Experiments in gear configuration to reduce bycatch in an estuarine squid-trawl fishery

Abstract—Three experiments were performed in an estuarine squid-trawl fishery in New South Wales, Australia, to test modifications to trawl nets. Lateral mesh openings were experimentally increased and physical bycatch reduction devices (BRDs) were placed in codends. These modifications aimed to reduce nontargeted catches of fish, while maintaining catches of the targeted broad squid (*Photololigo etheridgei*) and bottle squid (*Loliolus noctiluca*). Compared to conventional codends made with 41-mm diamond mesh, codends made with different posterior circumferences and larger 45-mm mesh had no significant effect on the catches of any species. The best performing configurations involved the installation of BRDs designed to separate organisms according to differences in behavior. In particular, versions of a composite square-mesh panel reduced the total weight of bycatch by up to 71% and there was no significant effect on the catches of squid. The results are discussed in terms of the probable differences in behavior between fish and squid in codends. After this study, a square-mesh panel BRD was voluntarily adopted throughout the fishery.

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The incidental catch of nontarget organisms (termed "bycatch") by commercial fishing gears will remain an important issue in the management of fisheries. Article 7.6.9 of the Food and Agriculture Organization's Code of Conduct for Responsible Fisheries (FAO, 1995) notes "States should take appropriate measures to minimize waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species, and negative impacts on associated or dependent species, in particular endangered species." Several options are available for achieving these aims (Hall, 1996), but the most common strategy involves technological improvements to fishing gears that reduce unwanted mortality due to fishing (Kennelly and Broadhurst, 2002).

Much research into gear design to reduce bycatch has been undertaken in demersal trawl fisheries and especially those targeting shrimp (for reviews see Kennelly, 1995; Broadhurst, 2000). This research reflects the seriousness of bycatch issues in these fisheries and, in particular, the incidental mortality of key species such as marine turtles and juveniles of commercially and recreationally important fish. Considerably less work

has been done on bycatch in other fisheries, including those targeting cephalopods.

The global catch of squid has been estimated at 2.8 million tonnes (t) per year (FAO[1]). Squid are harvested with highly-selective jigs or less selective gill nets, seines and, more commonly, trawls (Rathjen, 1991; Morais da Cunha and Moreno, 1994; Simón et al., 1996). Large-scale use of pelagic gill or drift nets has been restricted because of concern about incidental catches (e.g., Burke et al., 1994; Piatt and Gould, 1994). Despite their widespread use, very little work has been done to modify towed gears so that they selectively harvest squid. In one of the few studies relevant to this issue, Glass et al. (1999) attached video cameras to the anterior sections of trawls targeting longfin squid (*Loligo pealeii*) in the Atlantic Ocean and observed that squid positioned themselves considerably higher in the trawl than fish. It was suggested that this difference in behavior could be used to separate catches.

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[1] Food and Agriculture Organization (FAO). 2005. FAO Fisheries Global Information System. www.fao.org/fi/figis [accessed on 23 Nov 2005]. Average annual global production of all squid species for 2000 to 2003.

In New South Wales (NSW) Australia, arrow squid (*Nototodarus gouldi*), mitre squid (*Photololigo* sp.) and southern calamari (*Sepioteuthis australis*) are important in the legally retained bycatch from fish and prawn trawlers working in oceanic waters. In addition, two species of squid are specifically targeted by up to 20 trawlers with modified, single-rigged prawn trawls in Broken Bay (Fig. 1). Broad squid (*P. etheridgei*) (typically 30–290 mm mantle length [ML] when harvested) represent the majority of the total catch (approximately 25–50 t per year since 1997), although the smaller bottle squid (*Loliolus noctiluca*) (30–90 mm ML when harvested) are also retained and sold, primarily as bait for recreational anglers. Additional details on the local biology of *P. etheridgei* can be found in O'Donnell (2004).

