this excluder was especially high. The catch data from this cruise was analyzed separately for the standard and reduced escape ports.

Excluder Construction

All excluders tested were mounted in an extension, a cylindrical tube of shrimp netting, just long enough to mount the excluder panels at a 45-48° angle. The excluder panels were inclined fore to aft and an escape port was cut in the extension web, above the excluder panel. We mounted the excluder sections immediately aft of the "intermediate" section of each net. We supplied new nylon codends, (approx. 5.8 m long or 200 meshes), which were mounted to the aft end of the excluder sections. Mean codend mesh size was 26.7 mm (between knots). All of the excluders we tested were designed to be disabled and enabled quickly. Each soft-panel excluder had some form of seam in the middle with a "zipper" that could be untied to allow fish to pass into the codend. Disabling was achieved by opening the excluder panel seam and sewing shut the escape port. In the case of the Nordmore grate, disabling was accomplished using a special mounting frame for the grate (Figure 6).

The soft-mesh excluders tested, and their extension sections (Figures 1 and 2), were constructed by two different net manufacturers. The 5 and 8 inch mesh versions were designed and constructed by George McMurrick of the Astoria Net Shop, Astoria, Oregon (Figure 1). The extension sections of these two excluders were made of 35.5 mm braided blue-green polyethylene mesh, were approximately 3.5 m long (100 meshes), and were 200 meshes in circumference. The excluder panels were made of braided orange poly mesh. Each was mounted at approximately a 45 degree angle. The panels had a pre-cut "inverted U" shaped tongue which was sewn back into place when the excluder was enabled. The escape port was a lateral slit (90° to long axis of net), 0.029 m wide in the 5 inch version and 0.036 m wide in the 8 inch.

In our tests of the 3 inch mesh excluder, we used excluders that had been purchased and used previously by the owner of the F/V Ginger B. These excluders were designed and constructed by Bob Driscol of the J & B Net Co., Warrenton, Oregon (Figure 2). The extension section was made of dark colored braided nylon mesh, was approximately 3.6 m long, and 250 meshes in circumference. The excluder panel was made of dark colored braided nylon mesh. It was mounted at approximately a 45 degree angle. The escape port was a longitudinal slit approximately 48 meshes long, terminating several meshes forward of the top of the excluder panel, creating a "lip" of sorts.

The Nordmore grate we tested was a rigid polyethylene panel (1.34 m long by 0.66 m wide) consisting of vertical bars with 1" spacing (Figure 3). It was purchased from Woodex Bearing Co., Georgetown, Maine. A frame of heavy gauge 2" diameter aluminum pipe was fabricated (Halco Welding Co., Newport, Oregon) to facilitate disabling the excluder for our tests. The grate was mounted within the frame by using three stainless steel rods, passing laterally through eye straps on the grate and securing into holes in the frame (Figure 6). Rods were placed near the bottom, middle and top of the grate. To disable the device, the middle and top rods were removed, allowing the grate to lay down, pivoting on the bottom rod.

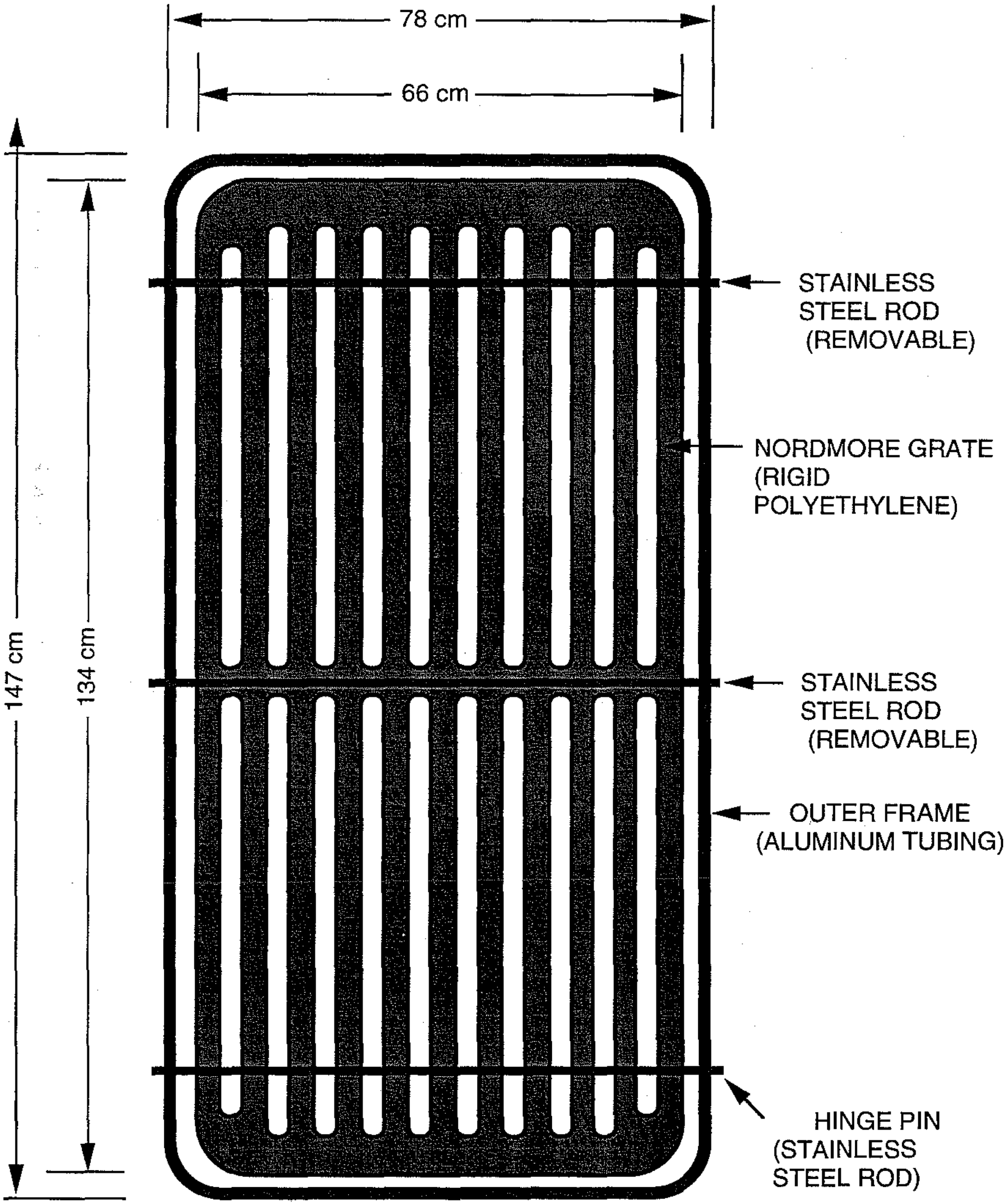


Figure 6. Schematic of the Nordmore grate and aluminum frame allowing rapid disabling.

The Nordmore extension section was constructed by Astoria Net Shop according to specifications provided by Larsen et al. (1991). The section was 4.9 m long (140 meshes) and was 200 meshes in circumference (Figure 3). The netting used was 35.5 mm blue-green polyethylene mesh. The Nordmore grate and its frame were mounted at a 45-48° angle from the horizontal in the aft end of the extension section. An accelerator funnel was mounted at the forward end of the extension, tapering aft toward the bottom of the grate. The escape port was triangular in shape, roughly 66 cm on a side. The base of the triangular escape port was placed directly at the top of the grate. Four orange 11 cm diameter floats were placed immediately aft of the top of the grate to help maintain the grate in an upright position.

Video Equipment Components and Arrangement

The underwater video system we used consisted of the following parts: a camera with an adjustable swivel mount and protective shroud, a light with a protective shroud, a video recorder (camcorder) and batteries in a sealed pressure housing, and a sealed housing for the light batteries (Figure 4). Waterproof cable was used to interconnect the components. Components were attached directly to the shrimp trawl web in positions likely to give desired views. Camera repositioning was often required.

Bottom time with the video system was limited by video tape length and by battery life. The video recorder had to be turned on (with tape running) before it was placed in the pressure housing. It often took 1/2 hour or more to load the housing, attach it to the net, make other necessary connections and set the trawls. We used 2 hour Hi-8 video tapes, which limited our bottom time for each tow to less than an hour. The batteries we used generally lasted through two tows.

Video tapes were reviewed on-board after each tow. A television and spare camcorder were used for the review while a new tape and batteries were loaded into the pressure housings. Camera and light adjustments could then be made to improve our field of view on the next tow.

Field Collection Methods

Catch evaluation included sorting and weighing all the catch by species from each tow, as well as gathering count-per-pound samples and length data. The catch from the port and starboard nets was sorted and weighed separately. This was accomplished by emptying each codend into its respective side of a divided hopper. Catch from one side was completely sorted before sorting of the other side began. Sorting personnel included three biologists and two crew members.

Two types of divided hopper were used. One simply had a plywood partition placed centrally. The other was divided into three side-by-side compartments. Each of the lateral compartments could be emptied independently into the central compartment, which supplied the sorting belt. Occasionally, some catch fell into the wrong side of the bin. These tows were either not used, or when possible, were corrected using a visual estimate of the catch that had entered the wrong compartment.

Halibut were removed from the hopper as soon as the codends were emptied. They were measured (fork length, inches) and released immediately. We used an International Pacific Halibut Commission (IPHC) length-weight relationship to estimate the weight of these fish. Dungeness crab, and occasionally other species, were also removed for release when possible.

Fish, and invertebrates other than shrimp, were sorted from the catch as it passed from the hopper over the sorting belt. We used color coded baskets; red for starboard and grey for port, to prevent intermixing the catch from each side. This was a quick preliminary sort enabling us to weigh and ice the shrimp catch from both sides as quickly as possible. A Morris Scale Co. manual flatbed scale was used for weighing catch to the nearest 0.1 pound. After all shrimp were placed in the hold, we re-sorted the baskets of fish by species. Eelpouts and other small and uncommon fish and invertebrates were simply discarded.

Occasionally, there was too much bycatch to weigh and count all the fish in the time available. Normally, shrimpers would simply dump such tows, due to the lack of shrimp, and move to a different area. We chose to try and use these tows since they provided useful information on how excluders work when bycatch is heavy. We processed these tows by subsampling. Some tows had abundant and diverse flatfish or baitfish. For such tows, subsamples were taken of the mixed catch. The subsamples were sorted, counted and weighed, and this data was expanded to the total weight of the mixed fish, shrimp and other invertebrates. When large fish (i.e. adult Pacific hake) were abundant, we weighed the first 50 individuals and counted the rest. The average weight was used to calculate the total weight of the species.

Two count-per-pound samples were collected from each side of gear for each tow. The samples were collected directly from the hopper or from the shrimp that came off the sorting belt. A magnetically dampened triple beam balance was used for weighing approximately one hundred shrimp per sample to calculate count-per-pound.

