Fishery-specific differences in the size selectivity and catch of diamond- and square-mesh codends in two Australian penaeid seines

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Abstract

Two experiments were done to compare the selectivities and catch compositions of conventional 30-mm diamond-mesh codends and a new square-mesh design made from 20-mm mesh hung on the bar for river and lagoon penaeid seines in southeastern Australia. Compared to conventional codends, the square-mesh design significantly improved the selectivities of the river seine for school prawns, Metapenaeus macleayi (Haswell), and the lagoon seine for greasyback prawns, Metapenaeus bennettiae (Racek & Dall), by increasing their carapace length at 50% probability of retention (L⁵₀) and by decreasing the between-haul variability in selectivity. The presence of weed reduced the L⁵₀ for greasyback prawns caught in the conventional diamond-mesh codend during the lagoon-seine experiment. Differences among codend performances between the seines are discussed in terms of their methods of operation and composition of catches. These differences highlight the need to develop and manage modifications to improve the selectivity of fishing gears on a fishery-specific basis.
Introduction

The capture and mortality of non-target organisms (termed ‘bycatch’ – sensu Saita 1983) during commercial fishing has raised considerable concerns over the last two decades and resulted in extensive efforts to improve the selectivity of problematic gears for the targeted organisms (Kennelly & Broadhurst 2002). Owing to their small diamond-shaped meshes and active method of operation throughout areas typically characterized by large abundances of small organisms, penaeid (shrimp or prawn) trawls have received the majority of attention (for reviews see Andrew & Pepperell 1992; Alverson, Freeberg, Murawski & Pope 1994; Broadhurst 2000). Numerous studies have been done to test the utility of alterations to the sizes and/or shapes of mesh used in trawls as well as physical modifications specifically designed to exclude unwanted catches (termed ‘bycatch reduction devices’ – BRDs – see Broadhurst 2000 for a review). Considerably less work has been done with other types of towed penaeid-catching gears such as seines, despite their wide-scale use in many of the same areas as trawls throughout the world’s temperate and tropical penaeid fisheries (e.g. Vendeville 1990; Alverson et al. 1994).

In the Australian state of New South Wales (NSW), seining for penaeids involves the use of similar gears (all with a minimum legal mesh size of 30 mm), which are operated slightly differently so as to target mostly (i) school prawns, *Metapenaeus macleayi* (Haswell) in rivers, or (ii) greasyback prawns, *Metapenaeus bennettae* (Racek & Dall), and eastern king prawns, *Penaeus plebius* (Hess), in coastal lagoons. These different estuarine systems and their associated ecologies, combined with the large geographic range of the fishery means that there is considerable spatial and temporal variation in the compositions and abundances of catches (Gray 2001; Gray, Kennelly & Hodgson 2003). One common problem, however, is the bycatch of many organisms smaller than the targeted penaeids, and especially conspecifics considered too small for sale (i.e. < 15-mm carapace length – CL; Macbeth, Pollard, Steffe, Morris & Miller 2002). Despite evidence to suggest that the 30-mm mesh used throughout penaeid seines in NSW is inappropriate (Broadhurst, Millar, Kennelly, Macbeth, Young & Gray 2004), no formal studies have been done to determine selectivity or the extent to which this might be improved.

One of the simplest strategies for improving the selectivity of towed gears is to orientate the codend meshes so that they are square shaped (e.g. Thorsteinsson 1992; Tokaç, Lök, Tosunoglu, Metin & Ferro 1998; Broadhurst, Larsen, Kennelly & McShane 1999; Broadhurst et al. 2004). Unlike diamond-shaped meshes in codends, which tend to have variable lateral openings typically < 25% of the stretched inside-mesh length (SIML – Ferro & Xu 1996), square-shaped meshes maintain their maximum openings (i.e. at 50% of SIML) during fishing (MacLennan 1992). This means that relatively small square mesh (e.g. SIML up to half that of the existing conventional diamond mesh) can significantly improve selectivity. The utility of square-mesh codends has already been demonstrated for other penaeid-catching gears, although with some variability. For example, Broadhurst et al. (2004) and Macbeth, Broadhurst & Millar (2005) showed that compared to conventional diamond-mesh trawl and stow-net codends (SIMLs of 40 and 30 mm, respectively), a codend made from 20-mm knotless mesh hung on the bar selected school prawns at greater CLs at 50% probability of retention (L$_{50}$ – e.g. increase from 8.6 to10.3 mm and from 8.5 to 9.7 mm, respectively), with similar or smaller selection ranges (SR – e.g. reductions from 3.9 to 3.5 mm and from 3.6 to 2.6 mm, respectively).

