

Intra-fleet variability in the size selectivity of a square-mesh trawl codend for school prawns (*Metapenaeus macleayi*)

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Abstract

A covered-codend experiment was done to assess the size selectivity of a codend made from 27-mm mesh hung on the bar (i.e. square mesh) for school prawns (*Metapenaeus macleayi*) across 10 vessels within the New South Wales (NSW) estuarine penaeid-trawl fishery. Prior to starting the experiment, a codend cover (18-mm diamond-shaped mesh) was tested and demonstrated to have no effect on the catching efficiency of a typical estuarine trawl, thereby validating its use for assessing size selectivity. There was substantial variability in the estimated carapace lengths at 50% probability of retention ($L_{50} \pm \text{S.E.}$: between 7.90 ± 0.97 and 13.76 ± 0.23 mm) and selection ranges (SR: between 2.70 ± 0.18 and 6.71 ± 1.72 mm) of the 27-mm square-mesh codend among trawlers and estuaries. Multi-level, generalised linear mixed-effects modelling demonstrated that this variation was explained by: (i) the catch weight of school prawns; (ii) the particular estuary being fished; and (iii) random between-tow and -trawler variability. The results are discussed in terms of the various operational, biological and environmental factors unique to each fishing operation. Despite the variability in the performance of the 27-mm square-mesh codend, an overall improvement in size selectivity compared to conventional diamond-mesh designs, combined with a high survival rate of escapees, justifies its adoption and legislation throughout the NSW estuarine penaeid-trawl fishery as a means for mitigating unwanted fishing mortalities. We also conclude that similar codends may have application in other penaeid-trawl fisheries around the world.

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1. Introduction

In New South Wales (NSW) Australia, up to 204 small vessels are permitted to trawl for penaeids (mainly school prawns, *Metapenaeus macleayi*) in a total of three estuaries: the Clarence (114 vessels), Hawkesbury (61) and Hunter (29) rivers. Like in nearly all penaeid fisheries throughout the world, the conventional trawls used in NSW estuaries have poor species and size selectivity and so large quantities of bycatch, including juvenile school prawns considered too small for sale (typically between approx. 5 and 15 mm in carapace length, CL), are

caught and discarded (e.g. Liggins and Kennelly, 1996). The mortality of discarded juveniles of several economically important species, and the subsequent potential for growth overfishing of the targeted school prawns, has raised serious concerns over the sustainability of estuarine trawling (Kennelly, 1995).

In an effort to improve species selection, over the past 15 years several studies have been done to test a range of bycatch reduction devices (BRDs—for a review see Broadhurst, 2000) in trawls. These BRDs were designed to maintain catches of penaeids, but reduce problematic bycatches. The BRDs that were subsequently mandated reflect fishery-specific characteristics in each estuary and the main bycatch species of concern. Specifically, Clarence and Hunter river trawlers often catch jellyfish, *Catostylus* sp. and teleosts, which are considerably larger in size than the targeted school prawns (Liggins and Kennelly, 1996). BRDs comprising rigid or flexible panels and designed

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to separate organisms based on their sizes (e.g. the ‘Nordmøre-grid’ – Isaksen et al., 1992 or ‘blubber chute’ – Broadhurst and Kennelly, 1996) were recommended for use in these estuaries at certain times and areas. Conversely, a key bycatch of Hawkesbury River trawlers is juvenile mullet, *Argyrosomus japonicus*; commonly similar in size to the targeted school prawns and too small to be excluded by mechanical-separating type BRDs. Also, Hawkesbury River trawlers often catch large quantities of waterweed, *Egeria densa*, which can block rigid BRDs like the Nordmøre-grid. To address these different bycatches, a BRD termed the Hawkesbury River square-mesh panel was developed (Broadhurst and Kennelly, 1995). By exploiting differences in behaviour, this design excludes up to 44% of small mullet while retaining school prawns and, because it has no rigid components, it is not easily fouled by waterweed.