The designs of trawls used to catch these squid vary among operators, but all are restricted by lengths of the headline (<11 m) and sweeps (<5 m) and minimal and maximal mesh openings of 40–60 mm in the body and 40–45 mm in the codend. To maximize catches of the smaller bottle squid, all operators use codends of the minimal legal mesh size of 40 mm, with anterior sections of 100 meshes in circumference attached to posterior sections of at least 150 meshes in circumference (made with thick twine), which are designed to reduce lateral-mesh openings (Broadhurst and Kennelly, 1996).

The configuration of conventional codends in the Broken Bay squid-trawl fishery means that these trawls are poorly selective and therefore, in addition to the targeted squid, they also retain large quantities of bycatch. Preliminary data from a 3-year observer-based study of catches in the early 1990s (DPI[2]) indicated a bycatch-to-squid ratio of up to 4:1 (by weight). Although a subset of this bycatch includes some species that the fishermen are legally permitted to retain, most of the bycatch is small, unwanted fish, including juveniles of several commercially and recreationally important species. Concerns over the mortality of these individuals and the negative impacts on stocks led us to test the utility of modifications to fish- and prawn-trawl codends for improving selection of species in squid trawls. Such experimental work has not previously been completed in squid-trawling fisheries.

A series of explicit hypotheses were tested in the fishery. It was proposed that devices designed to reduce bycatch would 1) cause differential changes in catches, by reducing bycatch but causing no important reduction in catches of squid; 2A) not cause disproportionate bycatch of small or large fish (i.e., would not influence the distributions of sizes of fish caught); 2B) not cause differential effects, so that subsequent incidental catches had similar mixtures of types and relative abundances of fish species as before; and, 2C) not cause relatively
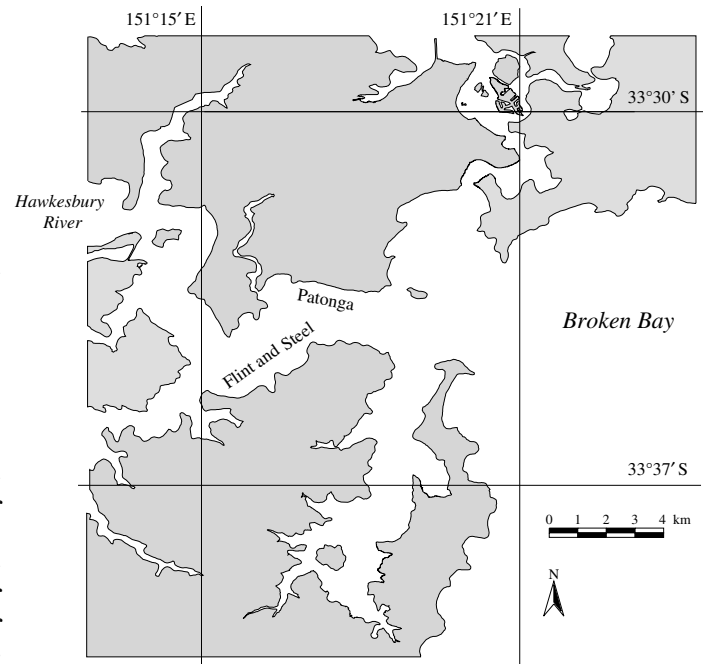

Figure 1

Location of Broken Bay and the two areas trawled (Patonga, and Flint and Steel). Broken Bay is 35 km north of Sydney, New South Wales, Australia.

