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Preliminary Tests of a Shrimp-fish Separator Section for Use in Shrimp Trawls

by

C.W. West, J.W. Valdemarsen, and B. Isaksen
Institute of Fishery Technology Research
Box 1964, N-5011 Bergen-Nordnes, Norway

ABSTRACT

A prototype shrimp-fish separator to be installed between the body and codend of a shrimp trawl was designed and constructed. The separator uses large square meshes to provide an escape path for fish, while funnels constructed of small mesh webbing keep the shrimp away from the big meshes and act as leading panels to guide the fish out of the trawl. A prototype was installed in the cut away after parts of a shrimp trawl, which was then mounted on an oval steel frame and towed just below the surface so that necessary adjustments could be identified and tested. After a satisfactory design had been developed, fishing trials were carried out in May, 1984, and further modifications to improve the separating efficiency were made. Preliminary analysis of this data shows that up to 61% of haddock less than 39 cm escaped, and up to 30% of cod less than 42 cm. Visual observations of a similar separating section were carried out with a remotely controlled underwater TV vehicle, and these are described.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

Substantial by-catches of juvenile cod (Gadus morhua) and haddock (Gadus aeglefinus) constitute a major conservation problem in the Norwegian shrimp (Pandalus borealis) fisheries. In order to conserve these fish the Norwegian Directorate of Fisheries conducts test fisheries on productive shrimping grounds and opens the grounds for commercial fishing only when the catch of sublegal (less than 39 cm) haddock and sublegal (less than 42 cm) cod falls below 3 fish per 10 kg of shrimp. In its efforts to develop shrimp-fish separator trawls that will permit continued shrimp production while holding the fish by-catch to acceptable levels, Fiskeriteknologisk Forskningsinstitutt (FTFI) has investigated several alternative potential separation methods. This note will describe the preliminary work done with one of these methods.

Norway is not alone in its efforts to reduce fish by-catches during shrimp trawling operations. FAO sponsored a conference in 1973 at which fishing gear experts from all over the world described efforts in their home countries to develop selective shrimp trawls (Anon., 1973). Efforts since then have continued in several countries including Canada (Way and Hickey, 1978), France (J C Brabant, pers. comm.), and the USA (Watson, 1983), as well as in Norway (Karlsen, 1978, and Isaksen, 1982). Most of the separators tested have used some kind of panel of webbing placed in the mouth or throat of the trawl to guide fish towards an escape opening while allowing shrimp to pass through the relatively large meshes of the panel and into the codend.

In many instances this approach has given promising results under ideal conditions only to perform poorly in the field for one reason or another. Some designs have proven too complex and fragile to withstand the abuse of daily production fishing, while others have shown a tendency to become blocked with flatfish or debris, with subsequent unacceptable rates of shrimp loss. A few designs have given sustained good results in one or two trawl types, but are difficult to adapt to other trawls, a problem in fisheries where a wide variety of gear types are used.

A different approach was taken with a design developed in 1983 at FTFI (Valdemarsen and Isaksen, 1984). The "double trawl" is made up of two small, mirror-image trawls joined together side by side and fished from a single pair of doors (Figure 1). The trawl on the port side has a port wing but no starboard wing, and vice versa, so the effect is of two trawls fishing from a single headrope and a single footrope. Where the two trawls are joined, a gap (adjustable from 0.5 to 3.0 m) has been left. In principle, fish guided down the wings and concentrated in front of the center of the footrope should detect this gap and swim out between the trawls, while the more passive shrimp would be captured.

Another design, a device originally developed for the US Gulf of Mexico shrimp fisheries to reduce the by-catch of sea turtles, has shown strong potential as a fish separator (Watson, 1983). Known as the "Trawling Efficiency Device," or TED, it is installed in the trawl just in front of the codend. It consists of an open steel or plastic framework, roughly cubical in shape, covered with webbing (Figure 2). A sharply tapering funnel of small mesh webbing is sewn into the front opening of the framework, with the small end of the funnel ending just in front of an array of bars, which slant up and back within the framework. Turtles and other large objects such as sponges that have passed down the trawl and through the funnel are mechanically ejected when they strike these slanted bars and are forced up through a hinged door. Shrimp, fish, and other objects small enough to pass between the bars are carried on through and out of the TED in the jet of accelerated water behind the funnel outlet.

The potential of the TED as a separating device was first detected when divers observing the passage of sea turtles through it during tests noticed that fish had a tendency to turn and swim radially out of this accelerated flow and then swim forward inside the TED in the zone of relatively slack water above, below, and alongside the funnel. They swam forward as far as they could until they were blocked by the walls of webbing around the framework, then for the rest of the tow they kept station within the TED. After this had been reported, openings were made in the webbing to allow the fish to escape, situated in front of the funnel exit. Thus the only route to the escape openings was down the trawl, through the funnel and between the slanted bars, then forward again within the TED but outside the funnel. Shrimp, being relatively weak swimmers, were not able to reach the openings, while most fish could do so with ease. Comparative fishing trials demonstrated that in the daytime separation rates of as much as 98% could be achieved for some fish species, with negligible losses of shrimp.

These are among the best separation rates that have ever been achieved, so there was considerable interest at FTFI in finding a way to adapt this method to the Norwegian shrimp fisheries. Unlike the US Gulf of Mexico shrimp fisheries, however, almost all of the Norwegian shrimpers use net reels to shoot and store their trawls, and it was felt that a rigid framework would not be practical in this situation. Consideration of the separating principle employed in the TED suggested that with some modifications, it might be possible to achieve the same effect in a "soft" structure made entirely of webbing, or webbing and ropes. In addition to being easy to handle with a net reel, such a design should be easily adaptable to any existing shrimp trawl design. The ultimate goal was a separator design that fishermen and trawl manufacturers could build themselves to install in any trawl, working from a set of simple guidelines or sample plans.

The FTFI design (Figure 3) adopted the principle of using funnels of webbing to concentrate fish and shrimp toward the longitudinal axis of the gear while providing escape avenues for fish through slack water towards openings. However, instead of a rigid frame, the FTFI design relies on hydrodynamic forces and careful tailoring of the components to hold them in the right shape and the right spatial orientation to each other.

This design, referred to hereafter as the Radial Escape Section, or RES, consists of a cylinder of large square mesh webbing within which are installed two funnels, or cones, of small mesh webbing. The large or leading end of the first funnel is sewn to the front of the cylinder and the second funnel is sewn into the cylinder just behind the exit from the first funnel.

To install the RES, the shrimp trawl is cut at the point where its cross-sectional diameter, when towing, is equal to the diameter of the cylinder. The RES is inserted into the gap and mended into the trawl, effectively lengthening the trawl by the length of the cylinder. The expectation is that when towing, water passing through the trawl will inflate the webbing of the body section and hold the square meshes of the cylinder open. Shrimp and fish will pass back through the body of the trawl and into and through the first funnel. The second funnel is positioned just behind the end of the first so that it will collect the shrimp coming out of the first funnel and pass them on into the small meshed webbing of the intermediate and codend sections behind the RES.

The RES is installed further forward in the trawl than the TED for two reasons: First, since the RES relies on the shape of the rest of the trawl to hold it open, it must be installed where the trawl's shape is roughly cylindrical and of the right dimensions. Second, by installing the RES relatively far forward, it is hoped that the fish will not be completely exhausted from panic escape reactions, as they might be further back towards the codend, and will still have sufficient reserves of strength to take advantage of the escape openings.

Two funnels instead of one are used for the following reasons: Underwater television observations conducted by scientists at the DAFS Marine Laboratory, Aberdeen, showed that codend "flappers" often stimulated a herding response in fish, where they turned and swam in front of the flapper until they were exhausted and fell back through it (Main and Sangster, 1983). The funnels are similar to these flappers in many ways and might provoke the same reaction. The first funnel should stimulate a panic response in the fish as they pass through it so that they are more likely to take advantage of the escape openings after they have emerged from the end of the funnel. The escape response should be heightened by the oncoming second funnel. As they flee from the second funnel, the outer surface of the first funnel should guide them towards the big meshes and escape. Any fish passing through the second funnel would get another chance to turn and swim forward and out through the big meshes between its leading edge and the aft end of the RES. The second funnel must be close enough to the end of the first funnel to intercept the shrimp before they have a chance to fall out through the big meshes, whereas the farther aft it is mounted, the greater the fish escape area will be. A compromise between fish escape rates and shrimp loss rates must be reached, and tandem funnels constitute one way to increase the potential escape area while holding shrimp losses to a minimum.

As is clear from the above description, for the RES to function the various components must assume the correct shapes when towing and must have the proper orientation relative to each other. The big meshes must be well open, the first funnel must be tapered and oriented so that objects passing through it will be scooped up by the second funnel, which must have its outlet well within the small meshed intermediate section. The small mesh funnels cannot block the big meshes or the fish will not be able to escape. For these reasons, during preliminary design stages it was necessary to visually observe the separator and adjacent trawl sections during a tow in order to adjust the details of the construction and positioning of the various separator components.

The next chapter of this report will describe the process by which the RES design was refined into a form suitable for fishing trials. Later chapters will give some of the preliminary results from the first series of fishing trials and describe visual observations of fish reactions to a RES variant during actual fishing operations.

Chapter 2. Towing Tests of the Mockup

Introduction

Before going to the considerable trouble and expense of building a RES prototype and installing it in a shrimp trawl, then conducting fishing trials, it was necessary to answer several questions: Would the funnels and the square mesh escape section take the right shapes and orientation to each other when under tow, and if not, could they be modified so that they would? If this problem could be solved, would the water flow patterns within the RES contribute to its function of sorting out fish while retaining shrimp, or would there be zones of turbulence that might cause shrimp losses or otherwise reduce its effectiveness? Would the towing resistance of the RES be unacceptably high?

