Abstract.—Several bycatch-reducing devices (BRD's) were compared for their effectiveness in reducing bycatch while maintaining catches of prawns in an estuarine prawn-trawl fishery in New South Wales (NSW), Australia. A solid separator-panel (the Nordmøre grid), a soft separator panel (the commercially used blubber chute), and four secondary BRD's (the fisheye, extended mesh funnel, Allerio Brothers grid, and square-mesh panel) each attached to a Nordmøre grid, were compared against each other in a series of paired comparisons in the Hunter River prawn-trawl fishery. The results showed that the Nordmøre grid and all secondary BRD's caught less bycatch and more prawns than the commercially used blubber chute. Most bycatch seemed to escape with use of the Nordmøre grid, and there was no significant advantage in adding a secondary BRD to this design. The efficiency of the Nordmøre grid has led to its voluntary adoption by many commercial prawn-trawl fishermen throughout NSW estuaries.

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Evaluations of the Nordmøre grid and secondary bycatch-reducing devices (BRD's) in the Hunter River prawn-trawl fishery, Australia

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In New South Wales (NSW), Australia, estuarine prawn-trawling occurs in five localities and is valued at approximately A$7 million per annum. Like the majority of the world's prawn-trawl fisheries, significant numbers of nontarget organisms, or bycatch, are captured incidentally with targeted prawns (for reviews see Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994; Kennelly, 1995).

In recent years, bycatch from these fisheries has become of increasing concern to a broad cross section of the fisheries community. As a result, a 3-yr observer-based study was undertaken from 1990 to 1992 to quantify the distributions and abundances of bycatch species (Liggins and Kennelly, 1996; Kennelly[1]). The results from these studies showed that, despite large spatial and temporal variabilities in the bycatches of many species, some juveniles of commercially and recreationally important species were caught in large numbers throughout the trawling seasons. The quantities involved raised concerns over the potential impacts of prawn-trawling on subsequent stocks of these species. These concerns led to the current investigation, which examines various modifications to trawling gear and trawling practices that minimize undesirable bycatches while maintaining catches of prawns.

A number of recent attempts to exclude bycatch from prawn-trawls have concentrated on modifications that incorporate bycatch-reducing devices (BRD's) (Christian and Harrington, 1987; Averill, 1989; Kendall, 1990; Isaksen et al., 1992; Rulifson et al., 1992; Broadhurst et al., 1996). In previous experiments (Broadhurst and Kennelly, 1994, 1995, 1996; Broadhurst et al., 1996) we showed that the successful application of various BRD's is specific to individual fisheries and depends upon several factors, including the type of species to be excluded. Further, to promote acceptance by industry, BRD's should be designed so that they do not adversely influence normal commercial operations.

[1] Kennelly, S. J. 1993. Study of the bycatch of the NSW east coast trawl fishery. Final rep. to the Fisheries Research and Development Cooperation. Project 88/108, ISBN 0 7310 2096 0, 520 p.

In estuarine prawn-trawl fisheries in NSW, many of the individual fish in bycatch are larger than the targeted prawns and include organisms such as jellyfish or jelly "blubber"—*Catostylus* spp. For the past 30 years, many of the estuarine prawn-trawlers in NSW have routinely used a BRD designed specifically to exclude these individuals. Commonly called "blubber-chutes," these BRD's consist of a funnel of soft mesh inserted into the aft belly of the trawl. Organisms larger than the mesh in the funnel are guided through an opening in the top of the trawl, while prawns and smaller individuals pass through the mesh into the codend (see Broadhurst and Kennelly, 1996). In the Hunter River (HR) prawn-trawl fishery (Fig. 1), the abundance of jellyfish means that commercial fishermen use blubber chutes throughout most of the trawling season.

In a series of experiments that examined the performance of several types of BRD's (Broadhurst et al., 1996; Broadhurst and Kennelly, 1996), we showed that a rigid separator-panel (the Nordmøre grid) significantly reduced the mean weight of bycatch in two estuaries and had no effect on the catches of prawns. Compared with the commercially used blubber chute, the Nordmøre grid also retained significantly less bycatch but caught more prawns.

Bycatch-reducing devices, such as the Nordmøre grid and the blubber chute, function by mechanically partitioning the catch according to size (see Broadhurst et al., 1996), and therefore are generally not as effective in excluding unwanted individuals that are of a similar size or that are smaller than the targeted prawns. Previous studies have shown, however, that it may be possible to exclude these smaller individuals by exploiting behavioral differences between some species of fish and prawns (Watson et al., 1986; Broadhurst and Kennelly, 1994, 1995; Broadhurst et al., 1996). For example, studies by Watson et al. (1993) in the Gulf of Mexico showed that small individuals of red snapper (*Lutjanus campechanus*), Atlantic croaker (*Micropogon undulatus*), Atlantic bumper (*Chloroscombrus chrysurus*) and whiting (*Menticirrhus* sp.) were passively excluded from trawls by various BRD designs comprising strategically placed panels of netting and escape exits. These designs were located posteriorly to a larger mechanical separating grid (designed to exclude turtles) and effectively functioned as secondary BRD's.