We also tried to obtain length data for each species from several tows, each day. Time limitations often prevented us from measuring all species from every tow. In these instances, several species were selected for measurement based on what was needed to achieve our daily goal. A subsample of a species was taken whenever there were more than about 50 individuals on a side. Subsampling was achieved by mixing the fish and counting out the first 50 for measurement. Depending on the species, either fork or total lengths were taken, and rounded to the next lowest centimeter.

Data Analysis

In comparative fishing experiments, it is common for some species to be present in some hauls but absent from others. Likewise, a particular length range of a species can be present at times and then absent later. This can make it difficult to make meaningful comparisons at the "species" level. To deal with this problem, we grouped fish of similar body shapes for catch analysis and also for analysis of size selectivity of the excluders. We used slightly different groupings for the two analyses. For the catch data, which was analyzed based on total weight, we grouped the fish as shown in Table 1, combining species of similar average size and body shape. For analysis of length selectivity, we grouped fish of similar body shape, without regard to size (Table 2). With the exception of some distinctively shaped fish that were uncommon, such as skates and rays, this approach yielded sufficient data for meaningful analysis of all groups. We also assessed the exclusion efficiency of the various excluders, by weight, for all fish species combined.

We analyzed the catch data using three factor analysis of variance (ANOVA) with haul number, the presence or absence of an excluder and the "side" of gear as main effects (without interaction). Using this type of analysis, we tested for differences in fishing efficiency between the port and starboard nets along with the effect of the excluder device. Occasionally, we deleted one or two hauls to balance the design. When no significant difference was found between sides of gear, this factor was deleted, and the test was recalculated. Similarly, we tested whether the excluders caused changes in the size distribution of shrimp using three-factor ANOVA. Two replicate measurements of count-per-pound from each side of gear constituted the dependent variable.

To make our analysis as comprehensive as possible, we also included some additional data from earlier tests of the 8 inch mesh soft-panel excluder. These data were obtained in 1993 on a "ride-along" trip on the F/V Prospector, using similar methods to the present study. In this earlier effort, only information on the weight of shrimp and fish bycatch, by species group, was obtained.

We log-transformed the catch data prior to ANOVA. The log transformation was used because we expected both fish escapement and shrimp losses through the escape port to be proportional to the total catch in the control net. Accordingly a multiplicative, rather than an additive model is appropriate. This transformation is also generally helpful with catch data, since it tends to normalize a skewed distribution. To estimate the percentage reduction in catch caused by an excluder device, the means of the transformed data were back transformed and the percentage calculated.

A simple graphic approach was used to evaluate how each excluder performed at excluding different sizes of fish. We overlayed graphs of the cumulative length frequency for the experimental and control nets, for each gear type tested. While not a statistical test, this approach provides information on the length frequency of fish

Table 1. Species composition of groups used for analysis of fish excluder catch data.

Catch Group	Species Included	Scientific Name
Ocean Shrimp	Ocean shrimp	*Pandalus jordani*
Adult Hake	Pacific hake (>33 cm)	*Merluccius productus*
Juvenile Hake	Pacific hake (≤33 cm)	*Merluccius productus*
Large Flatfish	Pacific halibut	*Hippoglossus stenolepis*
	Arrowtooth flounder	*Atheresthes stomias*
Medium Flatfish	Dover sole	*Microstomus pacificus*
	English sole	*Pleuronectes vetulus*
	Petrale sole	*Eopsetta jordani*
	Rock sole	*Pleuronectes bilineatus*
Small Flatfish	Rex sole	*Errex zachirus*
	Pacific sanddab	*Citharichthys sordidus*
	Slender sole	*Eopsetta exilis*
	Flathead sole	*Hippoglossoides elassodon*
Large Rockfish	Canary rockfish	*Sebastes pinniger*
	Yellowtail rockfish	*Sebastes flavidus*
Small Rockfish	Darkblotched rockfish	*Sebastes crameri*
	Rougheye rockfish	*Sebastes aleutianus*
	Greenstriped rockfish	*Sebastes elongatus*
	Miscellaneous rockfish	--
	Shortspine thornyhead	*Sebastolobus alascanus*
Skates/Rays	Big skate	*Raja binoculata*
	Longnose skate	*Raja rhina*
	Sandpaper skate	*Bathyraja interrupta*
	Pacific electric ray	*Torpedo californica*
Dogfish Sharks	Spiny dogfish	*Squalus acanthias*
Baitfish	Pacific herring	*Clupea pallasi*
	Pacific sardine	*Sardinops sagax*
	Smelt spp.	Osmeridae
Assorted Roundfish	Sablefish	*Anoplopoma fimbria*
	Lingcod	*Ophiodon elongatus*
	Pacific cod	*Gadus macrocephalus*
	Chub mackerel	*Scomber japonicus*
	Jack mackerel	*Trachurus symmetricus*
Misc. Fish	Spotted ratfish	*Hydrolagus colliei*
	American shad	*Alosa sapidissima*
	Giant wrymouth	*Cryptacanthodes giganteus*
	Pacific tomcod	*Microgadus proximus*
	Pacific argentine	*Argentina sialis*
Hagfish/Lamprey	Hagfish	*Eptatretus* spp.
	Pacific lamprey	*Lampetra tridentata*
Dungeness Crab	Dungeness crab	*Cancer magister*

Table 2. Species composition of groups used for analysis of length selectivity of the excluder devices.

Catch Group	Species Included	Scientific Name
Ocean shrimp	Ocean shrimp	*Pandalus jordani*
Hake	Pacific hake	*Merluccius productus*
Flatfish	Pacific halibut	*Hippoglossus stenolepis*
	Arrowtooth flounder	*Atheresthes stomias*
	Dover sole	*Microstomus pacificus*
	English sole	*Pleuronectes vetulus*
	Petrale sole	*Eopsetta jordani*
	Rock sole	*Pleuronectes bilineatus*
	Rex sole	*Errex zachirus*
	Pacific sanddab	*Citharichthys sordidus*
	Slender sole	*Eopsetta exilis*
	Flathead sole	*Hippoglossoides elassodon*
Rockfish	Canary rockfish	*Sebastes pinniger*
	Yellowtail rockfish	*Sebastes flavidus*
	Darkblotched rockfish	*Sebastes crameri*
	Rougheye rockfish	*Sebastes aleutianus*
	Greenstriped rockfish	*Sebastes elongatus*
	Miscellaneous rockfish	--
	Shortspine thornyhead	*Sebastolobus alascanus*
Skates/Rays	Big skate	*Raja binoculata*
	Longnose skate	*Raja rhina*
	Sandpaper skate	*Bathyraja interrupta*
	Pacific electric ray	*Torpedo californica*
Dogfish Sharks	Spiny dogfish	*Squalus acanthias*
Baitfish	Pacific herring	*Clupea pallasi*
	Pacific sardine	*Sardinops sagax*
	Smelt spp.	Osmeridae
Roundfish	Sablefish	*Anoplopoma fimbria*
	Lingcod	*Ophiodon elongatus*
	Pacific cod	*Gadus macrocephalus*
	Chub mackerel	*Scomber japonicus*
	Jack mackerel	*Trachurus symmetricus*

encountered by each device as well as how readily fish of different sizes were excluded.

Catch data from the control side of gear, in combination with catch data from the calibration tows, was also summarized to provide a "snapshot" of the bycatch we encountered. As mentioned previously, we observed definite differences in the catch rates of our port and starboard nets on one of the vessels we chartered, which changed in response to minor changes in the amount of chain on the footrope. Different shrimp vessels use a variety of designs for their net footropes (ODFW unpublished data), almost certainly causing variation in bycatch between vessels. It's also clear that bycatch rates and composition vary significantly over time and between areas. Accordingly, our data is not representative of the bycatch for the entire fishery for 1995. However, we believe our data is a reasonable approximation of the bycatch being encountered by the fleet in the areas and months in which we fished. Accordingly, the bycatch data are tabulated by month and PSMFC area (Figure 7).

B. Project Management

This project was conducted by the following staff of the Oregon Department of Fish and Wildlife:

Project Manager/Principal Investigator	Robert W. Hannah
Assistant Project Manager	Stephen A. Jones
Other Participants	Vicki J. Hoover Susan Riemers
Other Participants (at-sea sampling)	James T. Golden Robert Mikus Mark Vargas John Schaefer
NMFS Cooperators	Craig Rose Scott McEntire

The skippers and crew of several shrimp vessels also participated in this study. These were the F/V's Prospector and Ginger B out of Astoria, Oregon and the F/V Lady Kaye out of Newport, Oregon. These vessels were chartered by the Oregon Department of Fish and Wildlife to conduct the at-sea portion of this project, which was completed in four sets of cruises.

The first cruise, aboard the F/V Prospector was conducted out of Astoria, Oregon between 10/9/94 and 10/12/94. This cruise was dedicated to underwater video assessments of three types of fish excluder, the Nordmore grate (Figure 3) and 5 and