There were no satisfactory techniques available to FTFI for observing the RES during fishing operations, installed in a shrimp trawl. It was felt that the quickest and easiest way of getting answers to the above questions would be to build a mockup consisting of a RES installed in the after parts of a shrimp trawl similar to the one in which it would be used during fishing trials, with the whole assembly mounted to a steel frame of the size and shape necessary to simulate the shape the gear would take when fishing. This mockup (Figure 4) was then towed just below the surface at a range of speeds while observations of its shape and other performance characteristics were made from a small boat towed just above it. Necessary modifications were made, and the process was repeated until a design suitable for fishing trials was achieved.

Materials

A prototype RES was constructed (Figures 5 and 6a), consisting of a cylinder of square mesh webbing (290 mm bar length) 29 bars (8.4 m) in circumference and 14 bars (4.1 m) long. Within this cylinder were installed two funnels of shrimp webbing (36 mm stretched-mesh length). The first funnel was sewn to the front of the cylinder and the second funnel was sewn in 8 rows behind the first.

Plans had been made to conduct the first fishing trials of the RES with it installed in one side of the FTFI double trawl referred to in Chapter 1. A scale model of the double trawl had been tested in a flume tank, so data were available on its shape when under tow. The wings of one of these half-trawls were cut away and the RES was installed where the model test data suggested that the diameter of the trawl when towing would be approximately the same as the diameter of the big mesh cylinder. This left some 75 rows of meshes of the original trawl section extending forward from the RES. Using the hanging coefficient derived from the flume tank data, the meshes at the forward end were hung to a loop of nylon rope, 9.2 m in circumference. To this rope were attached 24 carabiner clips spaced every 38 cm.

An oval steel ring was fabricated, to which the mockup could be attached using the carabiner clips. Its dimensions and shape were calculated to hold the mockup open in the shape indicated by the model studies. The ring was 3 m 50 cm wide by 2 m 50 cm high and 9 m 60 cm in circumference. Six bridles, three on each side of the ring, distributed the towing strain evenly around the its circumference. The first two days of tests the frame was towed from two towing warps, one on each side, each warp attached to the three bridles on that side of the ring. However, to facilitate the tension measurements conducted on the third day only one tow line was used, going into all six bridles. This required some slight adjustment of bridle lengths to get even strain distribution.

Methods

All tows were conducted in calm water in Bergen harbor from the R/V "Fjordfangst," a 13 m, 185 HP multi-purpose vessel operated by FTFI. To keep the frame in a stable, upright attitude about 1 m below the surface, an anchor was attached to the bottom center of the frame and two large plastic floats were tied on short tethers to the top. At this depth the mockup was easily observed through a glass-bottomed bucket, held over the side of a small (about 2 m) skiff towed on its own towline.

Deploying the mockup and frame and observing it was a straightforward process. The mockup, the floats and anchor, and towing lines were all attached to the frame and everything was made ready at the stern of "Fjordfangst." Steaming ahead at 1-2 kn (measured with the ship´s Doppler log), the mockup was thrown into the water and after a brief visual inspection to ensure that the webbing was clear the frame was lowered into the water. The towing warps were paid out evenly by hand until it appeared that the mockup was out of the ship´s wake and propwash (usually about 40 m behind the ship) and then they were tied off. The observer then boarded the skiff, and its towline paid out until the skiff was just above the frame. At this point, using the glass-bottomed bucket the observer made sure that the frame was moving straight ahead through the water, using a walkie-talkie to call for adjustments to one towing warp or the other until the tension was evened up. The skiff could be easily positioned over any point along the longitudinal axis of the mockup by paying out or hauling in the skiff´s towline, and by shifting his weight in the skiff the observer could easily control the lateral position of the skiff. All parts of the trawl and RES could easily be seen through the glass-bottomed bucket.

After the gear had been examined, it was hauled back aboard "Fjordfangst." If the observations of the RES had showed that modifications were necessary, they were made at this time and the mockup was made ready for the next observation tow.

On the third day of towing tests some additional observations were made. To determine whether or not eddies were present behind the outlet of the first funnel, 48 water-filled ping pong balls were released from a cage tied in the center of the opening of the frame. 24 of the balls were filled with fresh water and were thus slightly buoyant in seawater, while the 24 seawater-filled balls were slightly negatively buoyant. In addition, on the third day measurements of towing tension were made, which required that the mockup be towed from a single warp shackled to a load cell at "Fjordfangst´s" stern. After all the observations described above had been made, the mockup was towed to the NW at several speeds ranging from 1.4 to 2.5 kn, then the ship turned to the SE and repeated the sequence of speeds. Meanwhile, records of towing speed were written onto the paper chart of the load cell´s recorder in the wheelhouse. At the conclusion of the SE tow, the mockup was brought aboard, the RES was cut out, and the two sections of the trawl were mended back together. The speed/tension runs were repeated, in both directions. Finally, the trawl was removed from the frame and the speed/tension runs repeated with the frame only.

The observed towing tensions were plotted as a function of the speed. Since these relationships appeared to be linear over the range of speeds observed, six linear regressions were computed, one for each direction of tow for each of the three following cases:

Case 1. RES, trawl section and frame, NW and SE;

Case 2. Trawl section and frame, no RES, NW and SE;

Case 3. Frame only, NW and SE.

Using a t-test, the slopes of the NW regression and SE regression within each case were compared to determine if they were significantly different (Zar, 1974). Then the data from the NW and SE tows in each case were pooled and three new regressions were plotted for the pooled data, one for each case. The slopes from Cases 1 and 2 were again compared using a t-test to see if they were significantly different. It was not felt necessary to include Case 3 in this comparison. Using the regression parameters so derived, a table was prepared estimating the tension contributed by the different components of the mockup at various speeds.

Results

Promising results were achived during the trials on the first day. The mockup and frame were easy to handle and took a good shape under tow at 2 kn and it was easy to see all parts of the mockup from the skiff. The square meshes opened up well. However, some problems were apparent with the design of the funnels. Both of them had inflated a great deal under the force of the water flow and had expanded until they were blocking many of the big meshes (Figure 7a). Consequently both funnels were removed and substantial amounts of webbing were cut away, and they were re-installed within the cylinder (Figure 6b).

On the second day of towing tests the funnels looked much better, but some further refinements were called for. The second funnel had a very good shape. The forward funnel was no longer blocking the big meshes at its sides, but it was still too tall top-to-bottom (Figure 7b). In addition, on both the first and second days the first funnel had shown a tendency to fall through the big meshes during the setting phase, getting tangled and not coming clear.

Prior to the third day's trials, an additional 10 meshes were taken out of the center of the aft end of each of the two panels of the first funnel (Figure 6c). 4 strings were run radially from the top, bottom, and sides of the aft end of the first funnel to corresponding points around the mouth of the second funnel. This was done to prevent the front funnel going slack and fouling during setting.

These modifications worked well. The mockup set cleanly and both funnels assumed good, symmetrical shapes in the water, with no tendency to wobble or oscillate. The webbing of the funnels was taut, with all meshes fully opened, and there was no evident distortion either in the funnels or in the trawl sections fore and aft of the RES (Figure 7c). When the 48 ping pong balls were released they all passed cleanly through the first funnel and were captured by the second funnel, which spilled them back towards the codend. There were no suggestions of any turbulent flow that might divert shrimp laterally and out the big meshes. Because of some slight constriction in the after parts of the square mesh section it actually formed a section of a shallowly tapering cone, not a cylinder. However, the constriction did not appear to be severe enough to cause problems.

Towing tension was clearly related to towing speed for the three cases, but was additionally influenced by the direction of tow, at least for Cases 1 and 2. Figure 8 shows the tensions observed, plotted as a function of towing speed. This towing direction effect was undoubtedly attributable to tidal currents along the NW-SE axis in the towing area. To remove the effect of direction of tow, the data from the NW and SE tows in each case were pooled, and new regressions were plotted for each case. The regression coefficients for the three cases (NW tow, SE tow, and pooled data) are given in Table 1, while the t-test results comparing the slopes of the regressions for Cases 1 and 2 are shown in Table 2. Visual inspection of the regression lines shown in Figure 8 suggested that it was not necessary to evaluate whether or not the slope of the Case 3 regression was significantly different from the slopes for Case 1 and/or Case 2.

Table 3 shows the estimated drag contributed by each of the components of the mockup at various towing speeds. These estimates indicate that the extra drag contributed by the RES was low compared to the estimated drag of the codend without the RES, about 33% over the range from 1.4 to 2 kn. This is the range of speeds over which it was intended to test the RES during fishing trials, installed in a full-scale shrimp trawl.

Discussion

At the conclusion of these towing tests it was felt that a design had emerged that was ready for actual fishing trials, a design that had some chance of working as a shrimp-fish separator. All of the initial design objectives had been met: any passively drifting object that entered the RES would be spilled back towards the codend without being lost through the big meshes, the big meshes were well open and accessible to any organism capable of swimming forward to reach them, and the additional drag generated by the RES was felt to be within acceptable limits, unlikely to cause excessive distortion of the trawl within which it was to be installed for fishing trials.

The remaining questions about the effectiveness of the RES could be answered only during actual fishing trials on grounds with mixed fish and shrimp. It was not known if fish would be able to perceive and take advantage of the escape openings. It was not known if shrimp within the RES would be able to swim or drift out through the escape openings and thus be lost. Then there was the possibility that the tests with the mockup were not sufficiently realistic. Perhaps the frame from which the mockup was towed forced the mockup to take a shape unlike the shape that would be assumed by an actual trawl with a RES installed. For instance, perhaps the trawl would collapse so that the big meshes would be blocked, keeping fish from escaping, or perhaps the funnel exits would not line up properly, spilling shrimp towards the openings of the big meshes. Last, there was the possibility that the RES was simply too fragile structurally to withstand the stresses found in real fishing: the funnels might be torn or the trawl might part where the RES was installed, losing the codend.

