Effects of square-mesh panels in codends and of haulback delay on bycatch reduction in the oceanic prawn-trawl fishery of New South Wales, Australia

Matt K. Broadhurst
Steven J. Kennelly
Gerard O'Doherty
Fisheries Research Institute, N.S.W. Fisheries
P.O. Box 21 Cronulla, New South Wales 2230, Australia

Abstract.—Two experiments were conducted in the New South Wales oceanic prawn-trawl fishery, 1) by comparing catch from a conventional codend with that from two new codend designs with square-mesh panels and 2) by showing the effects on catches of a short delay in haulback of trawls with square-mesh panels. The two new codend designs incorporated panels of netting (85-mm mesh) sewn such that the meshes were square-shaped (measuring 7 × 11 bars) and inserted lengthwise and widthwise into the tops of the anterior sections. Simultaneous comparisons among these designs and a conventional codend showed that both designs performed similarly by significantly reducing the weights of bycatch that would be discarded (by 46% and 38%, respectively) without significantly reducing the catch of the prawn *Penaeus plebejus*. The second experiment showed that juvenile red spot whiting, *Sillago flindersi*, an important commercial finfish, escaped from the square-mesh panels in the trawl during a 10–15 second haulback delay. Trawls without any haulback delay showed no significant reduction in the bycatch of this species. The results are discussed in terms of the probable behavior of fish in the modified trawls and in terms of the implications that factors such as haulback delay may have on the survival of fish escaping through square-mesh panels in codends.

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In many of the world's prawn-trawl fisheries, significant numbers of nontarget organisms (collectively termed "bycatch," sensu Saila, 1983) are caught incidentally with targeted prawns. This bycatch often includes a large and diverse assemblage of small fish, some of which are juveniles of commercially and recreationally important species (for reviews see Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994; Kennelly, 1995). The incidental capture and mortality of large numbers of these juveniles has been of worldwide concern in recent years because it may reduce the potential biomass and yield of stocks that form the basis of other fisheries (Gordon, 1988; Foldren, 1989).

In New South Wales (NSW), Australia, oceanic prawn trawling involves approximately 300 vessels that usually operate during the night from 11 ports. This fishery is valued at approximately A$17 million per annum and primarily targets the eastern king prawn, *Penaeus plebejus*, although a significant proportion of the total income is derived from the sale of legally retained bycatch (termed "byproduct"), which comprises several commercially important species of fish, crustaceans, and cephalopods (see Kennelly et al., 1992). However, a recent survey examining the spatial and temporal distributions and abundances of the catch and bycatch from four ports in this fishery showed that juveniles of commercially important species comprised a significant portion of the bycatch (Kennelly[1]). Athough many of these juveniles showed large temporal and spatial variabilitiy in their occurrence, some (e.g. red spot whiting, *Sillago flindersi*, and eastern blue spot flathead, *Platycephalus caeruleopunctatus*), were consistently caught in large numbers throughout the sampling period. Although there are few data available on the population structure and dynamics of the key bycatch species or on the extent of their post-trawl mortalities, the quantities involved have raised concerns regarding potential detrimental impacts of prawn trawling on future stocks of these species (Kennelly, 1993). We therefore began an investigation that examined various modifications to trawling gear and trawling practices that minimize undesirable bycatch while maintaining catches of prawns and commercial byproduct.

[1] Kennelly, S. J. 1993. Study of the bycatch of the NSW east coast trawl fishery. Final report to the Fisheries Research and Development Corporation, P.O. Box 222, Deakin, ACT, 2600, Australia. Project No. 88/108. ISBN 0 7310 2096 0, 520 p.

One suite of modifications to trawls that has been successful throughout the world in reducing bycatches while retaining the target catch involves the use of square-mesh panels in codends (Robertson and Stewart, 1988; Carr, 1989; Briggs, 1992; Broadhurst and Kennelly, 1994; Robertson[2]; Isaksen and Valdemarsen[3]; Suuronen[4]). Quantifying the effectiveness of square-mesh panels in codends has been approached by a variety of experimental methods. At the simplest level, catches and bycatches from control and modified codends have been compared by using alternate tows (Robertson and Stewart, 1988; Broadhurst and Kennelly, 1994), by towing both codends as twin gear (Briggs, 1992), by using trouser trawls (Walsh et al., 1992; Suuronen[4]), or by towing either gear from two adjacent vessels (Thorsteinsson, 1992). Alternatively, covers of small-mesh netting over modified codends have provided estimates of the quantities of fish escaping (Robertson and Stewart, 1988).

Although these kinds of experiments have determined the effectiveness of square-mesh panels in codends, without direct observations by divers or cameras there is no information available on the patterns of behavior of escaping fish or on the period when escapement occurs during tows. The latter point raises an important issue with respect to the survival rates of escaped catch. Because fish are exhausted to varying degrees owing to the stress associated with capture (see Wardle, 1983; Main and Sangster[5]), the ultimate efficiency of square-mesh panels in reducing bycatch mortality is determined by the rate at which nontarget individuals are excluded. The survival of these individuals is probably inversely proportional to the time spent in the trawl, because studies have shown that fish that remain in the codend are subjected to high levels of stress and fatigue (Main and Sangster[5]; Main and Sangster[6]).

