Flow-related effects in prawn-trawl codends: potential for increasing the escape of unwanted fish through square-mesh panels

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Abstract.–Two experiments were done in a flume tank to quantify the effects of codend mesh circumference and weight of catch on water flow. The mesh circumference of the posterior section of prawn-trawl codends (with and without bycatch reducing square-mesh panels) were assessed with three weights of catch (30 kg, 50 kg, and 70 kg). Compared with a codend with a circumference of 100 meshes throughout its entire length, a codend with an anterior section of 100 meshes and a posterior section of 200 meshes in circumference significantly increased the displacement of water forwards (up to 1120 mm from the end of the codend). This result varied with the weight of catch in the codend. The second experiment involved placing composite panels of square-shaped mesh (bycatch reducing devices) into the tops of the anterior sections of two codends with the same configurations as those above (termed the "100 panel codend" and "200 panel codend," respectively). There was a displacement of water forwards immediately under the square-mesh panel in the 200 panel codend (by up to 2200 mm from the end of the codend). The results are discussed in terms of 1) the probable effects that codend mesh circumference and water displacement in codends have on fish behavior, and 2) implications for the future development of bycatch reducing devices like square-mesh panels in prawn-trawls.

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Oceanic prawn-trawling occurs from nine major ports in New South Wales (NSW) Australia and has a total value of approximately A$17 million per annum. The principal target species is the eastern king prawn (*Penaeus plebejus*), although a significant proportion of the total value is derived from the sale of legally retained bycatch comprising individuals of several species of fish, crustaceans, and cephalopods (see Kennelly, 1995). In addition to this landed catch, however, significant numbers of nontarget organisms of no commercial value are also captured and discarded, including juvenile fish of species which, when larger, are targeted in other commercial and recreational fisheries (Kennelly, 1995).

Concerns over the incidental capture and mortality of large numbers of juvenile fish have led to the development of various bycatch reducing devices (BRDs), designed to minimize undesirable bycatch while maintaining catches of prawns and other commercially valuable individuals (Broadhurst et al., 1996; Broadhurst and Kennelly, 1996; 1997). In particular, a new design comprising composite panels of square-shaped mesh (referred to as the composite square-mesh panel) was shown to increase catches of prawns (by up to 14%) (Broadhurst and Kennelly, 1997) while significantly reducing up to 40% of total unwanted bycatch and up to 70% of the numbers of small individuals of commercially important species such as whiting (*Sillago* spp.) (Broadhurst and Kennelly, 1996).

The results from these experiments are attributed primarily to differences in the behavior of fish and prawns in the trawl. Fish are believed to be herded close together in the anterior section of the codend, upsetting the normal balance of the school and initiating an escape response towards the sides and top of the net and out through the open square-shaped meshes (Broadhurst and Kennelly, 1996). A contributing factor towards this escape is the displacement and change in direction of water flow due to the circumference of meshes in the posterior section of the codend. In an experiment to test this hypothesis, Broadhurst and Kennelly (1996) showed that a conventional codend made from an anterior section of 100 meshes circumference and a posterior section 200 meshes in circumference (a common commercial configuration) was less selective (i.e. retained more bycatch) than a conventional codend with a 100 mesh circumference throughout its entire length (see also Robertson and Stewart, 1988; Armstrong et al., 1990; Reeves et al., 1992; Galbraith et al., 1994). However, a comparison of codends with the same netting configurations as above but containing composite square-mesh panels located in their anterior sections showed that the effects on selectivity due to increased circumference in the posterior section were negated by a significant increase in the escape of small fish (e.g. red spot whiting, *Sillago flindersi*) through the square meshes.

These results led to the hypothesis that increased twine area and smaller mesh openings in codends with posterior sections of 200 meshes circumference increased the displacement of water forwards and out through the meshes in the anterior section (see also Watson, 1989). In turn, this water movement may have 1) physically directed small fish out through the strategically positioned composite square-mesh panel; 2) assisted them to maintain position in front of the catch in the codend, increasing their likelihood of randomly encountering square meshes; and (or) 3) stimulated their lateral line receptors and thus their overall escape response. The reaction of prawns to this stimuli was thought to be minimal, given their inability to sustain escape responses in trawls (see Lochhead, 1961; Newland and Chapman, 1989).