It is apparent that several options exist for ways of excluding bycatch from prawn trawls. In the present study we wanted to determine which of these various devices (i.e. the Nordmøre grid, blubber chute, or some type of secondary BRD) is most appropriate for use in the HR prawn-trawl fishery. Our specific goals, therefore, were 1) to assess the performance of four secondary BRD's located behind the Nordmøre grid (including designs previously tested in the Gulf of Mexico by Watson et al., 1993) in reducing smaller unwanted individuals in the HR prawn-trawl fishery; 2) to compare the two most appropriate secondary BRD's from 1) against a standard Nordmøre grid and the commercially used blubber chute; and 3) to test a standard Nordmøre grid (with no secondary BRD) against the commercially used blubber chute.

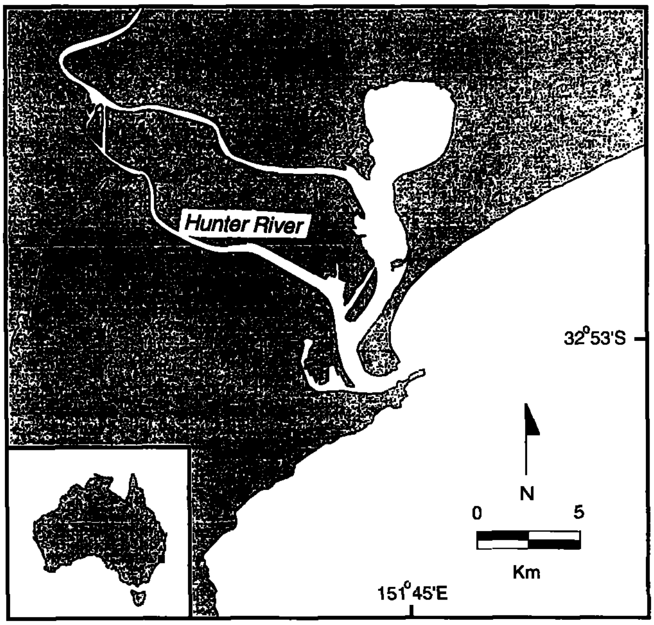

Figure 1
The location of the Hunter River in New South Wales.

Materials and methods

Two experiments were performed on commercial prawn-trawl grounds in the Hunter River (32°53'S, 151°45'E, Fig. 1), between November and December 1995 with a chartered commercial prawn-trawler (12.72 m). Three Florida flyers (mesh size=40 mm), each with a headline length of 9.14 m, were rigged in a standard triple gear configuration (see Andrew et al., 1991, for details) and towed at 2 knots across a combination of sandy and muddy bottoms in depths ranging from 2 to 8 m. Each of the identical outside nets were rigged with zippers to facilitate changing the codends (see Broadhurst et al., 1996). Because the middle net was not rigged in an identical manner to that used on the outside nets, its catch was excluded from analysis.

The codends used in the experiments measured 50 meshes long (2 m) and were constructed from 40-

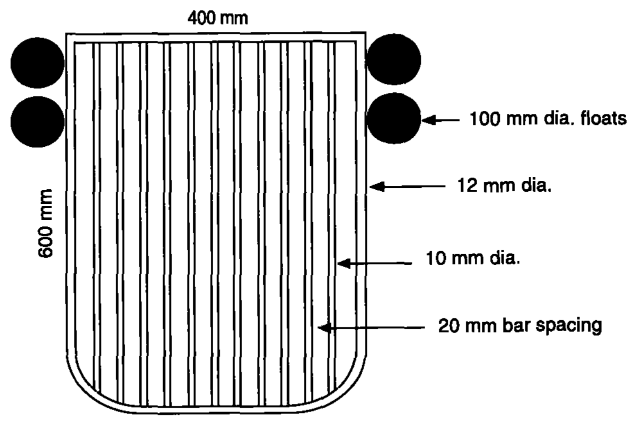

Figure 2
Diagram of the aluminum grid used in the Nordmøre grid bycatch-reducing device. dia. = diameter.

mm netting. They comprised two panels. The anterior panel was 100 meshes in circumference, 25 meshes in length, and constructed of 400/36 ply, UV-stabilized, high-density polyethylene twine. The posterior panel was 150 meshes in circumference, 25 meshes in length, and constructed of 3-mm diameter braided polyethylene twine. Two standard Nordmøre grids (each measuring 600 × 400 mm and weighing 1.9 kg, Fig. 2) were constructed and located in 2-m extension pieces (made from 400/36 ply, UV-stabilized, high-density polyethylene twine, mesh size = 40 mm) immediately anterior to each codend (Fig. 3A, see also Broadhurst and Kennelly, 1996, for details).