Observations from divers, from video cameras, and from towed submersibles, have provided conflicting information on the behavior of escaping fish (Wardle, 1983, 1989; Watson, 1989; Briggs, 1992; Watson et al., 1993). For example, in the Irish Sea, Briggs (1992) observed that the escape of European whiting, *Merlangius merlangus,* occurred continually throughout the duration of the tow. In contrast, Watson et al's (1993) studies in the Gulf of Mexico showed that red snapper, *Lutjanus campechanus,* maintained their position within the codend throughout the tow and escaped only when haulback was initiated.

In the NSW oceanic prawn-trawl fishery there is commonly a delay of up to 15 seconds (s) between slowing the vessel and engaging the winch to haul in the trawl (termed haulback delay). Because of this delay, possible effects, such as those observed by Watson et al. (1993), need to be investigated prior to interpreting the effectiveness of square-mesh panels in codends. Direct observations of such effects, however, always assume that the divers or cameras have no artificial effects on the behavior of the fish or on the normal commercial operation of the gear. While it may be reasonable to assume minimal effects in conditions with adequate light, Wardle (1989) found that the use of cameras with artificial light at night or in turbid conditions (below 10^{-3} lux) disorientated fish and disturbed their behavior. The possibility of such effects makes this technique unsuitable for assessing the effects of haulback delay on square-mesh panels in the NSW oceanic prawn-trawl fishery which operates at night.

Our specific goals in this experiment were 1) to investigate the effectiveness of square-mesh panels in reducing the bycatch from the NSW oceanic prawn-trawl fishery and 2) via a manipulative experiment, to provide an accurate and inexpensive means to determine the effects of haulback delay on the performance of these designs.

Materials and methods

Two experiments were conducted on commercial prawn-trawl grounds east of Yamba, New South Wales (29°26'S, 153°22'E), between August and October 1994 by using a commercial prawn trawler (13.8 m). Three florida flyers (mesh size 42 mm), each with a headline length of 12.8 m, were rigged in a standard triple gear configuration (see Andrew et al., 1991, for details) and towed at 2.5 knots. Each of the identical outside nets were rigged with zippers (no. 10 nylon open-ended auto lock plastic slides) to facilitate changing of the codends (see Broadhurst et al., in press). Because the middle net was not rigged

[2] Robertson, J. H. B. 1983. Square mesh cod-end selectivity experiments on whiting (*Merlangius merlangus* (L.)) and haddock (*Melanogrammus aeglefinus* (L.)). Int. Counc. Explor. Sea, council meeting 1983/B:25, 13 p. [Mimeo.]

[3] Isaksen, B., and J. W. Valdemarsen. 1986. Selectivity experiments with square mesh codends in bottom trawl. Int. Coun. Explor. Sea, council meeting 1986/B:28, 18 p. [Mimeo.]

[4] Suuronen, P. 1990. Preliminary trials with a square mesh codend in herring trawls. Int. Counc. Explor. Sea, council meeting 1990/B:28, 14 p. [Mimeo.]

[5] Main, J., and G. I. Sangster. 1988. Scale damage and survival of young gadoid fish escaping from the cod-end of a demersal trawl. *In* J. DeAlteris (ed.), Proceedings of selectivity and survivability workshop, p. 17–34. Univ. Rhode Island Sea Grant Advisory Service, Narragansett, RI.

[6] Main, J., and G. I. Sangster. 1991. A study of haddock (*Merlanogrammus aeglefinus* (L.)) behavior in diamond and square-mesh codends. Scot. Fish. Work. Paper 19/91, 25 p.

exactly like the outside nets (see Andrew et al., 1991), it was excluded from our analyses.

The codends used in the experiments measured 75 meshes long (3 m) and were constructed from 40-mm mesh netting (Fig. 1). They comprised two panels. The anterior panel was 100 meshes in circumference and constructed of 25 meshes of 48-ply twine attached to 25 meshes of 35-ply twine. The posterior panel was 200 meshes in circumference and constructed of 3-mm diameter braided twine.