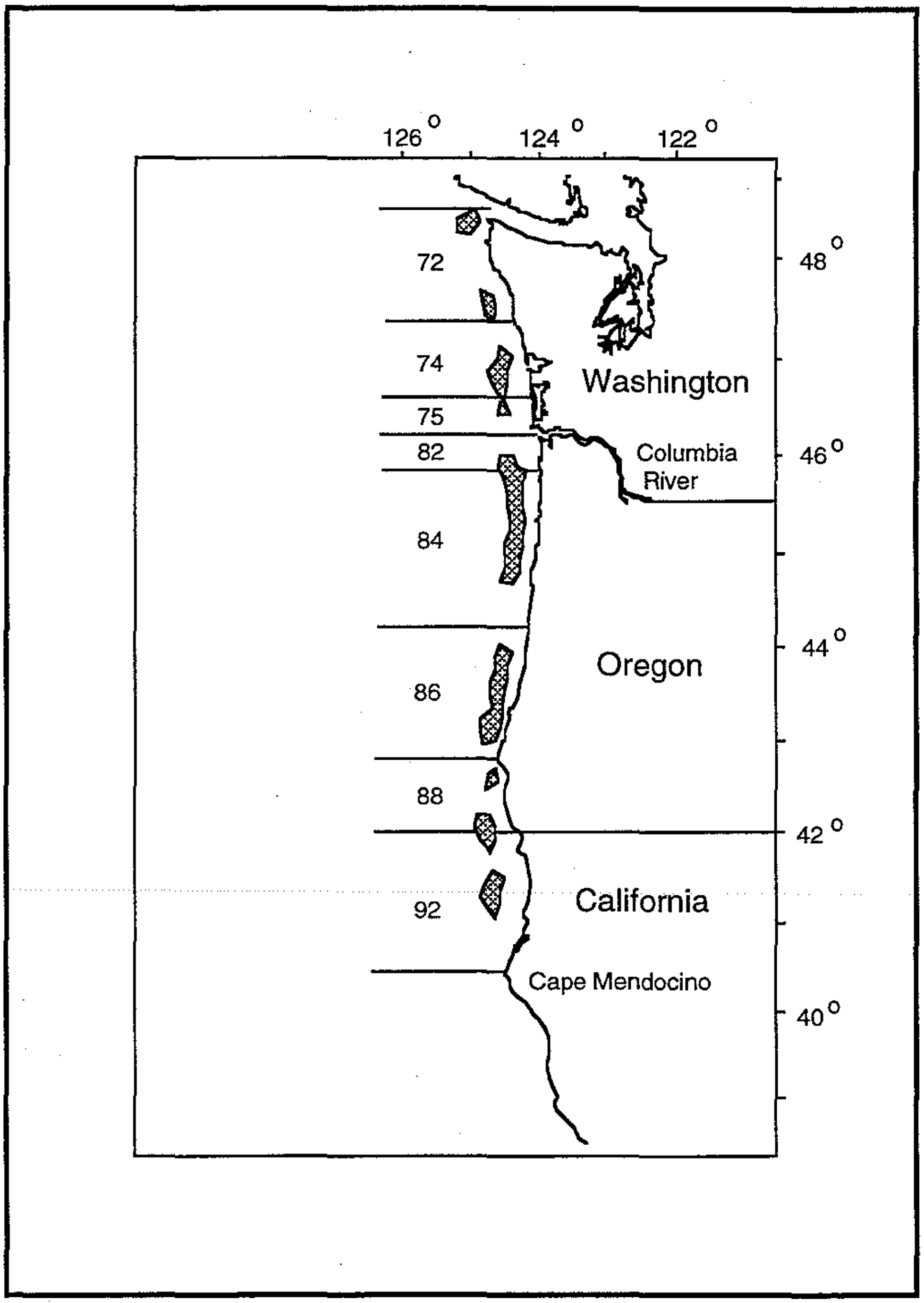


Figure 7. Location of commercial concentrations of pink shrimp *Pandalus jordani* along the U.S. Pacific coast (shaded areas) in PSMFC statistical areas 72-92.

8 inch mesh versions of the soft-panel excluder (Figure 1). The underwater video work was conducted in cooperation with National Marine Fisheries Service Resource Assessment and Conservation Engineering Division, who supplied the underwater video system and considerable technical advice and expertise. The objective of this cruise was to determine if the three devices were constructed and functioning properly prior to conducting comparative fishing experiments. The video footage necessary to evaluate each device was successfully obtained, and the necessary gear modifications were implemented prior to the comparative fishing experiments.

The second set of cruises was conducted out of Astoria, Oregon aboard the F/V Ginger B, and consisted of three cruises of four days each conducted between 5/24/95 and 6/16/95. On the first cruise, we fished the 5 inch mesh soft-panel excluder against a control net, following the procedures described earlier. On the second four-day cruise, the Nordmore grate was fished against a control net, while on the third cruise, the 8 inch mesh soft-panel excluder was similarly evaluated. The third cruise was actually broken up into two segments of two days each because of adverse weather conditions.

The third set of cruises was conducted out of Newport, Oregon aboard the F/V Lady Kaye, and consisted of three cruises of four days each, conducted between 6/28/95 and 7/16/95. On these cruises, we also fished each gear for four days, using the same order; 5 inch, then the Nordmore grate followed by the 8 inch mesh excluder.

The fourth set of two cruises, of four days each, was conducted out of Astoria, Oregon, once again aboard the F/V Ginger B. These two cruises were made possible by cost savings on earlier cruises. All charter cruises were procured via competitive bidding and the marketable catch was sold and deducted from the charter cost. Accordingly, a combination of competitive bids and successful fishing created cost savings allowing additional at-sea work. The first of these two cruises was used to conduct some additional tests of the Nordmore grate, while the final cruise was used to evaluate a 3 inch mesh version of the soft-panel excluder which came into use in the shrimp fishery in 1994.

VI. Accomplishments

A. Findings/Results

Video Assessment

Our video observations of the soft-panel excluders indicated that the 8 inch panel was installed properly but the 5 inch panel was not. The angle of the 5 inch panel was too shallow and video footage showed that much of the water flow and catch was exiting the escape port. The 5 inch mesh panels were subsequently modified to more closely approximate the angle in the 8 inch mesh device, which appeared to be working properly. Poor mesh spreading observed with the 5 inch excluder was probably also caused by the improper installation.

Observations of the Nordmore grate suggested that it was also installed at too shallow an angle. We used an inclinometer attached to the downstream side of the grate to provide a direct measurement of the angle, recorded on video. The grate was remounted at-sea and we were able to verify that the correct angle was achieved, by moving the bottom of the grate back about 12 meshes. It should be noted that the grate was hung and tied in the net shop at a 45 degree angle and that the effective angle while fishing was different.

Video footage taken in the codend revealed another problem associated with the excluder extension sections. The codend was poorly filled out at times, indicating that water flow through the excluder and into the codend was insufficient. After consulting with our net supplier, we shortened the excluder extension sections as much as possible to minimize water loss through the extension meshes. Although not attempted in this study, other options were to use smaller mesh or larger twine in the excluder sections, or to mount the excluder panels directly in the intermediate, eliminating the extension section entirely. Additional underwater video work could help determine the most effective strategies for resolving this problem when it occurs.

Fish Exclusion Efficiency

We found all four devices to be effective at substantially reducing the total weight of fish caught (Figure 8 and Tables 3-7). However, the Nordmore grate and the 3 inch mesh soft-panel excluders were more effective, yielding roughly an 80% reduction, while the 5 and 8 inch mesh devices reduced fish bycatch by roughly 55%. The overall fish exclusion performance we observed for both the Nordmore grate and 3 inch mesh excluder is consistent with the performance reported by others for the Nordmore grate (Isaksen et al. 1992, Kenney et al. 1992a, Kenney et al. 1992b, Ryan and Cooper 1991). We also observed substantial variation in exclusion efficiency between trips, with the same excluder device. This is most likely due to variation in the size and species composition of the bycatch encountered.

An examination of the percent reduction, by weight and species group, for the Nordmore grate (Table 6), shows that this device is extremely effective on all large fish and also somewhat effective on small fish, such as juvenile hake, baitfish and small flatfish. For most species groups, the 5 and 8 inch mesh excluders gave somewhat lower, but similar, performance to the Nordmore grate (Tables 3 and 4), while the 3 inch mesh device yielded performance very comparable to the Nordmore grate, especially with adult hake (Table 7). As expected, the eight inch mesh device was less effective at excluding fish, even large ones, however it's overall performance was surprisingly good with a variety of fish groups that can readily pass through 8 inch mesh, notably adult hake, and small and medium flatfish. In contrast to the good performance of even the 8 inch excluder on some

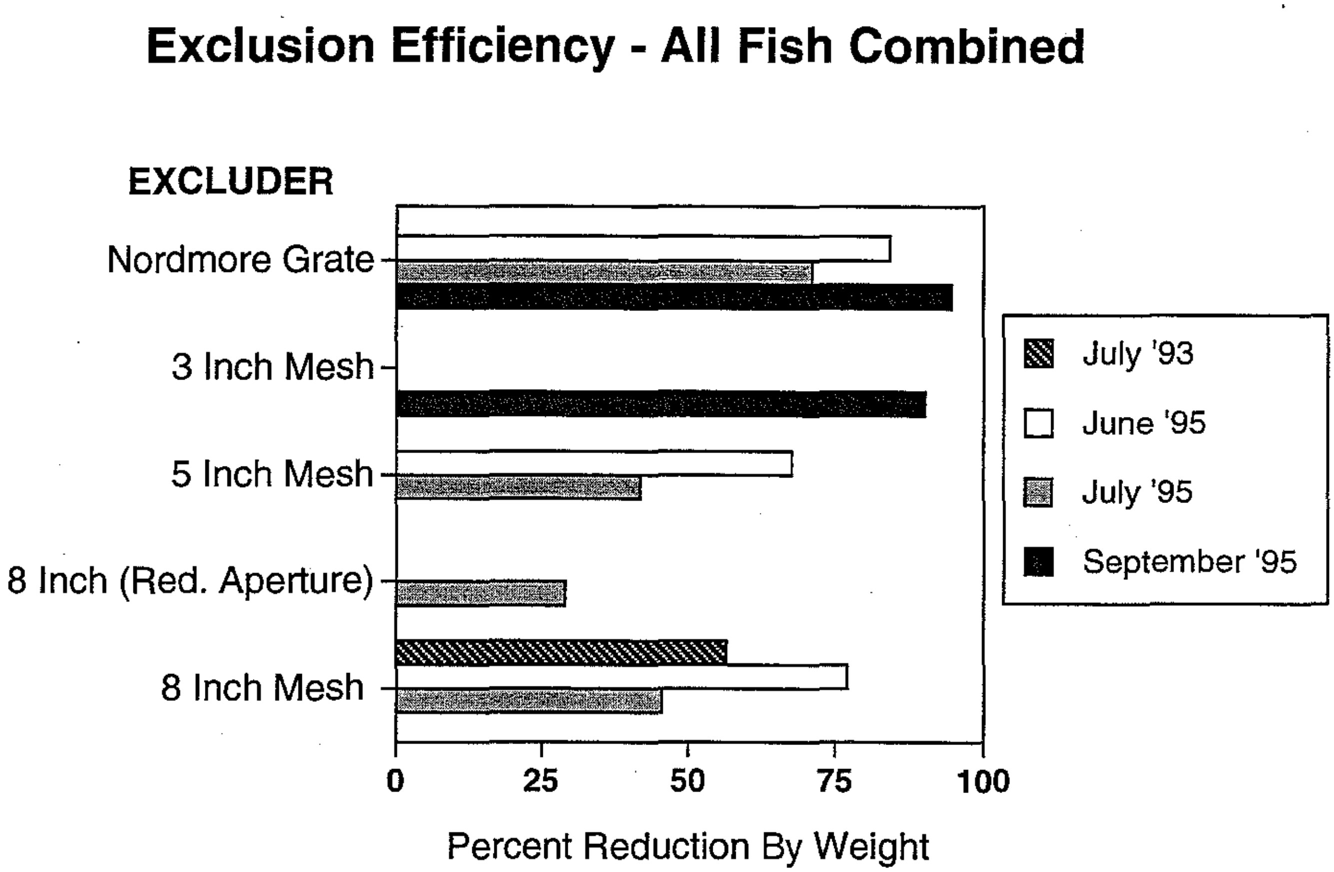


Figure 8. Percent reduction by weight obtained with four fish excluder devices, for all fish species combined.

Table 3. Percent reduction by weight and species group for the 5 inch mesh excluder. Reduction estimates are significant at $p < 0.01$ unless noted.