Experiment 1 (comparisons of secondary BRD's)

Four designs of secondary BRD's were constructed and installed into the codends described above, behind the Nordmøre grids. The first design (termed the fisheye) consisted of a stainless steel pyramid-shaped frame inserted 12 meshes to the left of the center of the top anterior section of the codend (Fig. 3B, see also Watson and Taylor[2]; Watson[3]). The second design (termed the square-mesh panel) had a panel of 50-mm knotless netting, hung on the bar and inserted into the top anterior section of the codend (Fig. 3C). The third design (termed the extended mesh funnel or EMF) comprised a guiding funnel surrounded by larger square-shaped mesh (see Watson and Taylor[2]; Watson[3]) and was located in the anterior section of the codend (Fig. 3D). The fourth design (termed the Allerio Brothers grid, Watson[4]) was constructed like the Nordmøre grid but included additional lateral fish escape windows posterior to the aluminium grid (Fig. 4).

All four designs were compared against each other, one pair of each design on the outside nets of the triple-rigged gear (i.e. 6 separate paired comparisons). The position and order of each secondary BRD was randomly determined, and during 6 days in the trawling season in the Hunter River, we completed a total of 12 replicate 30-min tows for each paired comparison. The location of each tow was randomly selected from the available prawn-trawl locations that were possible under the particular conditions. Prior to the trials, we rigged both nets with normal commercial codends to ensure that there were no differences in fishing characteristics.

Experiment 2 (comparison of two secondary BRD's, standard Nordmøre grid and blubber chute)

In this experiment, the fisheye and EMF, each attached to a Nordmøre grid, were compared against a standard Nordmøre grid (with no secondary BRD) and the commercially used blubber chute. The standard Nordmøre grid and blubber chute were also compared against each other (providing a total of five

[2] Watson, J. W., and C. W. Taylor. 1996. Technical specifications and minimum requirements for the extended funnel, expanded mesh and fisheye BRDs. Mississippi Laboratory, NMFS, NOAA, P.O. Drawer 1207, Pascagoula, MS 39567.

[3] Watson, J. W. 1996. Summay report on the status of bycatch reduction devices development. Mississippi Laboratory, NMFS, NOAA, P.O. Drawer 1207, Pascagoula, MS 39567.

[4] Watson, J. W. 1995. Mississippi Laboratory, NMFS, NOAA, P.O. Drawer, 1207, Pascagoula, MS 39567. Personal commun.

