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Selectivity of penaeid trap nets in south-eastern Australia*

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SUMMARY: Two experiments were done to estimate the selectivity of commercial and modified trap-net configurations in New South Wales (NSW), southeastern Australia. In the first experiment, a commercial trap net made entirely from 25 mm mesh and designed for use in shallow water was alternatively fished with a fine-meshed (9.5 mm netting) trap net (used as a control). In the second experiment, two trap-net configurations designed for use in deeper water and comprising the same anterior section (made from 25 mm mesh), but with different bunts made from (i) the conventional 25 mm mesh and (ii) 31 mm mesh were alternately fished against the control. Both of the conventional trap nets (comprising 25 mm mesh throughout) had low amounts of bycatch and similarly selected eastern king *Penaeus plebejus,* greasyback *Metapenaeus bennettae* and school prawns *Metapenaeus macleayi* across narrow selection ranges (< 3.4 mm) and at 50% retention lengths (between 18.53 and 21.50 mm) that were larger than the average commercially-accepted sizes (15-17 mm CL). Analyses of the selectivities and relative efficiencies of the trap-net configurations comprising the 25 and 31 mm bunts showed no benefit, in terms of maintaining prawn catches and reducing unwanted bycatch, associated with increasing mesh size in these gears. The utility of trap nets for selectively harvesting penaeids is discussed. We conclude that this type of fishing gear appears to have few deleterious impacts.

Key words: Penaeids, selectivity, trap net, fishing gear, south eastern Australia.

RESUMEN: SELECTIVIDAD DE LAS NASAS DE RED PARA PENEIDO EN EL SUDESTE DE AUSTRALIA. – Con el fin estudiar la selectividad de nasas comerciales y la configuración de nasas con redes modificadas, se realizaron dos experimentos en el New South Wales (NSW), al sudeste de Australia. En el primer experimento, se comparó una nasa comercial hecha con malla de 25 mm y diseñada para ser usada en aguas poco profundas con una de 9,5 mm usada como control. En el segundo experimento se utilizaron dos nasas diseñadas para aguas profundas las cuales tenían la misma sección anterior de 25 mm de malla, pero con distintos sacos hechos de (i), malla convencional de 25 mm y (ii), malla de 31 mm. Ambas nasas convencionales (de 25 mm de malla), pescaron poca cantidad de especies acompañantes y seleccionaron de manera similar al langostino *Penaeus plebejus, Metapenaeus macleay* y *Metapenaeus bennettae* a través de una sección estrecha con menos de <3,4 mm de rango de variación y con un 50% de retención entre las longitudes de 18,53 y 21,50 mm CL. Los análisis de selectividad y eficiencia relativa de las configuraciones de nasas de red comprendiendo 25 y 31 mm de saco no mostraron ningún beneficio en términos de gestión para las capturas de langostinos, pero sí reducción de las especies acompañantes no deseadas al aumentar la malla de estos artes. Se discute la utilidad de las nasas de red para la selectividad en los desembarcos de peneidos. Concluimos que este tipo de arte de pesca tiene poco impacto nocivo en la pesquería.

Palabras clave: Penaeids, selectividad, nasa de red, arte de pesca, sudeste australiano.

INTRODUCTION

Penaeids form the basis of several important commercial fisheries in New South Wales (NSW), Australia that have a total value of more than $A26 M per annum. Catches include 6 species, although eastern king *Penaeus plebejus*, school *Metapenaeus macleayi* and greasyback prawns *Metapenaeus bennettae* account for more than 98% of the total annual production (approx. 2000 t). These 3 species are

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targeted throughout their distributions across nearshore and estuarine habitats (Coles and Greenwood, 1983) using a combination of static (stow and trap nets) and towed (otter trawls and seines) fishing gears.

All of these gears are managed by a range of input controls that include limits on their dimensions, effort, methods and areas of operation and minimum and maximum legal mesh openings (for a definition, see Ferro and Xu, 1996). These legal mesh sizes vary between 40 and 45 mm in the codends of otter trawls, 30 and 36 mm throughout seines and stow nets and 25 and 36 mm in trap nets. The use of these small-meshed gears throughout habitats that are typically characterised by diverse assemblages and abundances of small fauna (Bell *et al*., 1988; Gray *et al*., 1996) is of considerable concern and has resulted in several quantitative studies of catches (e.g. Gray *et al*., 1990; Andrew *et al*., 1995; Liggins and Kennelly, 1996; Liggins *et al*., 1996; Kennelly *et al*., 1998; Gray, 2001). These studies revealed that at some locations and times, penaeid fishing gears, and especially otter trawls, retain incidental catches (collectively termed 'bycatch' *sensu* Saila, 1983) that often comprise juveniles of commercially-important teleosts, molluscs and crustaceans, including small, unwanted conspecifics (< approximately 15 mm carapace length - CL; Broadhurst *et al*., 2004) of the targeted species. Concerns over the mortality of these organisms and the potential impacts on their stocks have resulted in successful attempts at improving gear selectivity. The majority of this work has concentrated on otter trawls used throughout various marine (e.g. Broadhurst and Kennelly, 1997) and estuarine (Broadhurst and Kennelly, 1994; 1996; Broadhurst *et al*., 2004) fisheries. Considerably less attention has been directed towards assessing static gears (but see Macbeth *et al*., 2004) and no work has been done on trap nets.

Trap netting in NSW involves up to 95 operators who are permitted to fish in 12 coastal lakes and lagoons, although more than 40% of the effort is concentrated at Tuggerah Lakes (33°19'S, 151°30' E). Fishing mostly occurs at night and between the last and first quarter phases of the moon. All of the trap-net configurations used in NSW are similar, and consist of a wall of 25 mm netting (i.e. the minimum legal mesh size for this gear) up to 140 m in length. The width of this wall of netting varies from approximately 1 to 6 m, depending on the depths fished. For example, trap nets used at sites that are shallow and with slow currents typically have a narrow (e.g. 1 m) anterior section made from stiff, positively-buoyant polyethylene (PE) netting, which helps to maintain net distension during fishing (Figs 1A and 2B). In contrast, trap nets used in deeper (e.g. > 2 m), faster-flowing water have wide transverse sections (i.e. up to approx. 6 m) of negatively-buoyant polyamide (PA) netting throughout.

Trap nets are set by attaching one end to a vertical stanchion near the shore and the other end to the horizontal gunwale of a dory anchored on the lake (Fig. 2A and B). Currents cause the anterior section of the netting to distend and assume a parabolic shape, effectively trapping migrating penaeids and directing them along the wall of netting towards the horizontally-orientated bunt (at the dory). Fishers facilitate this movement of catch by regularly lifting and hauling sections of the headline and footrope over a second dory so that it passes underneath the trap net and the catch is progressively rolled towards the bunt (Fig. 2C).