Although the results from the paper discussed above led to several hypotheses about changes in water flow and fish behavior due to changes in codend geometry, we lacked the quantitative information on flow rates necessary to support or refute them. Such information is important for developing new designs of codends and understanding where to position square-mesh panels and other BRDs. Our goals in the present study were to quantify the effects on water flow at various positions in codends and under square-mesh panels in two flume tank experiments. We simulated commercial conditions in the flume tank by using different weights of catch in various codend designs.

Materials and methods

Two experiments were undertaken in May 1996 at the Australian Maritime College with the Faculty of Fisheries and Marine Environment's flume tank. This facility consists of a recirculating flow tank of fresh water, measuring 17.2 m long, 5 m wide, and 2.5 m deep and comprises three levels: 1) an upper level where nets, etc., are placed into the tank; 2) an observation level, with a continuous perspex viewing-window; and 3) a water-return channel. The two lower levels feature a series of delivery bends and screens that maintain constant water velocity throughout the depth of the tank without any swirls or vortices. Several electric motors, hydraulic pumps, and impellor shafts provide water flow of up to 1.5 m/s.

An electromagnetic current meter was attached to the base of a stainless steel stanchion (Fig. 1A) and linked to a computer by means of a coaxial cable. The stanchion was attached to a movable carriage positioned on rails over the upper level of the flume tank. This assembly enabled the current meter to be repeatedly located at several predetermined positions within the tank.

A full-scale Florida flyer prawn-trawl (material: 18 ply twine; mesh size: 40 mm) with a headline length of 5.4 m, was rigged to two fixed stanchions, located on the sides of the forward section of the flume tank. The trawl was rigged with a zipper (no. 10 nylon open-ended auto-lock plastic slides) to facilitate changing the codends. The codends used in the experiments were of normal commercial size and materials, measuring 58 meshes long (2.3 m) and constructed from 40-mm mesh netting and 60-ply UV-stabilized high-density polyethylene twine. These codends comprised two sections: the anterior section, which was 33 meshes long and attached to a zipper and the posterior section, which was 25 meshes long (for details see Fig. 1, B and C —see also Broadhurst and Kennelly, 1996).

Experiment 1

Two codend designs were compared. The codends (termed the 100 and 200 commercial codends) were made entirely of diamond-shaped meshes and comprised anterior sections with a circumference of 100 meshes, attached to posterior sections with circumferences of 100 and 200 meshes, respectively (Fig. 1, B and C). Three incisions of the same size as the width of the current meter's stanchion (three meshes in length), were made in the tops of each codend at distances of 2200 mm, 1120 mm, and 560 mm forward from the end of the codends to facilitate placement of the current meter inside the codends (Fig. 1B).

Experiment 2

The two codends compared in this experiment were similar to the 100 and 200 commercial codends described above but included composite square-mesh panels made of 60-mm and 40-mm netting (3-ply and 48-ply UV-stabilized high-density polyethylene twine, respectively) cut on the bar and inserted into the tops of the anterior sections (termed the 100 panel and 200 panel codends) (for details see Fig. 1C and Broadhurst and Kennelly, 1996). Because the current meter (and not its stanchion) was inserted only 5 cm into the tops of the codends (Fig. 1C), it was not necessary to cut the meshes of these codends. Instead, four positions were labeled with a permanent marker at 2200 mm, 1720 mm, 1490 mm, and 1130 mm forward from the end of the codends (Fig. 1C).

