The composite square-mesh panel: a modification to codends for reducing unwanted bycatch and increasing catches of prawns throughout the New South Wales oceanic prawn-trawl fishery

Matt K. Broadhurst
Steven J. Kennelly
N.S.W. Fisheries Research Institute
P.O. Box 21 Cronulla, New South Wales 2230, Australia
E-mail address: broadhum@fisheries.nsw.gov.au

Abstract.—The effectiveness of a new bycatch reduction device (BRD) was tested across a wide geographical range to determine its use in the NSW oceanic prawn-trawl fishery. Using four commercial trawlers, each from a different port located in the fishery, we compared the catches and bycatches from conventional trawls with those from trawls containing composite panels of netting (60 mm and 40 mm) hung on the bar and inserted into the top anterior section of the codend (termed the composite-panel codend). This panel was designed so that the 40-mm mesh 1) would allow some small fish to escape and 2) would distribute the load anterior and lateral to the 60-mm mesh (which was located in an area where waterflow was thought to be greatest), allowing the 60-mm mesh to remain open and thus facilitate the removal of larger fish. Simultaneous comparisons against a control codend showed that the composite-panel codend significantly reduced the weights of discarded bycatch at all four locations (means reduced by 23.5% to 41%) and the numbers of juveniles of commercially important species, such as whiting, *Sillago* sp. (by up to 70%). At three of the locations the composite-panel significantly increased the catches of the prawn *Penaeus plebejus* (5.5% to 14%) and, although not statistically significant, showed a similar trend at the fourth location (mean increase of 4%). As a result of this study, the composite-panel codend has been adopted and voluntarily used by fishermen throughout the New South Wales oceanic prawn-trawl fishery.

Manuscript accepted 4 April 1997.
Fishery Bulletin 95:653–664 (1997).

In New South Wales (NSW), Australia, oceanic prawn-trawling involves over 300 vessels operating from 11 major ports along 1,000 km of coastline and is valued at approximately A$17 million per annum. Vessels operating in this fishery primarily target the eastern king prawn, *Penaeus plebejus*, although a significant portion of the total value in the fishery is derived from the sale of legally retained bycatch (termed "by-product")—comprising several species of fish, crustaceans, and cephalopods. As in the majority of the world's prawn-trawl fisheries, however, significant numbers of nontarget organisms are also captured and discarded in this fishery (for reviews see Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994; Kennelly, 1995). In NSW, this discarded bycatch includes individuals of byproduct species that are smaller than the minimum commercial size and a large assemblage of noncommercial species (see Kennelly, 1995).

Unwanted bycatch has been reduced in several of the world's prawn-trawl fisheries by means of modifications to codends that contain bycatch reduction devices (BRD's) (e.g. Watson et al., 1986; Matsuoka and Kan, 1991; Isaksen et al., 1992; Rulifson et al., 1992; Renaud et al., 1993; Christian and Harrington[1]). In general, these modifications have involved either 1) some form of rigid structure that functions by mechanically separating larger unwanted individuals or 2) a strategically placed escape "window" made of netting that works by exploiting behavioral differences between prawns and smaller finfish. Although many of these modifications have proven effective in reducing bycatch from prawn trawls, sometimes they have not been favored by commercial fishermen (see Kendall, 1990; Renaud et al., 1993) because of their size (in relation to the codend), their often complex design (e.g. Mounsey et al., 1995), and, in some cases, their failure to maintain prawn catches at the same levels as conventional trawls (e.g. Rulifson et al., 1992; Robins-Troeger et al., 1995; Christian and Harrington[1]).

One modification that has been successfully tested and adopted in

---

[1] Christian, P., and D. Harrington. 1987. Loggerhead turtle, finfish and shrimp retention studies on four excluder devices (TEDs). *In* Proceedings of the nongame and endangered wildlife symposium; 8–10 September 1987, Georgia, p. 114–127. Dep. Nat. Resources, Social Circle, GA.

several trawl fisheries in the North Atlantic involves inserting large panels of square-mesh in codends (Robertson and Stewart, 1988; Carr, 1989; Briggs, 1992; Isaksen and Valdermarsen[2]; Suuronen[3]). These studies have shown that square-mesh panels often reduce the bycatch of juvenile roundfish while retaining a large proportion of the targeted catch. In previous experiments (Broadhurst and Kennelly, 1994, 1995, 1996; Broadhurst et al., 1996), we have shown that relatively small panels of square-mesh, inserted into the top anterior sections of penaeid prawn-trawl codends, allowed large numbers of small fish to escape without any losses of prawns. In these experiments, the majority of fish were thought to have been herded together in the narrow anterior section of the codend, immediately in front of the catch (see also Wardle, 1983). This concentration of fish was thought to upset the balance of the school and to initiate a response in the fish to escape by swimming towards the sides and top of the net and out through the open square-meshes. In addition, we showed that codend circumference and differences in hydrodynamic pressure had significant effects on the rates of movement of these fish through the square-mesh panel. The reaction of prawns to these stimuli was considered to be fairly limited, given their inability to maintain an escape response to trawls (see Lochhead, 1961; Main and Sangster, 1985).

In a recent experiment (Broadhurst and Kennelly, 1996) in one location in NSW, we tested a new design of codend, comprising composite panels of square-shaped mesh (referred to as the composite-panel codend), designed for and located in the codend, to take advantage of the theory discussed above. The results showed that this design was effective in reducing up to 40% of the total unwanted bycatch and up to 70% of the numbers of juveniles of commercially important species with no significant reduction in the catches of prawns and other commercially important species. Although not validated statistically, there was also some evidence to suggest that the trawls with the composite square-mesh panel retained, on average, slightly more prawns than a conventional trawl (means increased by up to 3%). This latter result, in particular, led numerous local fishermen to install the composite-panel voluntarily in their trawls and use it as part of normal commercial operations.

To assess the performance of this design throughout the full geographic range of this fishery (encompassing the range of fishing conditions and catches) and to promote its voluntary acceptance, our specific goals in the present study were to investigate the effectiveness of the composite-panel under normal commercial operations at four major ports along the NSW coast in 1) reducing unwanted bycatch, 2) maintaining catches of commercially important byproduct, and 3) increasing catches of prawns.

Materials and methods

This study was performed between December 1995 and February 1996 with four commercial vessels (see Table 1 for details) on prawn-trawl grounds offshore from four ports (Port Stephens, Southwest Rocks, Yamba, and Ballina) in New South Wales, Australia (Fig. 1). Each vessel was rigged with three Florida flyers (mesh size=42 mm) in a standard triple gear configuration (see Kennelly et al., 1993 for details), towed at 2.5 knots. Each of the identical outside nets on each vessel were rigged with zippers (no. 10 nylon open-ended auto-lock plastic slides) to facilitate removal and attachment of the codends. Because each of the middle nets were not rigged in exactly the same way as the outside nets, their catches were excluded from any analysis.