	Percent Reduction By Weight	
Species Group	June 1995	July 1995
Pink Shrimp	7 **	15
Adult Hake	80	67
Juvenile Hake (≤ 33 cm)	31	35
Large Flatfish	94	100
Medium Flatfish	85	95
Small Flatfish	55	52
Large Rockfish	100	97
Small Rockfish	56 **	ns
Skates/Rays	100	100 **
Dogfish	79	--
Baitfish	56	60
Assorted Roundfish	96	97
Misc. Fish	73 **	90
Hagfish/Lamprey	ns	ns
Dungeness Crab	c	c

"--" = insufficient data, ns = non-significant ($p > 0.10$), c = some crab observed, all or mostly in non-excluder side
*$p < 0.10$, **$p < 0.05$

Table 4. Percent reduction by weight and species group for the 8 inch mesh excluder. Reduction estimates are significant at $p < 0.01$ unless noted.

Species Group	Percent Reduction By Weight		
	July 1993	June 1995	July 1995
Pink Shrimp	6 ns	Inc	31
Adult Hake	41	70	81
Juvenile Hake (≤ 33 cm)	ns	24 **	ns
Large Flatfish	71	97	100 *
Medium Flatfish	84	89	100 *
Small Flatfish	43 *	55	63 **
Large Rockfish	44	100	100 *
Small Rockfish	65 **	47 *	78 *
Skates/Rays	--	100	--
Dogfish	78	72 **	100 *
Baitfish	ns	67	83
Assorted Roundfish	81	94	--
Misc. Fish	--	92	97 *
Hagfish/Lamprey	--	ns	ns
Dungeness Crab	--	c	--

"--" = insufficient data, ns = non-significant ($p > 0.10$), c = some crab present, all or mostly in non-excluder side, Inc = Increased catch in excluder side.
*$p < 0.10$, **$p < 0.05$

Table 5. Percent reduction by weight and species group for the 8 inch mesh excluder with the fish escape opening reduced in size approximately 35%. Reduction estimates are significant at $p < 0.01$ unless noted.

	Percent Reduction By Weight
Species Group	July 1995
Pink Shrimp	2 ns
Adult Hake	62
Juvenile Hake (≤ 33 cm)	26
Large Flatfish	--
Medium Flatfish	83 *
Small Flatfish	32 *
Large Rockfish	87 **
Small Rockfish	ns
Skates/Rays	ns
Dogfish	--
Baitfish	48
Assorted Roundfish	--
Misc. Fish	89 **
Hagfish/Lamprey	ns
Dungeness Crab	--

"--" = insufficient data, ns = non-significant ($p > 0.10$), c = some crab observed, all or mostly in non-excluder side
*$p < 0.10$, **$p < 0.05$

Table 6. Percent reduction by weight and species group for the Nordmore grate excluder. Reduction estimates are significant at $p < 0.01$ unless noted.

Species Group	Percent Reduction By Weight		
	June 1995	July 1995	September 1995
Pink Shrimp	Inc	10	Inc
Adult Hake	100	99	100
Juvenile Hake (≤ 33 cm)	30 *	55	64
Large Flatfish	100	100	100
Medium Flatfish	94	80 *	86 **
Small Flatfish	46	58	75
Large Rockfish	100	100	95 **
Small Rockfish	60 **	54 **	84
Skates/Rays	96	--	93 *
Dogfish	100	93 **	100
Baitfish	70	--	71
Assorted Roundfish	100	99	100
Misc. Fish	94	53 *	87
Hagfish/Lamprey	ns	ns	ns
Dungeness Crab	c	c	c

"--" = insufficient data, ns = non-significant ($p > 0.10$), c = some crab present, all or mostly in non-excluder side, Inc = Increased catch in excluder side.
*$p < 0.10$, **$p < 0.05$

Table 7. Percent reduction by weight and species group for the 3 inch mesh excluder. Reduction estimates are significant at $p < 0.01$ unless noted.

Species Group	Percent Reduction By Weight September 1995
Pink Shrimp	7 **
Adult Hake	97
Juvenile Hake (≤ 33 cm)	40
Large Flatfish	99
Medium Flatfish	97
Small Flatfish	69
Large Rockfish	100
Small Rockfish	71
Skates/Rays	100
Dogfish	95
Baitfish	65
Assorted Roundfish	96
Misc. Fish	89
Hagfish/Lamprey	ns
Dungeness Crab	c

"--" = insufficient data, ns = non-significant ($p > 0.10$), c = some crab observed, all or mostly in non-excluder side
*$p < 0.10$, **$p < 0.05$

small and medium-sized species, none of the devices significantly reduced the catch of hagfish, a common, but not abundant, bycatch species.

One important area in which the 3 inch and Nordmore devices out-performed the other devices was in the exclusion of adult and juvenile hake. On average, the Nordmore grate and 3 inch excluders removed nearly 100% of the adult hake and 40-50% of the juvenile hake, by weight. The 5 and 8 inch devices removed roughly 70% of the adult hake and 8-33% of the juveniles. Since hake were quite abundant during the study, these differences may account for much of the difference in overall performance between the devices (Figure 8). It should be noted, however, that juvenile hake were increasing in size as the field season progressed, skewing the juvenile numbers somewhat. For example, the exclusion efficiency of the Nordmore grate for juvenile hake increased from 30% in June 1995, to 55% in July 1995, to 64% in September 1995. The 3 inch mesh device was only tested in September, while the 5 and 8 inch devices were only tested in June and July, 1995. Accordingly, the apparent differences in exclusion efficiency for juvenile hake may be somewhat overstated by the catch data.

Exclusion by Fish Size

In general, the length data show that all of the devices were very efficient at excluding large fish and less efficient with smaller ones (Figures 9-15). Also, as expected, the Nordmore grate and three inch soft-panel excluder were somewhat better at excluding small fish than the 5 and 8 inch excluders. The exclusion efficiency of hake and spiny dogfish, by length, followed this general pattern (Figures 9 and 15). However, there were some fish groups in which one, or both, of the larger mesh excluders performed comparably to the Nordmore grate and three inch mesh excluder. This was the case for rockfish (Figure 11), where the 3, 5 and 8 inch mesh excluders performed similarly, while the Nordmore grate excluded fish more effectively than the other three devices. The exclusion efficiency for roundfish was high for all 4 devices (Figure 12). Somewhat surpising was the fine performance of the 5 and 8 inch mesh soft-panel excluders at excluding smaller flatfish (Figure 10), which were not excluded at high rates by the Nordmore grate and the 3 inch excluder. One possible explanation for the lower performance of the Nordmore grate at excluding small flatfish is that the vertical bars allow small and medium-sized flatfish to pass through very easily if they turn sideways.

The Nordmore grate performed better at excluding small baitfish than the other devices (Figure 13). For baitfish above 15 cm, the 5 and 8 inch excluders showed roughly similar performance to the Nordmore grate, while the 3 inch mesh excluder was somewhat less efficient. The baitfish graph for the 3 inch mesh excluder also shows that the control net was more efficient at catching small and medium sized baitfish than the net with the excluder device. This graph was strongly influenced by the catch from one particular tow in which the starboard net on the F/V Ginger B, with the excluder, caught several times more herring than the port net. If this tow is excluded from the analysis, the performance of the 3 inch

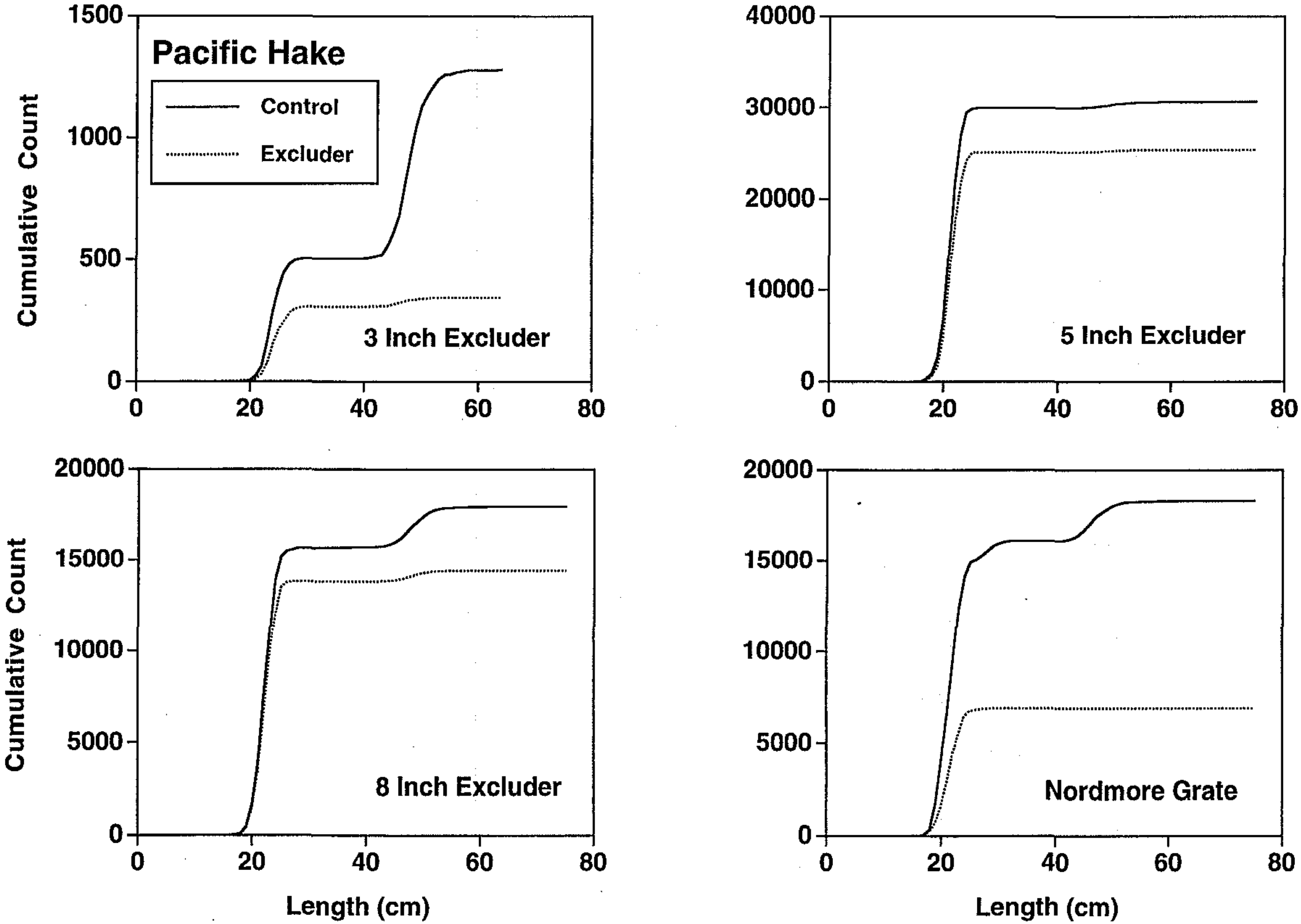


Figure 9. Cumulative length frequency distribution (cm) of Pacific hake retained by the experimental and control nets during tests of four fish excluder devices.