BRDs have addressed many of the problems associated with the unwanted capture of juveniles of economically important fish in NSW penaeid fisheries (Broadhurst, 2000). Nevertheless, because these modifications are designed to maintain catches of school prawns, a remaining issue is the discarding of conspecifics considered too small for sale. During recent studies in the Clarence and Hawkesbury rivers, Broadhurst et al. (2004) and Macbeth et al. (2004) demonstrated that conventional diamond-mesh codends, made from 40-mm mesh, were poorly selective for all sizes of school prawns, but that new codends made from 20-mm (tested in both estuaries) and 25- and 29-mm (tested in the Hawkesbury River only) mesh hung on the bar (i.e. square-shaped mesh) incrementally improved size selectivity, although with some variability. Similar results were observed for a range of square-mesh codends (made from between 20- and 29-mm mesh) tested with penaeid seines in other estuaries (e.g. Macbeth et al., 2005a,b). Based on this work, many estuarine trawlers voluntarily adopted codends made from 27-mm square-shaped mesh.

Currently, there is no information available on the size selectivity of this new codend, or the extent to which its performance might vary among and within the different estuaries; precluding assessment of its utility as a management tool for reducing the unwanted catches of small school prawns. The most appropriate experimental method for acquiring these data is to use a fine-mesh, hooped cover over the codend, designed to retain all escapees (Wileman et al., 1996; Herrmann et al., 2007). This configuration facilitates direct quantification of the population entering and escaping from the codend, and also allows selection curves to be estimated for all replicate hauls. However, an inherent assumption that should be validated is that the cover has no effect on the performance of the trawl (Wileman et al., 1996). Given the above, our aims here were to: (i) test the hypothesis of no cover effect on a typical estuarine penaeid trawl; before (ii) using this assembly to quantify the size selectivity of a 27-mm square-mesh codend among different trawlers in the Clarence, Hawkesbury and Hunter rivers.

2. Methods

This work was done using 10 trawlers working in the Clarence, Hunter and Hawkesbury rivers during summer 2004.

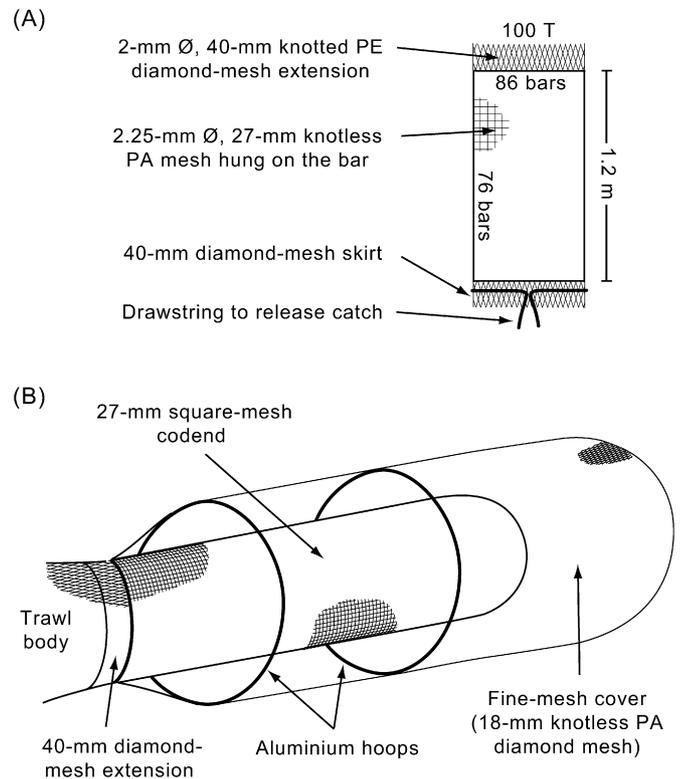


Fig. 1. Schematic diagram of: (A) the 27-mm square-mesh codend; (B) with the covered codend attached. (Ø) diameter; (T) transversals; (B) bars; (m) metres; (PA) polyamide; (PE) polyethylene.

All vessels were rigged with similar trawls (based on the Florida Flyer design; Hughes, 1972), configured according to local regulations that included: (i) twin trawls (each with a headline length of 7 m) in the Clarence River (e.g. Broadhurst et al., 2004) and (ii) single trawls (headline length of 11 m) in the Hunter and Hawkesbury rivers (e.g. Macbeth et al., 2004). Two identical codends and a hooped cover were constructed for use with these trawls. The codends comprised 86 × 76 bars of 27-mm knotless polyamide (PA) mesh (Ø 2.25-mm braided twine) (Fig. 1A). The hooped cover (18-mm knotless PA diamond-shaped mesh) measured 1.6 and 2.4 m in length and circumference, respectively, and was designed so that it enveloped the entire length of the codends (Fig. 1B).