The codends used in the study measured 58 meshes long (2.3 m) and were constructed from 40-mm mesh

Table 1

Summary of vessels, trawl headline lengths, and depths trawled for each of the four ports.

Port	Vessel and (length in m)		Trawl headline length for each net (m)	Depth trawled (m)
Port Stephens	*Fairwind*	(16)	16.45	75–88
Southwest Rocks	*Shelley-Anne*	(13.7)	10.97	47–53
Yamba	*L-Margo*	(15.93)	12.8	20–49
Ballina	*New Avalon*	(18.5)	14.63	29–55

---

[2] 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.

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

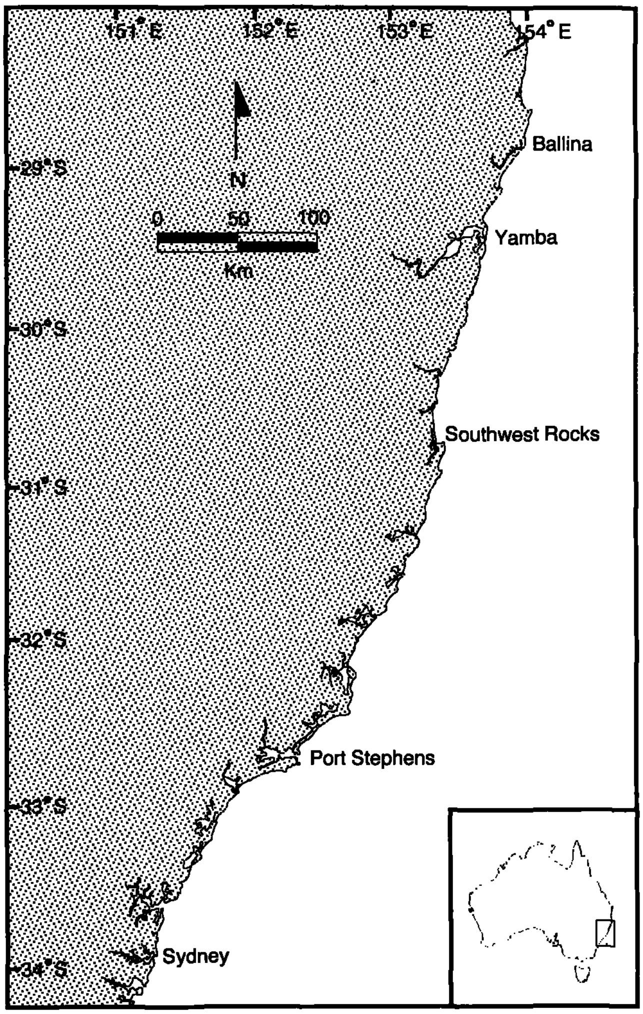

Figure 1

Map of New South Wales showing locations of the four ports that were sampled (Ballina, Yamba, Southwest Rocks, and Port Stephens).

netting and 48-ply twine (Fig. 2). They comprised two sections: the anterior section was 100 meshes in circumference, 33 meshes in length, and attached to a zipper; the posterior section was 150 meshes in circumference and 25 meshes in length. Two designs of codend were compared. The control codend was made entirely of diamond-shaped meshes (Fig. 2A). The second codend (termed the composite-panel codend) was similar to the control but had composite panels made of 60-mm and 40-mm netting cut on the bar and inserted into the top of the anterior section (Fig. 2B—see also Broadhurst and Kennelly, 1996). The composite-panel codend was designed so that the load was distributed anteriorly and laterally to the panel of 60-mm square-mesh, allowing this 60-mm panel to remain open. We predicted that 1) large numbers of fish would escape through this panel, located at the point where waterflow was thought to be greatest and that 2) in addition to reducing load on the 60-mm panel, the 40-mm square-mesh would also facilitate the escape of smaller fish.

The two codends were compared with each other in independent, paired trials, with the two outside nets of each vessel at each location. The codends were used in normal commercial tows of 90-min duration and alternated after each shot (to eliminate biases between different trawls and sides of the vessels). Because some significant effects of a delay in haulback (the period between slowing the vessel and engaging the winch to haul the trawl) were detected in a previous experiment (Broadhurst et al., 1996), all tows were performed with no delay in haulback. The location of each tow was randomly selected from the available prawn-trawl locations that were possible under the fishing conditions. During a period of four nights at locations offshore from each of the four ports, we completed a total of 16 replicate tows (i.e. four separate paired comparisons of 16 replicate tows each throughout the fishery).

After each tow, the two codends were emptied onto a partitioned tray. Prawns and all commercially important species larger than the minimum legal size (retained commercials) were separated. The remaining bycatch (termed "discarded by-catch") 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 as follows: the total weight of king prawns and a subsample (50 prawns from each codend) of their sizes (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 retained and discarded commercial species; the weights and the numbers of the most commonly occurring noncommercial species; and the total numbers of discarded commercial species. Several species (commercial and noncommercial) were caught in sufficient numbers to enable meaningful comparisons (see Table 2).

Data at each port for all replicates that had sufficient numbers of each variable (defined as >2 individuals in at least 8 replicates) were analyzed with one-tailed, paired *t*-tests (i.e. four separate analyses). Because a previous experiment had shown that trawls with the composite-panel have the potential to retain more prawns than conventional trawls (Broadhurst and Kennelly, 1996), we tested the hypothesis that the composite-panel codend caught more prawns but less total bycatch than the control codend. Where analyses provided similar results for weights and numbers of taxa, only data about numbers were included in the figures to conserve space. Size frequencies of prawns, as well as discarded stout