Anecdotal information from fishers suggests that trap nets have low amounts of bycatch and are more selective than other gears used to target penaeids in NSW. However, there are no formal estimates of the selectivity of the various configurations or of the effects of any modifications on their performance. Our aims in the present work were to address this lack of information by (i) quantifying the selectivity of the most common configurations used and (ii) examining the relative efficiency of a larger mesh size in the bunt of one of these gears.

MATERIAL AND METHODS

This study was done at commercial trap net sites in Tuggerah Lakes between the last and first quarter moon phases of January and February 2003. All sites ranged in depth from 0.5 to 3 m and encompassed a combination of sloping sand and mud bottoms with patches of seagrass.

Trap-net configurations examined

Four trap-net configurations were used at these sites. All trap nets were made from dark netting that had a maximum stretched depth of approx. 6 m and hung at 50% on buoyed headlines and weighted footropes, 140 m in length (Fig. 1). The first configuration, termed the 25 mm PE/PA trap net, represented those commercial designs that are typically

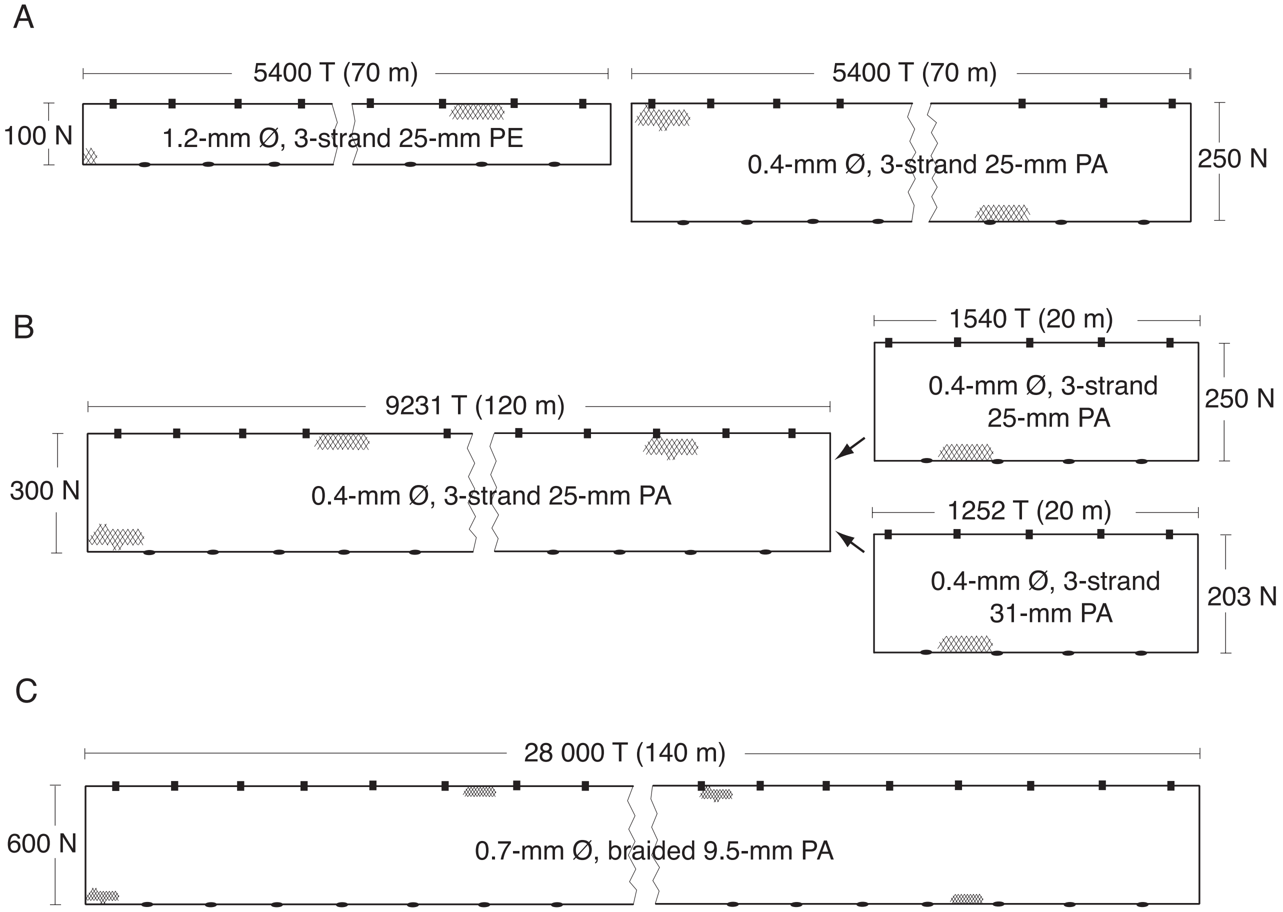

FIG. 1. – Diagrammatic representation of the A) 25 mm PE/PA, B) 25- and 31 mm bunt and C) control trap-net configurations (m: metres; N: normals; T: transversals: PA: polyamide; PE: polyethylene; ș: diameter).

fished at shallow sites (e.g. < 1 m deep—see discussion above) and comprised two sections that were each 70 m in length and made from 100 meshes (normal direction - N) of 25 mm knotted PE (approx. 1.2 mm diameter – Ș, 3-strand twisted twine) and 250 N of 25 mm knotted PA (approx. 0.4 mm Ș, 3-strand twisted twine) netting respectively (Fig. 1A). The second and third trap-net configurations had the same anterior section (300 N of 25 mm knotted, PA netting—i.e. the same material as that used above—120 m in length), but different bunts. Both bunts were 20 m long, approx. 6 meters wide and made from 0.4 mm Ș, 3-strand twisted PA twine, but with mesh sizes that were 25 and 31 mm respectively (Fig. 1B). These bunts and the anterior section of the trap net were rigged with zippers (Buraschi S146R, 6 m in length) to facilitate their attachment. The 25 mm bunt attached to the anterior section described above represented the majority of the commercial trap-net configurations used throughout NSW (Fig. 1B). The larger-meshed, 31 mm bunt attached to the anterior section represented a modified and previously untested trap-net configuration. We hypothesised that this larger-meshed bunt would increase the size selection of the trap net for penaeids and small individuals comprising the bycatch. The fourth trap net was termed the control, and comprised 600 N (i.e. approximately 6 m stretched depth) of 9.5 mm knotless PA netting (0.7 mm Ș, braided twine) throughout (Fig. 1C).