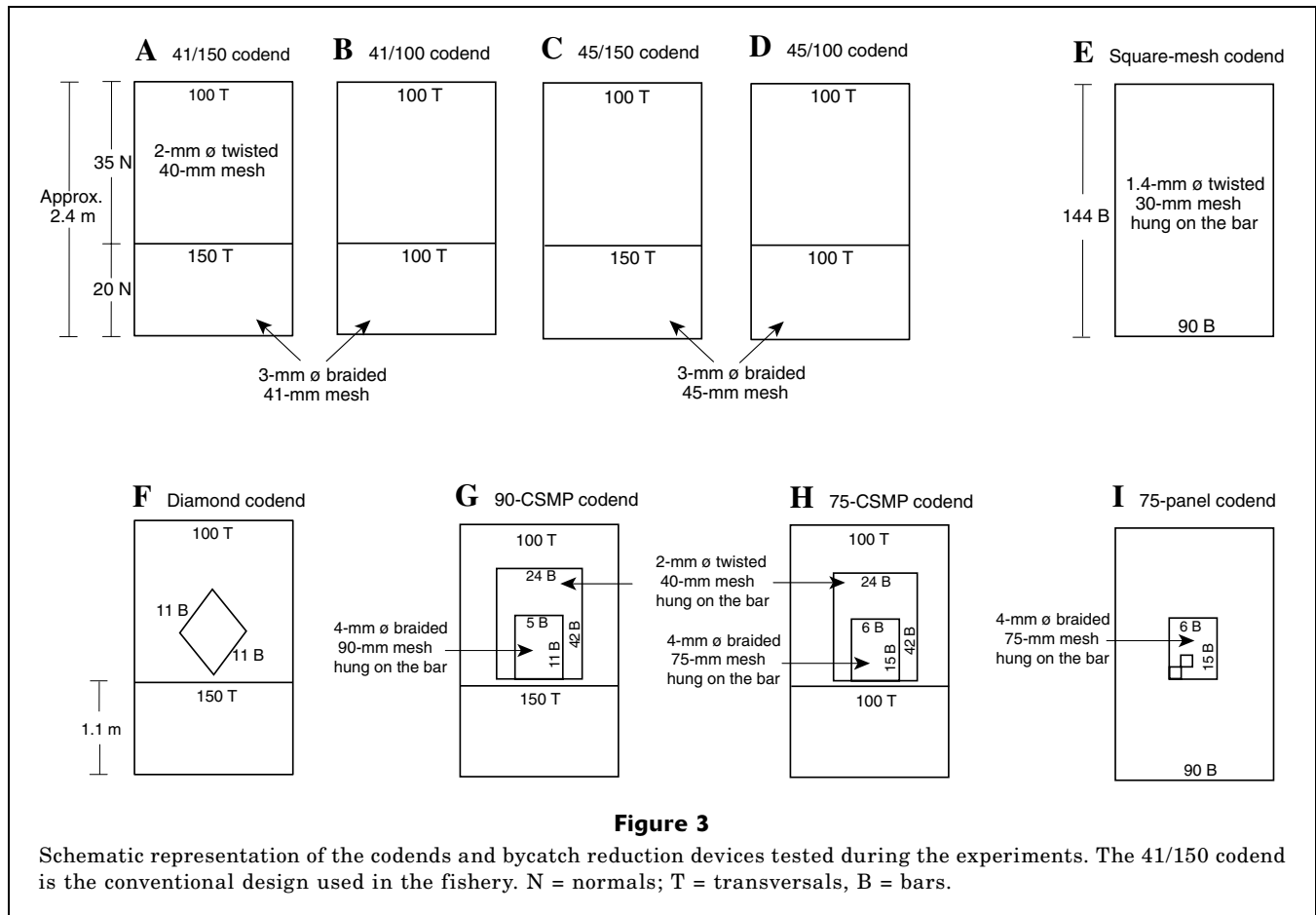larger catches of particular fish species, nor of juveniles of commercial species.

Materials and methods

This research was completed on two commercial squid-trawl grounds in Broken Bay NSW (Fig. 1) between February and September 2002 by using a chartered squid trawler (9.2 m in length). The vessel was rigged with a single, conventional 4-seam otter trawl made from 60-mm (all mesh sizes refer to stretched opening) polyethylene (PE) netting (headline of 11 m; Fig. 2) towed between 0.8 and 1.8 m/s over a sandy substratum at depths ranging from 5 to 15 m. A zipper (Buraschi S146R, Milan, Italy, 1.5 m in length) was attached at the posterior body of the trawl to facilitate changing codends (Fig. 2).