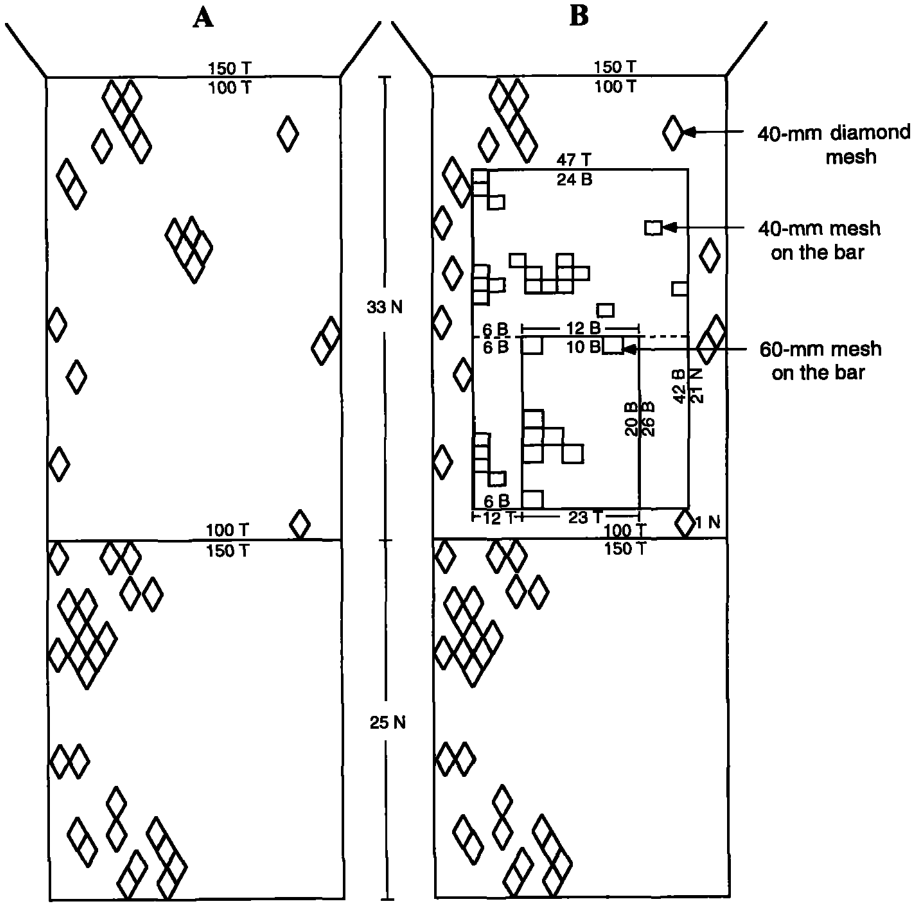

Figure 2

Diagrammatic representation of (**A**) the control codend and (**B**) the composite-panel codend. T = transversals; B = bars; and N = normals.

whiting, red spot whiting, and retained red mullet (where there were sufficient numbers) were plotted for each port and compared with two-sample Kolmogorov-Smirnov tests (P=0.05).

Results

Compared with the control codend, the composite-panel codend significantly reduced the weights of discarded bycatch (means reduced from 23.5% to 41%) at all four ports and significantly increased the catches of prawns at Port Stephens, Yamba, and Ballina (means increased by 14%, 5.5%, and 6%, respectively) (Fig. 3, A and B; Table 3). Although not to a significant degree (4%), the composite-panel codend used at Southwest Rocks also retained, on average, more prawns than the control codend (Fig. 3A). There were no significant reductions detected in the numbers and weights of commercial species retained by the composite-panel codend at any of the four ports (Fig. 3; Table 3).

The mean numbers and weights of discarded red spot whiting and stout whiting were reduced by the composite-panel codend at all locations where there were sufficient numbers to enable meaningful analysis (means reduced by up to 73%) (Fig. 3, F–G; Table 3). At Port Stephens, the composite-panel codend significantly reduced the numbers and weights of discarded john dory (by 50% and 57%, respectively) and blackeyes (by 45%) (Fig. 3, H and M; Table 3). There was a significant reduction in the numbers and weights of flutefish at Southwest Rocks (by 37% and 34%, respectively) and in the numbers and weights of red bigeye at Yamba (by 38.5% and 44%, respectively) and Ballina (by 35%) (Fig. 3, L and K; Table 3). There was also a significant reduction in the numbers and weights of leatherjacket (by 17% and 31%, respectively) and gurnard (by 41.5%) with the composite-panel codend at Ballina (Fig. 3, J and N; Table 3).