Our aim in the present study was to quantify and compare the selectivities and catch components of conventional diamond-mesh codends and a new square-mesh design in two distinct estuarine penaeid-seine fisheries: a river and lagoon fishery targeting school and greasyback prawns, respectively, via selectivity experiments involving replicate hauls performed under commercial conditions. Considerable, and often extreme, between-haul variation in selectivity can occur under replicate deployments of a fishing gear (Fryer 1991), with spurious inference resulting if this variability is not considered in the analysis of selectivity data. Some of this variability may be due to measurable covariates, such as catch size (e.g. Campos, Fonseca & Erzini 2002; 2003), and amount of debris accumulated in the codend (Polet 2000). Therefore, two contrasting methods of estimating selectivity were used, with one also able to quantify the influence of explanatory variables.
variables (such as catch size and presence/absence of debris) that may account for between-haul variability.

Materials and methods
Two separate experiments were done in the Richmond River (28° 53’ S, 153° 35’ E) and Smiths Lake (32° 23’ S, 152° 29’ E), NSW using commercial river and lagoon seines, respectively. The seines had similar bodies and were both made entirely from 30-mm knotted polyethylene (PE) netting (approx. 1.2 mm diameter – ø, 3-strand twisted twine). The river seine had a wing depth of 130 normals (N), a buoyed 40-m headline and a 35-m footrope attached to a weighted leadline by 100-mm chain drops. Hauling ropes (130-m; 8-mm ø, 3-strand twisted PE) were attached to a bridle at each wing end. The lagoon seine had a wing depth of 100 N, a headline and footrope both measuring 140 m, separated at each wing end by timber spreader bars attached to 100-m hauling ropes (10-mm ø, 3-strand twisted PE). Both seines had zippers (Buraschi S146R, 1.1 m in length) attached at the posterior end of their bodies to facilitate changing the codends. The lengths of these zippers were based on the expected fishing circumference of the majority of conventional codends, which was calculated as the estimated fractional mesh opening (0.35) x the circumference in meshes x the mesh size (Broadhurst et al. 1999).

Five codends were constructed: three treatments and two controls. All codends were made from dark netting and had a total length and fishing circumference of 3 and 1.1 m, respectively. Zippers (see above) were attached to the anterior sections of these codends and a 1.1 m length of 5-mm chain sewn to the end of the posterior sections, as per normal commercial operations. Commercial fishers suggested that the drag created by this chain helps to prevent the codends from fouling during deployment. The first and second treatment codends, termed the 100- and 150-diamond codends, represented normal commercial diamond-mesh designs and were made entirely of the same 30-mm knotted PE netting (1.4-mm ø, 3-strand twisted twine), but had circumferences of 100 and 150 meshes, respectively (Fig. 1A & B). The third treatment codend was made entirely of 20-mm knotless polyamide-PA netting (2.5-mm ø braided twine) hung on the bar (i.e. square-shaped mesh with a bar length of 10 mm) and was termed the 20-mm square codend (Fig. 1C). The two controls were termed the diamond- and square-control codends and were made entirely of 16- and 12-mm knotless PA netting (1.5-mm ø braided twine) that was hung on the diamond and bar, respectively (Fig. 1D & E).

All diamond-mesh codends were made from a continuous section of netting and rigged with traditional draw strings to facilitate the removal of catch (Fig. 1A, B & D). In contrast, the two square-mesh codends were constructed in two sections; comprising upper and lower panels sewn together with opposite knot directions (see Broadhurst et al. 1999 for details). Appropriate-sized circular panels of square-shaped mesh were attached to their posterior ends and, instead of a conventional drawstring, zippers (Buraschi S146R, 0.3 m in length) were sewn into each of the lateral seams to allow removal of the catch. Broadhurst et al. (2004) hypothesised that these circular panels of mesh would improve the encounter probability of organisms and therefore the selectivity of the codends.

Experiment 1 - River seining
Experiment 1 was done over two periods (each comprising five days) during appropriate tides in September and October 2002. Each replicate haul involved the fisher securing a buoyline and buoy (to a tree or submersed anchor) upcurrent from the area to be fished. One of the 100-m hauling ropes was attached to the buoy and the entire hauling rope-seine configuration deployed from a dory in an arc around the fishing area. The fisher returned to the buoy, securing the dory to it and then retrieved the two hauling ropes (guided by gantries) at a velocity of approx. 0.5 ms⁻¹ using a small, motorized winch. The seine was then hand-hauled into the dory and the codend emptied. The entire process took approx. 15 minutes.

All five of the codends were alternately zippered to the body of the river seine and fished according to the method described above. To minimise any potential confounding effects, the testing order of
codends was randomised in three blocks (each block comprising one replicate haul of the five codends) on each day. Over 10 days, we completed a total of 30 replicate hauls for each codend (i.e. 2 periods x 5 days/period x 3 replicates/day).