Experimental design

All fishing was done at night (between 20:00 and 03:00) and according to normal commercial procedures. During all sets, the headline and footrope of the anterior end of the particular trap-net configuration being used (see below for details) were secured to a staked stanchion and the net set from a dory along the bottom of the lake in a straight line (Fig. 2A). The headline and footrope of the bunt were horizontally secured to a second dory that was

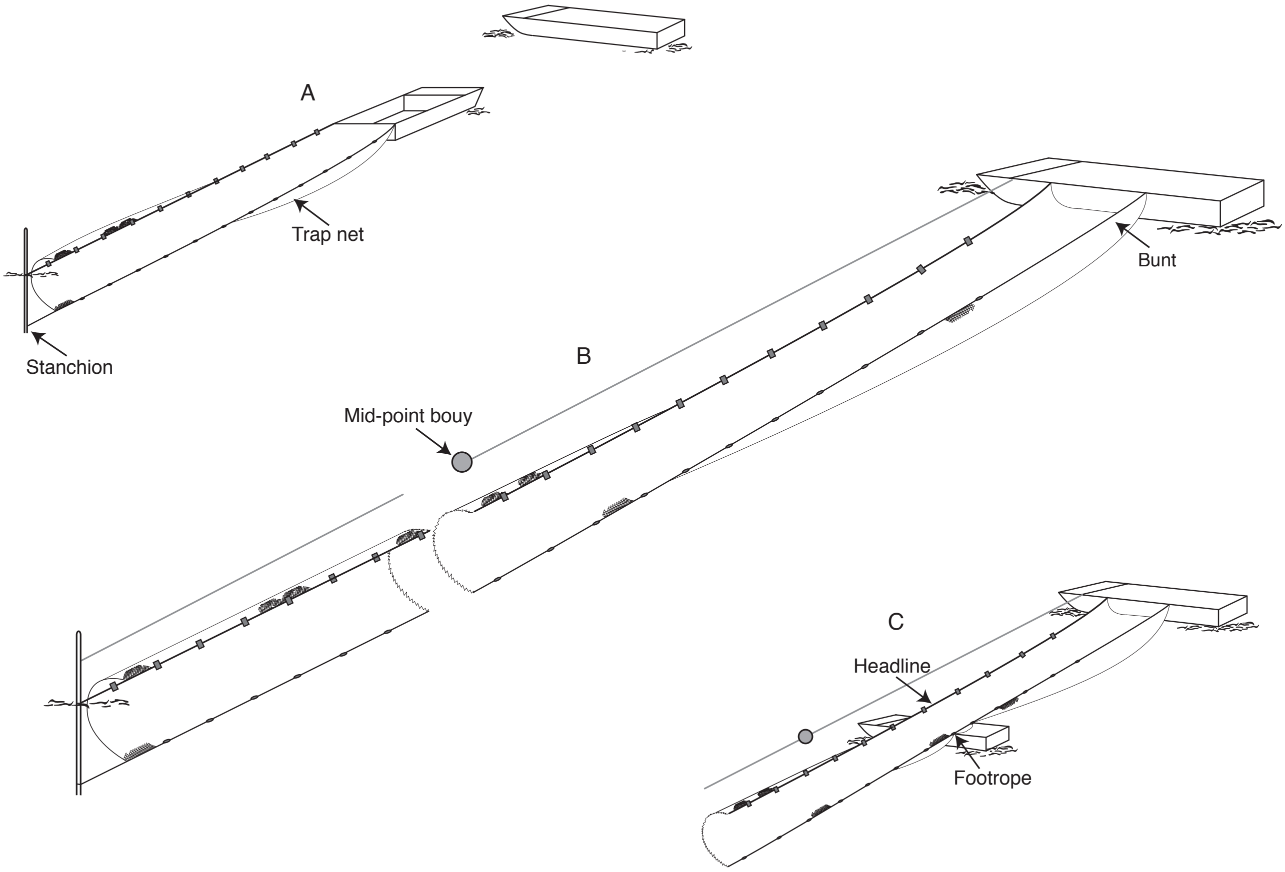

FIG. 2. – Diagrammatic representation of A) the method for setting the trap nets, B) the traps nets during fishing and C) using a dory to progressively concentrate the catch towards the bunt.

anchored in position (Fig. 2A and B). To mark the middle of the trap net, approx. 140 m of 4 mm Ș, PE rope was attached between the stanchion and the second dory, and a large float was clipped at 70 m (Fig. 2B). Each trap net was left to soak for 25 minutes, after which the first dory returned to the middle of the gear and the headline and footrope were lifted onboard (Fig. 2C). Two fishers simultaneously hauled the headline and footrope so that the dory passed under the trap net and the catch was concentrated towards the bunt and then into the first dory (Fig. 2C). The trap net was then removed from the lake and the next configuration was set.

Using this fishing method, two experiments were done during consecutive phases of the new moon. In the first experiment, the 25 mm PE/PA trap net was alternatively fished against the control at a shallow (< 1 m) commercial trap-net site. We attempted between 2 and 3 replicate, alternate 25 min sets of the treatment and control trap net on each night and completed a total of 15 balanced sets over 6 nights. In the second experiment, the 25 and 31 mm bunts were alternatively zippered to the anterior 25 mm PA trap-net section and fished against the control at two sites—which were determined randomly and/or according to the prevailing weather conditions (i.e. the direction and strength of wind and waves) each night. Over 8 nights, we attempted two replicate nightly sets of each trap-net configuration and successfully completed a total of 14 balanced replicates.

Data collected from all trap-net sets included: the number and weight of total prawns; the numbers, weights and all carapace lengths (CL to the nearest 1 mm) of greasyback, eastern king and school prawns; the weight of total bycatch; the numbers of all fish and their fork lengths (FL to the nearest 5 mm); and the numbers of all other species. Where it was not possible to identify individual species, these were grouped at the levels of genus or family.

Statistical analyses

Data from the two experiments were analysed in different detail. Attempts were made at modelling and comparing the selectivity of all treatment trap nets for the key species encountered in both experiments. In addition, because the control was alternately fished against a commercial and modified, larger-meshed trap-net configuration during experiment 2, specific hypotheses concerning gear-related effects on catches were examined using multivariate and univariate analyses (detailed below).

For both experiments, the size-frequencies of individuals of species caught in sufficient quantities (at least 100 individuals from each trap net configuration) were combined across all tows for the control and each of the treatment trap nets. Parametric selection curves (logistic and Richards) were fitted to these data using maximum likelihood (Millar and Fryer, 1999). These fits used an estimated-split SELECT model (Millar and Walsh, 1992) and were assessed by visual examination of residual plots and by comparing model deviances and associated degrees of freedom against a χ^2 distribution. The standard errors of parameter estimates (i.e. 50% retention length - L_{50} and difference in length between 25 and 75% retention lengths - selection range or SR) were adjusted according to an appropriately-derived replicate estimate of over-dispersion (Millar and Fryer, 1999). Pairwise bivariate Wald statistics were calculated using the estimated parameter vectors to test for differences between the selectivity curves for each of the treatment trap nets (Kotz *et al.*, 1982).

TABLE 1. – Scientific and common names and number (N) of organisms caught during the study.