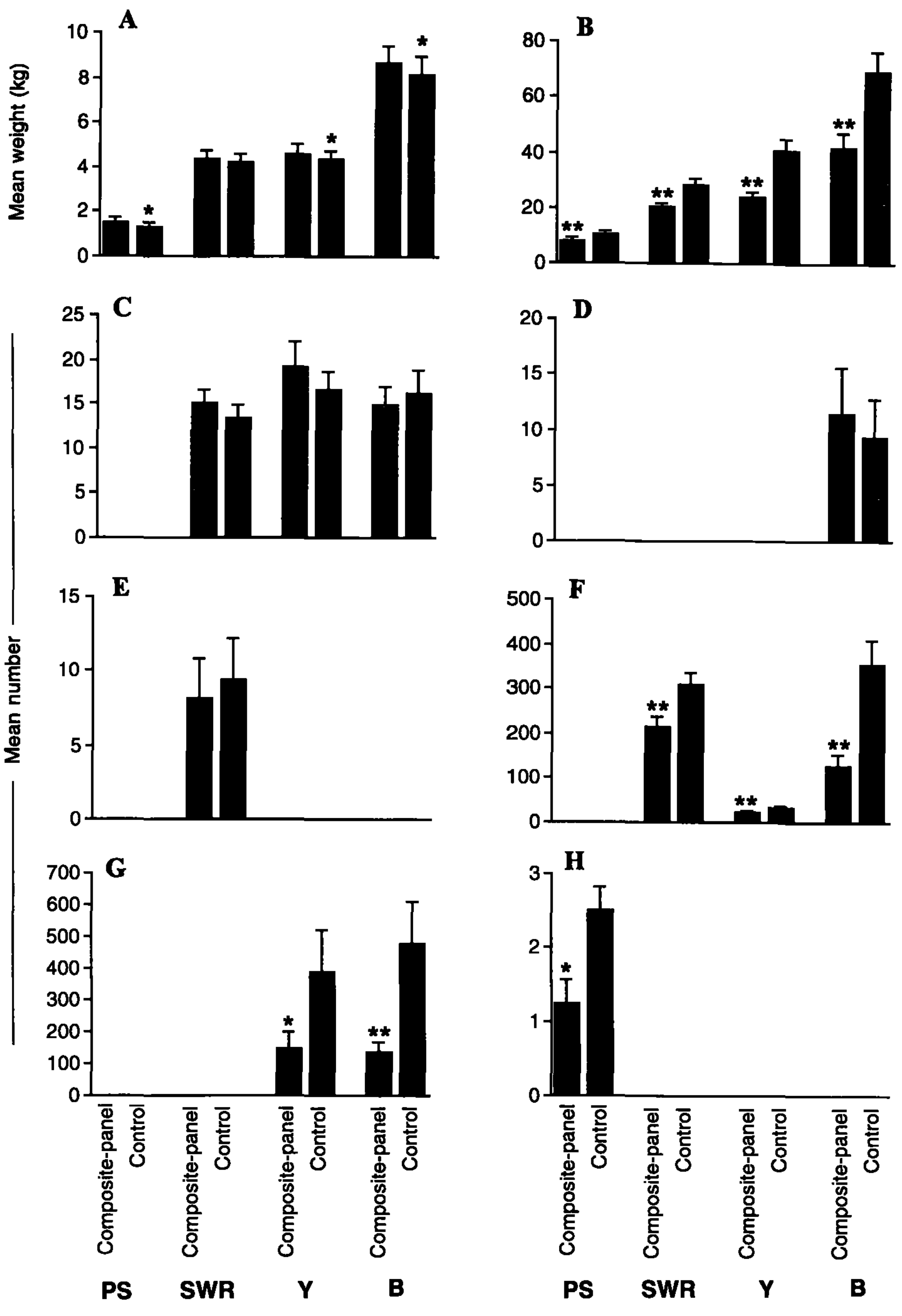

Figure 3

Differences in mean catches (± SE) between the control and composite-panel codends at each of the four ports: the weights of (A) prawns and (B) discarded bycatch; and the numbers of (C) retained octopus, (D) retained red mullet, (E) retained red spot whiting, (F) discarded red spot whiting, (G) discarded stout whiting, (H) discarded john dory, (I) discarded eastern blue spot flathead, (J) discarded leather jacket, (K) discarded red bigeye, (L) discarded flute fish, (M) discarded blackeyes, and (N) discarded gurnard. ** = significant ($P<0.01$); * = significant ($P<0.05$); PS = Port Stephens ; SWR = Southwest Rocks; Y = Yamba; and B = Ballina.

Two-sample Kolmogorov-Smirnov tests, comparing the size-frequency distributions for prawns, discarded red spot whiting, and retained red mullet measured from each sample at each site showed no differences in the relative size compositions of fish retained by the two codends (Figs. 4, 5, and 6C). There were no signifi-

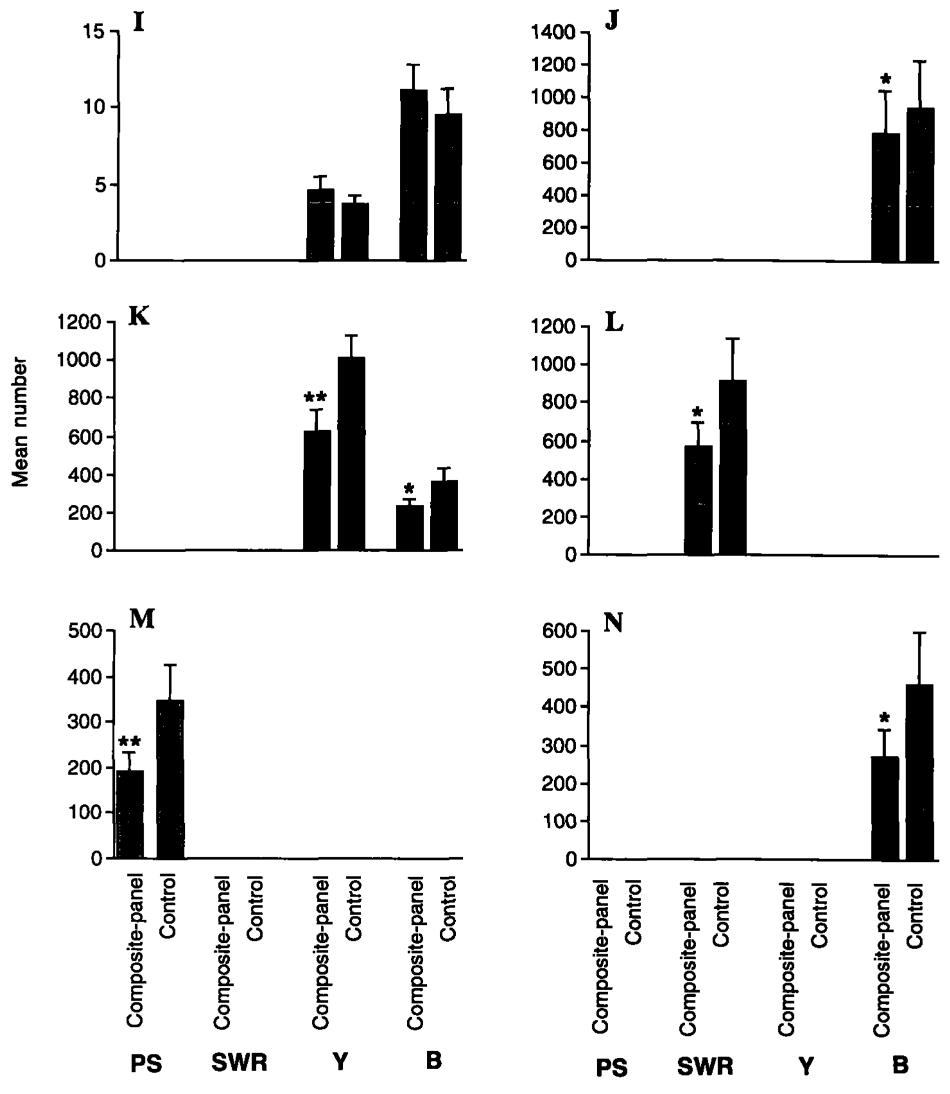

Figure 3 (continued)

Table 2

List of species caught in sufficient quantities to permit analyses.

Scientific name	Common name	Scientific name	Common name
Penaeus plebejus	eastern king prawn	*Platycephalus caeruleopunctatus*	eastern blue spot flathead
Octopus spp.	octopus	*Platycephalus richardsoni*	tiger flathead
Sepia spp.	cuttlefish	*Centroberyx affinis*	redfish
Sepioteuthis australia	southern calamary	*Paramonacantus filicauda*	threadfin leatherjacket[1]
Ibacus sp.	smooth bug	*Priacanthus macracanthus*	big redeye[1]
Pecten fumatus	scallop	*Macrorhamphosus scolopax*	flute fish[1]
Upeneichthys lineates	red mullet	*Apogonops anomalus*	blackeye[1]
Sillago flindersi	red spot whiting	*Lepidotrigla argus*	gurnard[1]
Sillago robusta	stout whiting		
Zeus faber	john dory		

[1] Denotes noncommercial species

Table 3

Summaries of one-tailed paired *t*-tests comparing the composite-panel and control codends. pt-v = paired *t*-value; *n* = number of replicates; all weights are in kilograms. disc = discarded; ret = retained; s. calamari = southern calamari; s. bug = smooth bug; rsw = red spot whiting ; sw = stout whiting; ebs = eastern bluespot flathead; and comm. sp. = commercial species. Significant *P*-values are in bold; insufficient data are marked by a dash.