Experiment 2 – lagoon seining
Experiment 2 was done at night between the last quarter and new moon phases in November and December 2002. Each replicate haul involved the fisher securing a buoy to the end of one hauling rope and deploying it, along with the hauling rope-seine configuration, over the stern of a dory and around the area to be fished. The dory then returned to the buoy and towed the entire seine configuration for 10 minutes at a speed of 0.5 m s\(^{-1}\) until the two 70-m wings of the seine came together. A second buoy was secured to the end of the second hauling rope and it was towed and repositioned so that the wings of the seine were stretched apart. The fisher then retrieved the first buoy, dragging it in an arc back to the second buoy. The entire seine configuration was then towed for another 10 minutes as per above. At the end of this second tow, the codend was hauled onboard and emptied.

The above procedure took approx. three times longer than that required to perform a single haul of the river seine. Consequently, there was insufficient time within nights to adequately replicate all five of the codends examined during experiment 1. Based on the results of this earlier work (see Results section), we selected only the 100-diamond, 20-mm square and square-control codends for testing during experiment 2. These three codends were alternately zippered to the body of the seine and used in two randomized blocks during each of nine nights, providing a total of 18 replicates for each codend.

Data collected
After each replicate haul, the contents of the codend were separated onboard the dories. The following categories of data (where applicable) were collected: the weight and number of each species of prawn or fish (where necessary, the number of the target species was estimated by scaling up a weighed sample of 250 individuals). In addition, the carapace lengths (CL) of all prawns in this sample (or entire catch if less than 250) and all other penaeids were measured, along with the total lengths of all fish, to the nearest mm. The presence or absence of weed and jellyfish was also noted, but not recorded as bycatch.

Analyses of size selectivity
Two methods for accounting for between-haul variability in size selectivity were employed. The first performs a combined-hauls analysis, but does so by using a simultaneous fit to the (scaled-up, where appropriate) data from each individual haul. This enables overdispersion in the data to be quantified using a replication estimate of dispersion (REP). This overdispersion includes the effects of between-haul variability and of the scaling-up of the length frequency data for catches that were subsampled (Millar, Broadhurst & Macbeth 2004). These combined-hauls analyses give selectivity parameter estimates and standard errors that are appropriate to the overall selectivity of a hypothetical fishery that consists of further replicate deployments of the gears, and is implicitly averaging out the between-haul variation. Here, the overall-selectivity curves of different mesh configurations were compared using the bivariate form of Wald’s F-test (Kotz, Johnson & Reid 1982).

The second approach uses the hierarchical mixed-effects model formulated by Fryer (1991), but employs a new way of fitting this model (Millar et al. 2004). The approach of Fryer (1991) fits a linear mixed-effects model to selectivity parameter estimates from individual fits to the data and is therefore crucially dependent on good distributional properties of the individual estimates. In contrast, Millar et al. (2004) uses recently developed generalized linear mixed model software to obtain an exact maximum likelihood fit to the (unscaled) data from each haul. This mixed-effects model approach is more formal and permits explanatory variables (catch size and presence/absence of debris) to be formally included and provides rigorous statistical inference via likelihood ratio tests.
Logistic and Richard’s selection curves were fitted via both methods using an estimated-split (p) SELECT model (Millar and Walsh 1992; Millar et al. 2004) to allow for unequal density of individuals entering the experimental and control gears. The REP estimate of Millar et al. (2004) estimates a split parameter (p) for each individual haul. The mixed-effects model allows p to vary randomly between hauls by assuming that q=\logit(p) is normally distributed with mean \mu_q and variance \sigma_q^2.

Analyses of catch components
The weights and/or numbers of total penaeids, each penaeid species, total bycatch, and the numbers of bycatch species were analysed using appropriate analyses of variance (ANOVA). Data were ln(x+1) transformed (to model treatment effects as approx. multiplicative) and tested for heterocedasticity using Cochran’s test. Data sets showing significant heterocedasticity were analysed at a significance level of P = 0.01 in the ANOVA to counteract the increased probability of type I error (Underwood 1981). In all analyses, where interaction terms were non-significant at P > 0.25, pooling with the residual was done to increase the power of the test for the main effect of codends. Significant F ratios were investigated using the relevant a priori planned comparisons.

Results
Experiment 1: river seining
School prawns were the only penaeids captured during experiment 1 and comprised approx. 97% (by number) of the total catch, with an additional 20 bycatch species also recorded. The catch weight of school prawns varied substantially during the experiment, and within each replicate sampling block. For example, over all hauls, the smallest school prawn catch was just 0.2 kg and the largest 34.8 kg (both being 150-diamond codend catches), and within block 20 the catch varied from 0.2 kg (150-diamond codend) to 34.2 kg (20-mm square codend).