Family	Scientific name	Common name	N
Crustaceans			
Penaeidae	*Metapenaeus macleayi*	School prawn[1, 2*]	1738
	Metapenaeus bennettae	Greasyback prawn[1, 2*]	1609
	Penaeus plebejus	Eastern king prawn[1, 2*]	3156
Portunidae	*Portunus pelagicus*	Blue swimmer crab[1, 2*]	10
	Scylla serrata	Mangrove crab[1, 2*]	1
Teleosts			
Ambassidae	*Ambassis* spp.	Glassy perchlets[1, 2]	2626
Anguillidae	*Anguilla reinhardti*	Long-finned eel[1,2*]	3
Antennariidae	*Antennarius striatus*	Striped angler[2]	1
Atherinidae	*Atherinomorus ogilbyi*	Hardyhead[1,2]	186
Balistidae	*Monacanthus chinensis*	Fan-bellied leatherjacket[2*]	2
	Meuschenia trachylepis	Yellow-finned leatherjacket[2*]	3
Belonidae	*Ablennes hians*	Barred long-tom[2]	3
Callionymidae	*Foetorepus calauropomus*	Common stinkfish[2]	2
Chaetodontidae	*Microcanthus strigatus*	Stripey[1, 2]	10
Clupeidae	*Herklotsichthys castelnaui*	Southern herring[1, 2*]	2037
	Hyperlophus vittatus	Whitebait[1, 2]	1318
Dasyatididae	*Dasyatis thetidis*	Estuary stingray[1, 2]	3
Diodontidae	*Dicotylichthys punctulatus*	Three-barred porcupine-fish[1, 2]	11
Engraulidae	*Engraulis australis*	Australian anchovy[2]	2
Gerreidae	*Gerres subfasciatus*	Silver biddy[1, 2*]	33
Gobiidae	Mixed spp.	Gobies[1, 2]	393
Hemiramphidae	*Hyporhamphus regularis*	River garfish[1, 2*]	167
Kyphosidae	*Girella tricuspidata*	Luderick[1, 2*]	11
Monodactylidae	*Monodactylus argenteus*	Diamond fish[1, 2]	81
Mullidae	*Upeneus tragula*	Bar-tailed goatfish[2]	1
Mugilidae	*Liza argentea*	Flat-tail mullet[1, 2*]	9
Platycephalidae	*Platycephalus fuscus*	Dusky flathead[1,2*]	2
Plotosidae	*Plotosis lineatus*	Striped catfish[2]	1
	Cnidoglanis macrocephalus	Estuary catfish[1, 2*]	2
Pomatomidae	*Pomatomus saltatrix*	Tailor[1,2*]	13
Scorpaenidae	*Centropogon australis*	Fortescue[1, 2]	77
Sillaginidae	*Sillago ciliata*	Sand whiting[2*]	2
Soleidae	*Aseraggodes macleayanus*	Narrow-banded sole[1]	1
	Synaptura nigra	Black sole[2]	3
Sparidae	*Acanthopagrus australis*	Yellowfin bream[1, 2*]	12
	Pagrus auratus	Snapper[1]	1
	Rhabdosargus sarba	Tarwhine[1,2*]	4
Sphyraenidae	*Sphyraenella obtusata*	Striped sea-pike[2*]	1
Tetraodontidae	*Tetractenos hamiltoni*	Common toadfish[1,2]	6
Terapontidae	*Pelates sexlineatus*	Six-lined trumpeter[1,2*]	142
Molluscs			
Loliginidae	*Photololigo etheridgei*	Broad squid[1, 2]	136
	Loliolus noctiluca	Bottle squid[1, 2]	25
Octopodidae	*Octopus* sp.	Octopus[1]	1

[1, 2]species recorded during experiments 1 and/or 2, respectively.
*commercially and/or recreationally important species.

Using the full data set from experiment 2, non-metric multivariate analyses were used to investigate differences in the structures of catches between the trap-net configurations, following the methodologies presented by Clarke and Warwick (2001). Abundances were √ transformed and used to develop Bray-Curtis similarity matrices. Ordination of the relationships among ranks of these similarities from individual sets of the three trap-net configurations was done by multi-dimensional scaling (MDS). Two-way crossed analyses of similarity (ANOSIM) were used to test for differences in catch assemblages from the 3 trap nets over the 8 nights fishing. Significant R values from these analyses were used to group the trap nets, which were subsequently explored using SIMPER (Clarke and Warwick, 2001).

Parametric univariate analyses were used to examine differences in the catches of the key species and groups identified above among the trap-net configurations used in experiment 2. To provide balanced analyses, only nights with two replicate sets of each trap-net configuration were considered. Data were ln(x+1) transformed, tested for heterogeneous variances, and analysed by appropriate 2-factor (nights and trap nets as random and fixed factors respectively) orthogonal analyses of variance (ANOVA). To increase power for the main effects of trap nets, where the interaction term was non-significant at $P < 0.25$, it was pooled with the residual (Winer, 1971). All significant main effects of the trap net were investigated using Student-Newman-Keuls (SNK) multiple comparisons. The means for all significant interactions were graphed, but not investigated further owing to the low level of replication within nights (i.e. only two replicate sets of each trap net).

RESULTS

Thirty three families comprising more than 43 species were captured during this study (Table 1). It was not possible to distinguish between 2 and 3 species of glassy perchlets and gobies respectively, so these were grouped by genus and family.

Sufficient quantities and appropriate sizes of eastern king, greasyback and school prawns (Fig. 3)