Whatever the outcome of the fishing trials might be, the towing trials with the mockup had demonstrated the value of this technique for answering specific questions about fishing gear performance. If fishing gear problems are amenable to this sort of technique, it provides a relatively easy and inexpensive alternative to model testing in a flume tank or observations of full-scale gears using divers or underwater vehicles.

Chapter 3. Preliminary Results from the First Fishing Trials

Introduction

The first opportunity to test the RES during fishing operations arose during fishing trials planned for the FTFI double trawl mentioned in Chapter 1. During these trials the double trawl was to be fished with various combinations of rigging, flotation, etc., to ensure that it would fish properly. After the best configuration had been achieved its shrimp and fish catching performance was to be compared with that of a conventional shrimp trawl typical of those used by many of the Norwegian shrimpers. In addition, trawl instruments were to be used to obtain measurements of the geometry of both trawls under various fishing conditions. Preliminary results from these trials are reported in Valdemarsen and Isaksen (1984).

The goals of the trials with the RES, to be conducted at the same time, were as follows: First, to determine if the sorting concept had any validity. If the first trials with the RES showed that it would in fact catch shrimp while allowing fish to escape, then efforts would be made to refine the design to maximize shrimp catch rates while minimizing the fish catch. It was felt that the best way to study its performance would be to install a RES in one side of the double trawl, then compare the catches from both codends. Thus each tow with the double trawl could be regarded as a comparative fishing experiment, without the usual disadvantages associated with comparative fishing.

As the results from the fishing trials have not yet been fully analyzed, this chapter will present only a preliminary analysis from selected tows, chosen to emphasize certain aspects of the performance of the RES. A complete analysis of the results from this and subsequent fishing experiments will be published later.

Materials and Methods

The trials were conducted on the R/V "Kystfangst," a multi-purpose fisheries research vessel operated by FTFI. "Kystfangst" is 70 ft long at the waterline and has two main propulsion engines of 270 horsepower each, driving a single controllable-pitch propellor. She is well equipped with instruments for monitoring various aspects of vessel performance such as engine RPM, engine temperature, and fuel consumption rates, storing these data automatically in an onboard computer.

All tows were conducted in Varangerfjord in Finnmark, during the second and third weeks of May, 1984. Large concentrations of shrimp were present on these grounds, with abundant small cod and haddock mixed in. All test tows were conducted during daylight hours, between 0700 and 2000. Light levels at the surface were measured during each tow with a photometer, recorded in microwatts per square centimeter.

Most tows were about two hours long, and were made at speeds between 1.5 and 2.3 knots. The water depths on the grounds ranged from 300 to 400 meters, and efforts were made during each tow to trawl along a constant depth contour. The scope to depth ratio was usually in the vicinity of 2.5 to 1. Side currents during most of the tows were negligible, as most tows were made either directly into or away from the current.

For these trials, the RES was installed in the starboard half of the double trawl between the body and intermediate sections (Figure 1). The double trawl was rigged with 20 m bridles and was fished from steel V-doors, each with an area of 4.3 square meters and weighing 870 kg.

At the conclusion of each tow, the catches from each of the two codends were kept separate, as was all the data from the analysis of the catch in the two codends. Catch analysis was as follows: All shrimp were sorted into baskets and shrimp weight was estimated from the number of baskets. For most tows, a one liter sample of shrimp from each codend was taken, and all the shrimp in the sample were measured from just in front of the eye to the end of the telson. All cod and haddock were sorted out and measured, using total length. All other fish were sorted out and counted, or their numbers were estimated if there were a lot of them.

As one of the goals of this study was to refine the sorting efficiency of the RES, many modifications in its design were made and tested. Since this paper is not intended to be an exhaustive report on the trials, only those variants whose performance will be discussed in this report will be described.

All of the test tows to be discussed in this paper were made with a new RES design based on the prototype described in Chapter 2. In concept it was not substantially different from the prototype, but some of the construction details and materials used did differ. The basic construction of this RES and details of its installation are given in Figure 9. All of the variants tested featured minor modifications of this basic design (Figure 10a-f). The first variant to be discussed, Type C, had an extension piece 17 meshes long and 60 meshes in circumference mended to its outlet, thus extending back into the second funnel (Figure 10a). In addition, three constricting loops of string were installed equidistant along the first funnel, each loop having a circumference 50% of the circumference of the funnel at that point. No such loops were installed in the second funnel. Type D was exactly the same, except the extension piece was removed from the first funnel and another constricting loop was installed at its outlet (Figure 10b). In Type E the first funnel was not modified, but two 50% constricting loops were installed in the second funnel (Figure 10c). The only modification made in Type F (Figure 10d) was to cut away 10 meshes at the end of the first funnel. Type G (Figure 10e) was exactly the same, except that the length of the constricting loop nearest the outlet of the first funnel was reduced to 35% of the stretched mesh circumference of the funnel at that point, thus reducing the diameter of the funnel outlet. Type H (Figure 10f) was built after the Type G suffered extensive damage from mud. It had only one funnel, the first funnel from the Type G, which had been salvaged. A new square mesh section was constructed, roughly half as long as the one used in the preceding variants, but since no large-mesh webbing was available, 56 mm bar length web was used. The circumference of the RES remained the same as before.

Results

For each of the RES variants described in this report, one or more tows were selected to exemplify its performance "at its best." However, even in the tows not selected the catches from the RES-equipped half-trawl demonstrated at least some level of fish-shrimp separation, as will be shown in the comprehensive report to be written later.

Table 4 summarizes the characteristics of the catch from each codend for each tow selected for this report. Fish in the catch were assigned to one of the following categories: haddock, cod, redfish (*Sebastes marinus*), flatfish (Pleuronectiformes), or "other fish," which included skates (Rajidae), blue whiting (*Micromesistius poutassou*), and capelin (*Mallotus villosus*). Fish numbers are given both in absolute numbers (or estimated numbers in the case of redfish and "other fish") and in terms of numbers per 10 kg of shrimp. Since the data given here are from tows deliberately chosen to best demonstrate the separation effect of the RES it was not felt appropriate to perform tests of significance on these indicated separation rates.

Tows 2 and 6 from Table 4 are examples of tows made before the RES was installed in the starboard side. On a species-by-species basis, comparisons between the two codends for each tow show some slight variability, which is to be expected. However, allowing for this variability, these results indicate that the two half-trawls were about equally efficient at catching shrimp and fish.

Tows 13 and 14 were made with the Type C RES, which had the 50% constricting loops and the extension piece on the first funnel. Shrimp catch rates for the two sides were roughly equal, although the shrimp in the side with the RES tended to be slightly larger. This version of the RES was not particularly effective at separating haddock. Separation rates for cod appeared to be somewhat better, but very few cod were caught in either codend, a recurring problem throughout these experiments. There was some reduction in the numbers of redfish caught. For tow 14, where flatfish were abundant in both codends, the RES seemed to function effectively as a separator. No separation effect was evident for flatfish in tow 13, but then flatfish numbers were generally low. For "other fish" the catches in the RES-equipped side were higher, a trend reflected throughout these experiments.

Tow 15 was made with the Type D RES, exactly the same as the Type C except the extension piece had been removed from the end of the first funnel. The shrimp catch was slightly lower with the RES, but once again the average size of the shrimp in the RES-equipped side was greater. This version appeared to be much more effective at separating haddock than the Type C, but less effective for cod. Catches of redfish and flatfish were considerably lower in the starboard side, but there was no discernible separation effect for "other fish."

Tow 20 was made with the Type E RES, which featured constricting loops on the second funnel. Some shrimp loss was apparent, but once again it appeared that only the smallest individuals were lost. The haddock separation rate was not quite as good as it was in tow 15, showing about a 25% reduction in haddock catch in the side with the RES. Very few cod were caught in either side, and no separation effect was evident. The redfish catch in the RES-equipped side was more than 50% lower. No flatfish were caught in the port side while 20 were caught in the starboard side. As usual, more "other fish" were caught in the side with the RES.

The RES Type F used on tow 25 differed from the Type E in that 10 rows of meshes were cut away from the end of the first funnel. Shrimp catch rates between the two codends were approximately the same, but the shrimp in the starboard codend were somewhat larger. The haddock separation rate appeared to be quite good, around 50%. Very few cod were caught in either side, so nothing can be said about the separation rate. There was some reduction in the redfish catch (16-20%), but not the striking reduction evident for tow 20. The flatfish catch was lower (17-20%), but very few were caught in either side so this is not very convincing. Unlike all of the other tows reported here, fewer "other fish" were caught in the starboard side.

The RES Type G used on tow 29 was the same as the Type F except the restricting loop closest to the outlet of the first funnel was reduced to 35% of the stretched circumference of the funnel at that point, constricting the outlet even more. The shrimp catch in the starboard side was greater than that in the port side, with a pronounced shift towards larger shrimp. The haddock reduction in the side equipped with the RES was 44% in absolute numbers of individuals and 48% in terms of individuals per 10 kg of shrimp. The cod catch in the two sides was exactly equal. There was a reduction in redfish catch (21% or 28%, depending on the reference used), and a slight reduction in the catch of flatfish, which were relatively abundant this tow. There was the customary slight increase in the catch of "other fish."

The Type H RES used for tow 31 was quite different from the variants used for previous tows. It had only one funnel, the first funnel salvaged from the Type G. The square mesh escape section was made of webbing with a much shorter bar length than before. A 9% reduction in the shrimp catch on the RES-equipped side was observed, with most of the difference concentrated in the smallest shrimp. There was a 47% (or 41%) reduction in the haddock catch in the starboard side. 4 sublegal cod were caught in the port side and 7 in the starboard side, a 75% increase. Redfish were unusually scarce in both sides, but there did appear to be a slight (15% or 7%) reduction in the starboard side. 8 flatfish were caught in the port and 13 in the starboard codend. More "other fish" were found in the starboard codend.