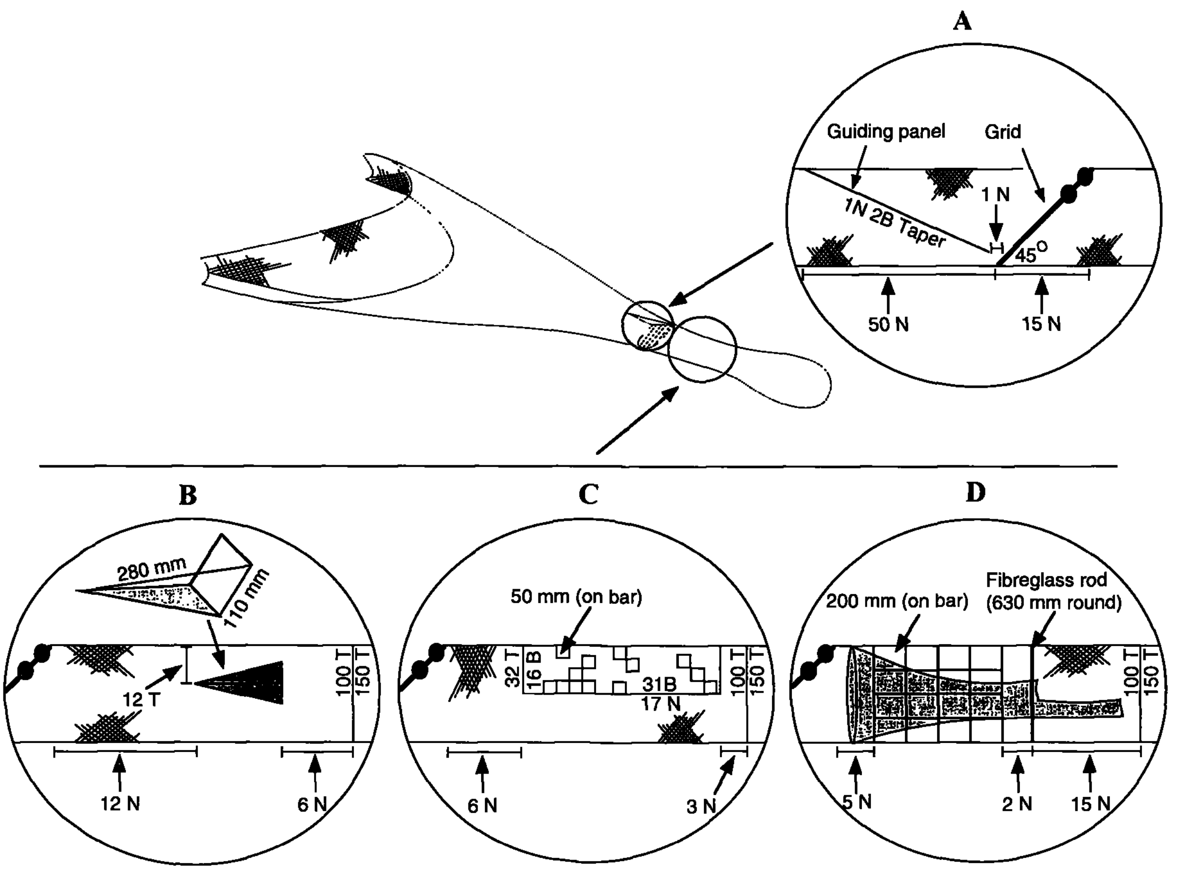

Figure 3

Diagrammatic representation of prawn-trawl and (A) Nordmøre grid, (B) fisheye, (C) square-mesh panel, and (D) extended mesh funnel (EMF) bycatch-reducing devices. T = transversals; B = bars; and N = normals.

paired comparisons). The blubber chute comprised a panel of netting (36-ply, UV-stabilized, high-density polyethylene with a mesh size of 90 mm) sewn into a funnel (with an anterior circumference of 100 meshes) located in a 2-m panel of mesh (mesh size of 40 mm) measuring 150 meshes in circumference (see Broadhurst and Kennelly, 1996, for details). The posterior point of the blubber chute was attached five meshes from the end of the 2-m panel. A 30-mesh opening (termed the escape exit) was cut immediately anterior to this point of attachment.

As was the case for experiment 1, the position and order of each design was randomly determined and used in normal commercial tows of 30-min duration. Over 8 days, we completed a total of 23 replicate tows for each of the five paired comparisons.

Data collected

After each tow in each paired experiment, the two codends were emptied onto a partitioned tray. All organisms were sorted according to species. The following data were collected from each tow: the total weight of prawns; the total weight of bycatch; the weights; numbers and sizes of commercially or recreationally (or both) important finfish (to the nearest 0.5 cm); the numbers of noncommercial or nonrecreational species; and the total numbers of noncommercial and commercial species in the assemblage. All prawns in a subsample of the total prawn catch from each tow in experiment 2 were measured in the laboratory (to the nearest 1-mm carapace length). Several species were caught in sufficient quantities to provide meaningful analyses. These were the commercially important school prawns (*Metapenaeus macleayi*) and large tooth flounder (*Pseudorhombus arsius*) and the commercially unimportant fortesque (*Centropogon australis*), narrow banded sole (*Synclidopus macleayanus*), bridle goby (*Arenigobius bifrenatus*), and catfish (*Euristhmus lepturus*).

Data from all replicates that had sufficient numbers of each variable (defined as >2 fish in at least 8

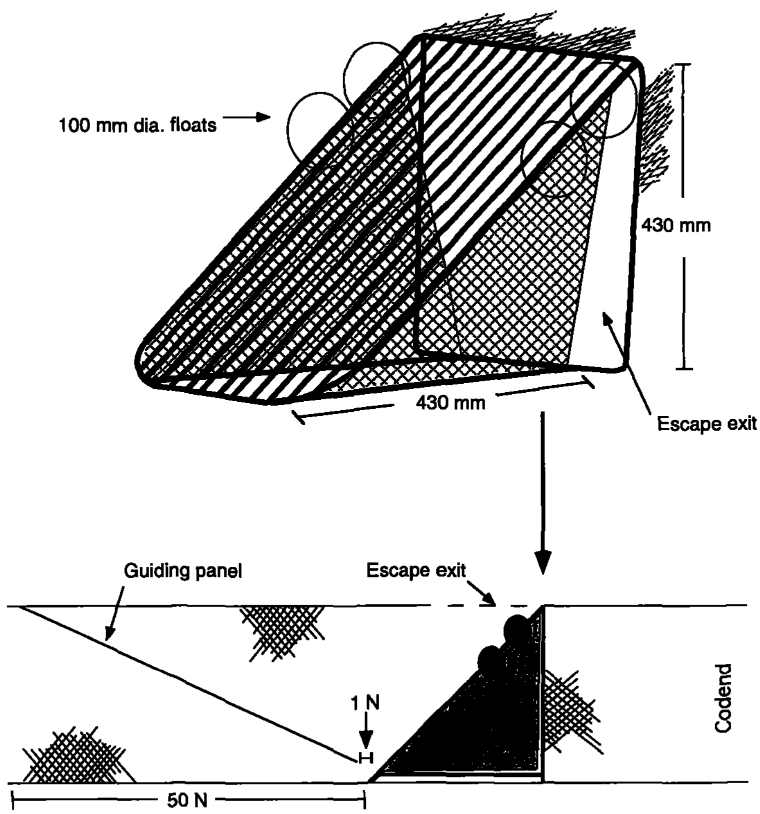

Figure 4
Diagrammatic representation of the Allerio Brothers grid. dia = diameter.