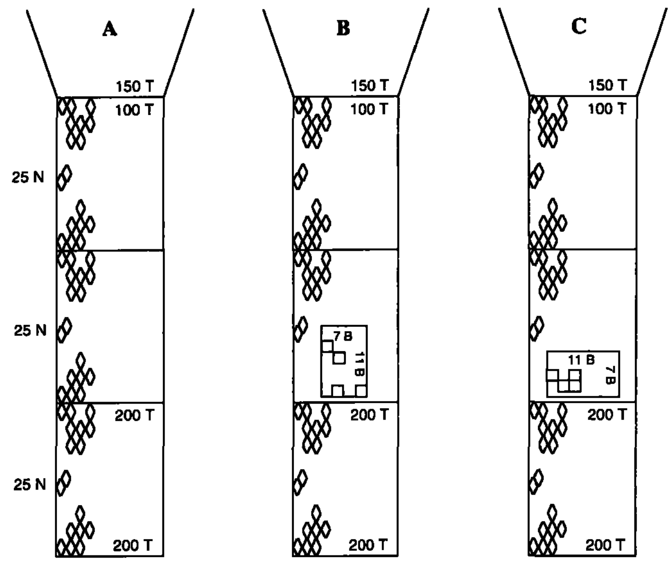

Figure 1

Diagrammatic representation of (A) the control codend, (B) the 85-mm-long codend and (C) the 85-mm-wide codend (T=transversals; B=bars; N=normals).

Experiment 1—evaluation of codends

Three codend designs were compared. The control codend was made entirely of diamond-shaped meshes (Fig. 1A). The second codend (termed the 85-mm-long codend) had a panel of 85-mm netting cut on the bar (7 bars × 11 bars) inserted lengthwise into the top of the anterior section (Fig. 1B). The third codend (termed the 85-mm-wide codend) had the same panel inserted sideways into the top of the anterior section (Fig. 1C).

All three codends were compared against each other in independant, paired trials. That is, in separate tows, the 85-mm-long codend was compared against the control; the 85-mm-wide codend was compared against the control; and the 85-mm-long and 85-mm-wide codends were compared against each other. The particular pair to be compared in a given tow were placed on each outside net of the triple-rigged gear. The position and order of each codend was determined randomly (to eliminate any biases between different nets) and the codends were used in normal commercial tows of 90-min duration (with a haulback delay of 10–15 s) on established prawn-trawl grounds. Over six nights we completed a total of 10 replicate tows of each paired comparison. Prior to the trials and at the end of each night, we rigged the outside nets with normal commercial codends and performed tows to ensure that there were no differences in the fishing characteristics of each net.

Experiment 2—effects of haulback delay

In this experiment the 85-mm-long codend from experiment 1 was tested against the control for possible effects due to haulback delay. The codends were interchanged between tows, and each night we completed two replicate 90-min tows that included 1) a 10–15 s haulback delay (measured as the duration between slowing the vessel and engaging the winch) and 2) no haulback delay. Over 4 nights we completed a total of 8 replicate tows for each type of haulback. To ensure independence among tows, the location and direction of each tow was randomly selected from the available locations on established grounds northeast of Yamba. The grounds trawled varied in depth and ranged between 20 and 25 fm.

Data collected from the experiments

After each tow in each experiment, the codends were emptied onto a partitioned tray. Prawns and all commercially important species larger than the minimum legal size (retained commercials) were separated from the remaining bycatch. The remaining bycatch (termed discarded bycatch) was then sorted. This included individuals of commercially important species that were smaller than the minimum legal size (discarded commercials). Data collected from each tow were the total weight of prawns and their size (to the nearest 1-mm carapace length); the weight of the discarded bycatch; the weights, numbers, and sizes (to the nearest 0.5 cm) of discarded commercial species and retained commercial species; and the numbers of noncommercial species in the assemblage. All individuals were counted without subsampling. Several commercially important species were caught in sufficient quantities to allow meaningful comparisons. These were eastern king prawn, *Penaeus plebejus*, cuttlefish, *Sepia* sp., Octopus, *Octopus* sp., red spot whiting, *Sillago flindersi*, eastern blue spot flathead, *Platycephalus caeruleopunctatus*, and smooth bug, *Ibacus* sp.

The paired comparisons done in experiment 1 were analyzed with one-tailed, paired *t*-tests. Data from experiment 2 were analyzed with two-factor analysis of variance (Underwood, 1981) after testing for homogeneity of variances (Cochran's test). Further, treating the data from each haulback-delay period separately, we compared data from the pairing of the 85-mm-long and control codends, using one-tailed, paired *t*-tests. Data from the 85-mm-long codend and its control (which used the haulback delay of 10–15 s in experiment 2) were combined with data from these codends in experiment 1, to provide a larger dataset for analysis of the results for the 85-mm-long codend. Size frequencies of prawns and red spot whiting from both experiments and the combined data were compared by using two-sample Kolmogorov-Smirnov tests (P=0.05).

Results

Experiment 1—evaluation of codends

Both the 85-mm-long and 85-mm-wide codends significantly reduced the weight of discarded bycatch (means reduced by 46% and 38%, respectively) (Fig. 2A; Table 1). The 85-mm-wide codend significantly reduced the number and weight of discarded red spot whiting (by 71% and 75%), and the number of trash species (Fig. 2, D–F; Table 1). There were insufficient data from the 85-mm-long codend to analyze data for red spot whiting (<2 fish per replicate). Neither of the codends with square-mesh panels significantly reduced the catch of prawns (Table 1), although the mean catches were 7.5% lower in the 85 mm long codend and 2.5% lower in the 85-mm-wide codend (Fig. 2G). Apart from a significant reduction in the number of trash species with the use of the 85-mm-long codend (Fig. 2F; Table 1), there were no other detectable differences between the two codends with square-mesh panels. Two-sample Kolmogorov-Smirnov tests comparing the size-frequency distributions for the king prawns and red spot whiting measured from each sample showed no significant differences in the relative size compositions between any of the codends tested.