Prior to starting the experiment, a twin-rigged Clarence River trawler was used to test the hypothesis that the cover had no effect on the catching efficiency of a conventional trawl. Zippers (1.5 m in length) were attached to the posterior ends of the trawl bodies, and anterior ends of the cover and the two 27-mm square-mesh codends, to facilitate attachment of the: (i) codends to the trawls; and (ii) cover to the codends. At the start of each tow, the cover was zippered (alternately) to one of the two 27-mm square-mesh codends, which were alternated between the trawl bodies. A total of 10 paired comparisons (tow durations between 20 and 60 min) of the covered and uncovered 27-mm square-mesh codend were completed on a single day. The weights of the school prawn catches were collected for each tow.

The above comparison showed no significant effect of the cover on catches (see Section 4), and so one of the 27-mm square-

mesh codends with the cover attached was subsequently fished on a total of 10 randomly selected trawlers: six vessels in the Clarence; two in the Hunter; and two in the Hawkesbury River. For each trawler, between two and six tows (10–75 min in duration) were completed during a single day. All tows were done according to normal commercial operations (with all trawls having an appropriate BRD) over a combination of sand and mud bottoms in depths ranging from 2 to 15 m. After each tow, data were collected on the total weights of school prawns and the CL (to the nearest 1 mm) of approx. 100 randomly selected individuals. Sizes were recorded irrespective of sex because Broadhurst et al. (2004) demonstrated no significant sexual dimorphism for the size range sampled.

3. Statistical analyses

Catch-weight data collected during the paired comparison of the covered and uncovered 27-mm square-mesh codend were $\ln(x+1)$ transformed (to model treatment effects as approx. multiplicative) and then analysed using two-tailed, paired *t*-tests. During the subsequent, main experiment, a total of 48 successful tows of the 27-mm square-mesh codend and cover was completed (Table 1). The size frequencies of measured school prawns retained in the 27-mm square-mesh codend and cover were entered on a tow-by-tow basis into single stacked data files and then modelled using two contrasting techniques: (i) combined-hauls (Wileman et al., 1996); and (ii) generalised linear mixed-effects (Wolfinger and O'Connell, 1993) analyses.

3.1. Combined-hauls analysis

Combined-hauls analysis of stacked (and scaled, if necessary, to correct for sub-sampling) size–frequency data provides estimates of CL at 50% probability of retention (L_{50}) and selection range (SR), in mm, equivalent to those obtained from a

simple combined-hauls analysis of the pooled size frequencies, but also allows the replication estimate of dispersion (REP), and therefore between-haul (or -tow) variation (BHV) to be estimated (Millar et al., 2004). Logistic and Richards models were fitted to the stacked data for each trawler and each estuary (trawlers combined) using *ccfit* (free R functions available from www.stat.auckland.ac.nz/~millar/selectware/code.html—last accessed 5/03/07). Standard errors (S.E.) associated with all parameter estimates were REP-corrected for BHV (see Millar et al., 2004 for details). Model fits were assessed by comparing REP-corrected deviances and associated degrees of freedom (d.f.) against a χ^2 distribution, and by visual examination of residual plots.

F-tests were used to compare the estimated parameter vectors (L_{50} and SR) between relevant pairs of subgroups of trawls. This method considers both the standard deviation of the estimated L_{50} s and SRs, and their correlation. The denominator d.f. was the combined number of tows in the two compared subgroups, minus two (due to the estimation of REP in each of the subgroups).

3.2. Generalised linear mixed-effects analysis

This technique uses generalised linear mixed-effects modelling (GLMM) to fit a multi-level, nested model to the unscaled data from each tow using pseudo-likelihood (i.e. approximate likelihood); which allows the fitting of random, nested parameters (e.g. tows nested within trawlers nested within estuaries). It also permits explanatory variables (such as 'estuary', 'catch weight of school prawns' and 'tow duration') to be formally modelled as fixed covariates, providing rigorous statistical inference via likelihood-ratio tests. This approach fits the logistic selection curve, $r(l)$, as a generalized linear model using the parameterization:

$$r(l) = \frac{\exp(a + bl)}{1 + \exp(a + bl)} \quad (1)$$

Table 1
Carapace lengths at 50% probability of retention and selection ranges (L_{50} and SR, respectively; in mm) from combined-hauls size-selection model fits to school prawn data for a 27-mm square-mesh codend (with cover attached) tested onboard 10 penaeid trawlers in the: (A) Clarence; (B) Hunter; and (C) Hawkesbury rivers