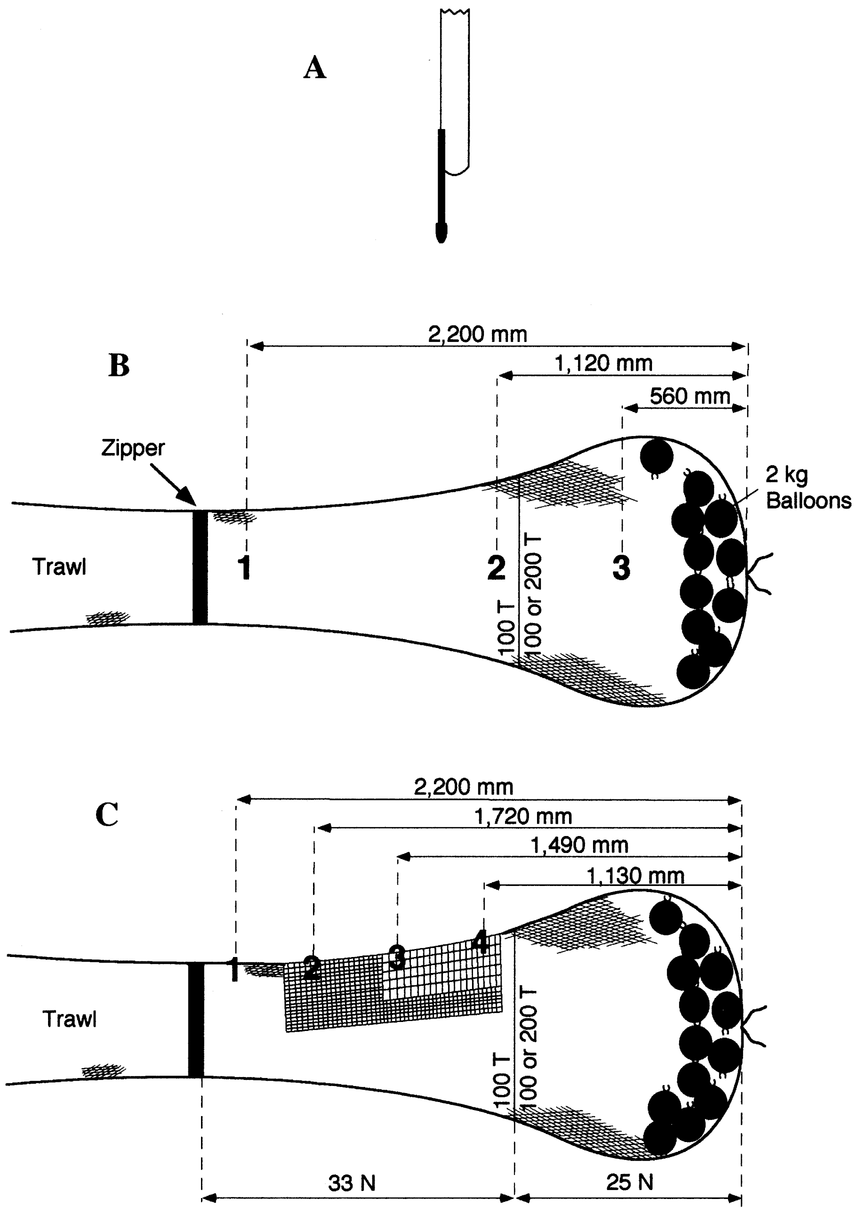

Figure 1

Diagrammatic representation of (**A**) the current meter and its stanchion, (**B**) 100 and 200 commercial codends and the three positions of water flow readings and (**C**) 100 and 200 panel codends and the four positions of water-flow readings. T = transversals; and N = normals

Experimental procedure

Thirty five rubber balloons were each filled with 2 liters of water, providing a total mass (in air) of 70 kg. These balloons were used to simulate masses of catch in the codends. In each experiment, the two codends were tested alternately. The particular codend to be examined was attached to the trawl and loaded initially with 15 balloons (i.e. 30 kg). The hydraulic pumps in the flume tank were activated and adjusted to produce a flow of 1.2 m/s (the standard towing speed during commercial operations). After a stabilizing period of 10 minutes, the stanchion containing the current meter was alternately lowered into each of the predetermined positions in the codends (three in experiment 1 and four in experiment 2). After a further stabilizing period of one minute at each position, the current meter was switched on and left for a period of one minute, during which the flow of water immediately anterior to the current meter was recorded at one second intervals and the data were transmitted to the computer. The mean flow rate from each minute of recording was calculated from these data and used in subsequent analyses. After each reading, the current meter was moved to the next position and the procedure repeated. After six replicate readings were collected for each position, the flow of water in the flume tank was reduced to approx. 0.5 m/s and additional balloons were added to the trawl to simulate an increase in the volume of catch. The above procedure was then repeated to obtain data on the flow of water at each position with 50 kg (25 balloons) and 70 kg (35 balloons) in each codend.