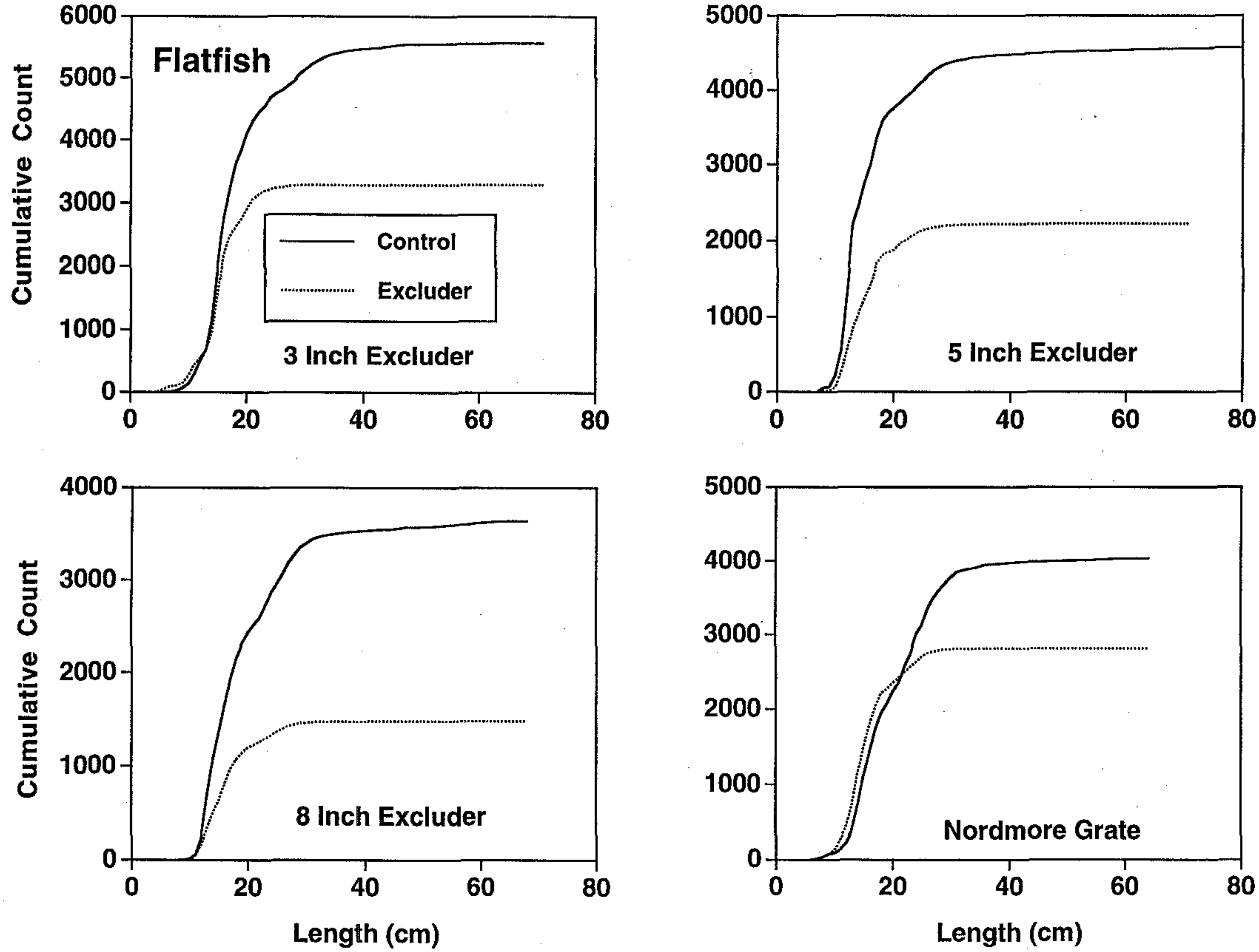


Figure 10. Cumulative length frequency distribution (cm) of flatfish retained by the experimental and control nets during tests of four fish excluder devices.

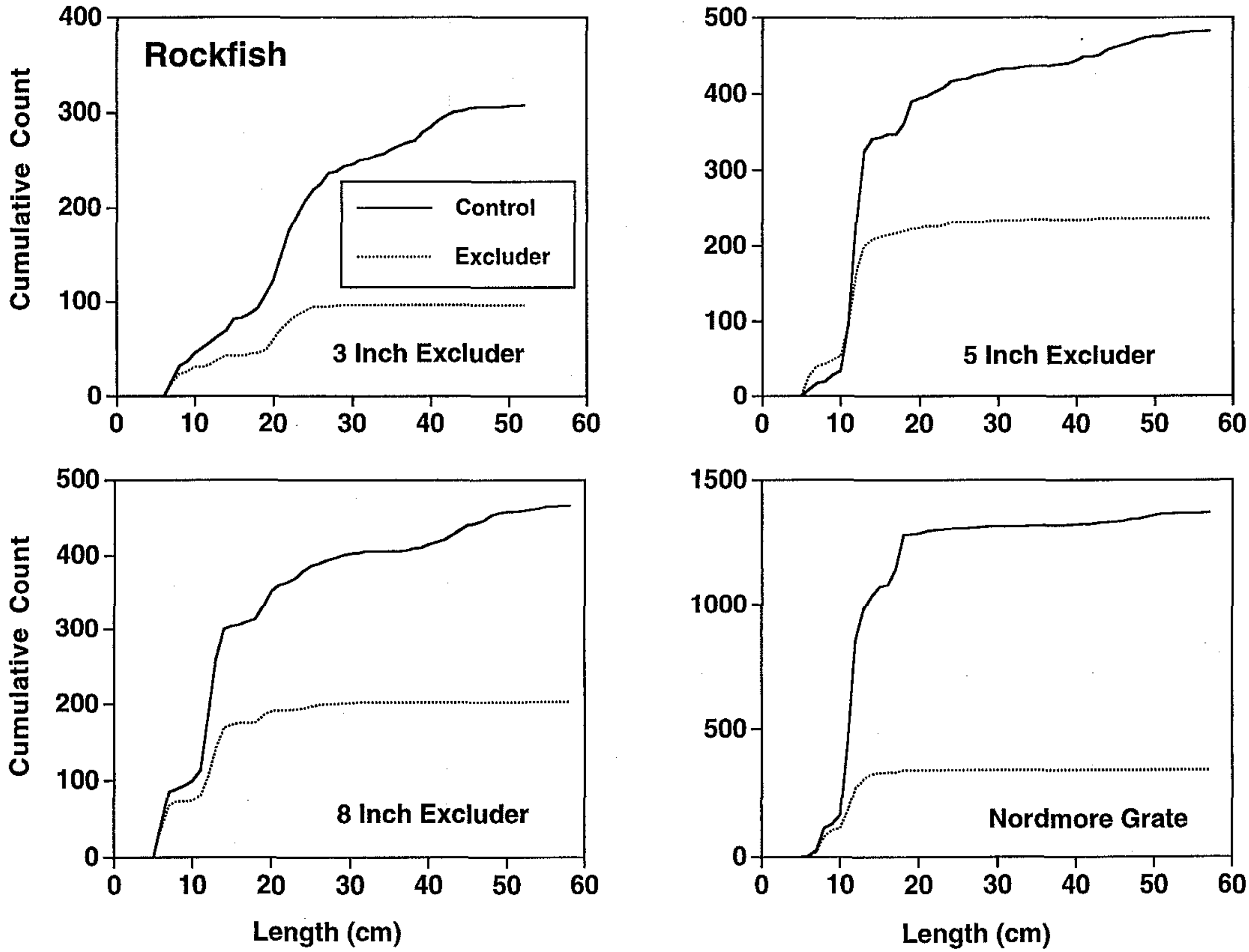


Figure 11. Cumulative length frequency distribution (cm) of rockfish retained by the experimental and control nets during tests of four fish excluder devices.

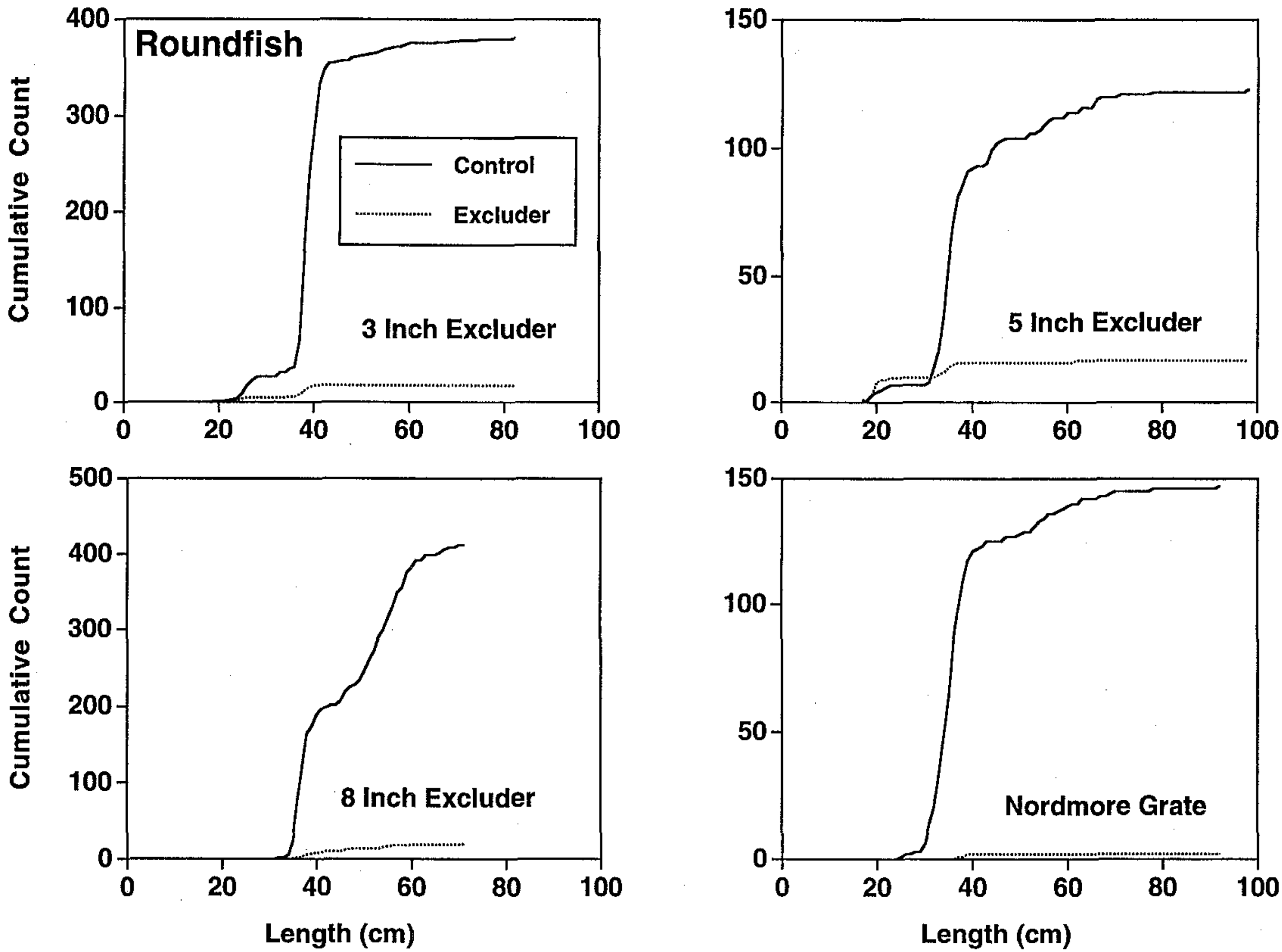


Figure 12. Cumulative length frequency distribution (cm) of roundfish retained by the experimental and control nets during tests of four fish excluder devices.