Analyses of size selectivity
For the combined-hauls analyses (via a simultaneous fit to individual-haul data), parametric selection models were successfully fitted to school prawn data for all of the treatment codends using each control codend. Fits were also obtained for narrow-banded sole, Aseraggodes macleayanus (Ramsay), a dorsally compressed fish, for the 100-diamond and 20-mm square codends using the diamond-control codend, and for the 150-diamond codend using the square-control codend. In all cases, there was no significant reduction in deviance associated with using a Richards curve and because residuals from the simpler logistic fit showed no serious problems, it was used throughout (Fig. 2A; Table 1).

For each of the three treatment codends, there was no significant difference between the school prawn selection curves derived using the diamond- and square-control codends (Wald’s tests, P > 0.05; Table 1). However, while the selectivity of the square-control codend could be modelled with the diamond-control as its control (L_{50} and SR of 4.44 and 2.52 mm, respectively - Table 1), the reciprocal model failed to converge. This result provides some evidence to indicate that of the two control codends, the diamond-control was the less selective for school prawns. Therefore, to maximize accuracy among comparisons of treatments for this species, only the parameter vectors derived with this control were used in subsequent tests. In contrast, the square control was used to describe the selectivity of narrow-banded sole from the 150-diamond codend because the selection curve failed to converge when using the diamond control (Fig. 2B; Table 1).

Bivariate Wald’s tests failed to detect significant differences in parameters L_{50} and SR for school prawns between the two diamond-mesh treatment codends (P > 0.05), but did detect a significant difference between the 20-mm square codend and each of the diamond-mesh codends (P < 0.01). This significant difference is primarily due to the considerably higher estimated L_{50} of the square-mesh codend (Fig. 2A; Table 1). The same pattern of statistical significance was observed for narrow-banded sole, except that the significant difference was primarily due to the considerably lower estimated L_{50} of the square-mesh codend (Fig. 2B; Table 1).
Mixed-effects models with the relative efficiency parameter and L_{50} as random effects were fitted to the school prawn data (Table 2A). Catch weight was also used as a covariate to test whether it explained variability in L_{50}. It was also attempted to model SR as random, but these fits would not converge. Catch weight was significant (P = 0.02) for only the 100-diamond codend, and hence is not significant if the p-value is multiplied by three to correct for multiple comparisons (Table 2A). It is notable that the mixed-effects model estimated extremely large variances in L_{50}.

Analyses of catch components

ANOVA detected a significant F ratio for the main effect of codends only for numbers of total bycatch (Fig. 3C; Table 3). A priori planned comparisons (at P = 0.05) showed that for this variable and numbers of bycatch species, the means caught in the control codends were significantly greater than those for the treatment codends (Fig. 3C & D; Table 3). There were no significant interactions between codends and days or periods, although significant F ratios were detected for the main effects of these temporal factors (Table 3). Specifically, the weights of school prawns and bycatch were significantly different among periods, while weight of school prawns, and number of total bycatch showed an effect due to days (Table 3).

Experiment 2: lagoon seining

Thirty-four species were recorded during experiment 2, including greasyback and eastern king prawns, which comprised approx. 91 and 1.1% (by number) of the total catch, respectively. Weed (of a matted filamentous type) and jellyfish (Class Scyphozoa) were commonly present in the catch. The variability in catch weight of prawns was not as great as observed in experiment 1. Over all hauls, greasyback prawn catch varied from 1.0 kg (100-diamond codend) to 14.9 kg (control codend).

Analyses of size selectivity

Of the two control codends, only the square was used during experiment 2. This was because (i) the sizes of penaeids were known to be larger in Smiths Lake than in the Richmond River and (ii) we hypothesised that this control would have a greater water flow (owing to more open meshes) that would facilitate the release of weed and therefore reduce the likelihood of excessive masking of meshes and drag on the seine. Using this control, size-selection models were successfully fitted for greasyback prawns caught in the 100-diamond and 20-mm square codends. As with experiment 1, there was no significant reduction in deviance associated with using a Richard’s curve so only the logistic models were presented (Fig. 2C; Table 4). A bivariate Wald’s test detected a significant difference in selectivity of the two codends (P < 0.01). The estimated L_{50} and SR parameters of the 100-diamond codend were both higher than those of the square codend, but had large standard errors and were therefore estimated with high imprecision (Table 4).