Data analysis

Data collected in each experiment were examined by using Cochran's test for homogeneity of variances and transformed if necessary. Data from experiment 1 were analyzed in a three-factor fully orthogonal, balanced analysis of variance. The factors were codends, positions, and weights. Data from experiment 2 were analyzed at each position in two-factor fully orthogonal, balanced analyses of variance (Underwood, 1981). Significant differences detected in these analyses were investigated by Student-Newman-Keuls (SNK) multiple comparisons of means.

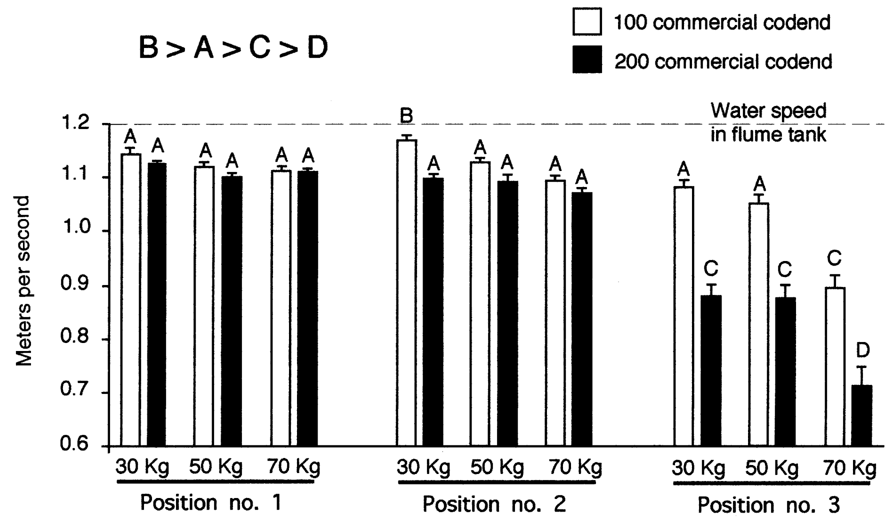

Figure 2

Differences in mean flow rates ±SE between the 100 and 200 commercial codends tested in experiment 1 (< and > indicate direction of differences in SNK tests).

Table 1

Summaries of *F* ratios from the analysis of variance to determine effects on water flow due to different codends (i.e. 100 and 200 commercial codends), position of current meter and weight in the codend. The square-root (sqrt(×)) transform was used to stabilize variances. In all tables *P = <0.05; **P = <0.01.

Treatment	df	Water flow (m/s)
Codends (C)	1	162.52**
Position (P)	2	388.16**
Weight (W)	2	62.42**
C × P	2	35.01**
C × W	2	8.04**
P × W	4	12.39**
C × P × W	4	0.81
Residual	90	

Results

Experiment 1

The analysis of variance showed that there were significant differences in flow rates between the type of codend, position of the current meter and weight in the codend, and significant interactions among codend-type, positions and weights (Table 1). SNK tests showed that mean water flow was greatest at position no. 2 (1.162 m/s) in the 100 commercial codend with a catch of 30 kg and lowest at position no. 3 (0.709 m/s) in the 200 commercial codend with 70 kg (Fig. 2). SNK tests also showed that, compared with the 100 commercial codend, there was a significant reduction in mean water flow in the 200 commercial codend with 30 kg at position no. 2 (mean difference of 0.071 m/s) and across all three weights (30 kg, 50 kg, and 70 kg) at position no. 3 (mean differences of 0.203 m/s, 0.176 m/s and 0.184 m/s, respectively) (Fig. 2; Table 1). Although SNK tests did not detect differences in mean water flow between codends with 50 kg and 70 kg at position no. 2, nor across all weights at position no. 1, these combinations of weight and position showed trends similar to those described above—i.e. a mean reduction in water flow with the 200 commercial codend (Fig. 2).