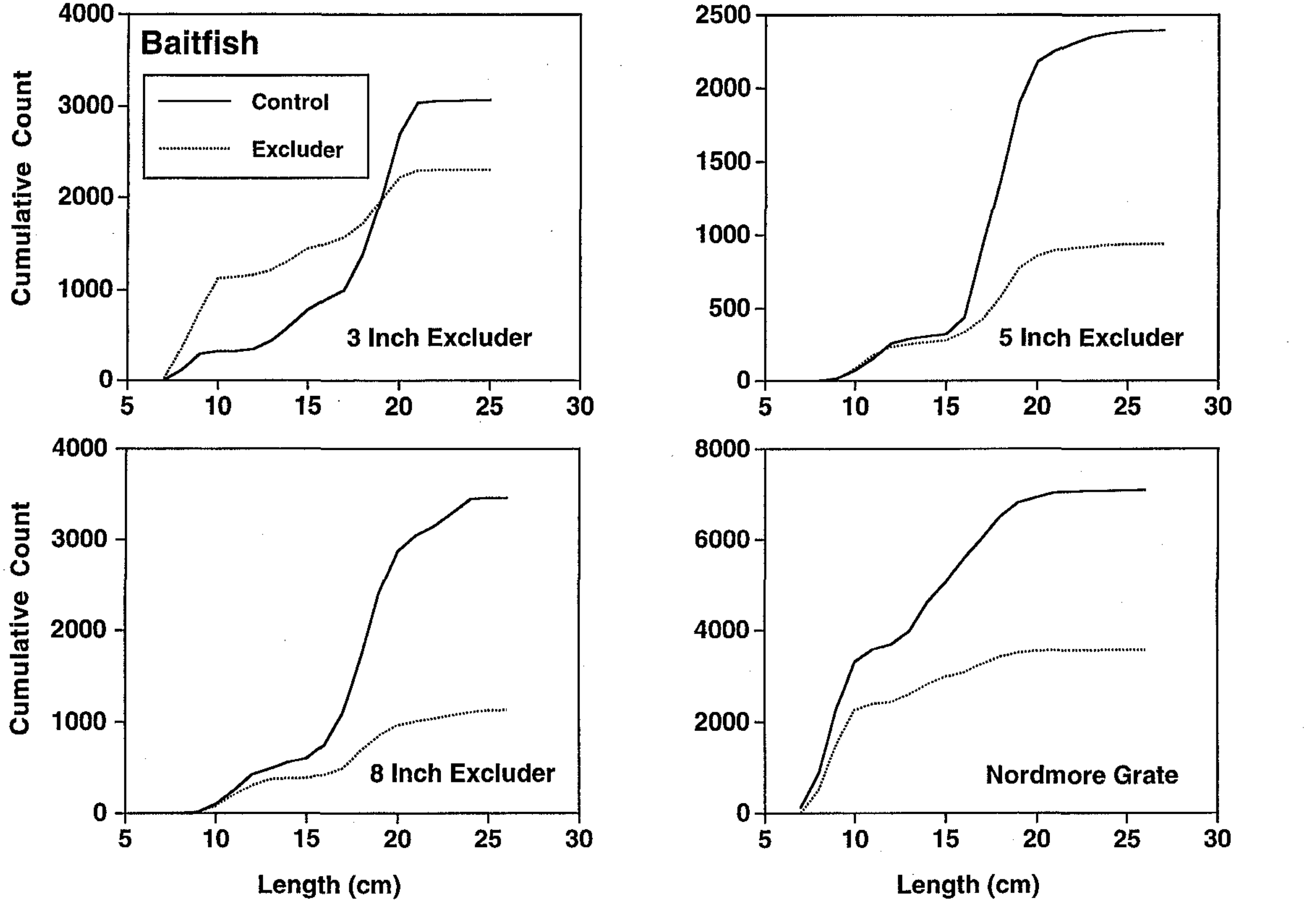


Figure 13. Cumulative length frequency distribution (cm) of baitfish retained by the experimental and control nets during tests of four fish excluder devices.

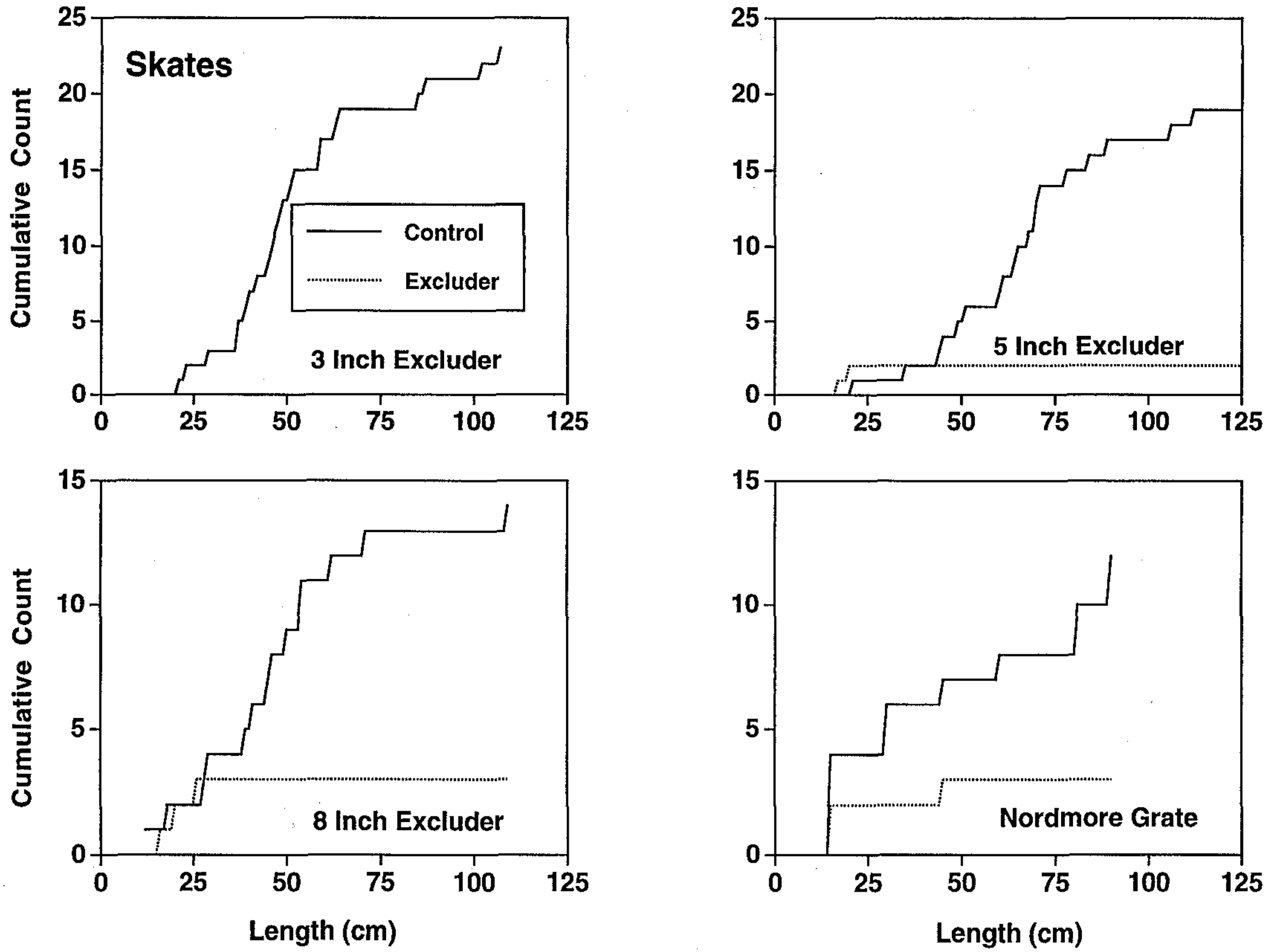


Figure 14. Cumulative length frequency distribution (cm) of skates retained by the experimental and control nets during tests of four fish excluder devices.

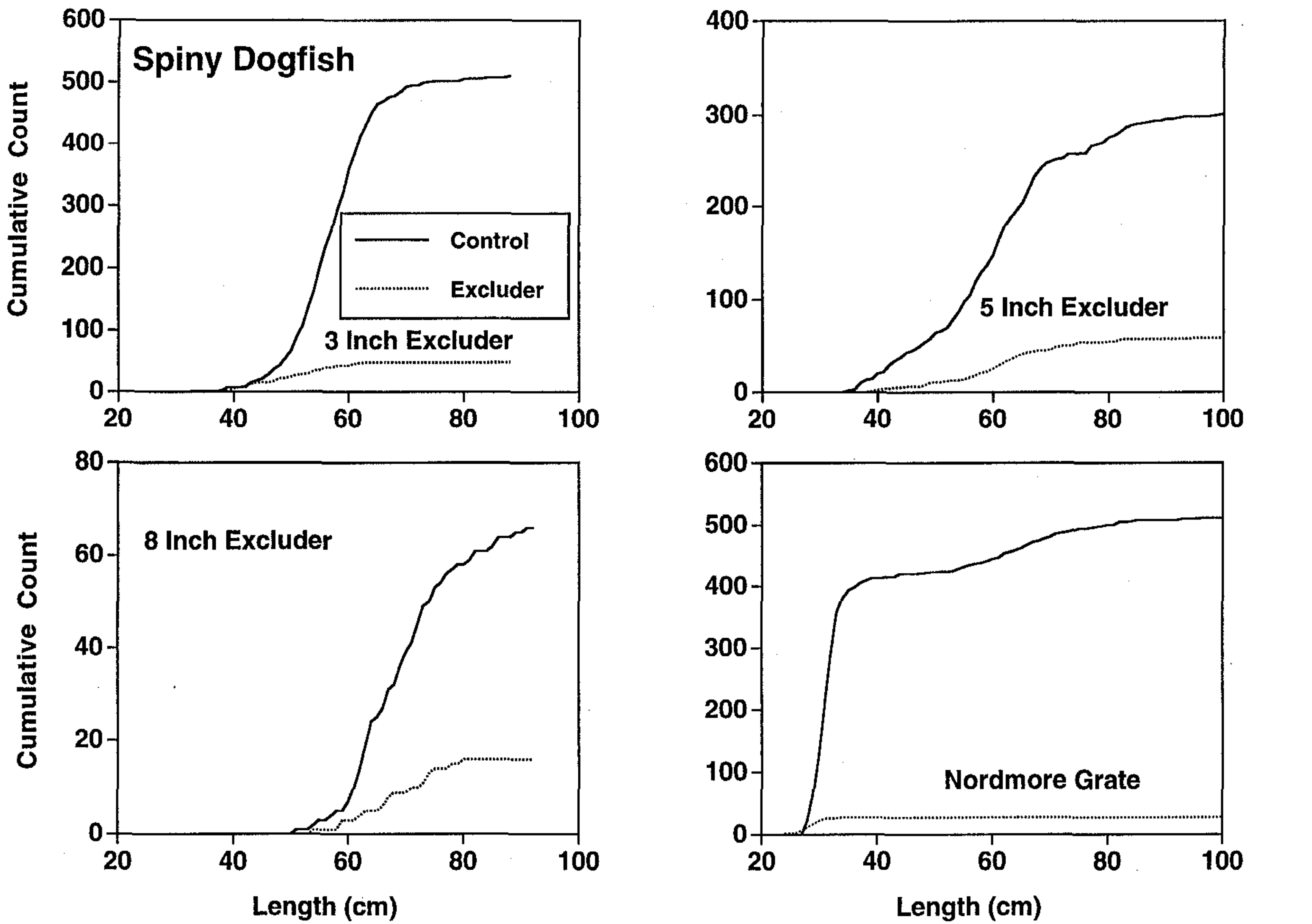


Figure 15. Cumulative length frequency distribution (cm) of spiny dogfish retained by the experimental and control nets during tests of four fish excluder devices.