The mixed-models used catch weight and the presence/absence of weed and jellyfish as potential explanatory variables to explain variability in L_{50}. None of these covariates was statistically significant for the 20-mm square codend, but presence of weed was significant for the 100-diamond codend (P < 0.01), effectively reducing L_{50} (Table 2B). The estimates of between-haul variability in L_{50} were noticeably smaller that those obtained from the mixed-model fits to the school prawn data from experiment 1 (Table 2). In particular, the variance of L_{50} for the square-mesh codend was just 2.4 mm, corresponding to a between-haul standard deviation of about 1.5 mm (Table 2B).
Analyses of catch components

ANOVA detected significant differences among codends for the numbers of greasyback prawns, total bycatch and bycatch species (Fig. 4B, E & F; Table 5). A priori planned comparisons showed that for greasyback prawns, the difference was due to significantly greater mean catches in the square-control codend than the combined means for the treatment codends (Fig. 4B; Table 5). Similarly, significant differences were detected between treatments and the control for the two bycatch variables listed above, however significant F ratios were also detected between the two treatment codends, with the 100-diamond retaining significantly greater numbers than the 20-mm square codend (Fig. 4E & F; Table 5). There were no significant interaction terms in any of the analyses done for variables in experiment 2, although significant differences were detected among nights for all variables analysed (Table 5).

Discussion

For the river seine, the 20-mm square codend had a larger $L_{50}$ than the diamond-mesh codends and a similar SR. These results are consistent with those recorded during some recent studies comparing diamond- and square-mesh codends in trawl and stow nets used elsewhere in NSW (Broadhurst et al. 2004; Macbeth et al. 2005). There was, however, substantial between-haul variability in catch and selectivity, as evidenced by the extremely high estimates of $\sigma^2 L_{50}$. The between-haul variability is exacerbated by the lack of school prawns below about 8-mm CL. This means that the data are concentrated over the range of CLs corresponding to only the upper limb of the selection curve, rather than over the entire effective selection range of the curve, and this is particularly true of the diamond-mesh codends. Thus, if only a small portion of the selection curve is being fitted to data, then two quite different selection curves can give very similar fits. In an extreme case, if only large prawns are caught then there will be no information on selectivity and an estimated selection curve with infeasible parameters (e.g. a negative $L_{50}$) could result. The extreme between-haul variability shown by the mixed-effects model fits is a consequence of this, and hence the combined-hauls results from the river-seine experiment are more useful.

In the lagoon-seine experiment, the combined-haul selectivity estimates for the 100-diamond codend had large standard errors and hence can not be considered reliable. An inspection of the raw catch data indicated that this codend retained very small prawns and released some large prawns. The mixed-effects model parameters for the 100-diamond codend are more reasonable, notwithstanding the implausible reduction in $L_{50}$ of 26.4 mm in the presence of weed. An inspection of the weeded hauls of this codend indicated that it had negligible selectivity. This resulted in model non-identifiability because any large negative value of the weed effect corresponds to a non-selective curve. This is reflected in the misleadingly large estimated effect and SE. The weed effect explains the extreme SR fitted in the combined-hauls analysis because in weeded hauls this codend did retain very small prawns, yet in weed-free hauls it had a mean estimated $L_{50}$ of 9.4 m and released some reasonable-sized prawns. The selectivity estimates from the combined-hauls and mixed-effects analyses of the square-mesh codend lagoon data were similar. Moreover, the square-mesh codend did not exhibit a weed effect, and between-haul variability in relative fishing efficiency ($p$) and $L_{50}$ were both relatively minor.

Given the above, the river- and lagoon-seine experiments both estimated the $L_{50}$ of the square-mesh codend to be approx. 3 mm greater than that of the diamond-mesh codends, but with reasonably similar SRs. Both experiments also showed that the square-mesh codend experienced less between-haul variability than the diamond-mesh codends. This was particularly evident in the lagoon experiment where the 100-diamond codend was rendered effectively non-selective by the presence of weed. These variations in selectivity parameters can be attributed to a combination of factors that include the different methods of operating the seines, the specific selection characteristics of the different mesh configurations, as well as the ecological features of the estuaries being fished.

A common operational characteristic of many seines, trawls and stow nets is the constant flow of water and hence tension on the netting during fishing, which maintains narrow lateral mesh openings throughout the posterior section of the gear. Further, small organisms are quickly washed
into the codend, where much of the selection probably occurs. In contrast, the lagoon seine was
towed for short periods and then the body and codend remained stationary (i.e. with no water flow)
for up to five minutes while the wings were repositioned. The lack of tension on the netting
probably resulted in an increase in lateral diamond mesh openings throughout the seine, allowing
most sizes of the greasyback prawns to easily move about and escape. This would explain the
slightly larger SRs observed for all treatment codends used with the lagoon seine compared with
those used with the river seine.