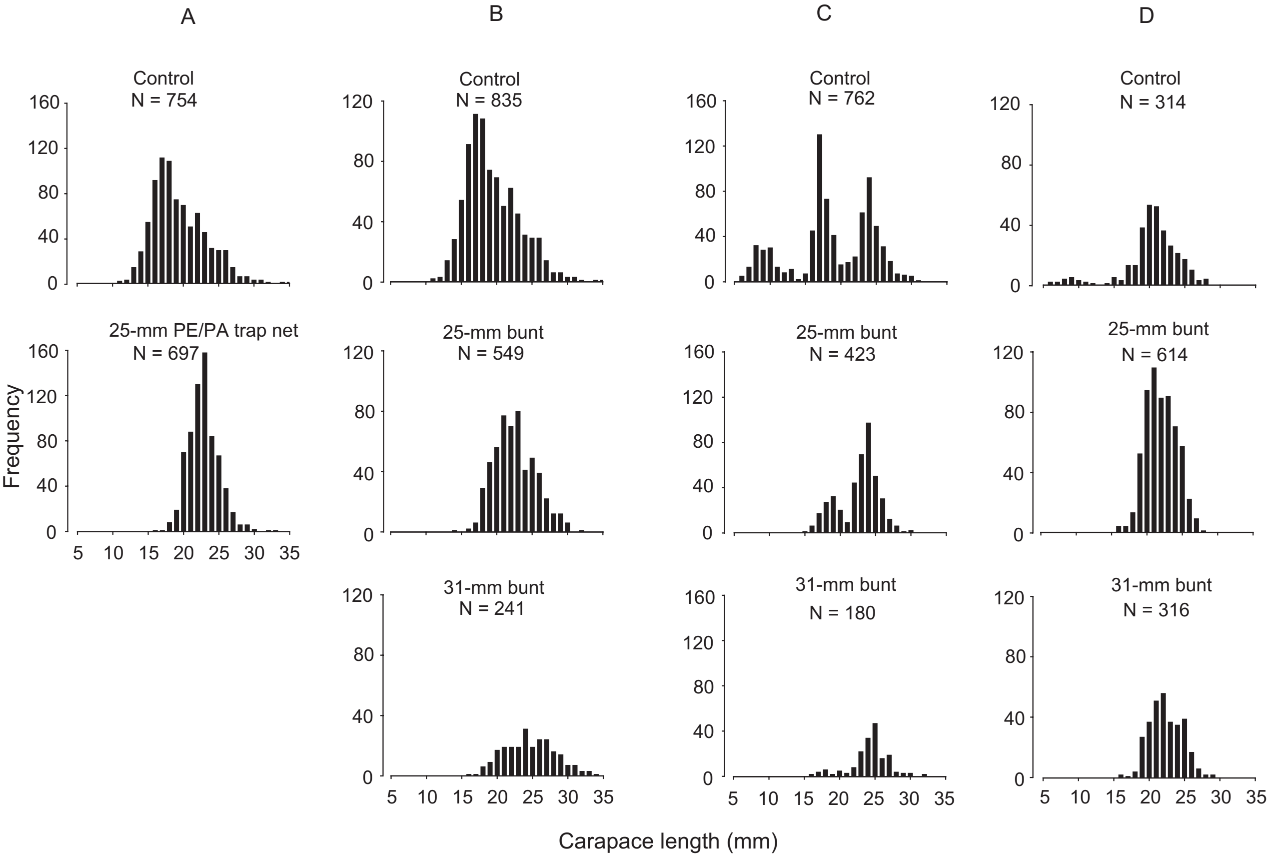

FIG. 3. – Size-frequency distributions of eastern king prawns captured during A) experiment 1 and B) experiment 2 and C) greasyback and D) school prawns captured during experiment 2.

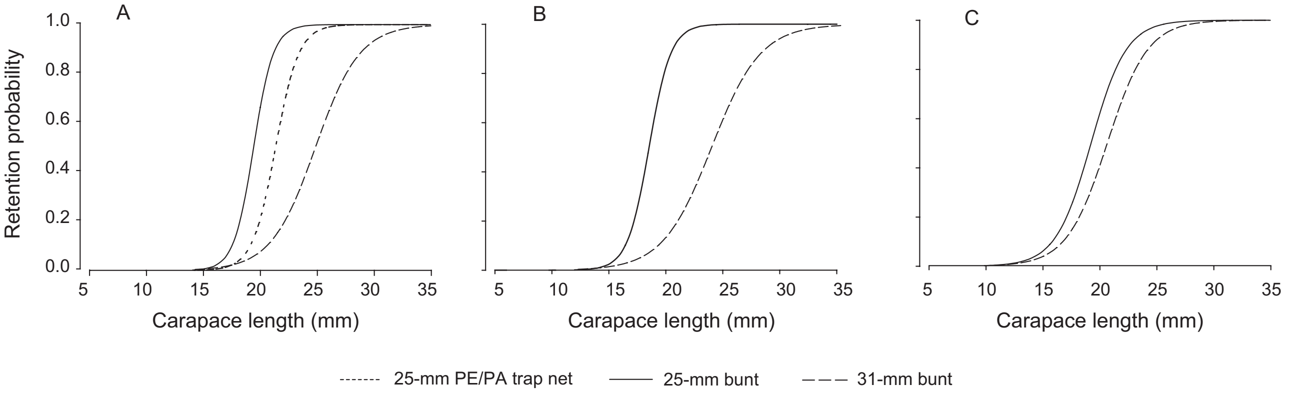

FIG. 4. – Logistic selection curves for A) eastern king, B) greasyback and C) school prawns for the various treatment trap-net configurations.

TABLE 2. – Carapace and fork lengths (mm) at 50% probability of retention (L_{50}), selection ranges (SR) and relative fishing efficiencies (*p*) for greasyback prawns, eastern king prawns, school prawns and southern herring from the various trap-net configurations. Standard errors are given in parentheses.

	Eastern king prawns	Greasyback prawns	School prawns	Southern herring
25-mm PE/PA trap net				
L_{50}	21.50(0.47)	—	—	76.33(4.48)
SR	2.23(0.34)	—	—	7.20(4.49)
p	0.73(0.03)	—	—	0.84(0.04)
25-mm bunt				
L_{50}	19.42(0.44)	18.53(0.30)	19.42(0.97)	—
SR	1.90(0.40)	2.09(0.38)	3.40(1.15)	—
p	0.60(0.03)	0.52(0.02)	0.75(0.04)	—
31-mm bunt				
L_{50}	24.97(1.91)	23.67(1.58)	20.70(1.46)	78.46(5.75)
SR	4.36(0.87)	4.71(0.87)	3.90(1.55)	8.12(7.30)
p	0.67(0.10)	0.48(0.07)	0.66(0.07)	0.70(0.04)

and southern herring (30-120 mm FL) were caught to enable attempts at modelling their selectivities for at least one of the treatment trap-net configurations in either experiment. A logistic model (Fig. 4, Table 2) was used in all cases because: (i) the null hypothesis for the goodness-of-fit test was not rejected ($P > 0.05$); (ii) the deviance residuals showed no clear structure; and (iii) there was no significant reduction in deviance associated with using a Richards curve.

Pairwise bivariate Wald tests detected significant differences in parameter estimates between the 25 and 31 mm bunts for eastern king and greasyback prawns, with the larger-meshed bunt selecting individuals at larger L_{50}s and across considerably greater SRs ($P < 0.01$, Fig. 4A and B, Table 2). No significant differences were detected in the estimated selection parameters for school prawns between these bunts ($P > 0.05$; Fig. 3C, Table 2). The 25 mm PE/PA trap net selected eastern king prawns at significantly greater and lower parameters than the 25 and 31 mm bunts respectively (Pairwise test $P < 0.01$, Fig. 3A, Table 2). The estimated selection parameters for southern herring were not significantly different between the 25 mm PE/PA trap net and the 31 mm bunt ($P > 0.05$, Table 2).