Codends and BRDs examined

Five codends of different design were made from dark PE netting with total lengths and anterior fishing circumferences (i.e., the expected circumference of the codend during towing—[Broadhurst et al., 1999]) of 2.4 and 1.5 m, respectively (Fig. 3, A–E). All codends had zippers (Buraschi S146R, 1.5 m in length) attached at their anterior ends. Four of the codends were made within existing regulations and had anterior sections made from 40-mm knotted netting (2-mm diameter-ø twisted twine) with a length and circumference of 35

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[2] DPI (New South Wales Department of Primary Industries). Unpubl. data. 1992. [Data are on file at New South Wales Department of Primary Industries, PO Box 21, Cronulla, 2230, NSW, Australia.]

Figure 2

Plan of the 4-seam squid trawl used in the study. N = normals; T = transversals, B = bars.

and 100 meshes, respectively, and posterior sections with a length of approximately 1 m, but different mesh circumferences and sizes (all meshes were made from 3-mm ø braided twine; Fig. 3, A–D). The first codend (41/150) represented commercially used designs with a posterior section of 41-mm mesh and a circumference of 150 meshes (Fig. 3A). The second codend (41/100) had a posterior section made from the same mesh, with a circumference of 100 meshes (Fig. 3B). The third and fourth designs (45/150 and 45/100, respectively) had posterior sections with the same circumferences as those above, but were made from 45-mm mesh (Fig. 3, C and D). The fifth codend design (termed the "square-mesh codend") was made entirely of 30-mm mesh (1.4-mm ø twisted twine) hung from the bar (i.e., the meshes were oriented so that they were square shaped) and had a total length and fishing circumference of 144 and 90 bars, respectively (Fig. 3E).

Four variations of behavioral-type bycatch reduction devices (BRDs) were tested in combination with certain codends (Fig. 3, F–I). All BRDs were installed in the top anterior section of the relevant codend at a distance starting 1.1 m anterior to the last row of meshes in the posterior section according to the specifications provided by Broadhurst et al. (2002). The first BRD (the diamond BRD; see Broadhurst et al. [2004]) was a diamond-shaped opening (11 × 11 bars) cut into a conventional 41/150 codend (Fig. 3F). The second and third BRDs

were composite square-mesh panels (CSMP; Broadhurst and Kennelly[1996]) with 90- or 75-mm mesh, respectively, hung from the bar in the main escape panels and were inserted into the conventional 41/150 and 41/100 codends. These modified codends were called the "90-CSMP" and "75-CSMP" codends (Fig. 3, G and H). The fourth BRD was inserted into the square-mesh codend (termed the "75-panel codend"; Fig. 3I); it was a simple panel of 75-mm mesh hung from the bar (and having the same dimensions as that used in the CSMP codend).

Experimental procedure

Three independent experiments were completed during 2002 to identify an appropriate combination of codend and BRD that minimised bycatch whilst maintaining catches of squid. Experiment 1 (25 February–1 March 2002, five days, two replicate hauls/day) tested predictions about the effect of 1) changing the posterior codend circumference within the maximal and minimal codend mesh sizes legally permitted in the fishery; and 2) using the diamond and CSMP BRDs located in the commercially used 41/150 codend. Experiment 2 (29 July–9 August 2002, 10 days, two replicate hauls/day) repeated experiment 1 above (but with additional replication to increase the power to differentiate between the codends) and also tested the effectiveness of the square-

Figure 3

Schematic representation of the codends and bycatch reduction devices tested during the experiments. The 41/150 codend is the conventional design used in the fishery. N = normals; T = transversals, B = bars.

mesh codend. Experiment 3 (26 August–6 September 2002, 10 days, three replicate hauls/day) compared the 41/100 and square-mesh codends (the most appropriate non-BRD codends; see Results section), with and without their respective 75-CSMP and 75-panel BRDs installed.

In each experiment, the daily position and order of the codends being tested were determined randomly and they were alternately used in normal commercial hauls of 30-min duration between 0700 and 1500 hours. Depending on the number of codends being tested, we attempted two or three balanced replicates of each treatment on each day. Haul location was determined by the skipper and varied between the two squid trawl grounds in Broken Bay (Fig. 1) according to the presence of jellyfish, *Catostylus* sp., which reduced the efficiency of the trawl. Data collected from each replicate haul included the numbers and weights of all taxa and the sizes of commercially and recreationally important species. When large numbers (several hundred) of any species were caught, a randomly selected subsample (approximately 25–50% of the total) was measured. Fish were measured to the nearest 0.5 cm fork length; carapace lengths of crustaceans were measured to the nearest 0.1 cm.