replicates) in experiment 1 were analyzed by using two-tailed, paired *t*-tests. Because a previous experiment in the Clarence River prawn-trawl fishery showed that the Nordmøre grid caught more prawns than the blubber chute (Broadhurst and Kennelly, 1996), in experiment 2 we tested the hypothesis that each of the three designs incorporating a Nordmøre grid caught more prawns but less bycatch than the commercially used blubber chute. These data were analyzed by using one-tailed paired *t*-tests. Size frequencies of prawns from experiment 2 were graphed and compared by using two-sample Kolmogorov-Smirnov tests (P=0.05).

Results

Experiment 1 (comparisons of secondary BRD's)

Apart from a significant reduction in the number of noncommercial species caught as bycatch by the Allerio Brothers grid, compared with the number caught with the square-mesh panel, there were no other detectable differences between any of the secondary BRD's tested (Table 1). However, because previous studies in the Gulf of Mexico showed that the EMF and fisheye were most effective in excluding small fish from the codend (Watson and Taylor[2]; Watson[3]), these two designs were tested further in experiment 2.

Experiment 2 (comparison of two secondary BRD's, standard Nordmøre grid and blubber chute)

Compared with the commercially used blubber chute, the standard Nordmøre grid, EMF, and fisheye all significantly increased the weight of prawns caught (means increased by 24%, 41%, and 23%, respectively) and decreased the weight of total bycatch (means reduced by 58%, 45%, and 55%, respectively) and number of noncommercial species in bycatch (Fig. 5, A, B, and H; Table 2). The fisheye also significantly reduced the mean number of catfish caught by 79.5% (there were insufficient catfish from the

Table 1

Summaries of two–tailed paired *t*–tests in a series of comparisons of various secondary BRD's in experiment 1. ** = significant ($P<0.01$); * = significant ($P<0.05$); *n* = the number of replicates that had sufficient data available for analysis (i.e. >2 fish in 8 replicates).

	Allerio Bros. vs. EMF			Allerio Bros. vs. square–mesh			Allerio Bros. vs. fisheye		
	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*
Wt. of prawns	–0.602	0.559	12	0.193	0.850	12	0.689	0.505	12
Wt. of total bycatch	–0.967	0.354	12	–1.827	0.095	12	0.958	0.358	12
No. of fortesque	0.000	0.999	9	0.886	0.398	10	2.200	0.052	11
No. of noncommercial sp.	–0.860	0.407	12	–2.46	0.031*	12	–1.146	0.276	12
No. of commercial sp.	–0.232	0.821	12	1.517	0.157	12	–1.698	0.120	12

	Square–mesh vs. EMF			Fisheye vs. square–mesh			Fisheye vs. EMF		
	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*
Wt. of prawns	–0.225	0.826	12	–1.36	0.200	12	–1.795	0.100	12
Wt. of total bycatch	–0.318	0.756	12	–1.821	0.095	12	–0.513	0.618	12
No. of fortesque	0.808	0.440	10	–0.683	0.544	8	–0.455	0.659	10
No. of noncommercial sp.	1.216	0.249	12	–1.431	0.180	12	–1.383	0.194	12
No. of commercial sp.	–0.890	0.392	12	–0.364	0.722	12	–1.190	0.256	12

Table 2

Summaries of one–tailed paired *t*–tests in a series of comparisons of various BRD's in experiment 2. Ng = Nordmøre grid. ** = significant ($P<0.01$); * = significant ($P<0.05$); *n* = the number of replicates that had sufficient data available for analysis (i.e. >2 fish in 8 replicates).