As noted above, the selectivity of greasyback prawns was decreased in the 100-diamond codend in
the lagoon-seine experiment when weed was present in the codend (Table 5). This sort of
correlation has been reported elsewhere (e.g. Polet 2000) and was probably due to a combination of
the weed masking the meshes throughout the posterior of the codend and the weight of the weed
reducing the lateral mesh openings along its anterior walls. These effects were absent for the
square-mesh design as the meshes remained open, allowing the small prawns to come in contact
with open meshes along the length of the codend during towing.

While the presence of jellyfish did not seem to reduce the selectivity of the treatment codends used
during the lagoon-seine experiment, there was an impact on the efficiency of the fishing operation
owing to the extra time required to sort the catch. Further, large quantities of jellyfish appeared to
negatively affect the condition of the prawns and bycatch (W.G. Macbeth, personal observation),
presumably because of the stinging nematocysts. This not only reduces the quality of the
marketable prawns, but would probably increase the mortality of small conspecifics and other
bycatch that pass through the meshes or are discarded onboard the vessel. Ideally, the bycatch of
large organisms like jellyfish should, if required, be addressed before or at least in conjunction with
further efforts to improve the size selectivity of penaeid seines. Specifically, the utility of various
types of BRD designed to exclude all organisms larger than commercially retained sizes of prawns
may warrant investigation (for a review, see Broadhurst 2000).

The quantity and composition of bycatch (excluding jellyfish and weed) varied considerably
between the two methods and this is reflected in the performance of the different codends tested.
Overall, relatively small quantities of bycatch were recorded during the river-seine experiment: an
observation consistent with previous observer-type studies done in this fishery (Gray et al. 2003).
With the exception of narrow-banded sole (which could actively squeeze through the 30-mm
diamond mesh, but not the 20-mm square mesh), most of the bycatch recorded during experiment 1
consisted of organisms too large to escape through the meshes of any of the codends trialled. In
contrast, much of the bycatch encountered during the lagoon-seine experiment consisted of
relatively small finfish, many of which were physically able to pass through the open meshes in the
20-mm square codend.

Our results have demonstrated that despite physical similarities among the two designs of penaeid
seines and their codends examined, inherent variability in fishing operations and local ecologies
means that these gears have considerably different selectivities. It seems inappropriate, therefore, to
impose the same gear-based regulations across these fisheries. For example, the utility of larger
square mesh may warrant immediate examination for the Richmond River prawn-seine fishery but
for the Smiths Lake fishery it is clear that other gear modifications (i.e. mechanical-type BRDs)
should also be considered. In future, strategies to improve size-and species-selectivity for NSW
penaeid seines, and indeed any other fisheries (penaeid or otherwise) that use these sorts of gears,
would best be investigated on a fishery-specific basis.
Acknowledgements
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References
Table 1. Combined-hauls fits to the Richmond River data. Carapace lengths at 50% probability of retention and selection ranges (L_{50} and SR, respectively, in mm) and relative fishing efficiencies (p) for school prawns and narrow-banded sole caught in the five codends used during experiment 1. Parameters were calculated using both the diamond- and square-control codends. Standard errors are given in parentheses and have been corrected for between-haul variation. --, unable to converge model. na, not applicable.