	Port Stephens			Southwest Rocks			Yamba			Ballina		
	pt-v	*P*	*n*	pt-v	*P*	*n*	pt-v	*P*	*n*	pt-v	*P*	*n*
Wt of prawns	2.139	**0.024**	16	1.366	0.090	16	2.104	**0.026**	16	1.963	**0.034**	16
Wt of disc bycatch	4.467	**0.0002**	16	2.930	**0.0001**	16	5.518	**0.0001**	16	8.254	**0.0001**	16
No. of ret octopus	—	—	—	–0.913	0.812	16	–1.959	0.964	15	0.904	0.190	16
Wt of ret octopus	—	—	—	–0.868	0.800	16	–0.298	0.615	15	–0.341	0.631	16
No. of disc octopus	—	—	—	0.000	•	10	—	—	—	—	—	—
Wt of disc octopus	—	—	—	–0.171	0.566	10	—	—	—	—	—	—
No. of ret cuttlefish	—	—	—	–0.324	0.624	13	—	—	—	—	—	—
Wt of ret cuttlefish	—	—	—	–0.434	0.664	13	—	—	—	—	—	—
No. of disc cuttlefish	0.631	0.272	10	0.500	0.312	16	—	—	—	—	—	—
Wt of disc cuttlefish	0.165	0.436	10	0.995	0.167	16	—	—	—	—	—	—
No. of ret s. calamari	—	—	—	1.011	0.166	13	—	—	—	—	—	—
Wt of ret s. calamari	—	—	—	1.532	0.075	13	—	—	—	—	—	—
No. of disc s. calamari	—	—	—	0.703	0.248	12	—	—	—	—	—	—
Wt of disc s. calamari	—	—	—	0.887	0.197	12	—	—	—	—	—	—
No. of ret s. bug	0.452	0.329	13	—	—	—	—	—	—	—	—	—
Wt of ret s. bug	1.214	0.124	13	—	—	—	—	—	—	—	—	—
No. of disc s. bug	—	—	—	–0.254	0.597	8	–0.541	0.701	15	—	—	—
Wt of disc s. bug	—	—	—	0.344	0.371	8	–0.593	0.718	15	—	—	—
No. of disc scollop	—	—	—	–0.377	0.644	16	–1.109	0.542	9	—	—	—
Wt of disc scollop	—	—	—	0.501	0.312	16	0.348	0.368	9	—	—	—
No. of ret red mullet	—	—	—	—	—	—	—	—	—	–1.012	0.833	12
Wt of ret red mullet	—	—	—	—	—	—	—	—	—	–0.345	0.632	12
No. of ret rsw	—	—	—	0.893	0.194	14	—	—	—	—	—	—
Wt of ret rsw	—	—	—	1.270	0.113	14	—	—	—	—	—	—
No. of disc rsw	—	—	—	4.911	**0.0001**	16	3.593	**0.004**	8	3.704	**0.001**	15
Wt of disc rsw	—	—	—	4.574	**0.0002**	16	2.554	**0.019**	8	3.979	**0.0007**	15
No. of disc sw	—	—	—	—	—	—	2.776	**0.011**	10	2.958	**0.005**	16
Wt of disc sw	—	—	—	—	—	—	2.566	**0.015**	10	3.077	**0.004**	16
No. of disc john dory	2.611	**0.012**	12	—	—	—	—	—	—	—	—	—
Wt of disc john dory	3.174	**0.004**	12	—	—	—	—	—	—	—	—	—
No. of disc ebs	—	—	—	—	—	—	–1.139	0.862	14	–1.037	0.842	16
Wt of disc ebs	—	—	—	—	—	—	–0.919	0.812	14	–0.971	0.826	16
No. of ret tiger flathead	–0.349	0.634	13	—	—	—	—	—	—	—	—	—
Wt of ret tiger flathead	–0.602	0.721	13	—	—	—	—	—	—	—	—	—
No. of disc tiger flathead	1.282	0.111	14	—	—	—	—	—	—	—	—	—
Wt of disc tiger flathead	1.71	0.055	14	—	—	—	—	—	—	—	—	—
No. of disc redfish	0.947	0.179	15	—	—	—	—	—	—	—	—	—
Wt of disc redfish	–0.131	0.551	15	—	—	—	—	—	—	—	—	—
No. of leatherjacket	—	—	—	—	—	—	—	—	—	2.404	**0.014**	16
Wt of leather jacket	—	—	—	—	—	—	—	—	—	2.15	**0.024**	16
No. of red bigeye	—	—	—	—	—	—	3.344	**0.002**	16	2.528	**0.012**	15
Wt of red bigeye	—	—	—	—	—	—	4.122	**0.0004**	16	2.548	**0.012**	15
No. of flutefish	—	—	—	1.841	**0.045**	13	—	—	—	—	—	—
Wt of flutefish	—	—	—	1.851	**0.044**	13	—	—	—	—	—	—
No. of blackeyes	4.364	**0.0003**	16	—	—	—	—	—	—	—	—	—
Wt of blackeyes	5.459	**0.0001**	16	—	—	—	—	—	—	—	—	—
No. of gurnard	—	—	—	—	—	—	—	—	—	2.392	**0.018**	15
Wt of gurnard	—	—	—	—	—	—	—	—	—	2.034	**0.033**	15
No. of disc comm sp	1.168	0.1306	16	–2.282	0.981	16	0.436	0.334	16	–0.674	0.744	16

cant differences detected in the size-compositions of stout whiting at Yamba (Fig. 6A); however, at Ballina, the control codend caught proportionally more small stout whiting than the composite-panel codend (Fig. 6B).

Discussion

This study has shown the effectiveness of square-mesh panels in allowing nontarget organisms to es-