Discussion

The underlying assumption for this series of experiments was that the two half-trawls were fishing the same, with any differences in the catch composition in the two codends directly attributable to the action of the RES installed in the starboard side. Was this a valid assumption? The catch results from the tows made before the RES was installed suggest that it was, but that differences from side-to-side could occur even without the RES being present. The reasons for this side-to-side variability are not known. Perhaps there were lateral currents at the bottom concentrating the fish towards one side or the other, or the fish may have been patchily distributed on a small-scale basis. Shrimp should be less susceptible to either of these perturbing influences than fish, and the fact that the shrimp catches were roughly equal in the two sides throughout these experiments suggests that the two sides were each sweeping the same amount of bottom.

A question could be raised about whether or not the RES should have been tested in a trawl that was designed to be selective itself. Data reported by Valdemarsen and Isaksen (1984) show that the double trawl succeeded in catching fewer fish than a conventional trawl while maintaining comparable shrimp catch rates. Keeping that in mind, the separation rates obtained with the RES during these experiments should not be uncritically regarded as indicative of its potential performance in other trawl types. However, the advantages of using the double trawl to get comparative fishing data, without the drawbacks of the more usual sort of comparative fishing experiment, outweighed the disadvantages.

The next question is, since the tows made before the RES was installed show that there was some side-to-side variability in catch rates for the various species being studied, could all of the observed differences be explained by this inherent variability rather than by any sorting effect due to the RES? A thorough statistical examination of all of the experimental data will be necessary before a definitive answer can be given, and this will be done in the near future. However, a tentative impression can be formed from an examination of the data presented here. If the RES had no effect whatsoever, then for any given species the catch in one side should be greater than the other about half of the time, and less the other half. While the actual separation efficiency for any species varied a great deal from tow to tow, the data show that catches of haddock, redfish, and flatfish were consistently lower in the side with the RES, and higher for "other fish." The numbers of cod caught were often too low to show any marked difference, but for most of the tows where a difference was detectable it appeared that fewer cod were caught in the side with the RES. It is plausible to conclude that the RES had a real separating effect, with the magnitude and direction of the effect depending on the species and on the configuration of the RES.

Assuming, then, that separation did occur, the data suggest that at least for haddock the strength of the separating effect was influenced by the size of the fish. While the total number of haddock caught was always lower in the side with the RES, quite often there were more small (less than 20 cm) haddock in this side than in the other. It is reasonable to assume that small fish, with reduced maximum swimming speed and lower endurance capabilities, would be less able to take advantage of the escape opportunities presented within the RES. This implies that the numbers of small fish ending up in the codend should be equal. However, the numbers of small haddock and "other fish" (mostly capelin and juvenile blue whiting less than 20 cm long) were consistently greater in the starboard codend. This suggests that those fish incapable of escaping through the RES are more likely to be retained by the codend than they would be in a trawl not fitted with a RES. Perhaps the large filtering area presented by the RES reduces the water flow behind it in the codend, thus causing the codend meshes to open up less. Alternatively, small fish struggling unsuccessfully to escape within the RES may become utterly fatigued and therefore less able to escape through the codend meshes. Perhaps the answer lies in some combination of these effects.

On the other hand, consistently fewer of the smallest shrimp (6 cm and less) were caught in the starboard codend. Considering the points mentioned above, this suggests that some mesh selection occurred within the RES itself, at least for shrimp. Perhaps the smallest shrimp were able to pass through the meshes of the funnels instead of being concentrated inwards towards the axis of the funnels, and thus were able to escape through the big meshes. In any case, this may turn out to be an unexpected benefit for the Norwegian shrimp fisheries. These small shrimp are of less value to shrimp buyers, so from a management standpoint it is better not to harvest them. It has not yet been determined whether the absence of these smallest shrimp in the starboard codend could have been responsible for the slight relative reductions in total shrimp catch weight observed on many of the tows.

The separation rates obtained for cod were somewhat disappointing, even allowing for the small numbers of cod observed in either codend. This suggests that cod were less likely (or less able) to take advantage of the RES as tested here. However, since very few cod were encountered in these trials, further experiments in areas where cod are more abundant are necessary before any firm conclusions can be made.

All of the tows made during these trials took place under daylight conditions. It remains to be seen if the RES will function efficiently as a separator during the hours of darkness.

The configuration of the RES appeared to affect its efficiency. As the first funnel was progressively shortened, and its diameter restricted, its effectiveness at separating haddock seemed to improve. In further experiments it is planned to increase the gap between the two funnels until a point has been reached where fish separation rates are at a maximum but there is no loss of shrimp.

At the conclusion of the experiments in May, examination of the double trawl showed that, perhaps due to stretching, the upper wings were some 40 cm longer than the lower wings. For a second series of fishing trials not reported here, the upper wings were correspondingly shortened. A cursory examination of the data from these later trials suggests that separation rates for small (less than 20 cm) haddock were dramatically improved, approaching the rates given in this report for larger haddock. This suggests that the shape of the gear in which it is installed influences the effectiveness of the RES. If slack in the upper panels of the trawl causes the RES to collapse downwards, then the escape area above the funnels would no longer be available. Conversely, fish taking a downwards escape path would have farther to swim to get out of the RES, so separation rates for species with a tendency to swim downwards, such as cod, would suffer accordingly.

Other questions remain about factors affecting the performance of the RES. Model tests showed that the cross-section of the double trawl at the point where the RES was installed should be elliptical, with the long axis parallel to the bottom. Will the performance of the RES be affected if it is installed in a trawl with a circular cross-section? What would be the effect of towing at speeds other than those tested? Will it be necessary to change the funnel spacing, or other design parameters, to compensate for other towing speeds? How will RES effectiveness be affected by the interrelationships between these factors: RES design, trawl design, operational factors such as towing speed, and biological factors such as species composition and size composition of the fish and shrimp present?

The first fishing trials with the RES demonstrated the validity of the concept and showed that its separation performance could be "fine-tuned" by making small adjustments in its design. Installing the RES in one side of a double trawl proved to be a quick and effective way of getting convincing data on separation rates. However, to improve the design further it will be necessary to actually observe the behavior of fish and shrimp within the RES with underwater cameras or television. This will become especially important when RES development work moves on, as it must, to conventional trawl designs where it will not be so easy to get good comparative fishing data.

Chapter 4. Visual Observations of RES Performance

Introduction

Following the experiments described in Chapter 3, one of the authors was a guest aboard the R/V "Clupea," operated by the Department of Agriculture and Fisheries for Scotland Marine Laboratory in Aberdeen. During this cruise observations of fish/gear interactions were being conducted using the Remote Controlled Towed Vehicle (RCTV) developed at the Marine Laboratory. An opportunity arose to construct a RES and install it in a trawl, then observe the RES and fish reactions to it using the RCTV. These observations will be described here.

Materials and Methods

The RES designs tested here (Figure 11) differed considerably from those described earlier but were based on the same principle using the materials available. A cut was made around the circumference of a bottom trawl (proprietary design, details not available for publication) at a seam joining two of the intermediate sections. Then the cut sections were separated and 12 ropes were mended longitudinally into the gap, leaving a 10 foot (3.1 m) space between the cuts. Thus the longitudinal ropes took the place of the large square meshes used in the earlier experiments.

Only one funnel at a time was used in these observations. During the first tow, the funnel was made of small (29 mm stretched mesh) webbing (Figure 11a). A funnel made of black canvas (Figure 11b), designed to have approximately the same dimensions and shape as the webbing funnel, was installed in its place for the second tow. In both cases the funnels were mended directly to the webbing at the front of the gap.

Towing and observation procedures were as follows: After the trawl and doors had settled and the tow was underway, the RCTV was deployed (for a description of the RCTV, see Main and Sangster, 1982). Guided by television the operator positioned the RCTV where the RES could be observed. All tows were made at three knots, in 30 meters of water in the Moray Firth.

Results

Figure 12a shows the shape assumed under tow by the webbing RES and adjacent trawl sections. The funnel inflated under the force of the water flow, and all meshes in the funnel were fully open. There was a space of about 6 ft (2 m) between the funnel outlet and the resumption of the trawl. The after section of the trawl streamed directly behind the RES and no instability or oscillation of the RES or the adjacent trawl sections was evident.

Several species of fish were seen during this tow, predominantly sandeels (Ammodytes sp.) and haddock (estimated length 20 to 40 cm), with some flatfish and a few cod. Most of the fish observed turned as they approached the funnel and swam in front of it, then passed through the outlet tail first. The only exceptions were some of the flatfish, who were flattened and held immobile against the webbing of the funnel, and some of the sandeels. When dense aggregations of sandeels encountered the funnel they would often attempt to swim out head first through the open meshes, occasionally getting meshed in the process. When an especially dense group of sandeels came along it appeared that some of them got caught while trying to pass through the meshes tail first, but this was unusual.

Once past the outlet of the funnel, the majority of the fish observed made some effort to swim radially out through the gaps between the ropes, out of the path of the oncoming codend. The strength of this response, and the probability of success, depended on the species. All of the remaining sandeels and most of the haddock were successful, but it seemed that most of the flatfish and the few recognizable cod did not manage to get away before being overtaken by the gear. The sandeels tended to swim upwards to get away, while the haddock swam away to either side as well as upwards.

After hauling back, the catch, though small, consisted mostly of flatfish with a few haddock and cod.

On the next tow the canvas funnel was observed, with strikingly different results. The funnel appeared to constitute a barrier to water flow, causing the webbing in front of it to inflate until all of the meshes were fully open (Figure 12b). That the water flows behind the funnel were weak was evidenced by the behavior of the after parts of the trawl which hung limply downwards, supported only by the longitudinal ropes of the RES.

The behavior of the fish observed was quite different as well. Very few fish were seen on this tow, but no fish at all were seen passing into or through the funnel. Most of the fish observed were swirling about in the apparently quite turbulent water in front of the funnel, and a few were seen attempting to escape through the open meshes at this point. At the end of the tow less than a basket of fish had been caught in the codend.