	Standard Ng vs. blubber chute			EMF vs. blubber chute			Fisheye vs. blubber chute		
	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*
Wt. of prawns	2.864	0.004**	23	3.764	0.0005**	23	2.020	0.027*	23
Wt. of total bycatch	3.515	0.001**	23	2.930	0.003**	23	3.306	0.002**	23
Wt. of large tooth flounder	0.979	0.173	14	0.729	0.239	14	1.394	0.103	8
No. of large tooth flounder	0.061	0.476	14	–0.879	0.802	14	0.747	0.239	8
No. of fortesque	0.286	0.389	19	–0.261	0.601	20	0.761	0.228	18
No. of narrow banded sole	1.064	0.164	8	—	—	—	1.440	0.090	10
No. of bridled goby	–0.414	0.654	8	—	—	—	–0.078	0.531	11
No. of catfish	—	—	—	—	—	—	3.490	0.003**	10
No. of noncommercial sp.	2.626	0.007**	23	2.040	0.026*	23	1.931	0.033*	22
No. of commercial sp.	–1.190	0.876	23	0.000	0.500	23	0.282	0.390	23

	Standard Ng vs. fisheye			Standard Ng vs. EMF		
	Paired *t*–value	*P*	*n*	Paired *t*–value	*P*	*n*
Wt. of prawns	0.618	0.271	23	–1.418	0.914	23
Wt. of total bycatch	0.721	0.239	23	0.512	0.307	23
Wt. of large tooth flounder	0.410	0.346	9	–0.507	0.689	13
No. of large tooth flounder	1.835	0.052	9	–0.456	0.672	13
No. of fortesque	–0.647	0.736	16	–0.128	0.449	19
No. of narrow banded sole	–0.147	0.556	9	0.741	0.241	8
No. of bridled goby	—	—	—	3.468	0.004**	8
No. of catfish	—	—	—	—	—	—
No. of noncommercial sp.	0.530	0.300	23	2.688	0.007*	23
No. of commercial sp.	1.156	0.130	23	0.755	0.229	23

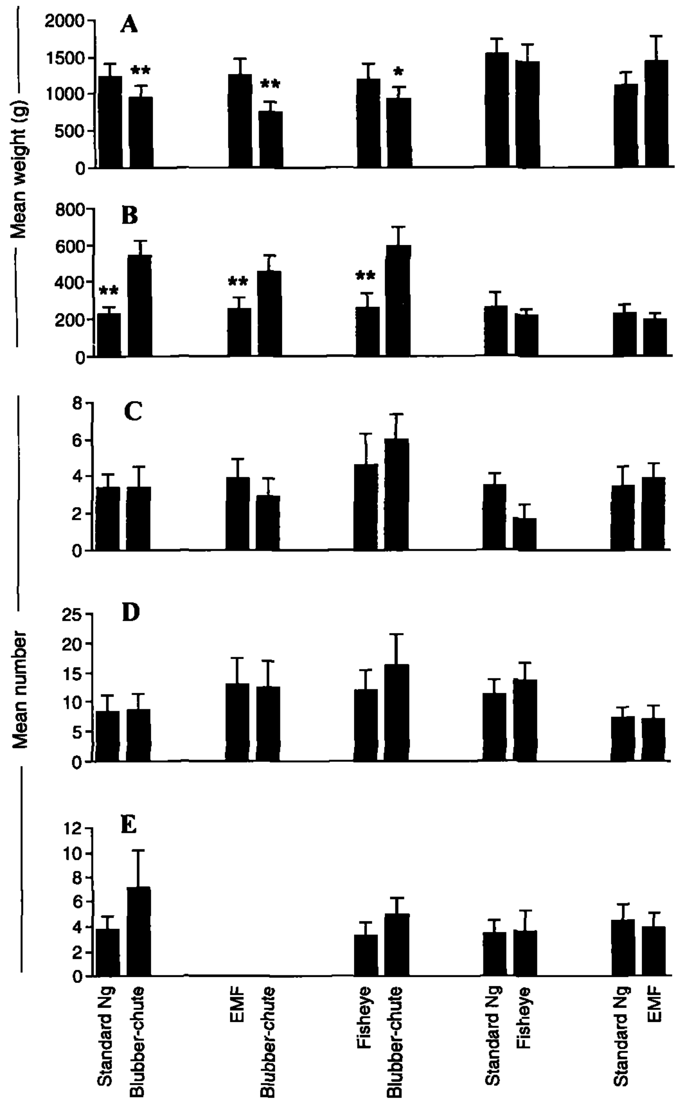

Figure 5

Differences in mean catch (± SE) between the various designs of (**A**) the weight of prawns (*Metapenaeus macleayi*), (**B**) the weight of total bycatch, (**C**) the number of large tooth flounder (*Pseudorhombus arsius*), (**D**) the number of fortesque (*Centropogon australis*), (**E**) the number of narrow banded sole (*Synclidopus macleayanus*), (**F**) the number of bridle goby (*Arenigobius bifrenatus*), (**G**) the number of catfish (*Euristhmus lepturus*), (**H**) the number of noncommercial species, and (**I**) the number of commercial species. * = $P<0.05$; ** = $P<0.01$. Ng = Nordmøre grid; EMF = extended mesh funnel.

standard Nordmøre grid and EMF for meaningful analyses) (Fig. 5G; Table 2). There were no significant differences detected between the standard Nordmøre grid and fisheye, whereas the EMF caught significantly fewer bridled gobies and noncommercial species than did the standard Nordmøre grid (Fig. 5, F and H; Table 2).