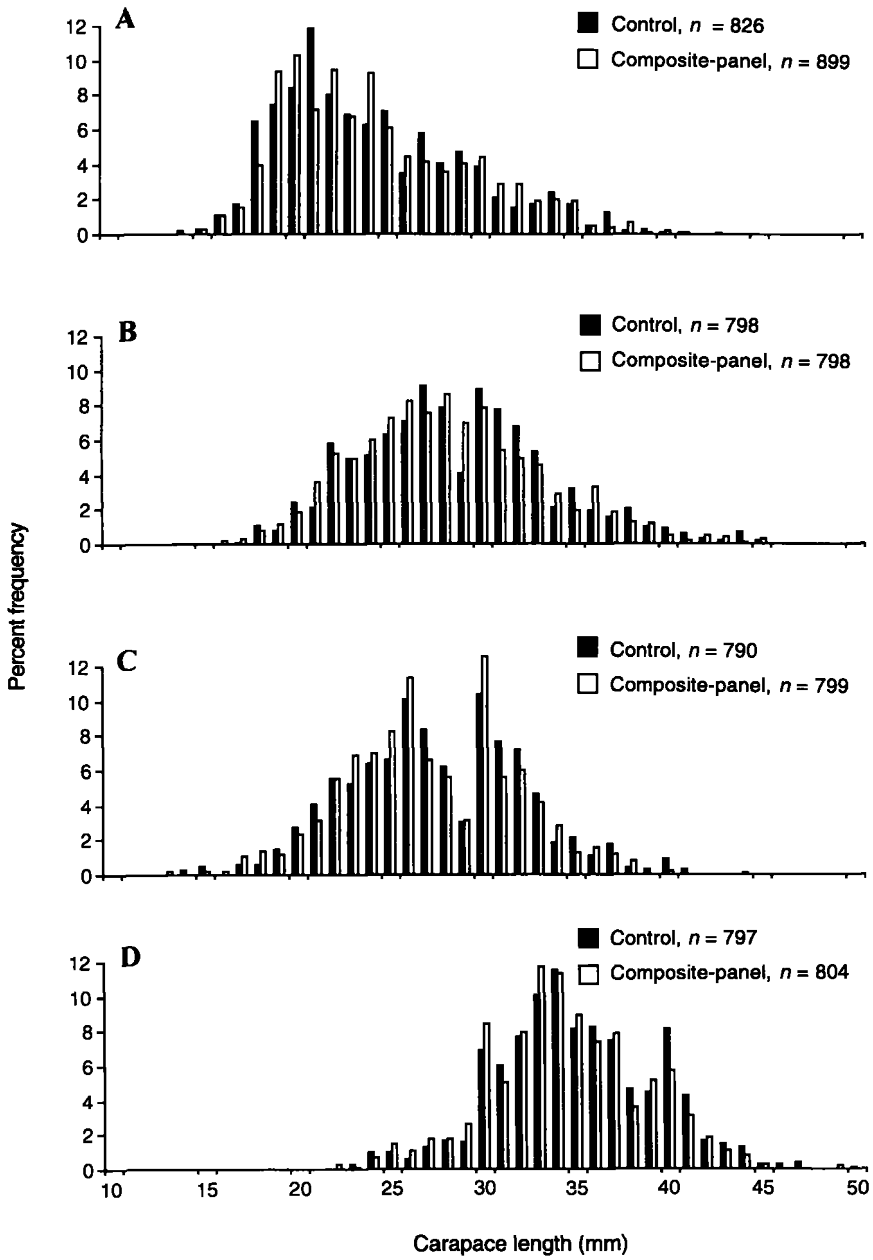

Figure 4

Size-frequency distributions of king prawns caught with control and composite-panel codends from (A) Port Stephens, (B) Southwest Rocks, (C) Yamba, and (D) Ballina.

cape trawls (see also Briggs, 1992; Fonteyne and M'Rabet, 1992; Broadhurst and Kennelly, 1994, 1995, 1996; Broadhurst et al., 1996) while maintaining catches of commercially important species. By conducting independent experiments on different vessels across four ports over a range of fishing conditions and catches, we have also provided information on the relative performance of the composite-panel throughout the full operational range of the NSW oceanic prawn-trawl fishery and have documented, for the first time, a significant increase in the catch of targeted prawns with this design.

The composite-panel codend was most effective in excluding large quantities of those discarded species that are relatively fusiform and of a size small enough to pass through the square-meshes. Species such as

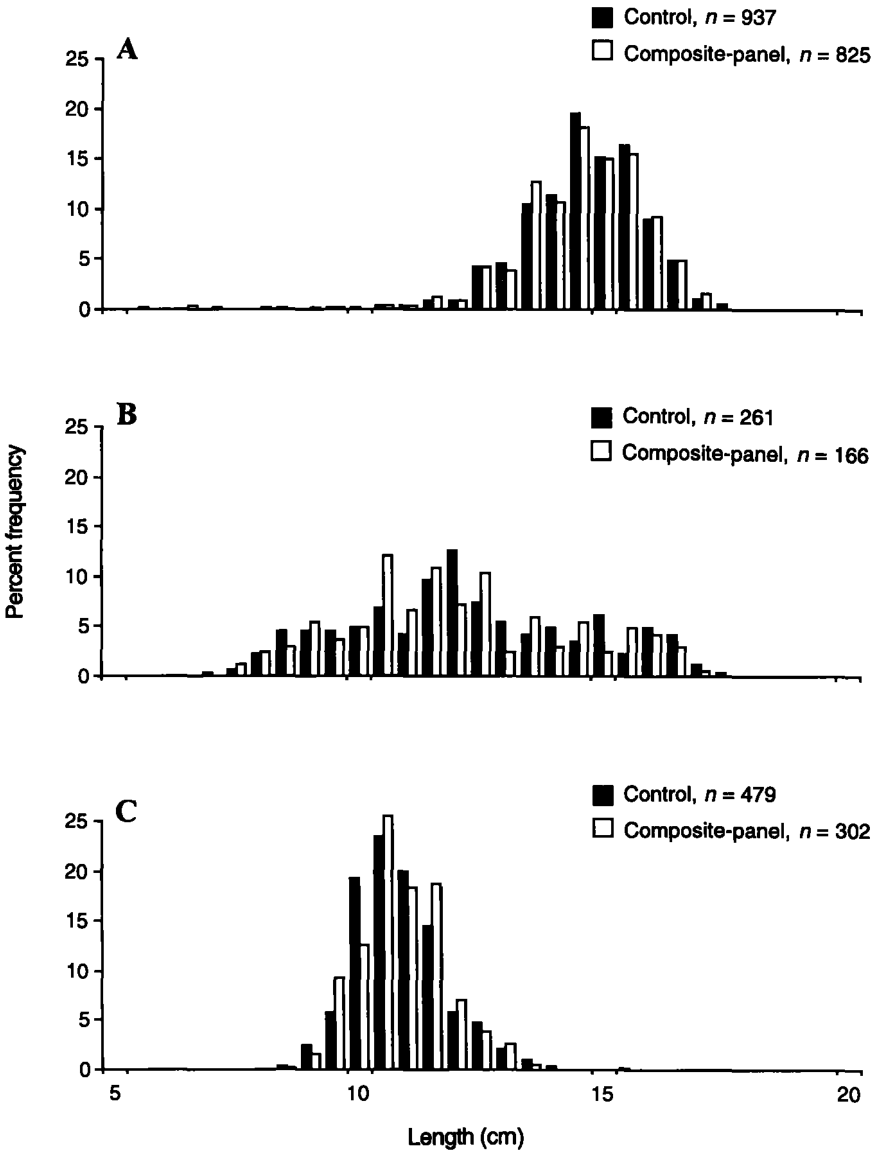

Figure 5

Size-frequency distributions of discarded red spot whiting caught with control and composite-panel codends from (A) Southwest rocks, (B) Yamba, and (C) Ballina.