Discussion

These observations showed that fish respond as expected to the RES, at least in the daytime. They also showed that different species respond in different characteristic ways, and that a design that successfully sorts out one species will not necessarily work equally well for another. The results implied that for successful separation of species that are less alert or are weaker swimmers, it may be necessary to lengthen the escape section to give them more time to respond and get out, or it may be necessary to tow at a slower speed to achieve the same effect. The observations showed that longitudinal ropes can work in the escape section, as an alternative to large square meshes. They also showed that funnels made of canvas or other solid fabrics are not likely to work, although canvas rings may find a place as "inflators" or scaring devices in later RES designs.

These observations demonstrated the value of having suitable equipment and techniques for observing the responses of fish and other organisms to experimental fishing gear. This is especially true when a gear relies on behavioral differences to function properly, or when it relies on having a certain configuration during fishing operations.

Due to the opportunistic nature of these observations, it was not possible to duplicate the conditions under which the earlier fishing trials were conducted. The RES designs observed here were quite different, they were installed in a completely different type of trawl, and they were fished on different grounds under different conditions. It was particularly unfortunate that no shrimp were seen. Despite all this, the observations made a very valuable contribution to our understanding of how fish respond to the RES, and will guide future RES development efforts.

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Table 1. Regression coefficients derived from the measurements of towing tension versus speed.

Case	Direction	Slope	Y-intercept	N	R
1	NW	238.6175	-240.4009	5	.95964
	SE	197.8921	-154.7049	6	.98774
	Pooled	218.4208	-200.1	11	.96995
2	NW	195.5172	-213.4345	5	.99749
	SE	140.0	-93.8	5	.99873
	Pooled	164.3939	-146.8879	10	.98179
3	NW	38.6454	-36.8924	4	.98649
	SE	38.9655	-37.731	5	.99539
	Pooled	38.7705	-37.2486	9	.99081

Case 1. RES, trawl section, and frame.
Case 2. Trawl section and frame, no RES.
Case 3. Frame only.

Regression model:
Estimated towing tension = Towing speed x slope + y-intercept

N = number of speed/tension observations
R = correlation coefficient

Table 2. Results of t-tests comparing the slopes of the tension versus speed regression lines.

Comparison	DF	t	Probability	Conclusion
Case 1, NW versus SE tows	7	2.329	.05<P<.10	Slopes are different
Case 2, NW versus SE tows	6	4.845	P<.05	Slopes are different
Case 3, NW versus SE tows	5	.0996	P>>.1	Slopes are not different
Case 1 versus Case 2	17	5.705	P<.05	Slopes are different

Case 1. RES, trawl section and frame;
Case 2. Trawl section and frame, no RES;
Case 3. Frame only.

DF: Degrees of freedom.
t: the value of the calculated t-statistic for that comparison.
Probability: the probability, given that value of the calculated t-statistic, that the observed difference in the two slopes being compared could be attributed to chance.

Table 3. Estimated drag contributions of the mockup components at various speeds.

Towing Speed (kn)	Estimated Drag Contribution (kg) RES	Codend (without RES)	Frame	Total
1.1	6.22	28.55	5.40	40.16
1.2	11.62	41.11	9.28	62.01
1.3	17.02	53.67	13.15	83.85
1.4	22.43	66.23	17.03	105.69
1.5	27.83	78.80	20.91	127.53
1.6	33.23	91.36	24.78	149.37
1.7	38.63	103.92	28.66	171.22
1.8	44.04	116.48	32.54	193.06
1.9	49.44	129.05	36.42	214.90
2.0	54.84	141.61	40.29	236.74
2.1	60.24	154.17	44.17	258.58
2.2	65.65	166.73	48.05	280.43
2.3	71.05	179.30	51.92	302.27
2.4	76.45	191.86	55.80	324.11
2.5	81.86	204.42	59.68	345.95
2.6	87.26	216.98	63.56	367.79

Table 4. Summarized catch results from selected tows made during the fishing trials with the double trawl.

Tow number	2		6		13	
Tow duration	2.0		1.5		2.1	
Separator type used	None		None		C	
Codend	P	S	P	S	P	S
Shrimp						
Estimated weight (kg)	250	250	200	180	140	150
% Difference*	0		-10%		+7%	
Catch rate (kg/hr)	125	125	133	120	67	71
Size distribution**						
Less than 6 cm					34	9
6 cm					55	53
7-8 cm					63	63
More than 8 cm					35	40
Haddock (numbers)						
Size distribution						
Less than 20 cm	111	91	38	47	20	33
20-38 cm	286	254	93	114	79	73
39 cm and over	0	0	0	0	0	0
Total sublegals	397	345	131	158	99	106
% Difference*	-13%		+20%		+7%	
Sublegals/10 kg shrimp	15.9	13.8	6.6	8.9	7.1	7.1
% Difference*	-13%		+35%		0	
Cod (numbers)						
Size distribution						
Less than 20 cm	1	4	3	5	2	0
20-41 cm	51	54	14	23	15	17
42 cm and over	6	3	0	0	3	3
Total sublegals	52	58	17	28	17	17
% Difference*	+12%		+65%		0	
Sublegals/10 kg shrimp	2.1	2.3	0.9	1.6	1.2	1.1
% Difference*	+10%		+78%		-8%	
Redfish (numbers)	367	432	552	675	138	108
% Difference*	+18%		+22%		-22%	
Redfish/10 kg shrimp	14.7	17.3	27.6	37.5	9.9	7.2
% Difference*	+18%		+36%		-27%	
Flatfish (numbers)	24	14	32	9	6	9
% Difference*	-42%		-9%		+50%	
Flatfish/10 kg shrimp	1.0	0.6	1.6	1.6	0.4	0.6
% Difference*	-40%		0		+50%	
Other fish (numbers)	11	7	59	33	24	40
% Difference*	-36%		-44%		+67%	
Number/10 kg shrimp	0.4	0.3	3.0	1.8	1.7	2.7
% Difference*	-25%		-40%		+59%	

* Referenced to the port codend, the one without the RES.
** Taken from a one-liter sample of shrimp.

Table 4 continued.

Tow number	14		15		20	
Tow duration	1.9		2.3		2.4	
Separator type used	C		D		E	
Codend	P	S	P	S	P	S
Shrimp						
Estimated weight (kg)	160	180	115	100	350	330
% Difference*	+13%		-13%		-6%	
Catch rate (kg/hr)	84	95	50	43	146	138
Size distribution**						
Less than 6 cm			14	3	6	2
6 cm			67	39	49	32
7-8 cm			65	48	63	78
More than 8 cm			35	42	36	34
Haddock (numbers)						
Size distribution						
Less than 20 cm	54	92	25	11	29	46
20-38 cm	111	66	114	43	98	48
39 cm and over	0	0	0	0	1	0
Total sublegals	165	158	139	54	128	94
% Difference*	-4%		-61%		-27%	
Sublegals/10 kg shrimp	10.3	8.8	12.1	5.4	3.7	2.8
% Difference*	-12%		-55%		-24%	
Cod (numbers)						
Size distribution						
Less than 20 cm	3	3	1	0	0	3
20-41 cm	11	7	9	7	4	1
42 cm and over	4	1	4	1	3	2
Total sublegals	14	10	10	7	4	4
% Difference*	-29%		-30%		0	
Sublegals/10 kg shrimp	0.9	0.6	0.9	0.7	0.1	0.1
% Difference*	-33%		-22%		0	
Redfish (numbers)	1013		1262	674	1410	585
% Difference*			-47%		-59%	
Redfish/10 kg shrimp	63.3		109.7	67.4	40.2	17.7
% Difference*			-39%		-56%	
Flatfish (numbers)	101	77	86	42	0	20
% Difference*	-24%		-51%			
Flatfish/10 kg shrimp	6.3	4.3	7.5	4.2	0	0.6
% Difference*	-32%		-44%			
Other fish (numbers)	87	123	413	371	438	571
% Difference*	+42%		-10%		+30%	
Number/10 kg shrimp	5.4	6.8	35.9	37.1	12.5	17.3
% Difference*	+26%		+3%		+38%	

* Referenced to the port codend, the one without the RES.
** Taken from a one-liter sample of shrimp.

Table 4 continued.

Tow number	25		29		31	
Tow duration	2.0		2.0		1.7	
Separator type used	F		G		H	
Codend	P	S	P	S	P	S
Shrimp						
Estimated weight (kg)	270	260	105	115	110	100
% Difference*	-4%		+10%		-9%	
Catch rate (kg/hr)	135	130	53	58	65	59
Size distribution**						
Less than 6 cm	3	2	25	0	146	37
6 cm	63	55	115	97	89	79
7-8 cm	60	67	42	39	55	75
More than 8 cm	31	36	27	45	22	27
Haddock (numbers)						
Size distribution						
Less than 20 cm	11	13	19	17	3	1
20-38 cm	34	10	38	15	29	16
39 cm and over	1	0	0	0	0	0
Total sublegals	46	23	57	32	32	17
% Difference*	-50%		-44%		-47%	
Sublegals/10 kg shrimp	1.7	0.9	5.4	2.8	2.9	1.7
% Difference*	-47%		-48%		-41%	
Cod (numbers)						
Size distribution						
Less than 20 cm	1	4	2	2	0	1
20-41 cm	8	3	9	9	4	6
42 cm and over	4	0	3	3	1	5
Total sublegals	9	7	11	11	4	7
% Difference*	-22%		0		+75%	
Sublegals/10 kg shrimp	0.3	0.3	1.0	1.0	0.4	0.7
% Difference*	0		0		+75%	
Redfish (numbers)	490	394	1020	809	33	28
% Difference*	-20%		-21%		-15%	
Redfish/10 kg shrimp	18.1	15.2	97.1	70.3	3.0	2.8
% Difference*	-16%		-28%		-7%	
Flatfish (numbers)	12	10	74	71	8	13
% Difference*	-17%		-4%		+63%	
Flatfish/10 kg shrimp	0.4	0.3	7.0	6.2	0.7	1.3
% Difference*	-25%		-11%		+86%	
Other fish (numbers)	718	574	172	216	12	15
% Difference*	-20%		+26%		+25%	
Number/10 kg shrimp	26.6	22.1	16.4	18.8	1.1	1.5
% Difference*	-17%		+15%		+36%	

* Referenced to the port codend, the one without the RES.
** Taken from a one-liter sample of shrimp.