Experiment 2—effects of haulback delay

There were no significant effects due to haulback delay on the differences in catch between the control and 85-mm-long codends for the weight of bycatch and prawns (Fig. 3, A–B; Table 2). However, haulback delay significantly increased the difference in catch between the control and 85-mm-long codends for the number and weight of red spot whiting and decreased the weight of retained cuttlefish (Fig. 3, C–E; Table 2). There were no significant effects among any of the other variables (i.e. retained octopus, discarded eastern blue-spot flathead, smooth bug, and trash species) due to haulback delay. The number and weight of red spot whiting were significantly differ-

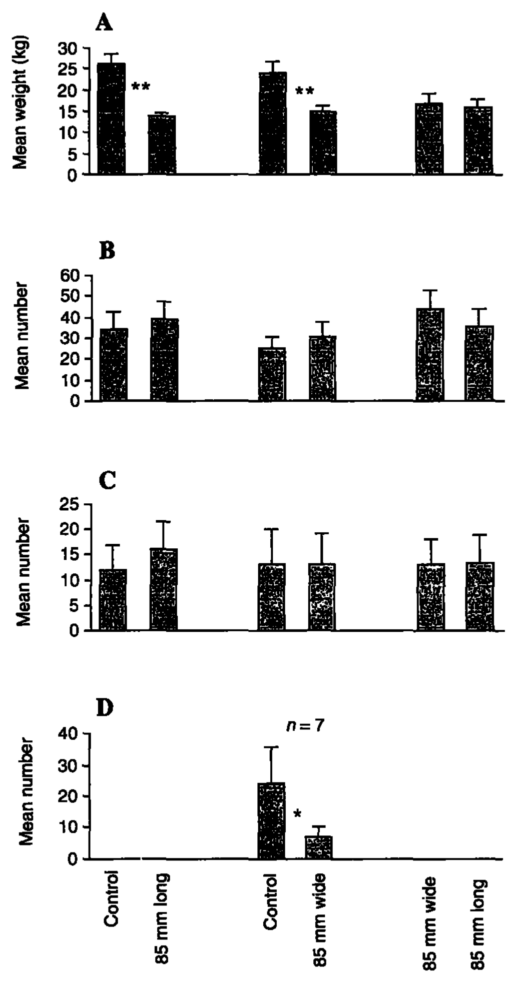

Figure 2

Differences in mean catch (±SE) between each of the codends in experiment 1 (evaluation of codends): (**A**) the weight of discarded bycatch; (**B**) the numbers of retained octopus (*Octopus* sp.); (**C**) the numbers of discarded cuttlefish (*Sepia* sp.); (**D**) the number of discarded red spot whiting (*Sillago flindersi*); (**E**) the weight of discarded red spot whiting (*Sillago flindersi*); (**F**) the number of noncommercial species; and (**G**) the weight of prawns (*Penaeus plebejus*). * = P<0.05; ** = P<0.01; unless stated otherwise, n = 10.

ent among nights in the experiment. No variables displayed significant interactions among haulback delay and nights (Table 2).

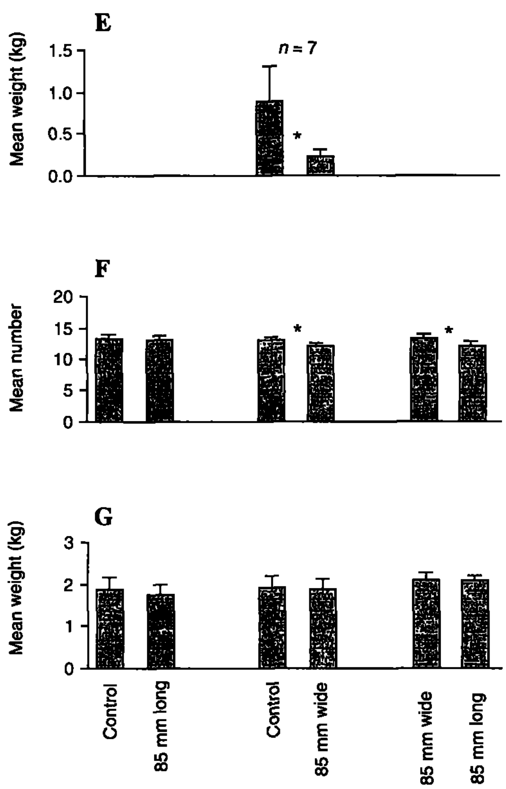

Figure 2 (continued)