mesh excluder at removing small baitfish closely mimics the performance of the 5 inch mesh excluder. The most reasonable explanation for these results is that a large school of herring entered the starboard net, by chance, skewing the overall results. The general tendency for the F/V Ginger B's starboard net to out-fish the port net probably also contributed to the problem.

All of the excluder devices tested showed some evidence of excluding Dungeness crab (*Cancer magister*), although crab were only encountered in abundance on one, very atypical, haul. In this instance, the last haul of the day yielded approximately 500 lbs of softshell crab in both the experimental and control nets, with no other species present. The Nordmore grate we were fishing at the time appeared to be ineffective at excluding such a large volume of crab. In this instance, the crab accumulated just forward of the grate. Market squid (*Loligo opalescens*) were also encountered, in moderate abundance, on one cruise. At that time we were also fishing the Nordmore grate and it appeared that this excluder reduced the squid catch by roughly half.

Shrimp Loss Through The Excluders

The shrimp loss caused by the devices showed wide variation between cruises, even with the same excluder device (Tables 3-7). For example, shrimp loss with the 5 inch device (Table 3) ranged from 7 to 15%. With the 8 inch mesh device, it ranged from a net increase to 31% (Table 4). On two of the three Nordmore grate cruises, the side with the excluder device also caught more shrimp than the control side, while on the other cruise a 10% loss of shrimp was measured (Table 6). Shrimp loss for this single cruise is well above the 2-4% shrimp loss reported in the literature (Isaksen et al. 1992, Kenney et al. 1992a, Kenney et al. 1992b, Ryan and Cooper 1991). One possible explanation for the high shrimp loss on this trip is that the average size of shrimp was very large for this trip, much larger than all of the other cruises (Table 8). This result suggests that a Nordmore grate with bar spacing greater than 1 inch may be needed for this fishery, especially in the more southern fishing areas, where shrimp are generally bigger. Larger bar spacing may, in turn, degrade the fish exclusion performance of the Nordmore grate, especially with smaller fish.

The Nordmore grate caused less shrimp loss than the 5 and 8 inch excluders (Tables 3-6). The data for the 3 inch mesh excluder and for the eight inch mesh excluder with a reduced escape aperature (Tables 5 and 7) suggest, however, that comparable performance may be attainable from the soft-panel excluders. Reducing the escape port on the 8 inch device appears to reduce shrimp loss, but this improvement in shrimp loss may be at the expense of fish exclusion efficiency. Since we obtained only a single shrimp loss estimate for these two variations, additional testing is needed to determine the full potential of the soft-panel excluders.

To maximize efficiency, the Nordmore grate employs a grate with narrow bar spacing to exclude even some small fish, along with an accelerator funnel to concentrate the catch near the bottom of the net and minimize shrimp loss (Figure

Table 8. Mean count-per-pound of ocean shrimp from the experimental and control nets, grouped by excluder type and cruise date. Asterisks denote levels of statistical significance for the observed difference in count-per-pound. ANOVA model is three factor with haul number, side of gear (port or starboard) and excluder (enabled or disabled) as main effects.

Excluder	Cruise Date	Number of Hauls	Mean Count-Per-Pound	
			Control	Experimental
5 Inch Soft-Panel	June 1995	18	144.0	143.0ns
5 Inch Soft-Panel	July 1995	20	127.5	131.5**
8 Inch Soft-Panel	June 1995	20	142.4	154.9***
8 Inch Soft-Panel	July 1995	20	131.1	131.4ns
Nordmore grate	June 1995	16	123.2	123.5ns
Nordmore grate	July 1995	14	91.1	90.5ns
Nordmore grate	Sept. 1995	14	122.8	134.9***
3 Inch Soft-Panel	Sept. 1995	20	123.5	124.8ns

ns = non-significant, $^{*}p < 0.05$, $^{**}p<0.01$, $^{***}p<0.001$

3). This makes the relatively good performance of the 3 inch mesh excluder somewhat surprising. If this excluder can consistently show low shrimp loss, it may be due to it's particular design, which differed from the other soft-panel excluders. Most significantly, the escape port on the 3 inch mesh excluder was oriented longitudinally on top of the net. The 5 and 8 inch devices had somewhat smaller escape ports, oriented perpendicular to the longitudinal axis of the net. In this design, additional strain on the net, from the drag of the catch, may stretch open the escape port, while in the longitudinal design, additional strain should have less effect on the escape port width. Additionally, while all of the mesh panels attach to the upper part of the codend slightly behind the escape port, creating a "lip" of sorts, the 3 inch device has a somewhat larger "lip". Some additional testing of the three inch mesh excluder, including some underwater video footage, is needed to verify it's performance and to evaluate how this design can be "tuned" to work even better.

Shrimp Size Composition

The comparison of average shrimp count-per-pound between the experimental and control nets suggests that sometimes the 5 and 8 inch excluders and the Nordmore grate can significantly increase the average count of shrimp ($p<0.01$, Table 8). Moreover, the trips with elevated counts in the excluder net were not consistently the trips showing high levels of shrimp loss (Tables 3-7). These results are difficult to explain fully, however Beardsley's (1973) research suggests a possible explanation. Beardsley (1973) examined the near-bottom vertical distribution of ocean shrimp and showed that sometimes shrimp are vertically segregated by size, with the larger shrimp higher off the bottom. If, on some of our cruises, larger shrimp were further off bottom, perhaps enough large shrimp were transported out the escape hole to increase the average count of the catch.

Summary of Observed Bycatch

The bycatch we encountered on our 8 research cruises varied substantially between cruises (Figure 16). Fish represented the majority of the control side catch for most of our cruises, and ranged from 25% to nearly 75% of the total catch. This level of fish catch is not unusual for this fishery, especially when shrimp abundance is low, as it was in 1995. The shifting nature of bycatch in this fishery is also well shown by the data we collected. For example, we encountered our lowest percentage of bycatch in PSMFC area 84 in June and our highest level in the same area the very next month (Figure 16). It is common in this fishery to see bycatch levels vary between different areas and months. In general, Pacific hake dominated the bycatch we encountered, although flatfish, baitfish (mostly Pacific herring) and spiny dogfish were also quite abundant in some samples (Table 9). The species mix we encountered was fairly typical for the shrimp fishery in PSMFC areas 72 -84.

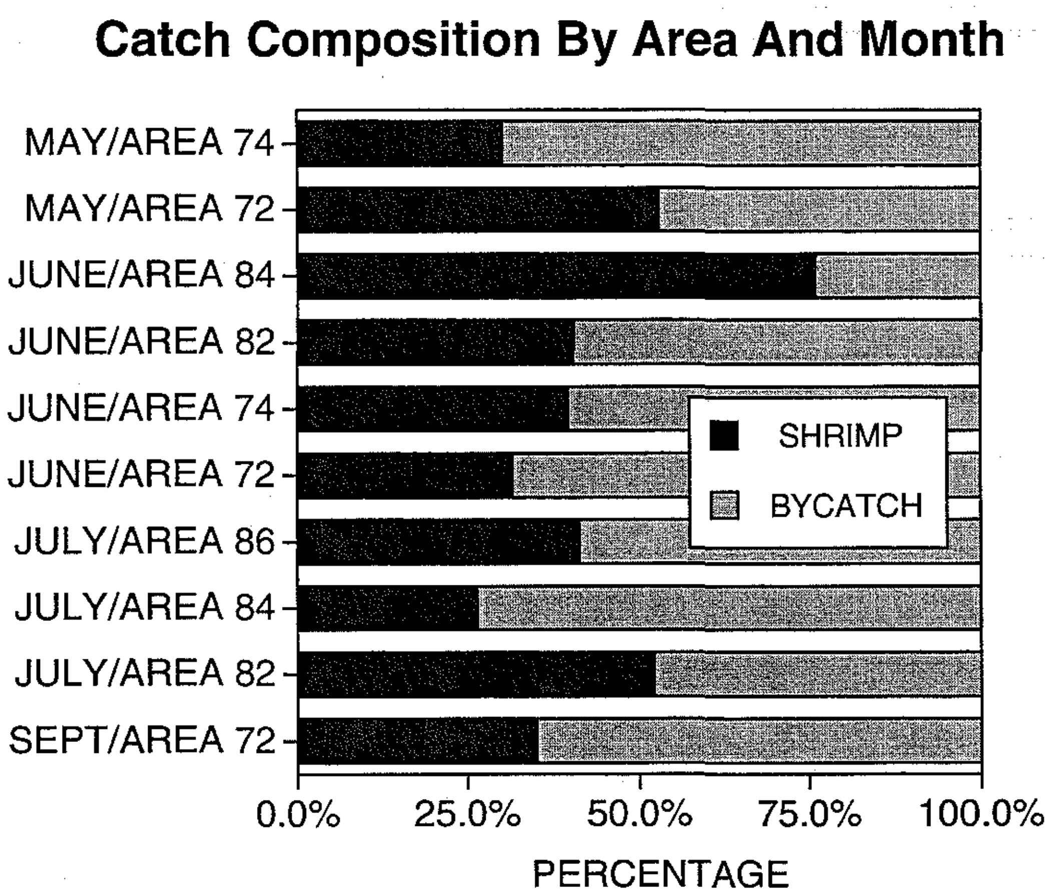


Figure 16. Composition of the catch in the control net by area and month.

Table 9. Percent composition by weight of the fish bycatch from the control net and all calibration tows, by PSMFC statistical area and month, 1995.