MDS of the abundance data from the control trap net and 25 and 31 mm bunts used in experiment 2 had a stress of 0.14 for the best two-dimensional ordination, indicating sufficient representation (Fig. 5). Catch structures were significantly different among

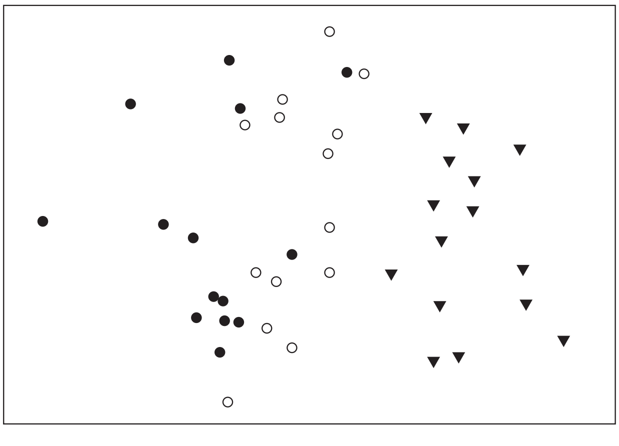

FIG. 5. – Two-dimensional ordination for the numbers of all species captured in the control and 25 and 31 mm bunts during experiment 2 (stress = 0.14; ● 31 mm bunt; ❍ 25 mm bunt; ▼ control).

TABLE 3. – Summaries from SIMPER analyses of the mean number per 25-min set, % contribution and cumulative % of species contributing to > 99% of the significant dissimilarities detected between the control and treatment (25- and 31-mm bunts) trap-net configurations in experiment 2.

Species	Mean no. Control	Mean no. Treatments	% contribution	Cumulative %
King prawns	58.73	28.25	16.41	16.41
Glassy perchlets	54.47	1.04	16.11	32.52
Whitebait	66.73	0.00	14.86	47.37
Greasyback prawns	52.00	21.54	14.50	61.87
Southern herring	16.67	47.11	12.23	74.10
School prawns	20.87	33.21	9.16	83.26
Gobies	22.27	0.00	6.22	89.48
Hardyhead	7.80	1.07	2.87	92.35
River garfish	6.47	1.14	2.10	94.45
Six-lined trumpeter	1.20	4.21	1.20	95.65
Broad squid	1.93	3.21	1.09	96.74
Fortescue	3.00	0.64	0.94	97.68
Diamond fish	1.40	1.36	0.66	98.35
Silver biddy	0.07	1.14	0.45	98.80
Luderick	0.47	0.11	0.20	99.00

nights (averaged across the three trap nets—ANOSIM Global R = 0.568, $P < 0.01$) and among trap-net configurations (averaged across the 8 nights—ANOSIM Global R = 0.68, $P < 0.01$). Pair-wise tests revealed that the 25 and 31 mm bunts were significantly different to the control (R = 0.918, $P < 0.01$ and R = 0.923, $P < 0.05$ respectively) but not to each to other (R = 0.167, $P > 0.05$) (Fig. 5). SIMPER analyses of these two groups (i.e. control vs. treatment trap nets) showed that all species of penaeids, along with several species of small fish (including glassy perchlets, whitebait, southern herring, gobies, hardyhead and river garfish) were responsible for the differences between the control and treatment trap nets (Table 3).

ANOVA of the appropriate univariate data from experiment 2 detected significant F ratios for the main effect of trap nets for the numbers of total, greasyback and eastern king prawns, hardyhead, river garfish and glassy perchlets (Table 4). SNK tests of these means showed that the 31 mm bunt retained significantly fewer total and eastern king prawns than the commercially-used 25 mm bunt (mean reductions of 44 and 52% respectively) and the control (Fig. 6A and C). Although not significant, the weights of total and eastern king prawns showed similar trends (Fig. 6B and D). Similarly, the 31 mm bunt caught fewer greasyback prawns and river garfish than did the 25 mm bunt (by 50 and 73% respectively) (Fig. 6G and J). Both treatment bunts retained comparable, and significantly fewer hardyhead and glassy perchlets than the control (Fig. 6I and K). Significant interactions were detected between nights and trap nets for the weight of greasyback prawns and the number of southern herring (Table 4). Like the results from above, the appropriate means of these differences revealed that the 31 mm bunt retained lower quantities of these species across most nights (Fig. 7A and B).

TABLE 4. – F ratios from analysis of variance to determine the effects on catches due to different trap nets and nights. All data were ln(x+1) transformed. $^{**}P < 0.01$; $^{*}P < 0.05$. Pld indicates that the interaction was non-significant at $P < 0.25$ and the sums of squares pooled with the residual.

		Total prawns		Greasyback prawns		King prawns		School prawns		Wt of
Source	df	no.	wt	no.	wt	no.	wt	no.	wt	bycatch
Trap net	2	9.45**	2.13	6.77**	2.27	4.87*	1.35	1.81	1.70	0.48
Nights	5	1.16	1.85	16.12**	29.19**	1.59	0.88	7.13**	5.87**	11.97**
Interaction	10	0.82^{pld}	0.77^{pld}	0.58^{pld}	3.67**	1.18^{pld}	0.90^{pld}	0.72^{pld}	0.41^{pld}	2.02
Residual	18									

Source	df	No. of southern herring	No. of hardyhead	No. of river garfish	No. of glassy perchlets	No. of broad squid
Trap net	2	0.98	8.30**	7.21**	98.70**	1.49
Nights	5	17.92**	1.27	1.52	0.58	48.16**
Interaction	10	3.25*	0.32^{pld}	0.44^{pld}	1.16^{pld}	1.53
Residual	18					