One tailed, paired t-tests comparing data from the control and 85-mm-long codends showed that the 85-mm-long codend significantly reduced the weight of bycatch and significantly increased the weight of prawns during both a 10–15 s delay and no delay in haulback (Fig. 3, A–B; Table 3). The 85-mm-long codend significantly reduced the number and weight of discarded red spot whiting compared with the control during the 10 to 15 s haulback delay (means reduced by 64% and 56%, respectively) (Fig. 3, D–C; Table 3). There was no significant reduction in these variables for this codend when there was no delay in haulback, although the mean numbers and weights of red spot whiting were reduced by 21% and 25%, respectively (Fig. 3, D–C; Table 3). The weight of retained cuttlefish was significantly decreased in the 85-mm-long codend when there was no delay in haulback (Fig. 3E; Table 3). No other variables showed any differences between the control and 85-mm-long codends either with or without a delay in haulback. Two-sample Kolmogorov-Smirnov tests comparing size-frequency distributions for king prawn and red spot whiting (Fig. 4) measured from each sample showed no significant differences in the relative size compositions between the 85-mm-long and control codends during either a 10–15 s delay or no delay in haulback.

Aggregated data for the 85-mm-long codend

Combining all the data for the 85-mm-long codend, we found that this modification significantly reduced

Table 1

Summary of one-tailed paired t-tests comparing number and weight of catch of three different codends. n = number of replicates; rsw = red spot whiting.

	Control vs. 85-mm-long			Control vs. 85-mm-wide			85-mm-long vs. 85-mm-wide		
	Paired t-value	P	n	Paired t-value	P	n	Paired t-value	P	n
Weight of prawns	1.458	0.089	10	–0.357	0.635	10	0.000	—	10
Weight of discarded bycatch	6.355	0.0001**	10	5.800	0.0002**	10	0.491	0.317	10
Number of discarded cuttlefish	–2.17	0.971	10	0.638	0.269	9	–0.066	0.526	10
Weight of discarded cuttlefish	–0.656	0.736	10	–0.219	0.584	9	–0.264	0.601	10
Number of retained cuttlefish	0.810	0.219	10	0.819	0.217	10	–1.213	0.871	10
Weight of retained cuttlefish	1.331	0.108	10	–0.599	0.718	10	–0.077	0.530	10
Number of retained octopus	–1.847	0.952	10	–2.202	0.973	10	1.451	0.090	10
Weight of retained octopus	–0.248	0.595	10	–0.972	0.822	10	0.346	0.368	10
Number of discarded rsw	(insufficient data)			2.242	0.033*	7	(insufficient data)		
Weight of discarded rsw	(<2 fish per replicate)			2.223	0.034*	7	(<2 fish per replicate)		
Number of noncommercial sp.	1.246	0.122	10	2.228	0.026*	10	2.283	0.024*	10

$^*P$=<0.05; $^{**}P$=<0.01.

the weight of bycatch (mean reduction of 37%) and the number and weight of red spot whiting (by 68% and 58%, respectively) (Figs. 5, A–C; Table 4). This codend did not significantly reduce the weight of prawns (although the mean catch was 3% lower) nor any of the other variables (Fig. 5E; Table 4). Two-sample Kolmogorov-Smirnov tests failed to detect any significant difference in the size compositions of prawns between the 85-mm-long and control codends (Fig. 6A). The sizefrequency distributions for red spot whiting, however, were significantly different between these codends (Fig. 6B).

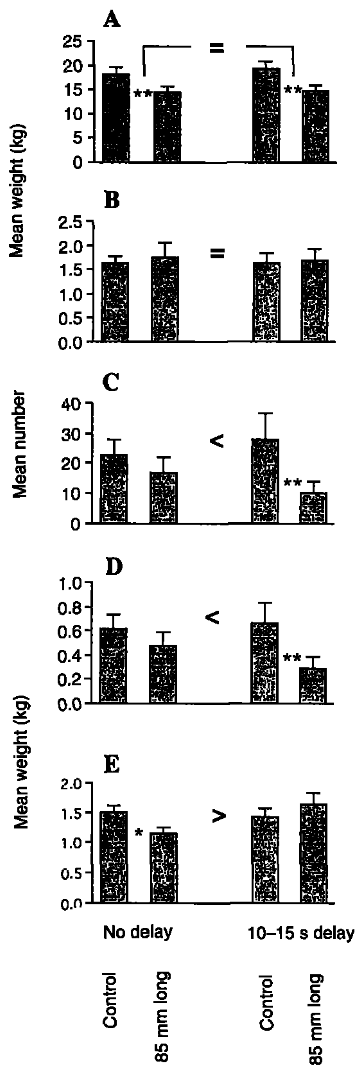

Figure 3

Differences in mean catch (±SE) between the control and 85-mm-long codends in experiment 2 (effects of haulback delay) for no delay and a 10–15 s delay in haulback (<, >, and = indicate direction of differences): (**A**) the weight of discarded bycatch; (**B**) the weight of prawns (*Penaeus plebejus*); (**C**) the number of discarded red spot whiting (*Sillago flindersi*); (**D**) the weight of discarded red spot whiting (*Sillago flindersi*); and (**E**) the weight of retained cuttlefish (*Sepia* sp.). * = $P<0.05$; ** = $P<0.01$.