Estuary (vessels combined)	<i>n</i>	Mean weight of school prawns (kg)	Combined-hauls selectivity-parameter estimates (mm)	
			L_{50}	SR
(A) Clarence River	26		11.82 (0.11)	3.72 (0.14)
Trawler 1	4	14.33 (5.41)	7.90 (0.97)	5.58 (0.79)
Trawler 2	2	7.40 (0.14)	13.76 (0.23)	4.08 (0.37)
Trawler 3	6	7.21 (3.03)	12.05 (0.19)	3.56 (0.22)
Trawler 4	5	6.80 (1.57)	12.23 (0.21)	3.96 (0.27)
Trawler 5	3	3.97 (3.69)	11.21 (0.30)	3.91 (0.44)
Trawler 6	6	3.80 (1.05)	12.08 (0.11)	2.99 (0.16)
(B) Hunter River	10		11.86 (0.17)	2.93 (0.18)
Trawler 7	6	5.27 (1.73)	11.94 (0.16)	2.70 (0.18)
Trawler 8	4	3.70 (2.63)	11.52 (0.59)	3.59 (0.57)
(C) Hawkesbury River*	12		11.64 (0.36)	6.30 (0.96)
Trawler 9*	6	4.57 (1.47)	10.52 (0.59)	6.71 (1.72)
Trawler 10*	6	3.20 (0.70)	12.96 (0.18)	3.30 (0.41)

*Richards model, otherwise logistic. Standard errors are given in parentheses and have been corrected for between-haul variation using the replication estimate of dispersion. *n*, number of replicate tows. Mean weight of school prawns tow⁻¹ (in kg; standard deviation shown in parentheses) is shown for each trawler.

Consequently, the main, fixed-effect parameters estimated by the model were mean a and b (i.e. μ_a and μ_b).

The L_{50} and SR are obtained from a and b as

$$L_{50} = -\frac{a}{b} \quad (2)$$

and

$$SR = \frac{2 \log(3)}{b} \quad (3)$$

From (2), note that variability in a induces the same response in L_{50} but not SR, while variability in b concomitantly affects both parameters in accordance with the principle of geometric similarity (Millar and Fryer, 1999). That is, variability in b induces the same relative variability in both L_{50} and SR.

The model was fitted with both a and b varying (randomly) between tows (nested within trawler) and between trawlers (nested within estuary), and with the explanatory variables mentioned above (i.e. estuary, catch weight of school prawns and tow duration) modelled as fixed covariates. These fits were implemented using SAS procedure GLIMMIX.

4. Results

Paired t -tests failed to detect any significant differences in the mean total weights of school prawns and non-penaeid bycatch between the covered (5.05 ± 1.69 and 0.45 ± 0.12 kg, respectively) and uncovered (5.20 ± 1.74 and 0.59 ± 0.19 kg, respectively) 27-mm square-mesh codends ($P > 0.84$ for both). These results are consistent with the presence of the cover having no effect on the total catching efficiency of the trawl.

4.1. Combined-hauls analysis

Combined-hauls size-selection models were successfully converged for school prawns caught in the 27-mm square-mesh codend on all trawlers (Fig. 2; Table 1). Although some estimated parameters had relatively high S.E.s (e.g. trawlers 1, 8 and 9) and some data had to be modelled using the asymmetrical Richards curve, the final fits satisfied the goodness-of-fit criterion in every case (Table 1). The estimated L_{50} s among all trawlers ranged from 7.90 (± 0.97) to 13.76 (± 0.23) mm, while the estimated SRs were between 2.70 (± 0.18) and 6.71 (± 1.72) mm (Fig. 2; Table 1). F -tests revealed that the three curves for estuaries (all trawlers combined within each) were significantly different from each other ($P < 0.01$), which was probably due to the different SRs and generally low associated S.E.s (Fig. 2; Table 1). Similarly, F -tests comparing curves among the 10 trawlers (all possible combinations) detected significant differences for all comparisons ($P < 0.01$ in most cases), except between trawlers 6 (Clarence River) and 7 (Hunter River) and four comparisons involving trawler 8 (Hunter River) (Fig. 2; Table 1). This latter result was mainly due to the relatively large S.E.s associated with parameter estimates for this vessel (Table 1).