Results

Bycatch and target squid

The primary hypothesis for this study was that the devices designed to reduce bycatch would cause changes in catches, by reducing bycatch but causing no important reduction in the catches of squid. This hypothesis was tested by using univariate statistical methods applied to the results from all three experiments. In Experiment 1, the diamond and 90-CSMP codends caught less bycatch (about 74% less on average) than the other types of gear (Table 1). About 50% of the bycatch were discards, including teleost fish such as tailor (*Pomatonus saltatrix*) and mulloway (*Argyrosomus japonicus*). There were, however, no significant reductions in catches of squid, although catches were smaller with the diamond codend. As a result, later experiments were mostly done with larger mesh sizes. There were no effects of altering other components of the gear (circumference or mesh-size of the codend). Catches of squid were significantly different on the two days (Table 1A), but there was no interaction with the type of codend; therefore differences among types of gear were consistent. Sources of variation that were determined to be nonsignificant at $P>0.25$

Table 1

Analyses of catches using six types of gear from experiment 1 during February–March 2002. Data are weights of catches from Flint and Steel, fished for 2 different days (a random factor). Codend (a fixed factor) is the comparison of 41/150, 41/100, 45/150, 45/100, diamond and 90-CSMP (composite square-mesh panel) codends. $n = 2$ replicate hauls for each treatment on each day.

A Analyses of variance

Source of variation		df	Bycatch			Squid		
			Mean square	F	P	Mean square	F	P
Codend	= C	5	1.51	3.16[a]	<0.04	0.24	0.63[a]	>0.65
Day = D	= D	1	0.46	0.96[a]	>0.30	2.50	6.51[a]	<0.05
C × D		5	0.39[p]			0.33[p]		
Residual		12	0.51[p]			0.40[p]		
[p]Pooled residual		17	0.48			0.38		

B Mean untransformed weight (kg, [±standard error, $n=4$]) of bycatch and squid per haul and Student-Newman-Keuls tests; "<" indicates significant differences at $P<0.05$; "=" indicates $P>0.05$.

	Codend										
	Diamond		90-CSMP		41/100		41/150		45/100		45/150
Bycatch	7.7 (2.3)	=	6.4 (1.7)	<	23.1 (6.1)	=	22.3 (2.2)	=	24.8 (6.9)	=	17.3 (7.0)
Squid	2.2 (0.6)	=	3.5 (0.8)	=	2.9 (0.7)	=	3.9 (1.2)	=	3.2 (1.2)	=	4.3 (1.2)

were pooled and catches were transformed to natural logarithms to stabilize variances (Underwood, 1997).

A second analysis compared the diamond and 90-CSMP with the conventional 41/50 codend in two areas (in estuarine waters off Patonga, and Flint and Steel, see Fig. 1), to check consistency across fishing-grounds. A balanced set of replicated hauls with each type of gear was obtained. Again, the two BRDs caused large and significant reductions in bycatch compared with the conventional net. Although catches of squid were smaller, they were not significantly so and there was a large reduction in the ratio of weight of bycatch to weight of squid caught. Strikingly, although there was considerable variation from day to day and between locations in the amount of bycatch, there were no interactions with experimental gear used. Therefore, reductions in bycatch were consistent under the different conditions that are typical to the fishery.

Experiment 2 compared catches with the four codends without BRDs, as in experiment 1, with catches with the square-mesh codend. There were complex differences in the amount of bycatch caught with different types of gear, despite many catches being smaller than those in experiment 1. More bycatch was caught with the 45/150 codend than with the 41/150 codend (i.e., an effect of mesh size). This difference was, however, detected only for the 150 codend. There was also an effect of circumference of the codends (41/100 caught more bycatch than did 41/150), but only for the commercial (41-mm mesh) codend. This finding explains the signifi-

cant interaction between mesh-size and circumference in the analysis in Table 2.