blackeyes, flute fish, red bigeye, and, in particular, stout and red spot whiting, were all significantly reduced by the composite-panel, which contributed towards a reduction in the mean weight of discarded bycatch at all locations from 23.5% to 41% (Fig. 3). Assuming minimal differences between the various vessels and their gear, the relative availability of these fusiform species throughout waters off New South Wales may explain the variations in the mean reductions of total discarded bycatch at each of the ports and across the fishery. For example, there were no red spot or stout whiting captured at Port Stephens (Fig. 3, E–G), and there was only a 23.5% reduction in total discarded bycatch by the composite-panel at that location (Fig. 3B). In contrast, the discarded bycatch at Yamba and Ballina included large numbers of whiting and red bigeye (up to 500 fish and 1,000 fish, respectively, from each tow in the control net) (Fig. 3, E–F and K) and correspondingly large percentage reductions in total discarded bycatch (41% and 39.5%, respectively) (Fig. 3B).

The above reductions in total discarded bycatch with the composite-panel provide a possible explanation for the significant increase in catches of

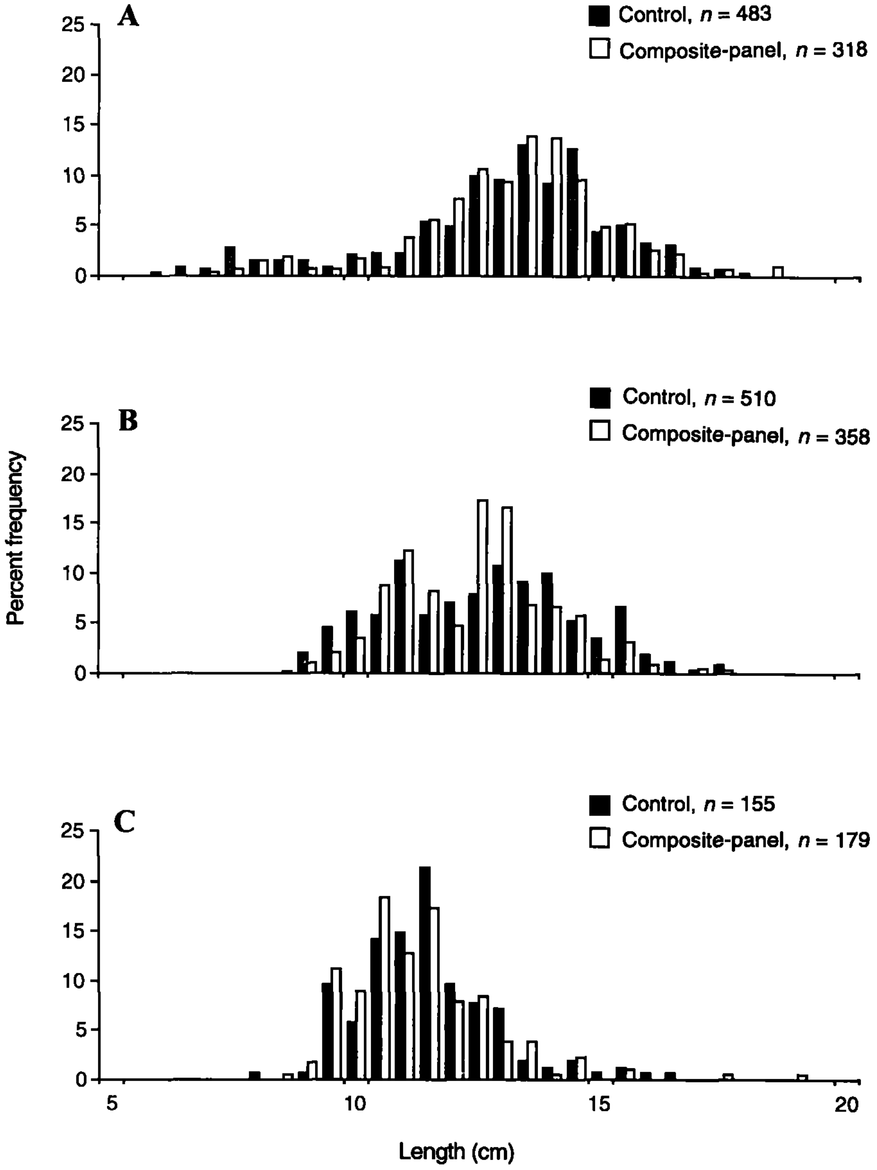

Figure 6

Size-frequency distributions of discarded stout whiting caught with control and composite-panel codends from (A) Yamba, (B) Ballina, and (C) size-frequency distributions of retained red mullet from Ballina.

prawns at Port Stephens, Yamba, and Ballina (by 14%, 5.5%, and 6%, respectively) and for the nonsignificant increase of 4% at Southwest Rocks (Fig. 3A). By reducing the amount of total discarded bycatch and therefore the weight and drag in the codend, the trawl with the composite-panel may have achieved greater spreads between the otter boards (i.e. an increased swept area) than did the control, thereby covering more of the seabed and capturing more prawns. These prawns were probably the same sizes as those that we sampled, because Kolmogorov-Smirnov tests failed to detect any significant differences in prawn sizes between the codends for any of the ports (Fig. 4).

In support of the theory discussed above, there was also an increase (although not statistically significant) in the mean numbers of retained octopus at Southwest Rocks and Yamba (by 11% and 14%, respectively), retained red mullet (by 17%) at Ballina, and discarded eastern blue spot flathead at Yamba and Ballina (by 19.5% and 14.5%, respectively) with the composite-panel (Fig. 3, C–D, and I; Table 1).

Given the physical profile of these individuals and their large size, it is unlikely that once captured by the trawl, they would have been able to fit through the small square-meshes of the composite-panel. In a previous study (Broadhurst and Kennelly, 1996), we showed that large quantities of small individuals of long spined flathead, *Platycephalus longispinis*, escaped through the square-meshes in the composite-panel (62% reduction compared with a conventional codend). Because the tiger and eastern blue spot flathead captured in the present study are physically similar to this species, it may be possible to facilitate their escape simply by increasing the size of mesh in the panel (assuming they display similar responses to stimuli from the trawl). Such a modification, however, would likely result in less retention of smaller individuals of commercially important species such as red spot and stout whiting (see Figs. 5 and 6, A–B), cuttlefish, and southern calamari. In addition, the composite-panel has been designed so that the load is distributed across the many bars of the 40-mm square-shaped mesh. Any major increase in this mesh size would result in the distribution of load across fewer bars, possibly altering the geometry of the codend and its overall performance.