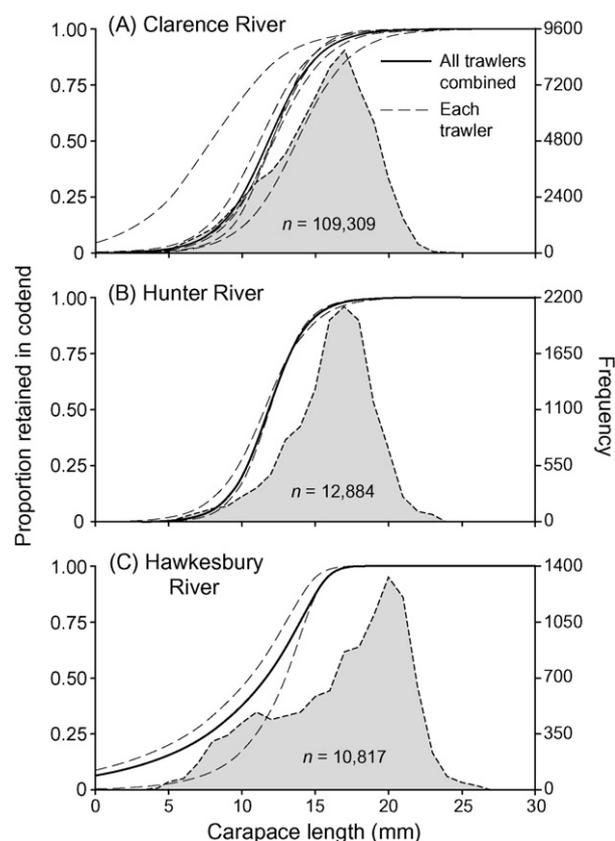


Fig. 2. Size-selection curves for school prawns caught in the 27-mm square-mesh codend for each trawler, and all trawlers combined, for the Clarence, Hunter and Hawkesbury rivers. Size-frequency distributions of all school prawns caught for each estuary (i.e. codend + cover = n) are also shown.

4.2. Generalised linear mixed-effects analysis

The preference for Richards curve fits in the cases of the two Hawkesbury River trawlers in combined-hauls analyses is not necessarily inconsistent with the GLMM assumption that the curves for individual tows are logistic, because the combination of differing (symmetrical) logistic curves can result in an asymmetrical curve. To explicitly test this assumption, logistic and Richards curves were fitted to the 12 individual tows done in the Hawkesbury River. Two of the twelve were better fitted by the Richards curve at the 5% level. However, applying the Bonferroni correction for multiple comparisons, the null hypothesis of logistic selection curves fitted throughout the Hawkesbury River tows was accepted ($P \approx 0.20$).

The GLMM fit to all of the data detected highly significant between-tow variability ($P \approx 0.002$) and also some evidence of between-trawler variability in parameter a ($P \approx 0.07$) (Table 2; note that the hypothesis test for the variance components is one-sided because variances cannot be negative). While not quite significant at the 5% level, we nonetheless included the between-trawler variability in the chosen model because we feel it does belong—its lack of significance being due to the limitations of the design. There was no evidence of random variability in b , either between tows or trawlers ($P \approx 0.50$).

Table 2

Generalised linear mixed-effects model fit to school prawn data for a covered 27-mm square-mesh codend tested onboard multiple prawn trawlers in the Clarence, Hunter and Hawkesbury rivers

Parameter	Estimate
μ_a	-10.05 (0.57)
$\mu_{b(\text{Clar})}$	0.76 (0.04)
$C_{\text{weight}(a)}$	0.39 (0.07)
$C_{\text{weight}(b)}$	-0.023 (0.004)
$\text{Hun}_{(b)}$	0.077 (0.033)
$\text{Haw}_{(b)}$	0.068 (0.034)
$\sigma^2_{a(\text{tow})}$	0.25 (0.09)
$\sigma^2_{a(\text{trawler})}$	0.39 (0.27)