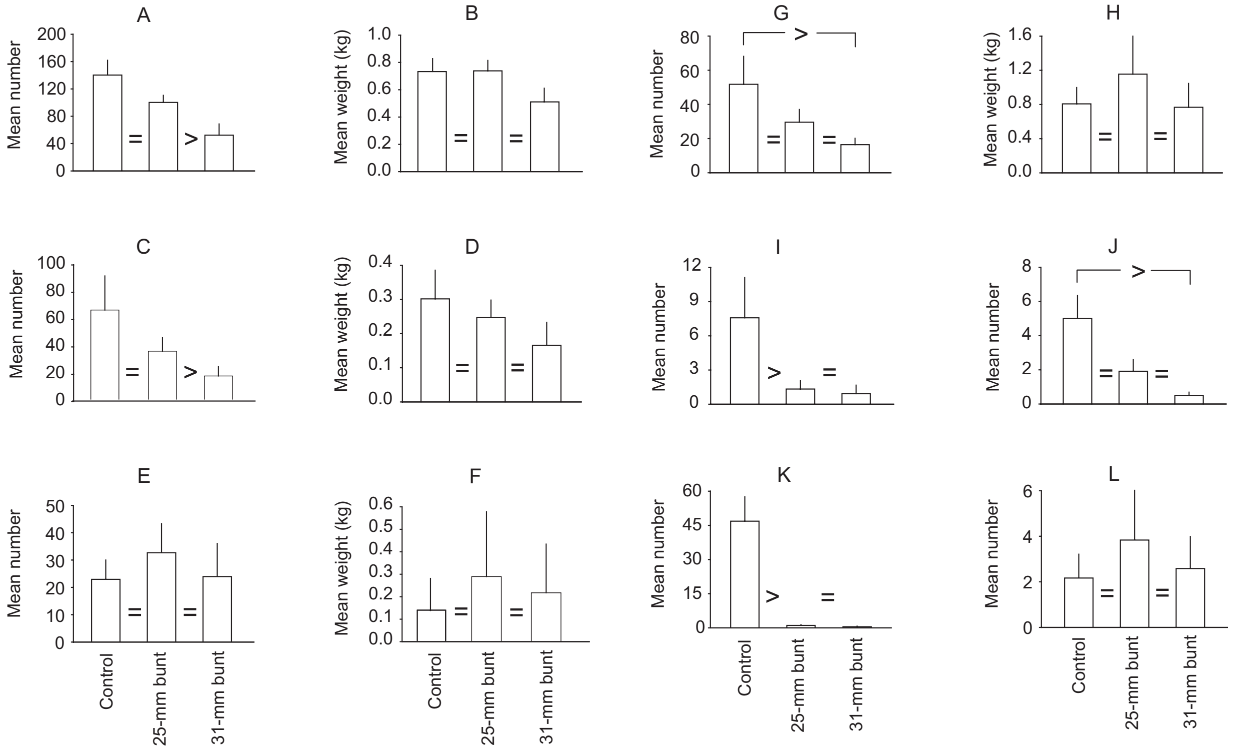

FIG. 6. – Differences in mean catch (+ SE) between the control and 25 and 31 mm bunts used in experiment 2 for A) number and B) weight of total prawns, C) number and D) weight of eastern king prawns, E) number and F) weight of school prawns, G) number of greasyback prawns, H) weight of bycatch and numbers of I) hardyhead, J) river garfish, K) glassy perchlets and L) broad squid. > and = indicate significant differences determined by SNK tests.

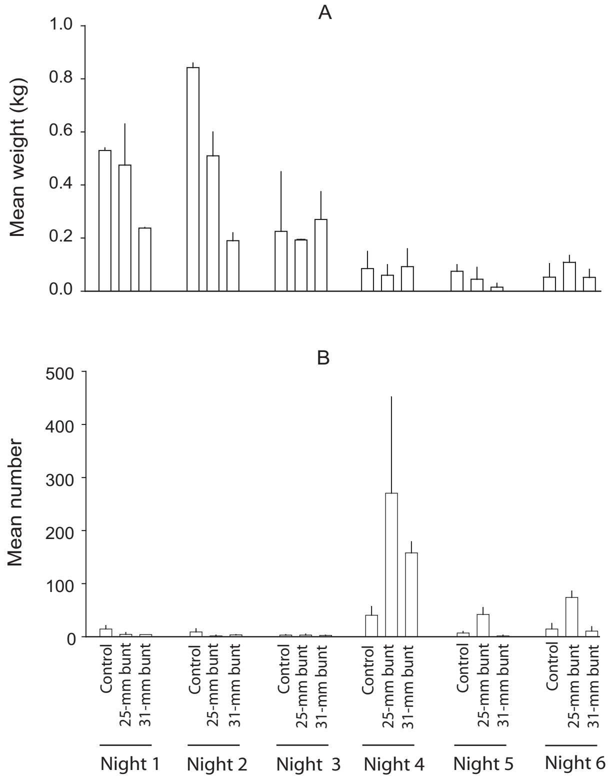

FIG. 7. – Differences in mean catch (+ SE) between the control and 25 and 31 mm bunts and nights in experiment 2 for A) weight of greasyback prawns and B) number of southern herring.

DISCUSSION

This study showed that (i) the commercially-used trap-net configurations had comparable and appropriate selectivity parameters for the targeted sizes of all three species of penaeids, and (ii) these trap nets are considerably more selective than other larger-meshed, static and towed gears used to target penaeids in south eastern Australia and throughout many other temperate and tropical fisheries (Vendeville, 1990; Sobrino *et al.*, 2000; Broadhurst *et al.*, 2004; Macbeth *et al.*, 2004). More specifically, the 25 mm bunt trap net selected all species at L_{50}s between 18.53 and 19.42 mm across SRs that were less than 3.4 mm (Table 2). This minimal inter-specific variability in selectivity parameters can be attributed to the considerable appendages and morphological discontinuities of penaeids, which strongly influence their selectivity irrespective of the species (Vendeville, 1990). These comparable L_{50}s and narrow SRs mean that the majority of all individuals of the 3 species less than between approximately 18 and 20 mm CL escaped through the 25 mm mesh. These escapees were larger than the average industry-accepted commercial sizes (approx 15-17 mm CL; Broadhurst *et al.*, 2004) targeted throughout all estuarine fisheries.

The selectivities of the commercially-used trap nets can be compared with other penaeid-fishing gears using a simple proportionality constant termed the 'selection factor' (SF) (Pope *et al.*, 1975) or 'coefficient of selectivity' (Vendeville, 1990), calculated by dividing the size of mesh into the L_{50} estimate. For the commercial trap nets examined here, all penaeid SFs ranged between 0.74 and 0.86. These values are considerably greater than those typically recorded for penaeid otter trawls, seines and stow nets, which frequently are less than 0.45 (e.g. Vendeville, 1990; Sobrino *et al.*, 2000) and often lower than 0.30 (e.g. Broadhurst *et al.*, 2004; Macbeth *et al.*, 2004). For example, in a study examining the selectivity of conventional otter trawls used in the Clarence River, NSW, Broadhurst *et al.* (2004) demonstrated that codends made from 40 mm diamond-shaped mesh had L_{50}s of 8.6 and 10.3 mm (i.e. SFs of 0.21 and 0.26) and SRs of 3.9 and 3.5 mm for school and eastern king prawns respectively. Although constructed from meshes that were almost 40 % smaller than these trawl codends, the commercially-used trap nets selected individuals at L_{50}s that were more than 2.5 times greater. Further, this selection occurred across a substantially narrower range of sizes.

Such a relatively more-defined selection by trap nets can be attributed to their design and method of operation. Hauling the headline and footrope of the entire posterior section (i.e. approx. 70 m) over the dory effectively spread large transverse sections of the netting (e.g. > 2 m) and maintained the maximum lateral mesh openings at an area where the catch was dispersed and being progressively rolled towards the bunt (Fig. 2C). This facilitated multiple contacts between all individuals in the catch and open meshes, providing numerous opportunities for selection to occur. In contrast, most of the selection processes in otter trawls, seines and stow nets occur in the codend. At this location, the mesh openings are mostly orientated parallel to the general movement of catch, frequently narrow in proportion to the mesh size, and often blocked by the distribution of the catch (Suuronen and Millar, 1992; Erickson *et al.*, 1996). These characteristics limit the probability of small organisms contacting open meshes and escaping.