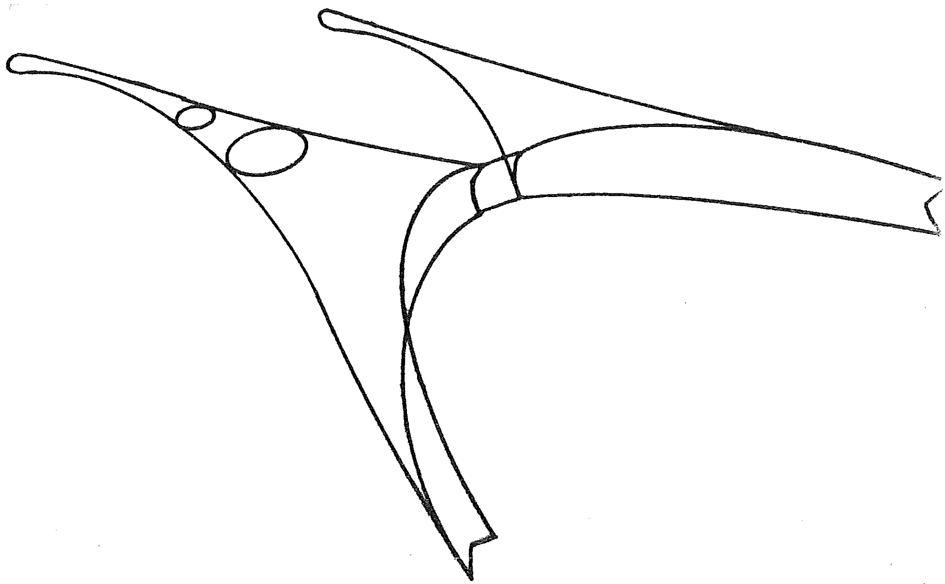


Figure 1. Sketch of "Double Trawl," indicating the position at which the Radial Escape Section was installed in the starboard side (see Chapter 3).

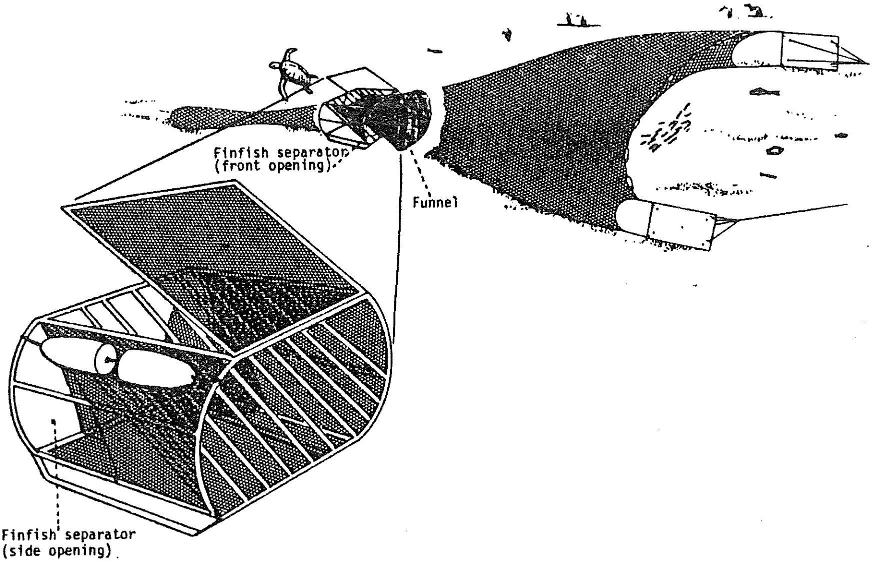


Figure 2. Trawling Efficiency Device as used in US Gulf of Mexico shrimp trawls. (from Watson, 1983)

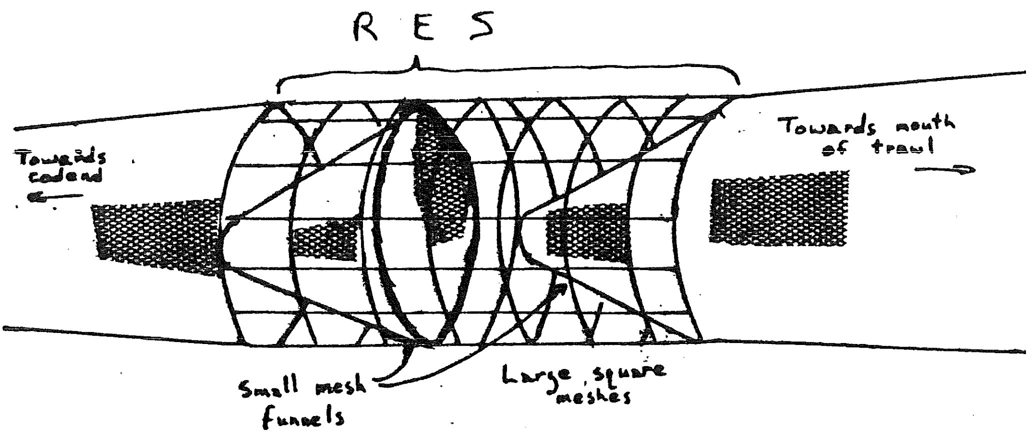


Figure 3. Conceptual sketch of Radial Escape Section.

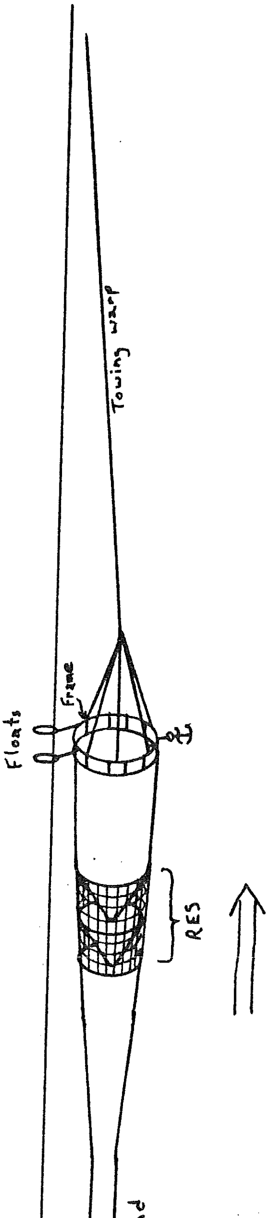


Figure 4. Sketch of mockup with RES installed under tow.

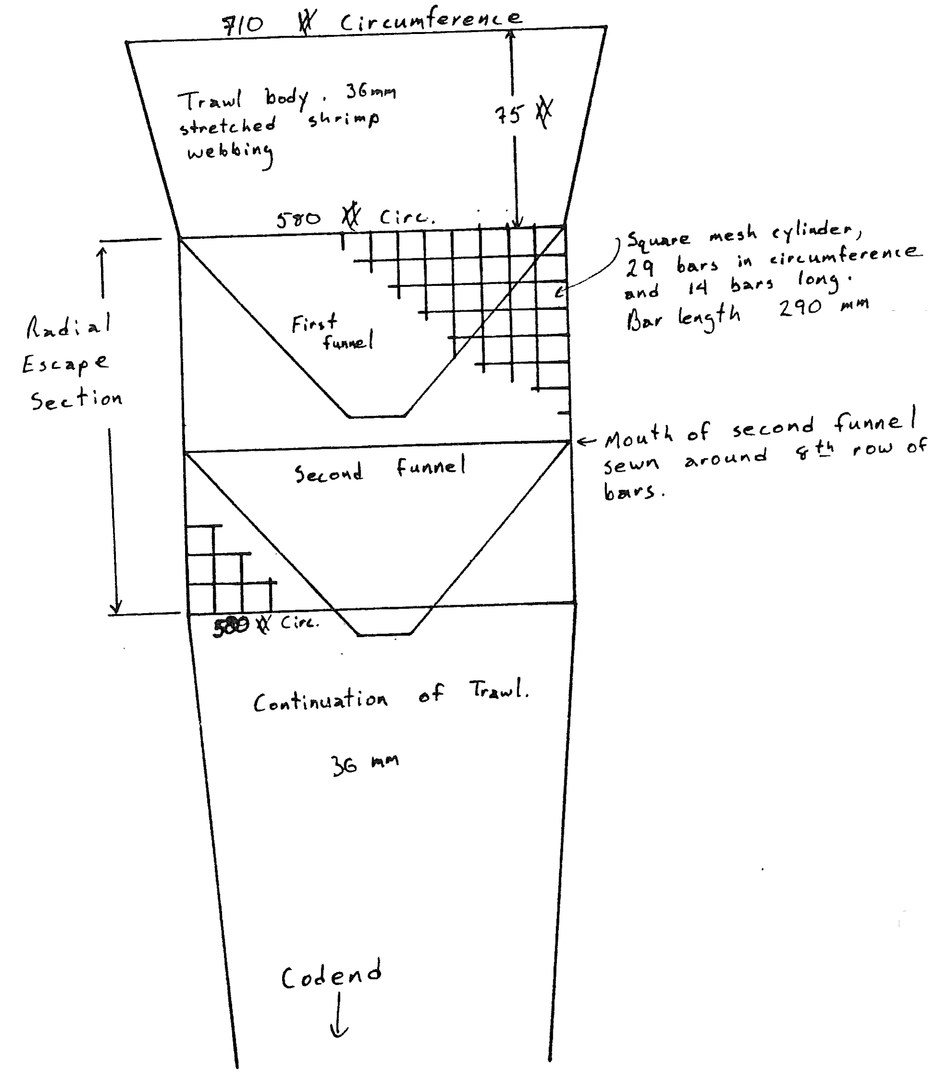
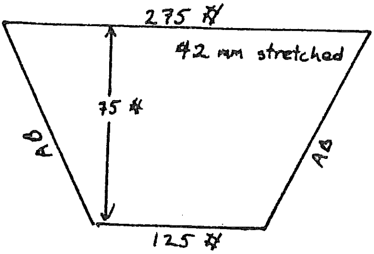
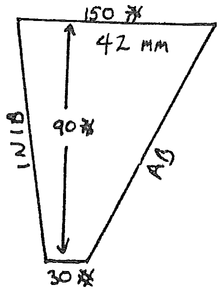


Figure 5. Installation of RES within mockup.