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<tr>
<td>SR</td>
<td>3.71 (0.47)</td>
<td>5.03 (0.66)</td>
<td>4.54 (2.29)</td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>0.54 (0.10)</td>
<td>0.54 (0.15)</td>
<td>0.52 (0.06)</td>
<td></td>
</tr>
<tr>
<td>Diamond-control</td>
<td>na</td>
<td>--</td>
<td>na</td>
<td>32.34 (3.10)</td>
</tr>
<tr>
<td>SR</td>
<td></td>
<td></td>
<td>3.54 (4.21)</td>
<td></td>
</tr>
<tr>
<td>p</td>
<td></td>
<td></td>
<td>0.52 (0.03)</td>
<td></td>
</tr>
<tr>
<td>Square-control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L_{50}</td>
<td>4.44 (1.70)</td>
<td>na</td>
<td>--</td>
<td>na</td>
</tr>
<tr>
<td>SR</td>
<td>2.52 (2.51)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>0.53 (0.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Mixed-effects model fits to A) school prawn data from the Richmond River experiment and B) greasyback prawn data from the Smiths Lake experiment. Parameters estimated: means for carapace length at 50% probability of retention and selection range (μ_L50 and μ_SR, respectively; units in mm), variance of L_50 (σ^2_L50), and mean and variance of the logit of relative fishing efficiency (μ_q and σ^2_q, respectively where q=\text{logit}(p)) and C_{weed} (change in L_50 with the presence of weed). Standard errors are given in parentheses. na, not applicable. † The 100-diamond data showed negligible selectivity in the presence of weed. This results in model non-identifiability because any large negative value of the weed effect corresponds to a non-selective selection curve. This is reflected in the misleadingly large estimated effect and standard error.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Codends</th>
<th>100-diamond150-diamond20-mm square</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A) School prawns – Richmond River</td>
<td></td>
</tr>
<tr>
<td></td>
<td>μ_L50</td>
<td>5.3 (1.8) 3.3 (2.5) 10.7 (0.9)</td>
</tr>
<tr>
<td></td>
<td>μ_SR</td>
<td>4.7 (0.5) 4.2 (0.7) 4.6 (0.3)</td>
</tr>
<tr>
<td></td>
<td>μ_q</td>
<td>0.4 (0.2) 0.3 (0.3) 0.4 (0.3)</td>
</tr>
<tr>
<td></td>
<td>σ^2_L50</td>
<td>45.7 (23.4) 34.2 (15.4) 19.6 (8.0)</td>
</tr>
<tr>
<td></td>
<td>σ^2_q</td>
<td>0.9 (0.3) 1.9 (0.5) 2.0 (0.5)</td>
</tr>
<tr>
<td></td>
<td>B) Greasyback prawns – Smiths Lake</td>
<td></td>
</tr>
<tr>
<td></td>
<td>μ_L50</td>
<td>9.4 (1.0) na 12.8 (0.5)</td>
</tr>
<tr>
<td></td>
<td>μ_SR</td>
<td>3.3 (0.4) 4.2 (0.4)</td>
</tr>
<tr>
<td></td>
<td>μ_q</td>
<td>-0.3 (0.2) 0.3 (0.2)</td>
</tr>
<tr>
<td></td>
<td>σ^2_L50</td>
<td>11.4 (5.9) 2.4 (1.1)</td>
</tr>
<tr>
<td></td>
<td>σ^2_q</td>
<td>0.6 (0.2) 0.3 (0.1)</td>
</tr>
<tr>
<td></td>
<td>C_{weed}</td>
<td>-26.4(904.5) †</td>
</tr>
</tbody>
</table>
Table 3. Experiment 1: summaries of F ratios from three-factor ANOVA and *a priori* planned comparisons comparing catches from five codends (3 x treatment – Treat, and 2 x control – Ctrl) tested over five days during two periods ($n = 3$). “Pld” indicates that the F ratio for the interaction term was non-significant at $P < 0.25$, and the sums of squares and df were pooled with the residual. All data were ln(x+1) transformed. **$P < 0.01$; *$P < 0.05$.  

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Wt of school prawns</th>
<th>wt</th>
<th>Bycatch no.</th>
<th>spp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codends (C)</td>
<td>4</td>
<td>0.63</td>
<td>0.64</td>
<td>2.48*</td>
<td>2.35</td>
</tr>
<tr>
<td>Treat vs. Ctrl</td>
<td>1</td>
<td>0.02</td>
<td>2.08</td>
<td>8.42**</td>
<td>8.31**</td>
</tr>
<tr>
<td>Among Treat</td>
<td>2</td>
<td>0.78</td>
<td>0.24</td>
<td>0.68</td>
<td>0.55</td>
</tr>
<tr>
<td>Among Ctrl</td>
<td>1</td>
<td>0.93</td>
<td>&lt;0.01</td>
<td>0.12</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Perioes (P)</td>
<td>1</td>
<td>7.87*</td>
<td>6.22*</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>C x P</td>
<td>4</td>
<td>Pld</td>
<td>Pld</td>
<td>Pld</td>
<td>1.64</td>
</tr>
<tr>
<td>Days (D)</td>
<td>8</td>
<td>2.43*</td>
<td>Pld</td>
<td>2.24*</td>
<td>Pld</td>
</tr>
<tr>
<td>C x D</td>
<td>32</td>
<td>Pld</td>
<td>Pld</td>
<td>Pld</td>
<td>Pld</td>
</tr>
<tr>
<td>Residual</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Combined-hauls fits to the Smiths Lake data. Carapace lengths at 50% probability of retention and selection ranges ($L_{50}$ and SR, respectively; units in mm) and relative fishing efficiencies ($p$) for greasyback prawns caught in the two treatment codends. The square-control codend was used. Standard errors are given in parentheses and have been corrected for between-haul variation.