Discussion

The results of these experiments show that codends with square-mesh panels have the potential to reduce bycatch of nontarget individuals (see also Robertson and Stewart, 1988; Briggs, 1992; Fonteyne and M'Rabet, 1992; Broadhurst and Kennelly, 1994). By experimentally examining the effects of haulback delay, we have also quantified, for the first time, the effects that such operational procedures can have on the escape of some individuals.

In previous experiments, Broadhurst and Kennelly (1994, 1995) showed that square-mesh panels in the anterior sections of codends were effective in releasing small fish (i.e. mulloway, *Argyrosomus hololepidotus*) from prawn trawls in the Hawkesbury River. These results were attributed to the differences in behavior of fish and prawns in their response to

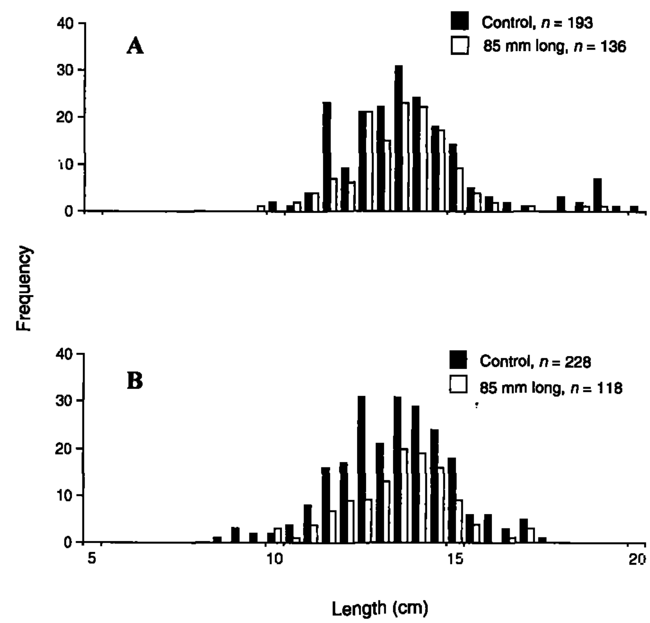

Figure 4

Length-frequency distributions of red spot whiting (*Sillago flindersi*) from the control and 85-mm-long codends for experiment 2: (**A**) during no delay in haulback and (**B**) a 10–15 s delay in haulback.

Table 2

Summary of F-ratios from two-way analyses of variance to determine effects on variables (weight and number of catch) due to haulback delay on different nights.

Treatment	df	Prawns (wt.)	Discarded bycatch (wt.)	Retained octopus		Retained cuttlefish		Discarded eastern blue spot flathead		Discarded red spot whiting		Discarded smooth bugs		Trash species
				(no.)	(wt.)	(no.)	(wt.)	(no.)	(wt.)	(no.)	(wt.)	(no.)	(wt.)	(no.)
Haulback delay (HD)	1	0.25	0.93	0.02	0.01	4.86	9.24*	0.13	0.06	8.25*	7.48*	0.26	2.77	0.02
Nights (N)	3	1.83	1.07	0.12	0.03	0.60	0.91	0.28	0.74	6.13*	5.95*	3.74	0.66	0.57
HD × N	3	2.51	2.26	0.21	1.13	1.78	0.60	0.44	0.96	0.156	0.58	1.07	0.48	1.30
Residual	8													

*P<0.05.

Table 3

Summary of one-tailed paired t-tests for the effect of haulback delay on weight and number of catch for control and 85-mm-long codends. n = 8 for all comparisons; rsw = red spot whiting; ebs = eastern blue spot flathead.

	No haulback delay		10–15 second haulback delay	
	Paired t-value	P	Paired t-value	P
Weight of prawns	0.903	0.198	–0.595	0.715
Weight of discarded bycatch	7.976	0.0001**	4.610	0.001**
Number of retained octopus	–0.242	0.592	–0.043	0.516
Weight of retained octopus	1.560	0.081	0.979	0.180
Number of retained cuttlefish	1.964	0.045*	–1.085	0.844
Weight of retained cuttlefish	2.694	0.015*	–1.843	0.946
Number of discarded ebs	–0.403	0.951	–0.989	0.823
Weight of discarded ebs	–0.956	0.815	–0.712	0.751
Number of discarded rsw	1.072	0.159	3.464	0.0005**
Weight of discarded rsw	0.778	0.231	3.984	0.002**
Number of discarded smooth bugs	–0.037	0.639	–0.716	0.752
Weight of discarded smooth bugs	–0.333	0.626	–0.477	0.676
Number of noncommercial sp.	0.477	0.334	0.174	0.433