Again, although there were differences in amounts of bycatch, there were no significant or detected differences in catches of squid (Table 2, A and B); therefore it was possible to achieve reductions in bycatch without any notable effect on the commercial catch.

During experiment 3 catches were generally small and patchy. Data were very variable, but it was possible to complete five days of trawling with the 41/100 and square-mesh codends with or without their square-mesh BRDs. There was a very marked reduction in bycatch when a BRD was added to a codend, regardless of whether there was a square-mesh panel in the codend or not (Table 3A). Again, there were no influences on the catches of squid, but the ratio of weight of bycatch to weight of squid was smaller for both types of mesh when a BRD was added (analysis of ratios in Table 3B).

Sizes of species in bycatch

The secondary hypotheses of this study, that devices to reduce bycatch would 2A) not cause disproportionate bycatch of small or large fish; 2B) not cause differential effects; and, 2C) not cause relatively larger catches of particular species, were tested with multivariate statistical methods.

Analyses of sizes of bycatch were uniform in their outcome—there was no measurable difference on the size composition of species caught for any of the devices tested. As examples, two species of fish were present in

Table 2

Analyses of catches from experiment 2 during July–August 2002. Data are weights of catches from two locations (Patonga, Flint and Steel; a random factor), each sampled over four different days (randomly, nested in location). Square-mesh panels were compared with the 41/150, 41/100, 45/150, 45/100 codends. There were $n = 2$ replicate hauls of each gear on each day in each location.

A Analyses of variance

Source of variation		df	Bycatch			Squid		
			Mean square	F	P	Mean square	F	P
Treatment	$= T$	4	1.61			0.55		
Square-mesh vs. others	$= S$	1	0.55	0.87	>0.35	0.72	1.3	>0.20
Mesh: 41 vs. 45	$= M$	1	1.14	1.80	>0.15	0.47	0.8	>0.35
Circumference: 100 vs. 150	$= C$	1	2.40	3.80	<0.05	0.30	0.5	>0.45
$M \times C$		1	2.40	3.70	<0.05	0.57	0.71	>0.20
Location	$= L$	1	2.17			1.13		
$T \times L$		4	0.80^p			0.19^p		
Days (L)	$= D(L)$	6	4.9	7.10	<0.001	0.69	1.2	>0.25
$T \times D$		24	0.72^p			0.62^p		
Residual		40	0.56^p			0.50^p		
^{p}Pooled residual		68	0.63			0.56		

B Mean weight (kg, (±standard error, $n=16$)) of bycatch and catch in various treatments

		Circumference (no. of meshes)			
		100	150	100	150
Mesh	41-mmm	56.8 (17.5)	28.1 (5.4)	14.6 (2.1)	11.6 (1.8)
	45-mm	44.6 (6.7)	60.0 (12.9)	13.2 (1.5)	13.9 (1.7)
	Square-mesh (30 mm)	48.7 (10.5)		15.2 (1.9)	

most hauls, were fairly abundant in bycatch, and were each represented by a range of sizes. Tailor (*Pomatomus saltatrix*) were grouped into five length classes with approximately equal numbers of fish in each class (140–145, 146–170, 171–195, 196–220, 221–280 mm); the snapper *Pagrus auratus* were also so grouped into five length classes (70–105, 106–120, 121–135, 136–155, 156–230 mm). Data were analyzed as the proportion of fish in each size class, to remove differences due to different numbers of fish caught in the various types of gear. Size classes were then used as variables in multivariate analyses to compare the various types of gear.

Using data from experiment 1, we detected no differences among types of gear in the proportional size frequencies of either tailor or snapper. The mean Bray-Curtis dissimilarities between pairs of samples were all very similar to the mean measures within samples (i.e., among replicates); therefore there was no suggestion of differences in size frequencies among types of gear for these species. Multidimensional scaling plots (not included, Clark and Gorley[3]) supported this result

because the centroids of the size classes of both species were not clustered by type of gear.