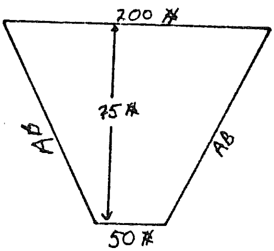


First funnel (2 identical panels).

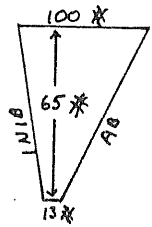


Second funnel (4 panels). Sides with AB cuts joined to each other, 1N1B edges likewise.

6a. Funnels as originally constructed and tested.

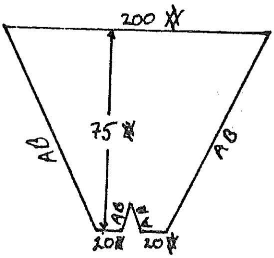


First funnel (2 panels).



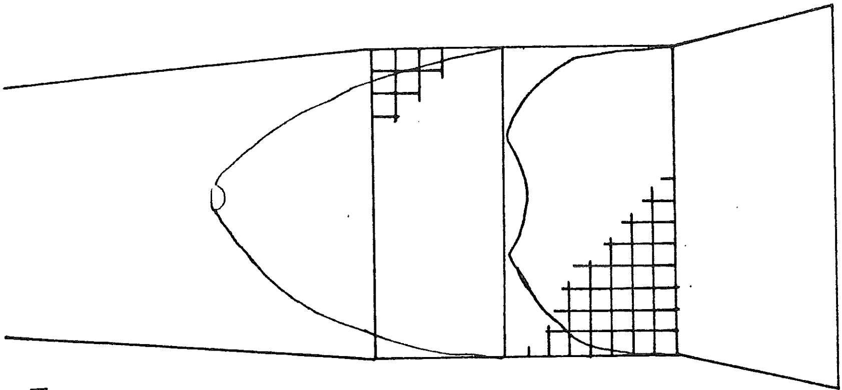
Second funnel (4 panels).

6b. Modified funnels as tested on the second observation tow.

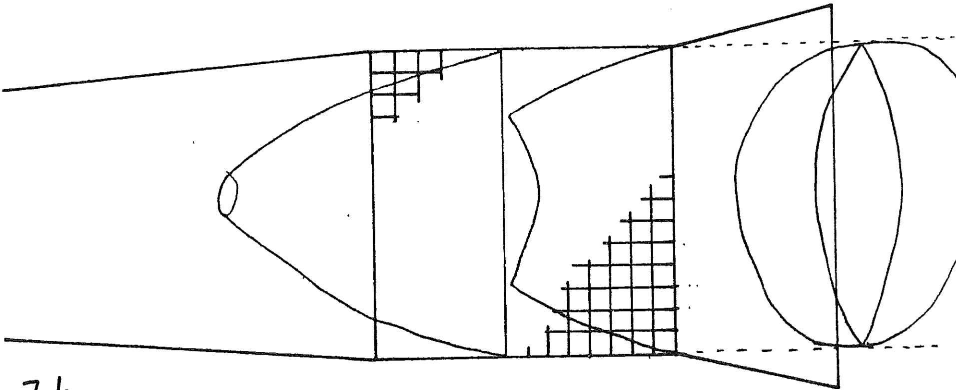


6c. Modifications made to both panels of the first funnel prior to the third tow. 10 meshes were cut out of the center of each panel at the outlet, then the cut edges were laced back together. No changes were made to the second funnel.

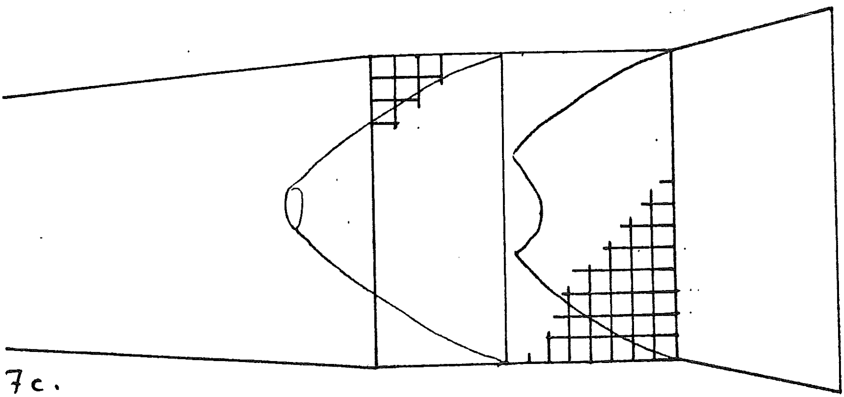
Figure 6. Construction drawings of RES funnel designs tested during the initial towing trials.



7a.



7b.



7c.

Figure 7. Shapes assumed by the funnels during the test tows.

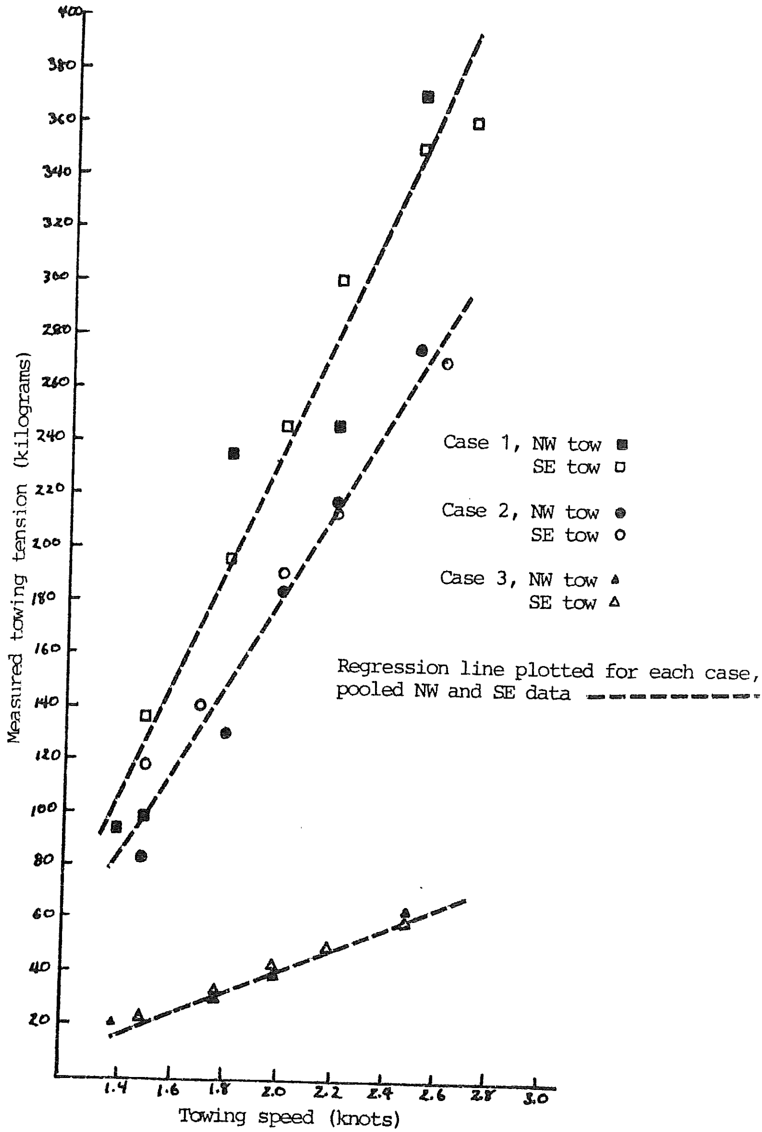


Figure 8. Plots of measured towing tension versus towing speed.