Month	PSMFC Area	Percentage Composition of the Fish Bycatch								
		Pacific hake	Flatfish	Rockfish	Baitfish	Roundfish	Spiny dogfish	Skates	Misc.	Total
May	74	40.4	33.0	5.4	10.6	1.0	6.6	2.2	0.8	100.0
May	72	51.8	10.9	9.6	8.2	4.2	12.4	2.7	0.2	100.0
June	84	53.5	28.7	2.8	4.9	4.7	0.0	1.1	4.3	100.0
June	82	86.6	10.3	1.0	0.1	0.7	0.0	0.4	0.9	100.0
June	74	62.0	12.3	1.3	22.6	0.8	0.7	0.0	0.3	100.0
June	72	79.4	8.9	2.5	0.5	6.7	1.6	0.2	0.2	100.0
July	86	81.5	8.1	1.1	0.1	3.3	4.6	0.6	0.7	100.0
July	84	93.8	2.5	1.8	1.3	0.4	0.0	0.0	0.2	100.0
July	82	90.0	3.3	1.8	2.3	0.5	0.1	0.5	1.5	100.0
September	72	68.5	7.2	2.2	11.0	3.9	5.5	0.8	0.9	100.0

Operational Assessment

Deployment and retrieval of nets with the soft mesh excluders was simple and straight-forward, with no operational problems observed. The deck crews set and hauled their nets as they normally would. However, the Nordmore grate system was fairly cumbersome to handle, causing crews to deviate from their normal net handling procedures. We found that the rigid Nordmore grate tended to hang-up on hard deck structures, which necessitated crew intervention. The grate and frame became hazardous at times while suspended above-deck during heavy seas. Part of the difficulties experienced were undoubtedly caused by the aluminum frame that we used around the Nordmore grate itself in order to facilitate disabling of the device. However, we feel that most of the on-deck handling difficulties would remain if a plain polyethylene Nordmore grate were used. The Nordmore grate also required more care when releasing the nets after unloading the codends. The crew needed to be quite careful to make sure that the net was released exactly as it had been brought in and not with a 360° twist. Such a twist is trivial with other excluders since the net is free to untwist as it is reset. With the rigid Nordmore grate, having floats at the top to keep the grate upright under water, the twist will not come out on its own. Rather, the nets had to be brought in, untwisted, and reset. One vessel also had to alter its standard procedure for loading the nets onboard at night to accomodate the Nordmore grate system. The crew of the F/V Lady Kaye generally used a net block to load the nets, which saves time. Since the rigid Nordmore grate could not pass through a net block, the more time consuming method of grabbing "bites" of the net, and hauling them onboard with the hydraulics, had to be used.

We noted a variety of factors which we believe may have influenced the performance of the excluders. Each of these factors need to be considered by excluder users, and solutions for achieving optimum performance should be expected to vary between different nets. First of all, we observed consistent excluder performance differences between the nets of the Ginger B and Lady Kaye, even though the same excluder extension section was used on both vessels and was installed in the same way. Catch did not wash back as readily into the codends of the Lady Kaye's nets as it did on the Ginger B. Apparently, water flow characteristics were different between the nets. The nets on these vessels were all high rise box trawls, but were supplied by different manufacturers. The nets presumably had construction differences. In addition to these differences, each skipper presumably tuned their nets differently, such as different footrope setbacks from the doors. It was beyond the scope of this study to define and evaluate the effects of these differences but it is important for fishermen and fishery managers to realize that excluders need to be tuned to individual nets.

Our observations convinced us that shape and size of the excluder escape port may have important impacts on performance. Mid-way through our test of the 8 inch soft-panel excluder on the Lady Kaye, we noted that shrimp loss appeared to be abnormally high. We had previously noted that the escape port was larger on this device than with the 5 inch mesh device but had deferred to current manufacturing norms. We decided to reduce the escape port size in an attempt to reduce shrimp loss, and were successful. There are obvious real limits to how small the escape port can be while still allowing passage of larger fish, but fishermen do have some latitude when tuning excluders for their nets. Another solution became apparent when we tested the 3 inch soft-panel excluder. This excluder utilized a longitudinal slit as the escape port instead of the side-to-side slit used with the other soft-panel excluders. Our video assessment showed that the side-to-side slit was kept open during fishing, apparently through a combination of water pressure and net tension. The 3 inch mesh device (Figure 2) was not assessed during our video work, but discussions with fishermen have convinced us that net tension tends to keep the longitudinal escape port more closed. Hence a relatively large escape port can be used to pass large fish without increasing shrimp loss.

The method we used to disable and enable the soft-panel excluders is commonly used in the shrimp fleet, but it may have had subtle influences on our ability to estimate shrimp loss. The inverted "U" shaped tongue cut in the excluder panel (Figure 1) was resewn by hand each time the excluder was enabled. Due to the awkward conditions imposed by limited access through the excluder escape port, imperfect alignment of the tongue and non-uniform tension on the suturing line may have caused some distortion in the excluder panel while fishing. Variation in exclusion efficiency or shrimp loss caused by such distortion could not be measured. Some fishermen in the fleet use a vertical slit in the center of the excluder instead of a "tongue". This design was incorporated in the 3 inch mesh excluder we tested (Figure 2). With this approach, fewer meshes need sewing, alignment is straight-forward, and a more uniform tension in the excluder panel is easier to achieve. Our observations suggest that the vertical slit is the preferred method for disabling and re-enabling these devices.

Fish gilling was less of a problem than we had anticipated with all of the devices. No gilling was observed between the bars of the Nordmore grate at all. Meshes in the accelerator funnel were readily clogged by some kinds of small fish, notably eelpouts (family *Zoarcidae*), but this didn't noticeably influence funnel performance. It is a potential problem for fishermen however, who must remove entangled dead fish from the net at the end of each trip. Access to the funnel for cleaning is poor. A long longitudinal zipper placed over the funnel could ease this problem and facilitate the removal of other debris as well. We experienced some gilling with all of the soft-panel excluders, primarily adult hake and dogfish. The fish were usually gilled high on the excluder panel near the escape port. It is unclear whether the fish were gilled while the net was fishing or during haulback. However, we did not observe any gilling during our video assessments, indicating that gilling during haulback is the most likely explanation.

B. Problems

The only significant problems that surfaced during this study were those caused by the differences in fishing efficiency between the port and starboard nets on the F/V Ginger B. For all of the cruises on this vessel, the "side" effect was statistically significant ($p<0.05$), with the starboard net consistently out-fishing the port net. This was never the case for the cruises on the F/V Lady Kaye ($p>0.05$). Our study design was set up specifically to account for between-net differences in efficiency, and we also made some adjustments to help minimize this problem (detailed above under Study Design). However, our application of ANOVA here assumes a linear additive model is appropriate for our log-transformed catch data and, implicitly, that all of the basic assumptions of ANOVA are also met. We think it's possible that departures from normality in the transformed data, in combination with major differences between port and starboard nets, may have made it more difficult to detect significant differences in shrimp catch caused by the excluders on the F/V Ginger B cruises. For subsequent work using double-rigged shrimpers for comparative fishing experiments, we recommend that a day is spent calibrating and modifying, as needed, the port and starboard nets prior to conducting experiments. Our experience suggests that for the ocean shrimp fishery, in which the height of the footrope above bottom seems to have a critical impact on catch rate, a video view of both footropes might be another way to quickly tune the nets to fish more evenly.

C. Need For Additional Work

These data show that the soft-panel excluders used in the ocean shrimp fishery exclude fish quite effectively, but cause somewhat higher shrimp loss than the Nordmore grate. They also suggest that the 3 inch mesh soft-panel excluder may have the potential to provide comparable performance to the Nordmore grate, at least in this fishery. Although the use of excluders in the ocean shrimp fishery is growing slowly, some fishermen are resistant towards using the devices, probably as a result of experiencing high levels of shrimp loss. Our data show that the fishermen's experiences are not unusual. We encountered a lot of variation in shrimp loss with all devices, despite prior underwater video assessments, a technique generally not available to fishermen. If the use of excluders is to grow, the devices need to be capable of consistently producing low levels of shrimp loss, while efficiently excluding the fish that are a nuisance to fishermen, especially hake, small baitfish and small flatfish. The next logical step is to try and replicate the performance of the three inch mesh excluder on an additional 2 trips. Another obvious step is to obtain some underwater video footage of this device to see how the size and orientation of the escape port is influencing shrimp retention, and how shrimp retention might be improved. Additionally, some video assessments should be conducted at a more basic level to determine how escape port size, shape and orientation influence codend shape and shrimp retention. Having this additional information should allow us to develop a fish excluder "primer" for fishermen; a pamphlet or video which helps fishermen and net shops trouble-shoot an excluder installation and obtain peak performance.

Our data suggest that shrimp retention with the Nordmore grate, in this fishery, might be improved by increasing the bar spacing to accomodate larger shrimp, which are sometimes encountered. It's also possible, however, that increased bar spacing may degrade fish exclusion performance. Additional field tests with a grate employing wider bar spacing are needed to answer these questions. Since excluders are not mandatory for this fishery, fishermen favor devices which can be readily disabled to take advantage of marketable bycatch when it is available. Accordingly, we consider further research with the Nordmore grate, which cannot be readily disabled, a lower priority than efforts to further improve the soft-panel devices which fishermen are using now voluntarily.

VII. Evaluation

While the results of this study do suggest some additional work that needs to be done, the objectives of the project were all met or exceeded. We determined the level of shrimp loss, and degree of variability in shrimp loss, that can be expected from the 3 devices that were originally scheduled for evaluation. Although our original objective of measuring shrimp loss was met, the level of variability we encountered suggests that additional tests could improve our knowledge of the average shrimp loss each device is likely to cause. We also collected some fish exclusion and shrimp loss data on an additional device, the 3 inch mesh excluder, which shows a lot of promise. Fish exclusion efficiency, by weight, and differentially by fish size, was also determined for all of the devices. We also found that some of the excluder devices can occasionally increase the average count of shrimp retained.

The findings from this study have already been disseminated to some degree and have met with favorable comments from scientists and industry members. Preliminary results were presented at the joint industry/agency bycatch workshop in Seattle, Washington, September 25-27, 1995. This conference was entitled "Solving Bycatch; Considerations for Today and Tomorrow". Updated results were next presented at the 9th Western Regional Groundfish Conference in Newport, Oregon, January 23-25, 1996.

To provide better public access to the results of this study, we produced a short VHS videotape summarizing this project and our principal findings, complete with narration and some underwater and on-deck footage. Copies of the video summary have been provided to all of our cooperators in the study, including the Oregon Otter Trawl Commission, Astoria Net Shop and to National Marine Fisheries Service Resource Assessment and Conservation Engineering Division. Copies of the videotape and this final report, are also available upon request from our regional office in Newport, Oregon. To further disseminate the findings of this study to the fishing industry, we also published a brief summary of the results in our annual shrimp industry newsletter, in March 1996.

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