Composition of bycatch

The types of species and relative abundances of species in the bycatch were analyzed from several times of sampling. Analyses used data without squid because numbers of squid are irrelevant to the bycatch. Typically, there were no detected differences in assemblages of species in the bycatch. One exception, in Experiment 2 is described. In our study, analyses of Bray-Curtis dissimilarities showed some differences among types of gear, where the square-mesh codend caught a different assemblage. It seemed that fewer whitebait (*Hyperlophus vittatus*) were being caught when the square mesh was used (this was confirmed by SIMPER[4] analysis, which showed that numbers of whitebait were an important variable for discriminating between samples). To test the validity of this conclusion, we performed analyses, omitting numbers of whitebait. This time, all differences

[3] Clarke, K. R., and R. N. Gorley. 2001. Primer version 5: user manual/tutorial, 91 p. Primer-E Ltd, Plymouth, U.K.

[4] See footnote 3.

Table 3

Analyses of catches from four codends (41/100, square-mesh, 75-panel, 75-CSMP [composite square-mesh panel]) from experiment 3 at Flint and Steel during August–September 2002. Data are weights of catches on five days, during each of which there were $n = 3$ independent hauls with each type of gear.

A Analysis of variance

		df	Bycatch			Squid			Ratio: bycatch/squid		
			Mean square	F	P	Mean square	F	P	Mean square	F	P
Mesh: 41 vs. square mesh	= M	1	0.9	1.4	>0.25	0.001	0	>0.95	0.3	0.8	>0.35
+BRD vs. –BRD	= B	1	4.5	6.6	<0.01	0.1	0.2	>0.60	2.4	3.1	>0.15
$M \times B$		1	2.5	3.6	>0.05	0.2	0.4	>0.50	1.0	0.4	
Days	= D	4	5.7	8.4	<0.001	0.7	0.7	>0.60	2.5	6.0	<0.001
$M \times D$		4	0.8p			0.5p			0.2p	0.4	>0.50
$B \times D$		4	0.8p			0.6p			0.8	1.8	>0.15
$M \times B \times D$		4	0.6p			0.4p			0.2p		
Residual		40	0.7p			0.6p			0.5p		
pPooled residual		52	0.7			0.6			0.41	(48 df)	

B Multiple comparisons: mean weight (kg, (±standard error, $n=30$)) of bycatch, squid. and ratio of bycatch/squid; * indicates a difference (Student-Newman-Keuls test; $P<0.05$).

	Bycatch		Squid		Ratio: bycatch/squid	
	–BRD	+BRD	–BRD	+BRD	–BRD	+BRD
	3.3 (0.5)	2.6 (0.4)*	1.6 (0.2)	1.6 (0.2)	6.0 (3.8)*	1.6 (0.4)

among types of gear disappeared. Whitebait are not an important concern for management in this fishery and results like these were not obtained in the other experiments; therefore no further consideration was given to this matter. Results from this study indicate that the composition of assemblages of bycatch was not altered by combinations of experimental gear and there were no detectable influences on particular species.

These multivariate results indicated that, with the exception of whitebait, none of the secondary hypotheses (2A, 2B, or 2C) could be rejected. These experiments did, however, have limited power to detected small effects because of the large variability of the catches and the relatively limited replication completed.

Discussion

The results demonstrated that the general concepts used to improve species selection in fish and shrimp trawls have similar application for squid. Nevertheless, the specific designs of modifications require careful consideration, according to several fishery-related factors. One of the starting points for reducing bycatch in all towed gears involves examining simple changes to the size and shape of mesh in the codend, because this is where most of the selection is believed to occur (Wileman et al., 1996). Broadhurst and Kennelly (1996) and Broadhurst et al. (2004) showed that codends made from thick twine and with large posterior circumferences, like those used conventionally by squid trawlers in Broken Bay, have very narrow lateral mesh openings and have poor selectivity. Three of the simplest methods for improving selection in codends involve 1) reducing the posterior circumference (e.g., Broadhurst and Kennelly [1996]), 2) increasing the mesh size (e.g., Reeves et al. [1992]), or 3) orienting meshes, typically orienting 60–90% of the size of the existing diamond-shaped mesh on the bar so that they are square shaped (e.g., Thorsteinsson [1992]; Broadhurst et al. [2004]).