The selection mechanisms described above for trap nets provide one explanation for the relatively high SRs observed for all penaeids from the 31 mm bunt (Fig. 4, Table 2). Owing to an increase in L_{50} proportional to the mesh size, this bunt maintained a SF of between 0.67 and 0.8 for all species. However, unlike the commercially-used 25 mm trap-net configurations, this selection occurred over a wide range of sizes (e.g. SRs ± SE between 4.36 ± 0.87 and 3.90 ± 1.55 mm, Table 2) more characteristic of towed gears. These wide SRs may be attributed to the comparatively short overall length (i.e. < 20 m) of larger-meshed netting available to select individuals in the 31 mm bunt section and their fewer contacts with open meshes as they were rolled towards the dory. Given the observations for the 25 mm trap nets, it is likely that the SRs of penaeids would be reduced if the entire posterior section (i.e. 70 m) was made from the 31 mm netting (and not just the 20 m bunt section).

Considering the results from the analyses of catch comparisons in experiment 2, it is apparent that using such a larger-meshed trap net would provide little benefit in terms of reducing unwanted bycatch while maintaining commercial catches. For example, MDS and the subsequent ANOSIM tests failed to detect any significant differences in overall catch structures between the 31 and the 25 mm bunts (Fig. 5). Compared to the control, both configurations were similarly effective in excluding large quantities of those small fish (such as whitebait, gobies, glassy perchlets and hardyhead) that typically inhabit coastal lakes and estuaries throughout NSW and are vulnerable to capture by penaeid-catching gears (e.g. Andrew *et al.*, 1995; Liggins and Kennelly, 1996; Liggins *et al.*, 1996; Gray, 2001) (Fig. 6, Tables 3 and 4). Further, there was no concomitant increase in the selection of southern herring (the most common larger-sized species), probably because this species has a high dorsal profile that limits their escape through diamond meshes, regardless of their size. The 31 mm bunt did exclude considerably greater numbers of small prawns, but a large proportion of commercial-sized individuals also escaped (Fig. 6A and C).

The results presented here confirm anecdotal claims by fishers that the trap-net configurations used in NSW selectively harvest penaeids across well-defined and targeted sizes. Compared to most other penaeid-catching gears, trap nets intuitively are less likely to negatively impact estuarine habitats. Future research into ways of mitigating the perceived deleterious effects of commercial penaeid fishing gears in some areas may therefore benefit from considering the utility and benefits of this fishing method.

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REFERENCES

Andrew, N.L., T. Jones, C. Terry and R. Pratt. – 1995. Bycatch from an Australian stow net fishery for school prawns (*Metapenaeus macleayi*). *Fish. Res.*, 22: 119-136.

Bell, J.D., A.S. Steffe and M. Westoby. – 1988. Location of seagrass beds in estuaries: effects on associated fish and decapods. *J. Exp. Mar. Biol. Ecol.*, 111: 133-144.

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.

Broadhurst, M.K. and S.J. Kennelly. – 1996. Rigid and flexible separator-panels in trawls that reduce the by-catch of small fish in the Clarence River prawn-trawl fishery, Australia. *Mar. Freshwater Res.*, 47: 991-998.

Broadhurst, M.K. and S.J. Kennelly. – 1997. 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. *Fish. Bull.*, 95: 653-664.

Broadhurst, M.K., R.B. Millar, S.J. Kennelly, W.G. Macbeth, D.J. Young and C.A. Gray. – 2004. Selectivity of conventional diamond- and novel square-mesh codends in an Australian estuarine penaeid-trawl fishery. *Fish. Res.* 67: 183-194.

Clarke, K.R. and R.M. Warwick. – 2001. *Change in marine communities: an approach to statistical analysis and interpretation.* PRIMER-E Ltd: Plymouth, UK, 144 pp.

Coles, R.G. and J.G. Greenwood. – 1983. Seasonal Movement and size distribution of three important Australian prawn species (Crustacea: Penaeidae) within an estuarine system. *Aust. J. Mar. Freshwater Res.*, 34: 727-743.

Erickson, D.L., J.A. Perez-Comas, E.K. Pikitch and J.R. Wallace. – 1996. Effects of catch size and codend type on the escapement of walleye Pollock (*Theragra chalcogramma*) from pelagic trawls. *Fish. Res.*, 28: 179-196.

Ferro, R.S.T. and L. Xu. – 1996. An investigation of three methods of mesh size measurement. *Fish. Res.*, 25: 171-190.

Gray, C.A. – 2001. Spatial variation in by-catch from a prawn seine-net fishery in a south-east Australian coastal lagoon. *Mar. Freshwater Res.*, 52: 987-993.

Gray, C.A., V.C. McDonall and D.D. Reid. – 1990. By-catch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. *Aust. J. Mar. Freshwater Res.*, 42: 13-26.

Gray, C.A., D.J. McElligott and R.C. Chick. – 1996. Intra- and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand. *Mar. Freshwater Res.*, 47: 723-735.

Kennelly, S.J., G.W. Liggins and M.K. Broadhurst. – 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. *Fish. Res.*, 36: 217-236.

Kotz, S., N.L. Johnson and C.B. Reid. – 1982. *Encyclopaedia of statistical sciences*, Vol. 9. Wiley, New York.

Liggins, G.W. and S.J. Kennelly. – 1996. By-catch from prawn trawling in the Clarence River estuary, New South Wales, Australia. *Fish. Res.*, 25: 347-367.

Liggins, G.W., S.J. Kennelly and M.K. Broadhurst. – 1996. Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. *Mar. Freshwater Res.*, 47: 877-888.

Macbeth, W.G., M.K. Broadhurst and R.B. Millar. – 2004. Improving selectivity in an Australian penaeid stow-net fishery. *Bull Mar. Sci.* (submitted).

Millar, R.B. and S.J. Walsh. – 1992. Analysis of trawl selectivity studies with an application to trouser trawls. *Fish. Res.*, 13: 205-220.

Millar, R.B. and R.J. Fryer. – 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. *Rev. Fish Biol. Fish.*, 9: 89-116.

Pope, J.A., A.R. Margetts, J.M. Hamley and E.F. Akyuz. – 1975. Manual methods for fish stock assessment. Part III. Selectivity of fishing gear. *FAO Fish. Tech. Rep.* No. 41 (Revision 1), 65 pp.

Saila, S.B. – 1983. Importance and assessment of discards in commercial fisheries. *FAO Fish. Circ.* No. 765, 62 pp.

Sobrino, I., T. García and J. Baro. – 2000. Trawl gear selectivity and the effect of mesh size on the deep-water rose shrimp (*Parapenaeus logirostris*, Lucas, 1846) fishery off the gulf of Cádiz (SW Spain). *Fish. Res.*, 44: 235-245.

Suuronen, P. and R.B. Millar. – 1992. Size selectivity of diamond and square mesh codends in pelagic herring trawls: only small herring will notice the difference. *Can. J. Fish. Aquat. Sci.*, 49: 2104-2117.

Vendeville, P. – 1990. Tropical shrimp fisheries: types of fishing gear used and their selectivity. *FAO Fish. Tech. Pap.* No. 261 (Revision 1), 75 pp.

Winer, B.J. – 1971. *Statistical principles in experimental design.* McGraw-Hill: Kogakusha, Tokyo.

Scient. ed.: F. Sardà