In the present study, we have shown that the composite-panel codend consistently increased catches of prawns over a range of operational conditions while removing large quantities of unwanted bycatch throughout the entire geographic range of the NSW oceanic prawn-trawl fishery. In another study in Australia, Robins-Troeger et al. (1995) tested a large and comparatively complex BRD (termed the "AusTED") off northern Australia and, despite reports of significant losses of prawns, concluded that "the AusTED system has the potential to be developed to suit trawling conditions encountered in different Australian prawn fisheries." It is unlikely, however, that any design of a BRD would be accepted and endorsed by fishermen if it did not consistently maintain catches of the target species throughout the range of the fishery—as is shown to be the case in the present paper for the composite-panel codend (see also Kendall, 1990; Renaud et al., 1992).

In terms of promoting a large-scale voluntary adoption of BRD's, like the composite-panel described in the present paper, it is useful to provide industry not only with evidence of catch rates similar to those obtained with conventional gear but also with evidence of additional benefits, such as a potential for increasing duration of tows, improving quality of catches (due to less damage from bycatch in the codend), increasing savings in labor and fuel, reducing sorting times, and reducing conflicts with other user groups (e.g. recreational and commercial fishermen targeting stocks of bycatch species). The realization of these incentives, along with the results from the present study, have resulted in many commercial fishermen using the composite-panel throughout the entire NSW oceanic prawn-trawl fishery.

Acknowledgments

This work was funded by the Australian Fishing Industry Research and Development Corporation (Grant No. 93/180). The authors are grateful to Gerry O'Doherty for his valuable expertise and assistance in the field, Tommy Richardson, Barry Williams, Duck Anderson, and Sparrow Castle for the use of their respective vessels, and to Chris Paterson for providing technical support.

Literature cited

Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope.
1994. A global assessment of fisheries bycatch and discards. FAO Fish Tech. Paper 339, 233 p.

Andrew, N. L., and J. G. Pepperell.
1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Annu. Rev. 30:527–565.

Briggs, R. P.
1992. An assessment of nets with a square mesh panel as a whiting conservation tool in the Irish Sea *Nephrops* fishery. Fish. Res. 13:133–152.

Broadhurst, M. K., and S. J. Kennelly.
1994. Reducing the by-catch of juvenile fish (mulloway *Argyrosomus hololepidotus*) using square-mesh panels in codends in the Hawkesbury River prawn-trawl fishery, Australia. Fish. Res. 19:321–331.
1995. A trouser-trawl experiment to assess codends that exclude juvenile mulloway (*Argyrosomus hololepidotus*) in the Hawkesbury River prawn-trawl fishery. Mar. Freshwater Res. 46:953–58.
1996. Effects of the circumference of codends and a new design of square-mesh panel in reducing unwanted by-catch in the New South Wales oceanic prawn-trawl fishery, Australia. Fish. Res. 27:203–214.

Broadhurst, M. K., S. J. Kennelly, and G. O'Doherty.
1996. Effect of square-mesh panels in codends and of haulback delay on by-catch reduction in the oceanic prawn-trawl fishery of New South Wales, Australia. Fish. Bull. 94:412–422.

Carr, H. A., ed.
1989. Proceedings of the square mesh workshop, held at the world symposium on fishing vessel and fishing gear design; November 1988, Department of Fisheries and Oceans, St. John's, Newfoundland, 133 p. Massachusetts Div. Mar. Fish., 100 Cambridge St., Boston, MA.

Fonteyne, R., and R. M'Rabet.
1992. Selectivity experiments on sole with diamond and square mesh codends in the Belgian coastal beam trawl fishery. Fish. Res. 13:221–233.

Isaksen, B., J. W. Valdemarsen, R. B. Larsen, and L. Karlsen.
1992. Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. Fish. Res. 13:335–352.

Kendall, D.
1990. Shrimp retention characteristics of the Morrison soft TED: a selective webbing exclusion panel inserted in a shrimp trawl net. Fish. Res. 9:13–21.

Kennelly, S. J.
1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish Biol. Fish. 5:213–234.

Kennelly, S. J., K. J. Graham, S. S. Montgomery, N. L. Andrew, and P. A. Brett.
1993. Variance and cost-benefit analyses to determine optimal duration of tows and levels of replication for sampling relative abundances of species using demersal trawling. Fish. Res. 16:51–67.

Lochhead, J. H.
1961. Locomotion. *In* T. H. Waterman (ed.), The physiology of the Crustacea, p. 313–356. Academic Press, New York, NY.

Main, J., and G. I. Sangster.
1985. The behavior of the Norway lobster *Nephrops novegicus* (L.) during trawling. Scot. Fish. Res. Rep. 34, 8 p.

Matsuoka, T., and T. T. Kan.
1991. Passive exclusion of finfish by trawl efficiency device (TED) in prawn trawling in Gulf of Papua, Papua New Guinea. Nippon Suisan Gakkaishi 57(7):1321–1329.

Mounsey, R. P., G. A. Baulch, and R. C. Buckworth.
1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. I: The AusTED design. Fish. Res. 22:99–105.

Renaud, M., G. Gitschlag, E. Kilma, A. Shan, D. Koi, and J. Nance.
1993. Loss of shrimp by turtle excluder devices (TEDs) in coastal waters of the United Sates, North Carolina to Texas: March 1988–August 1990. Fish. Bull. 91:129–137.

Robertson, J. H. B., and P. A. M. Stewart.
1988. A comparison of size selection of haddock and whiting by square and diamond mesh codends. J. Cons. Cons. Int. Explor. Mer. 44:148–161.

Robins-Troeger, J. B., R. C. Buckworth, and M. C. L. Dredge.
1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. II: Field evaluations of the AusTED. Fish. Res. 22:107–117.

Rulifson, R. A., J. D. Murray, and J. J. Bahen.
1992. Finfish catch reduction in South Atlantic shrimp trawls using three designs of by-catch reduction devices. Fisheries (17)1:9–19.

Saila, S. B.
1983. Importance and assessment of discards in commercial fisheries. FAO Fish. Circ. 765, 62 p.

Wardle, C. S.
1983. Fish reactions to towed fishing gears. *In* A. MacDonald and I. G. Priede (eds.), Experimental biology at sea, p. 167–195. Academic Press, New York, NY.

Watson, J. W., J. F. Mitchell, and A. K. Shah.
1986. Trawling efficiency device: a new concept for selective shrimp trawling gear. Mar. Fish. Rev. 48(1):1–9.