These three modifications were tested during the present study but, with the exception of the square-mesh codend, none were demonstrated to significantly improve species selection or influence the sizes of individuals caught. The considerable temporal variability in catches and a concomitant lack of power to detect small effects may partially account for the lack of differences detected, but a more likely explanation is that the magnitude of changes to mesh openings in relation to the sizes of target and bycatch species was insufficient. Given that some small fish escaped from the square-mesh codend, future work would probably benefit from further examination of increasing codend mesh openings as a means for reducing bycatch.

In contrast to subtle modifications to codend meshes that were tested, it was demonstrated that BRDs

designed from an understanding of the behavior of fish and squid were effective in allowing fish to escape and did not significantly reduce the catches of squid. The escape of fish through these BRDs was a direct consequence of 1) their behavior and species-specific swimming abilities in the trawl (Wardle, 1983; Watson, 1989) and 2) the location of the BRDs with respect to the influences of water-flow (Broadhurst et al., 2002). More specifically, when fish enter the codend they are often herded together and herding invariably initiates movement towards the top and sides. The density of the school and any species-specific behavioral responses (Watson, 1989) determine the extent of such movement. Panels of square-shaped mesh, if strategically positioned, have been demonstrated to allow actively swimming fish to escape the trawl through the large openings in the square-shaped mesh (Broadhurst, 2000). An important contributing factor is the effect of anteriorly displaced water in front of the catch, which reduces relative flow and assists small fish to maintain their position in the codend. Broadhurst et al. (2002) demonstrated that these effects diminish with increasing distance forward and that the optimal location for BRDs designed on fish behavior is up to 1.2 m anterior to the last row of meshes in the posterior section of the codend (i.e., the position of all BRDs examined in our study).

The behavior of squid in trawls, codends, or near BRDs has not been examined in detail. Glass et al. (1999), however, observed that the reaction of schooling *L. pealeii* during initial detection of the gear was similar to fish. Individuals orientated away and then, as a result of compensatory movements in response to shifts in their visual field (termed the optomotor response), attempted to maintain position in the mouth and body of the net. After a short period, all squid were observed to stop swimming, turn, rise in the net, and fall back toward the posterior section of the trawl and toward the codend. Their behavior in this region of the net was not documented, but, given the lack of significant reductions in the catches of squid (or other cephalopods) by prawn trawls containing behaviour-based BRDs (e.g., Broadhurst et al. 2002) and the results observed in our study, active escape is probably limited.

There was a nonsignificant reduction in the weight of squid from the codends containing BRDs in experiment 1, and especially the diamond BRD, but this reduction probably occurred during retrieval of the codend. Typically, once the trawl is winched to the surface, a delay of up to three minutes can occur while the vessel is stopped, the retrieval line is connected, and the codend is brought onboard. During this period, any squid in the anterior codend or extension section may wash forward and out of the escape opening in the BRD. Watson (1989) observed similar effects during the retrieval of prawn trawls in the Gulf of Mexico and, more recently, Brewer et al. (1998) highlighted this escape route as being a major cause of loss of prawns from several BRDs in trawls used in the Gulf of Carpentaria, Australia. A simple way of minimizing the potential for such losses when using the diamond BRD would be to keep the

vessel moving, thus maintaining drag on the codend, during retrieval. A simpler and more practical solution would be to substitute the square-mesh BRD with panels made from 75-mm mesh hung on the bar, since the 75-CSMP and 75-panel codends tested in Experiment 3 showed no evidence of loss of squids. Assuming that fish escaping from the CSMP survive the process (Broadhurst et al., 1997), the results presented in this study support the adoption of the CSMP codend in Broken Bay squid trawls. As a consequence of this study, and the co-operative relationship established between the NSW Department of Primary Industries and commercial fishermen, a square-mesh panel BRD has been voluntarily adopted throughout the Hawkesbury River squid-trawl fishery.

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