*P<0.05; **P<0.01.

stimuli from the trawl and to the hanging configurations of the codends. Fish were apparently herded together at the taper of the codend, invoking an escape response to the sides and top of the net. The attachment of an anterior panel of 100-mesh circumference to a posterior panel constructed of heavy twine and 200-mesh circumference, presumably created a back pressure of water that was directed out through the open anterior square meshes, facilitating the escape of fish. This sequence of events was assumed to occur continually throughout the duration of the trawl. The response of prawns to this stimuli appeared fairly limited; other studies have shown that prawns are not capable of maintaining active escape responses to the trawl and are quickly forced against the meshes and towards the back of the codend (Lochhead, 1961; Main and Sangster, 1985; Newland and Chapman, 1989).

The two square-mesh codends used in experiment 1 were designed to take advantage of the theory discussed above by incorporating a panel of square mesh on top of the anterior section only, so that small fish might escape without a reduction in the catch of prawns or of larger commercially important bycatch

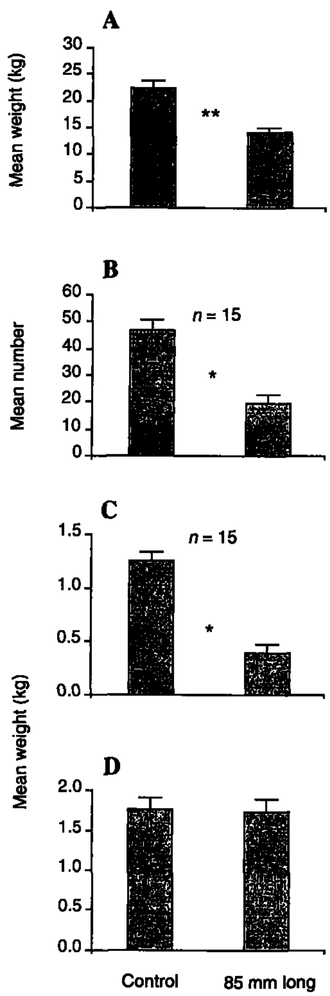

Figure 5

Differences in mean catch (± SE) between the control and 85-mm-long codend, combined across both experiments: (**A**) the weight of discarded bycatch; (**B**) the number of discarded red spot whiting, *Sillago flindersi;* (**C**) the weight of discarded red spot whiting, *Sillago flindersi;* and (**D**) the weight of prawns *Penaeus plebejus*. * = $P<0.05$; ** = $P<0.01$; unless stated otherwise n = 18.

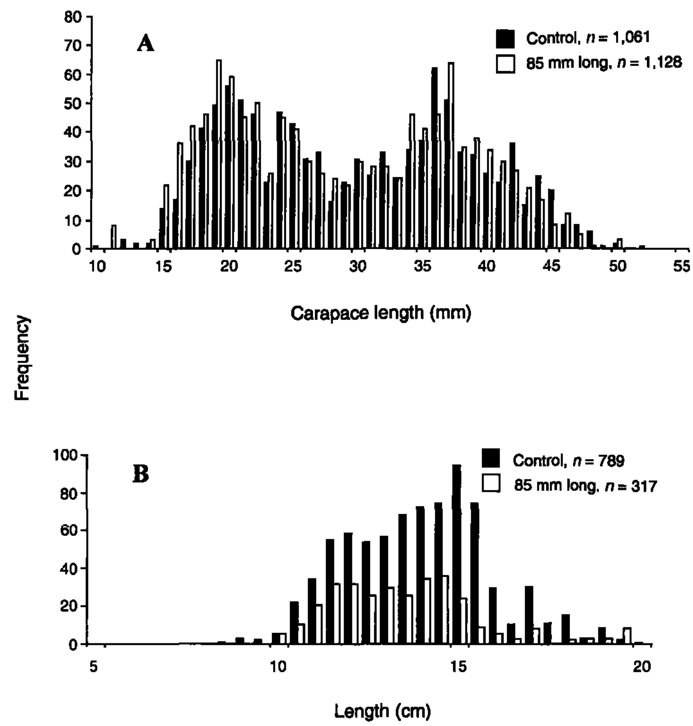

Figure 6

Length-frequency distributions of (**A**) king prawn, *Penaeus plebejus,* and (**B**) red spot whiting, *Sillago flindersi*, from the control and 85-mm-long codends combined across experiments.

species. Both the 85-mm-wide and 85-mm-long codends performed similarly, significantly reducing the weight of discarded bycatch (by 48% and 38% respectively) with no significant reduction in the weight of prawns or retained species (Fig. 2; Table 1). The 85-mm-wide codend also significantly reduced the number and weight of red spot whiting by 71% and 75%, respectively (Fig. 2; Table 1), whereas, based on the aggregated data, the 85-mm-long codend reduced these by 68% and 58%, respectively (Fig. 5; Table 4).