Fixed-effects parameter estimates presented are: means for a and b (μ_a and $\mu_{b(\text{Clar})}$, respectively); coefficient for the effect of codend penaeid weight on a and b ($C_{\text{weight}(a)}$ and $C_{\text{weight}(b)}$, respectively); estuary effects on b (i.e. with $\mu_{\text{SR}(b)}$ as the baseline, Clarence River value; $\text{Hun}_{(b)}$: Hunter River; $\text{Haw}_{(b)}$: Hawkesbury River). The random-effects parameter estimates are between-tow (nested within trawler) and between-trawler variances for a ($\sigma^2_{a(\text{tow})}$ and $\sigma^2_{a(\text{trawler})}$, respectively). Standard errors are given in parentheses.

There was no significant effect of tow duration on a or b ($P > 0.05$), while the catch weight of school prawns was significant for both ($P < 0.05$; Table 2). There was an estuary effect, with b significantly greater in the Hunter and Hawkesbury rivers than in the Clarence River ($P < 0.05$; Table 2). It is notable that these fixed-effects results were generally the same, irrespective of the inclusion of the between-trawler variability in the model.

5. Discussion

Most of the selection curves derived for the 27-mm square-mesh codend had L_{50} s that were considerably larger than those estimated for conventional 40-mm diamond- and 20- and 25-mm square-mesh codends tested during previous work in the same estuaries (Broadhurst et al., 2004; Macbeth et al., 2004), translating to a greater proportion of unwanted juveniles (i.e. < 15 mm in CL) escaping during fishing. Further, compared to a codend made from 29-mm mesh tested in the Hawkesbury River by Macbeth et al. (2004), fewer marketable prawns escaped from the 27-mm square-mesh codend in any of the three estuaries; indicating that, based on current commercial requirements, this mesh size may be close to appropriate for optimising size selectivity. However, as with many other studies testing modified gears across different spatial scales, there was considerable between-tow, -trawler and -estuary variability in its performance.

The extent of this variability was clearly illustrated by both analytical methods, and especially the GLMM. More specifically, the between-tow and -trawler variances in parameter a estimated by the GLMM were 0.25 and 0.39, respectively, corresponding to standard deviations of 0.50 and 0.62 (Table 2). While some caution is required when considering these estimates (primarily because of the relatively large estimation error associated with the between-trawler variance, Table 2), they nevertheless suggest that the variability between trawlers was similar or slightly greater than that observed

between tows (within trawlers). This random variability corresponds to variation in the individual selection curves, according to the principle of geometric similarity (Millar and Fryer, 1999).

The GLMM also identified an effect of estuaries on parameter b , which was smaller in the Clarence than in the Hawkesbury and Hunter rivers, corresponding to their relatively smaller L_{50} s and narrower SRs. In contrast, the combined-hauls model fits indicated that the Hawkesbury River had the widest SR of the three estuaries (i.e. 6.30 mm versus 3.72 and 2.94 mm, Table 1). Inspection of the parameter vectors estimated for individual tows in the Hawkesbury River revealed that there were many narrow SRs, while the L_{50} s showed some variability (see below). Large variability in the L_{50} s of individual tows will manifest as a wide overall SR, and so this type of analysis can, under such circumstances, provide misleading information about the characteristics of individual tows. Such between-tow variability also serves to highlight the fundamental differences between the two analytical methods.

Inspection of the individual data for each tow revealed that very few large school prawns escaped from the 27-mm square-mesh codend in the Hunter and Hawkesbury rivers. Indeed, in the Clarence River, 5% of commercial-sized school prawns (i.e. ≥ 15 mm in CL) were caught in the cover, compared to 2.8 and 1.1% in the Hunter and Hawkesbury rivers, respectively. The retention of large school prawns is consistent with sharper selectivity in these two rivers, and would explain the smaller L_{50} s and narrower SRs inferred by the GLMM.

The catch weight of school prawns was positively and negatively correlated with a and b , respectively. This corresponded to a clear increase in SR with catch weight, but a less obvious effect on L_{50} . By way of an example, for a tow catching 5 kg of school prawn in the Clarence River, the expected values of a and b are (from Table 2) $a_5 = -10.05 + 5 \times 0.39 = -8.10$ and $b_5 = 0.76 - 5 \times 0.023 = 0.65$, corresponding to an L_{50} and SR of 12.46 and 3.38 mm, respectively. With an increase in catch weight to 6 kg, these become $a_6 = -7.71$ and $b_6 = 0.62$, corresponding to an L_{50} and SR of 12.44 and 3.54 mm, respectively.