Experiment 2

There were significant differences in the mean water flow between the type of codend at position nos. 2, 3. and 4 and between weights at position nos. 2 and 3 (Table 2). There was a significant interaction between the type of codend and weight at position no. 1. SNK tests detected differences in the mean flow rates between the 100 and 200 panel codends at

Table 2

Summaries of *F* ratios from analyses of variance to determine effects on water flow at different positions due to different codends (i.e. 100 panel vs. 200 panel) and weights. The transforms used to stabilize variances (if required) are also listed.

Treatment	df	Position no. 1	Position no. 2	Position no. 3 sqrt(×)	Position no. 4
Codend (C)	1	2.21	5.88*	5.16*	7.92**
Weight (W)	2	2.29	3.95*	8.56**	1.34
C × W	2	7.81**	0.87	0.74	2.77
Residual	30				

position nos. 1, 3, and 4 (Fig. 3). Compared with the 100 panel codend, there was significantly less water flow in the 200 panel codend with a catch of 70 kg at position no. 1 (0.115 m/s difference between means) and at position no. 3 with 50 kg (difference of 0.102 m/s) (Fig. 3, A and C; Table 2). Conversely, at position no. 4, SNK tests detected an increase in the mean water flow in the 200 panel codend with a catch of 30 kg, compared with the 100 panel codend (difference of 0.067 m/s) (Fig. 3D). There was also a similar, although not significant result for 50 kg at this position. There were no other significant differences, although, at position nos. 2 and 3, there were similar trends across all weights (i.e. a reduction in water flow in the 200 panel codend) (Fig. 3, B and C).

Discussion

This study showed that the weight of catches and the configuration of the posterior section in codends can have significant effects on the displacement of water in the anterior section of codends. In interpreting these results, it is important to note that under the simulated conditions in the present study, water was forced through a stationary trawl (at 1.2 m/s). Any localized displacements of water forwards in the codends examined in this study, therefore, can be expressed as a reduction in the flow entering the trawl and calculated by subtraction from 1.2 m/s.

The flow of water at all positions in the four codends tested was less than 1.2 m/s, indicating that there was displacement of water anterior to the catch. However, the degree of this anterior water displacement varied significantly between the codends tested in each experiment (Figs. 2 and 3). For example, in experiment 1, the 200 commercial codend showed a significant increase (compared to the 100 commercial codend) in the displacement of water forwards at position no. 3 across all weights of catch (difference in mean flow of up to 0.203 m/s [Fig. 2; Table 1]). These differences in flow may be attributed primarily to the distribution of the balloons used to simulate catch in the two codends and consequent changes in codend geometry. In the 200 commercial codend, the balloons were observed to spread out evenly in the posterior section, providing a greater surface area of catch incidental to the flow than in the 100 commercial codend. This effect, combined with the increase in the area of twine in the 200 commercial codend probably caused an increase in the displacement of water forwards in this codend.

The above effects in the 200 commercial codend were also detected at position no. 2 with 30 kg of balloons and, although ANOVA failed to detect significant differences for the other weights at this position, the trends in the results were similar (i.e. a reduction in flow in the 200 commercial codend compared with the 100 commercial codend [Fig. 2; Table 1]). At position no. 1, for all weights, the force of the displaced water in front of the 200 commercial codend had dissipated to the extent where there were no significant differences between the two codends (Fig. 2; Table 1). It can be assumed, therefore, that the major influence of increased codend circumference on water displacement in the middle of the 200 commercial codend probably occurred up to some point between position nos. 2 and 3 (560 mm to 1120 mm from the end of the codend), in relation to the weight of catch.