Two sample Kolmogorov-Smirnov tests comparing the size-frequency distributions for school prawns showed that, apart from a significant difference between the standard Nordmøre grid and the EMF (Fig. 6E), there were no other differences in the relative size-compositions between any of the codends tested in experiment 2.

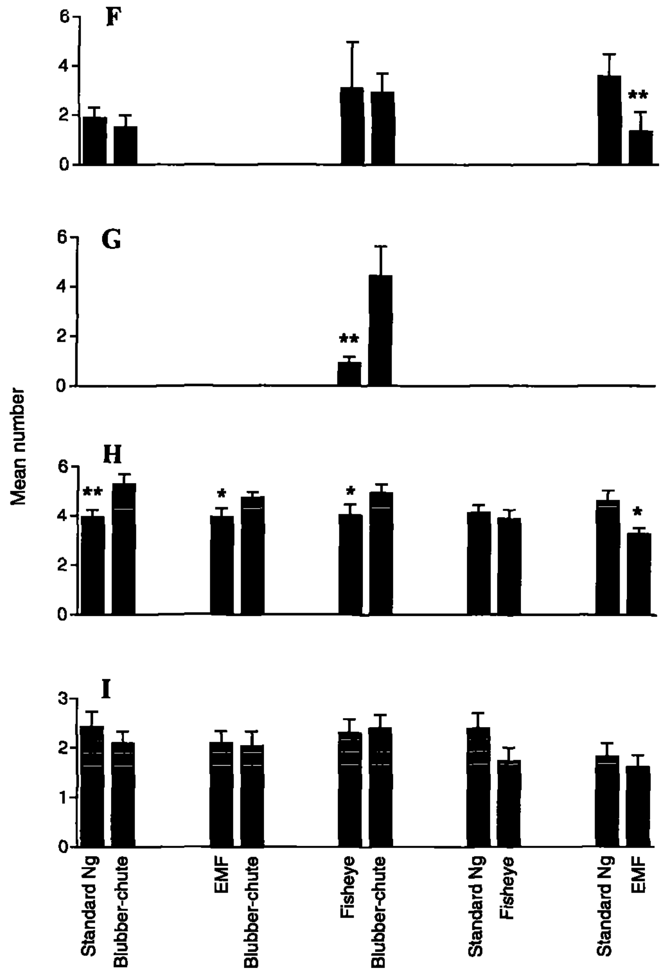

Figure 5 (continued)

Discussion

This study has confirmed the effectiveness of the Nordmøre grid in reducing bycatch while maximizing catches of prawns in NSW estuarine prawn-trawl fisheries (see also Broadhurst and Kennelly, 1996; Broadhurst et al., 1996). By comparing several secondary BRD's attached to a Nordmøre grid, we have also provided information on the relative effectiveness of these designs and their suitability in the HR prawn-trawl fishery.

The results from experiment 1 showed that apart from a significant reduction in the number of noncommercial species with the Allerio Brothers grid, compared with the square-mesh panel, there were no detectable differences in the relative performance of any of the secondary BRD's tested (Table 1).

Compared with the commercially used blubber chute, all three designs incorporating Nordmøre grids in experiment 2 (the standard Nordmøre grid and the Nordmøre grid incorporating the EMF and fisheye) significantly increased the catches of prawns (by 24%, 41%, and 23%, respectively) while significantly reducing the total bycatch (by 58%, 45%, and 55%, respectively) (Fig. 5; Table 2). In earlier papers (Broadhurst and Kennelly, 1996; Broadhurst et al., 1996), we concluded that the prawn-retention characteristics of the Nordmøre grid were attributed to its ability to remove seaweed and debris more effectively. In the present study we observed that, at the end of each tow, those designs incorporating the Nordmøre grid were observed to be relatively free of seaweed and debris, whereas the blubber chute often had large quantities entangled between the meshes, which may have decreased the lateral openings between the meshes in the blubber chute and contributed towards the escape of prawns with this design. Further, because Kolmogorov-Smirnov tests