<table>
<thead>
<tr>
<th>Codend</th>
<th>100-diamond</th>
<th>20-mm square</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{50}$</td>
<td>13.48 (5.09)</td>
<td>13.42 (0.73)</td>
</tr>
<tr>
<td>SR</td>
<td>13.07 (6.06)</td>
<td>5.84 (0.85)</td>
</tr>
<tr>
<td>$p$</td>
<td>0.59 (0.10)</td>
<td>0.61 (0.03)</td>
</tr>
</tbody>
</table>
Table 5. Experiment 2: summaries of F ratios from two-factor ANOVA and *a priori* planned comparisons comparing catches from three codends (2 x treatments – Treat, and 1 x control – Ctrl; 100-diamond – Diam, square – Squ) tested over nine nights (n = 2). "Pld" indicates that the F ratio for the interaction term was non-significant at $P < 0.25$, and the sums of squares and df were pooled with the residual. All data were ln(x+1) transformed. ** $P < 0.01$; * $P < 0.05$. Weight of bycatch was tested at $P = 0.01$ because a Cochran’s test of the transformed data was significant at $P = 0.05$.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Wt of total prawns</th>
<th>No. of greasyback prawns</th>
<th>No. of eastern king prawns</th>
<th>Bycatch wt</th>
<th>Bycatch no.</th>
<th>Bycatch spp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codends (C)</td>
<td>2</td>
<td>2.84</td>
<td>4.95*</td>
<td>0.14</td>
<td>0.87</td>
<td>26.87**</td>
<td>6.82**</td>
</tr>
<tr>
<td>Treat vs. Ctrl</td>
<td>1</td>
<td>2.93</td>
<td>7.86*</td>
<td>0.21</td>
<td>1.09</td>
<td>48.94**</td>
<td>6.17**</td>
</tr>
<tr>
<td>Diam vs. Squ</td>
<td>1</td>
<td>2.74</td>
<td>2.04</td>
<td>0.07</td>
<td>0.66</td>
<td>4.81*</td>
<td>7.48*</td>
</tr>
<tr>
<td>Nights (N)</td>
<td>8</td>
<td>5.36**</td>
<td>4.69**</td>
<td>3.44**</td>
<td>5.93**</td>
<td>7.51**</td>
<td>3.67**</td>
</tr>
<tr>
<td>C x N</td>
<td>16</td>
<td>1.46</td>
<td>1.42</td>
<td>Pld</td>
<td>Pld</td>
<td>Pld</td>
<td>Pld</td>
</tr>
<tr>
<td>Residual</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Captions to figures

Figure 1. Schematic diagram of the A) 100- and B) 150-diamond; C) 20-mm square; and D) diamond- and E) square-control codends. N, normals; T, transversals; B, bars; M, metres.

Figure 2. Logistic selection curves (where selectivity models were converged) for A) school prawns and B) narrow-banded sole caught in codends used during the river-seine experiment, and C) greasyback prawns caught in codends used during the lagoon seine experiment. 100-D, 150-D, Square, S-CON and D-CON refer to 100- and 150-diamond, 20-mm square, and diamond- and square-control codends, respectively. Size-frequency curves are for A) school prawns caught in the diamond-control codend, B) sole caught in the two control codends combined, both during experiment 1, and C) greasyback prawns caught in the square-control codend during experiment 2.

Figure 3. Differences in the mean catches (+SE) among the five codends used in experiment 1. 100-D, 150-D, Square, S-CON and D-CON refer to 100- and 150-diamond, 20-mm square, and diamond- and square-control codends, respectively. Catch data are for A) the weight of school prawns; the B) weight and C) number of total bycatch; and D) the number of bycatch species. Significant results of a priori planned comparisons are shown where applicable. Weights are in kg.

Figure 4. Differences in the mean catches (+SE) among the three codends used in experiment 2. 100-D, Square and S-CON refer to 100-diamond, 20-mm square and square-control codends, respectively. Catch data are for A) the weight of total prawns; numbers of B) greasyback and C) eastern king prawns; the D) weight and E) numbers of total bycatch; and F) numbers of bycatch species. Significant results of a priori planned comparisons are shown where applicable. Weights are in kg.
Reducing the discarding of small prawns

Project No. 2001/031

A) 100-diamond codend

B) 150-diamond codend

C) 20-mm square codend

- 1.4 mm ø twisted 30-mm PE mesh
- 2.5 mm ø braided 20-mm knotless PE mesh hung on the bar
- Zippers to release catch

D) Diamond-control codend

- 1.5 mm ø braided 16-mm knotless PE mesh
- Draw string

E) Square-control codend

- 1.5 mm ø braided 12-mm knotless PE mesh hung on the bar
- Zippers to release catch
A) School prawns - river seine

B) Narrow-banded sole - river seine

C) Greasyback prawns - lagoon seine

Size frequency of prawns (n = 105,496)
Size frequency of sole (n = 262)
Size frequency of prawns (n = 59,479)
Reducing the discarding of small prawns

Project No. 2001/031

A) Wt of school prawns

B) Wt of total bycatch

C) No. of total bycatch

D) No. of bycatch species

Codend
A) Wt of total prawns

B) No. of greasyback prawns

C) No. of eastern king prawns

D) Wt of total bycatch

E) No. of total bycatch

F) No. of bycatch species

Codend