In experiment 2, the effects of increased codend circumference on water displacement under the square-mesh panel were detectable at a greater distance from the end of the codend than those described above. Compared with the 100 panel codend, there were significant reductions in flow (corresponding to an increased displacement of water forwards) in the 200 panel codend at position nos. 1 and 3 (2200 mm and 1490 mm from end of the codend) with a weight of catch of 70 kg and 50 kg, respectively (mean differences in flow of 0.115 m/s and 0.102 m/s, respectively) (Fig. 3, A and C; Table 2). Although not significant, there were similar trends at position no. 2 for each weight and at position no. 3 for 30 kg and 70 kg (Fig. 3, B and C; Table 2). In contrast, there was a significant increase in the flow of water at position no. 4 in the 200 panel codend with 30 kg and a similar result (though not statistically significant) for 50 kg (Fig. 3D; Table 2). This anomaly may be explained by the fact that the balloons in the 200 panel codend (like those in the 200 commercial codend) were orientated evenly across the surface area of the posterior section, increasing its diameter and decreasing the angle of incidence of its netting as it led into the anterior section of the codend at position no. 4. Although the current meter was located immediately under the composite square-mesh panel, at this position it was effectively aligned slightly above the anterior section of the codend and may have been influenced by the current outside the trawl, negating some of the flow-related effects of codend mesh circumference.

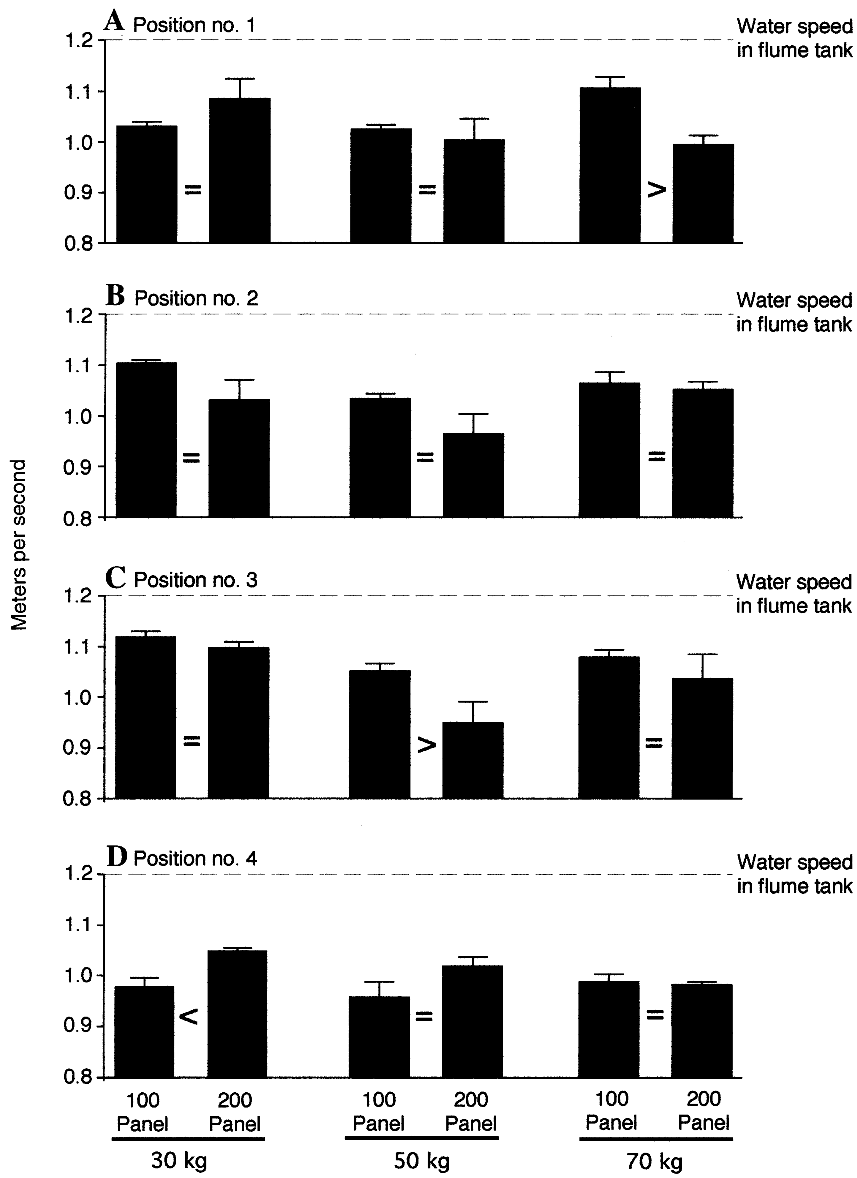

Figure 3

Differences in mean flow rates ±SE between the 100 and 200 panel codends tested in experiment 2 for each position of the current meter and for different weights (< and > indicate direction of differences in SNK tests of means).