Experiment 2 compared the differences between the control and 85-mm-long codends with and without a short (10–15 s) delay during haulback. The results suggest that the individuals comprising discarded bycatch escaped continually throughout the duration of the tow (Fig. 3A; Table 2). Their behavior and escape from the square-mesh panel may be explained, therefore, according to the theory discussed above. For red spot whiting, however, there was no significant reduction in number or weight when there was no delay in haulback (although the means were reduced by 21% and 28%, respectively), but there was a significant reduction of 64% and 56.6%, respectively, for the tows that included a 10–15 s delay (see Figs. 3 and 6; Table 3). Red spot whiting, therefore, did not appear to exhibit the same behavior as the other species because the majority of these fish appeared to escape during the 10–15 s delay in haulback.

Table 4

Summary of one-tailed, paired *t*-tests comparing control and 85-mm-long codends trialed with a 10–15 s haulback delay, combined over both experiments. *n* = number of replicates; rsw = red spot whiting.

	Control vs. 85-mm-long		
	Paired *t*-value	*P*	*n*
Weight of prawns	1.000	0.165	18
Weight of discarded bycatch	5.720	0.0001**	18
Number of retained cuttlefish	0.355	0.363	18
Weight of retained cuttlefish	0.566	0.289	18
Number of retained octopus	–0.948	0.822	18
Weight of retained octopus	–0.169	0.566	18
Number of discarded rsw	1.935	0.036*	15
Weight of discarded rsw	2.185	0.023*	15
Number of noncommercial sp.	1.587	0.065	18

*$P<0.05$; **$P<0.01$.

A possible reason why few red spot whiting escaped continuously during trawling is that there were insufficient stimuli generated in the codend to invoke an escape response. This hypothesis is supported by previous studies that have shown that physiological and behavioral differences between species are major factors in the effectiveness of escape panels (Robertson and Stewart, 1988; Briggs, 1992; Fonteyne and M'Rabet, 1992). The subsequent escape of red spot whiting from the 85-mm-long codend during the 10–15 s haulback delay may have been a result of additional stimuli generated by changes in the geometry of the codend. For example, Watson (1989) observed that during haulback, differences in the contours of the codend and associated water flow caused fish to aggregate and become disorientated. The fish then increased their swimming speeds and randomly charged the meshes around the codend. By opening the meshes in this area (i.e. by our inclusion of the 85-mm-long square-mesh panel), we may have stimulated some fish to escape the trawl.

The delayed escape of red spot whiting from the 85-mm-long codend raises important questions concerning the extent of their mortality during trawling and after escape. Because previous studies have shown that fish that remain in the codend experience greater stress and fatigue than those that escape continuously, those individuals escaping at the end of the tow may suffer greater mortality. Further, such post-trawl mortality, particularly among smaller fish, may increase in proportion to tow duration. Obviously such effects on red spot whiting should be investigated prior to commercial use of the 85-mm-long codend per se, because, unless most of the escaping fish survive, such designs are of little value.

It may be possible to reduce the problems of trawl mortality for red spot whiting by altering the design of the 85-mm-long codend so that more fish escape continuously during trawling. One possible modification to the design would be to make the square-mesh panel longer (see Briggs, 1992), allowing more red spot whiting to escape at random along the codend. This may also provide juveniles of other commercially important species (i.e. cuttlefish, octopus, and eastern blue spot flathead) the opportunity to escape, although there was little evidence in our experiments to suggest that these species displayed active escape response toward the square-mesh panel (see Figs. 2 and 3; Tables 1–3). Their lack of exclusion is more likely attributable to intraspecific variability in behavioral responses rather than to the design of the square-mesh panel (see also Robertson and Stewart, 1988; Briggs, 1992).

Another modification to allow more red spot whiting to escape the trawl continuously may be to increase the size of mesh used in the panels. However, the size-frequency composition of red spot whiting captured in the 85-mm-long codend and control showed that the size of mesh used in the panel allowed fish within the range of sizes sampled to escape, including some individuals of commercial size (>16 cm) (Fig. 4). Further, this size of mesh resulted in no significant reduction in the weight of prawns, nor were there any significant differences detected in the size composition of prawns between the control and the 85-mm-long or 85-mm-wide codends. Subsequent increases in the size of mesh may, therefore, result in further loss of commercial red spot whiting and possibly some reduction in the catch of prawns.

The square-mesh codends tested in these experiments provide further evidence of the effectiveness of this type of exclusion device in reducing the bycatch of unwanted species, while maintaining the catch of prawns and other species of commercial size. Further, for a fishery that retains a range of species, these designs offer a relatively simple and inexpensive method for eliminating a large part of the incidental catch. It is evident from the results, however, that not all species to be excluded behave in a similar manner and that the effects of operational procedures such as haulback delay can significantly influence the rate of exclusion of some species. Therefore, it is imperative that future research into exclusion designs, such as square-mesh panels, include an assessment of such operational factors so that the full impact of bycatch excluders on reducing the mortality of incidentally caught juveniles can be assessed.

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