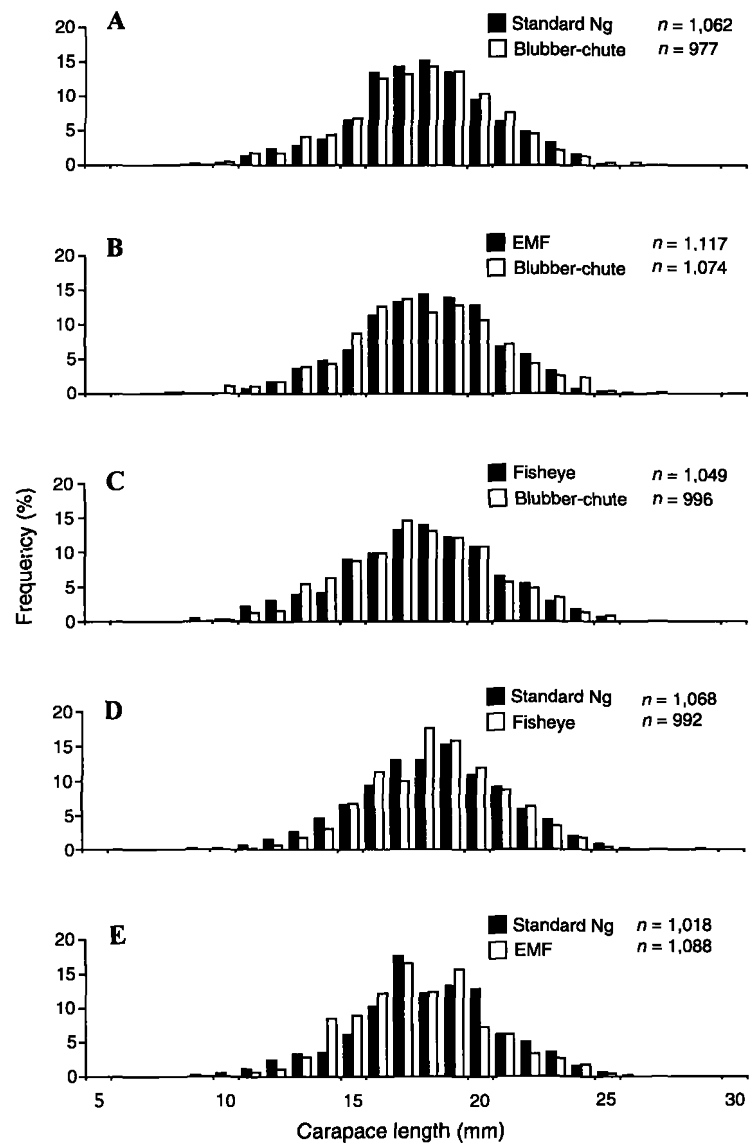

Figure 6

Size-frequency distributions of school prawns (*Metapenaeus macleayi*) caught with (**A**) the standard Nordmøre grid and blubber chute, (**B**) the extended mesh funnel and blubber chute, (**C**) the fisheye and blubber chute, (**D**) the standard Nordmøre grid and fisheye, and (**E**) the standard Nordmøre grid and extended mesh funnel.

on the size-frequency compositions of school prawns failed to detect any difference between the standard Nordmøre grid and the blubber chute (Fig. 6A), such escapees were probably of all sizes. Another hypothesis to explain the loss of prawns from the blubber chute is that some prawns became entangled within the tentacles and large subumbrella of captured jelly fish and were directed, along with the jellyfish, out through the escape exit. In contrast, the long guiding panel and smooth contours of the Nordmøre grid may have allowed the prawns to detach from the jellyfish and thus enabled them to pass into the codend.

Apart from a significant reduction in the numbers of bridle goby and noncommercial species caught by the EMF compared with the number caught by the standard Nordmøre grid in experiment 2, there were no other significant differences between the relative performance of the secondary BRD's and the standard Nordmøre grid (Fig. 5; Table 2). Given these results, therefore, it is likely that most of the fish escaped at the standard Nordmøre grid. While the relatively small bar spacings (20 mm) may have been sufficient to exclude a large number of individuals simply because of their size, it is also possible that smaller fish were able to escape passively. For example, in a previous paper (Broadhurst et al., 1996) we provided evidence that some small bream (*Acanthopagrus australis*) detected the grid in advance (either visually or by means of their lateral lines). These fish may have then orientated away from the grid into an area of reduced water flow behind the guiding panel. The geometric attitude of the grid possibly directed some of these fish out of the codend without mechanical separation through the bars.

Whatever the mechanism of escape, we conclude that, given the effectiveness of the Nordmøre grid in excluding large quantities of bycatch, there appears to be little advantage in attaching secondary BRD's behind grids in the HR prawn-trawl fishery. Because of this, the additional labor and time involved in the manufacture, maintenance, and deployment of these secondary BRDs is clearly unwarranted.

Like several recent studies, this study has shown that there is great utility for the Nordmøre grid in many of NSW estuarine prawn-trawl fisheries. The increases in prawn catches and reductions in bycatch shown in our work in these fisheries have already led many commercial fishermen to use the standard Nordmøre grid in preference to the traditional blubber chute. Such independent and voluntary adoption of the Nordmøre grid by industry may eventually lead to further refinements in design and should facilitate widespread acceptance of this bycatch-reduction gear throughout most of NSW's estuarine prawn-trawl fisheries.

Acknowledgments

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