With the exception of this latter result, the measured reductions in flow at most positions in the 200 codends (corresponding to increases in water displacement forwards) support the hypothesis that an increase in the circumference of meshes in the codend contributes towards the escape of small fish (between 5 and 20 cm) through the composite square-mesh panel (see Broadhurst and Kennelly, 1996; 1997). The size of these fish suggests that they are using anaerobic muscle power to maintain position in the moving trawl (1.2 m/s) and are fatigued when they enter the codend (see Beamish, 1978; Wardle, 1989). A relatively small increase in the displacement of water forwards (e.g. 0.203 m/s at position no. 3 in the 200 commercial codend or 0.1 m/s at position no. 3 in the 200 panel codend) may be sufficient 1) to assist small fish to swim forwards and out through the square meshes in the panel and [or] 2) to enable them to reduce their tail-beat frequencies and maintain their position in the codend for a longer period, increasing their chances of random escape through the panel; and [or] 3) to stimulate their lateral line receptors and thus their overall escape.

Without direct observations of fish swimming in the codend, it is difficult to determine their specific behavior during escape. Whatever their actual escape mechanism, however, the results obtained in this study provide important information for the subsequent design and location of BRDs like the com-

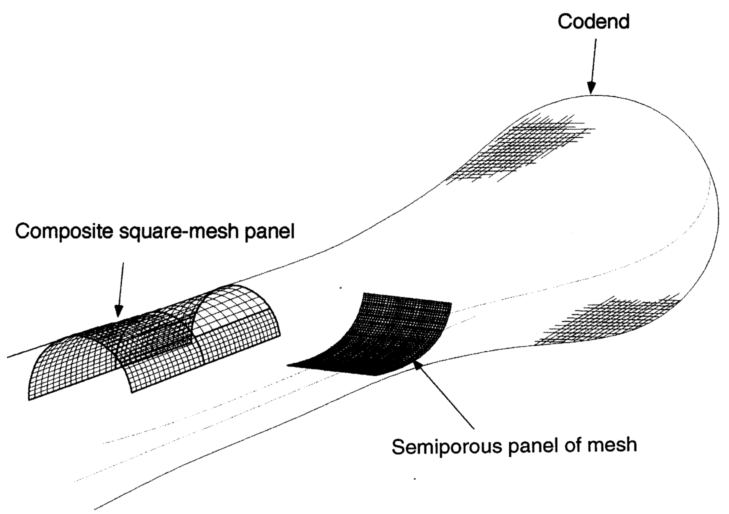

Figure 4

Diagrammatic representation of proposed modification to codends containing the composite square-mesh panel.

posite square-mesh panel. It is apparent that to maximize the effects of anteriorly displaced water in the posterior section of codends, the composite square-mesh panel should be located as close as possible to the end of the codend, but sufficiently in front of the anticipated build-up of catch to prevent prawns from accumulating past the square meshes and escaping through them. A solution to this problem would be to increase the codend mesh circumference in the posterior panel (i.e. the 200 panel codend), causing the catch to spread laterally in the back of the codend, rather than to accumulate in front. Although such a modification would also increase surface area, displacement of water forwards, and probably enhance fish escape through the square-mesh panel, it would also reduce mesh openings and the selectivity of the codend itself (Broadhurst and Kennelly, 1996).

An alternative modification that may increase displacement of water forwards (other than increasing codend circumference and catch) is to move the composite square-mesh panel forward in the codend and create areas of "artificial catch" by using semiporous panels (e.g. those with fine mesh). These could be positioned on the bottom of the codend, behind the panel and at an angle to the direction of tow (e.g. see Fig. 4). Such modifications would produce similar flow-related effects as those observed in our study, i.e. they would displace water anteriorly, directing fish towards the panel. Future research into the refinement of square-mesh panels and other BRDs in prawn-trawls that exploit the behavioral differences of fish in trawls, may benefit from these or similar modifications.

Acknowledgments

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