Most of the observed variability in the size selectivity of the 27-mm square-mesh codend discussed above probably reflects the various operational, biological and environmental factors unique to the fishing operations in each estuary. For example, in the Clarence River, all vessels except trawler 1 had combined-hauls L_{50} s between 11.21 and 13.76 mm. The low L_{50} for trawler 1 (7.90 mm) was caused by relatively greater catches of school prawns (mean of 14.33 kg tow⁻¹) compared to all other vessels, irrespective of the river (vessel means ranging between 3.20 and 7.40 kg tow⁻¹). Several studies have investigated the effects of catch volume (or catch weight) on size selection in codends – with mixed results (e.g. Robertson and Stewart, 1988; Suuronen et al., 1991; Campos et al., 2002; Herrmann, 2005). Significant relationships between catch weight and size selection in diamond-mesh codends usually have been attributed to variability in drag and, subsequently, the lateral mesh openings (e.g. O'Neill and Kynoch, 1996). However, owing to their mesh orientation, any major differences in geometry are less likely for square-mesh codends (Robertson and Stewart, 1988). There-

fore, at consistent densities, the escape of school prawns of a given size after entering the 27-mm square-mesh codend would have been less influenced by the ultimate catch quantity (providing this did not exceed the total volume of the codend). But, at greater densities (which occur sporadically), the probability of many school prawns (irrespective of size) encountering openings would be lower, owing to the obstruction of open meshes by their conspecifics (Casey et al., 1992). Such effects could at least partially account for the smaller observed L_{50} s for the tows by trawler 1 and the significant effect of catch weight of school prawns detected by the GLMM.

While no data were collected on the quantities and types of bycatches, it is possible that these might have similarly contributed towards some of the observed variation in size selectivity, and especially the smaller combined-hauls L_{50} for trawler 9 in the Hawkesbury River. Although the catch weights of school prawns were not particularly variable or extreme from this trawler (Table 1), three of the six tows had small L_{50} s (i.e. 6.85–9.87 mm) compared with the remaining tows (i.e. 11.70–12.81 mm), which may be attributable to the masking of meshes by waterweed, teleost bycatch and/or debris.

Other inter-related factors known to influence the size selectivity of trawls include their design (Reeves et al., 1992), as well as towing depth (Campos et al., 2002), speed (Macbeth et al., 2005b) and duration (Sobrinho et al., 2000). During the present study, tow duration did not have a detectable influence on size selectivity, although some of the other factors would have varied among trawlers and might have contributed to the observed differences in parameter vectors. Another important environmental factor may have been the effects of temperature. The Hawkesbury and Hunter rivers are located within a warm-temperate bioregion (33°34' and 32°53'S, respectively), while the more northern Clarence River (29°26'S) is classified as subtropical (IMCRA, 1998). Therefore, despite the possibility of some intra-river thermal variability, the temperatures in the Hunter and Hawkesbury rivers generally would have been relatively lower than in the Clarence River. Because the activity of crustaceans often decreases at low temperatures (e.g. Dall, 1958; Ruello, 1973; Penn, 1976), this might have influenced the ability of school prawns to respond to stimuli in the Hunter and Hawkesbury river trawls, and their subsequent escape through open, square-shaped meshes; translating to the observed smaller L_{50} s. More research is required to validate the potential for these and the other effects listed above.

Despite the observed variability in size selection by the 27-mm square-mesh codend, the general overall improvement compared to conventional 40-mm diamond-mesh designs, combined with evidence of a high survival of escapees (Broadhurst et al., 2002), justifies the use of this design for reducing unwanted fishing mortality in NSW estuarine trawls. Used in conjunction with appropriate BRDs, the 27-mm square-mesh codend would be a major step towards the sustainability of estuarine trawling in NSW. Further, because other local and international penaeid fisheries typically are also characterized by poor size and species selection (Andrew and Pepperell, 1992; Kelleher, 2005), future research may warrant some assessment of the utility of similar sorts of designs.

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