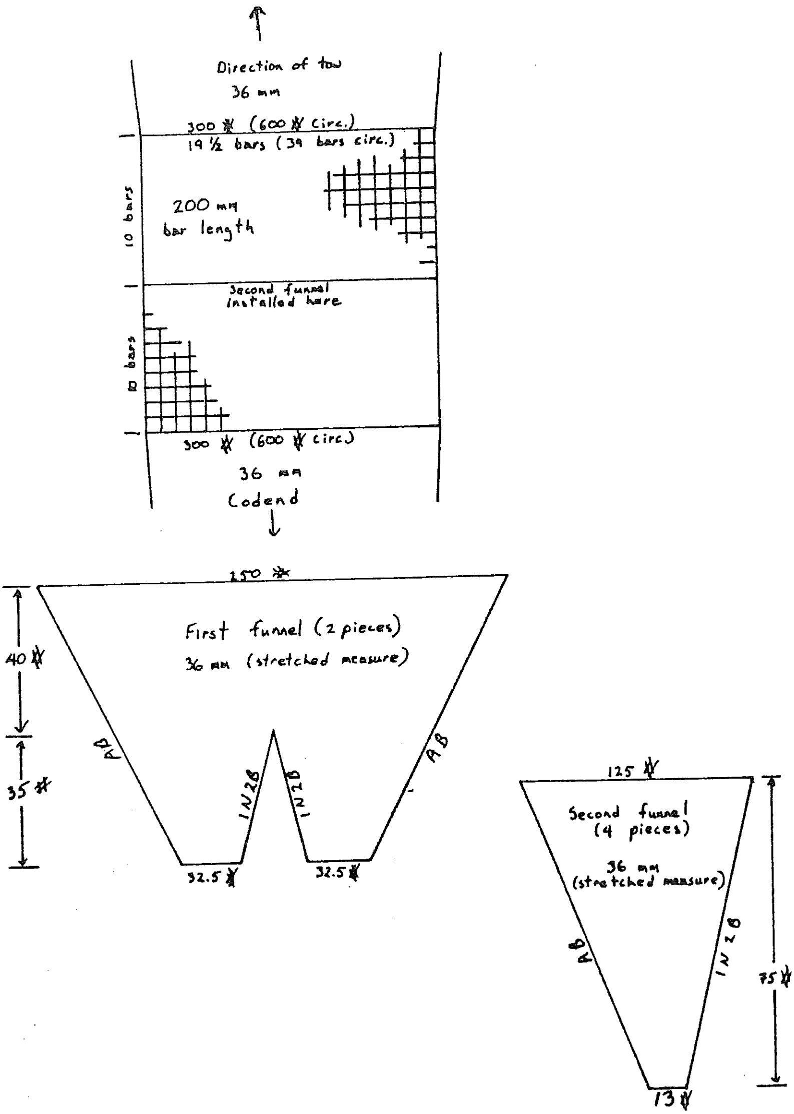
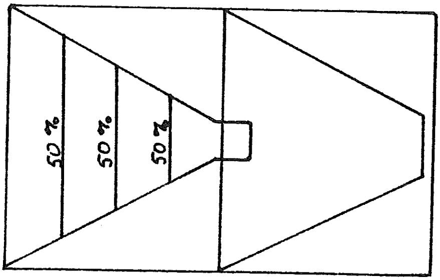
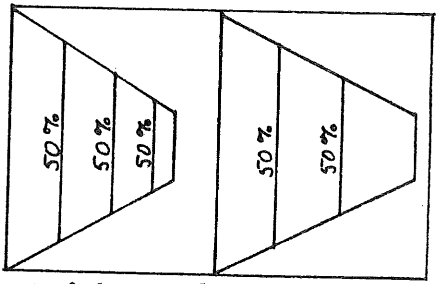


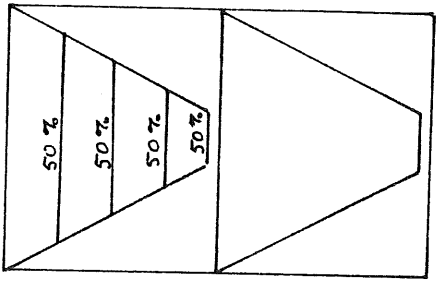
Figure 9. Construction drawings for the basic RES design tested during fishing trials.



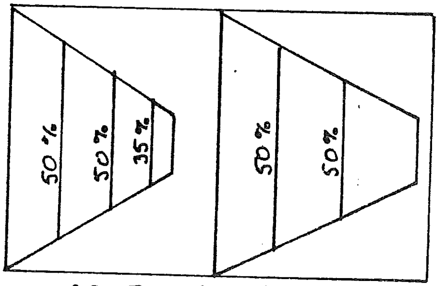
10a. RES Type C



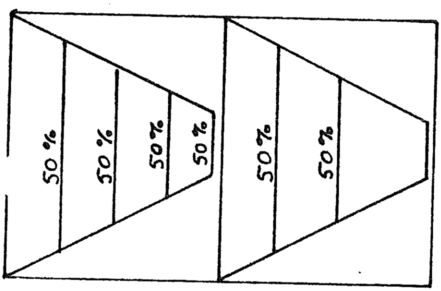
10d. RES Type F. Note: First funnel has been shortened by 10 rows.



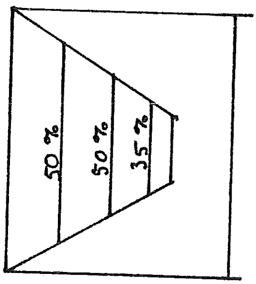
10b. RES Type D. Note: extension piece has been removed from first funnel.



10e. RES Type G. Note: Constricting loop nearest outlet has been shortened.



10c. RES Type E. Note: Constricting loops have been installed in second funnel.



10f. RES Type H. Note: Entire RES has been shortened and has only one funnel.

Figure 10. Selected variations of the basic RES design tested during fishing trials.

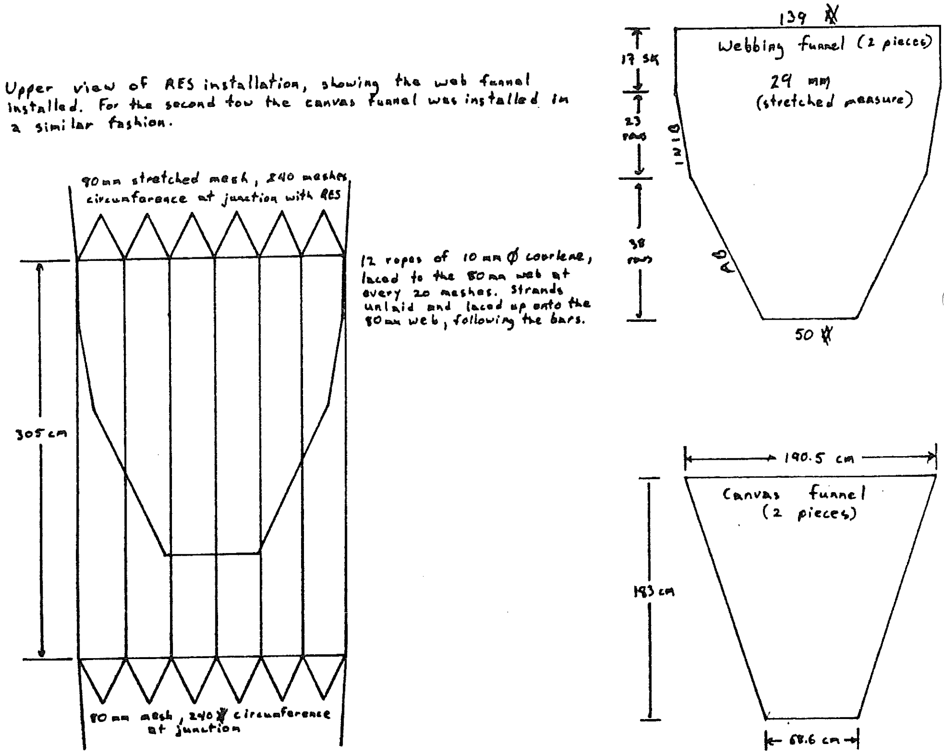


Figure 11. Construction drawings for the RES designs observed with an underwater television-equipped towed vehicle.

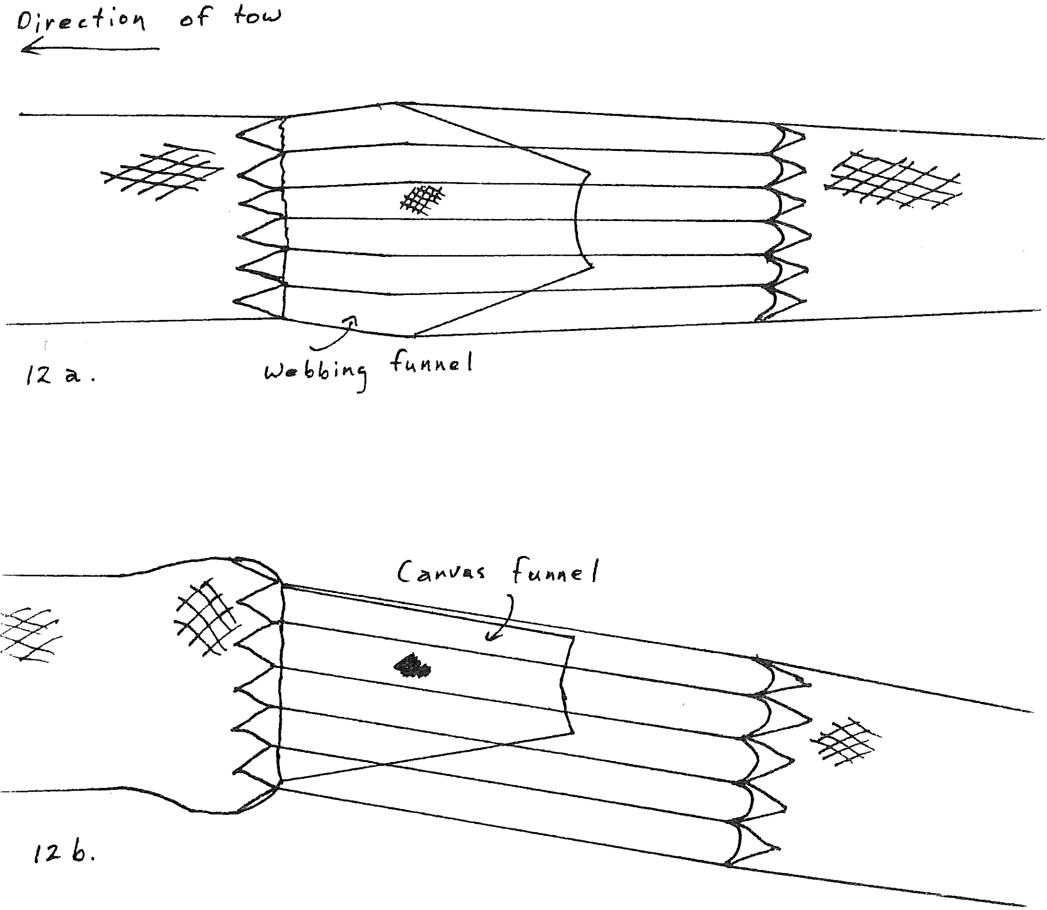


Figure 12. Shapes assumed during the observation tows by the RES and the adjacent trawl sections.