Selectivity of conventional diamond- and novel square-mesh codends in an Australian estuarine penaeid-trawl fishery

Matt K. Broadhurst\textsuperscript{a,}\textsuperscript{*}, Russell B. Millar\textsuperscript{b}, Steven J. Kennelly\textsuperscript{c}, William G. Macbeth\textsuperscript{a}, Damian J. Young\textsuperscript{a}, Charles A. Gray\textsuperscript{c}

\textsuperscript{a} NSW Fisheries, Conservation Technology Unit, National Marine Science Centre, PO Box J321, Coffin Harbour, NSW 2450, Australia
\textsuperscript{b} Department of Statistics, The University of Auckland, Private Bag 92019, Auckland, New Zealand
\textsuperscript{c} NSW Fisheries, Cronulla Fisheries Centre, PO Box 21, Cronulla, NSW 2230, Australia

Received 15 November 2002; received in revised form 24 April 2003; accepted 5 September 2003

Abstract

The selectivities and relative efficiencies of (i) two conventional diamond-mesh codends with posterior sections 100 and 200 meshes in circumference and (ii) two novel square-mesh codends with different circumferences throughout and comprising panels of square-shaped mesh instead of drawn-strings were investigated in a New South Wales estuarine penaeid-trawl fishery. Paired simultaneous comparisons (using twin trawls) of each of these four treatment codends with their respective small-meshed controls showed that the conventional diamond-mesh codend with a 200 mesh posterior circumference had no detectable selectivity for all sizes of the school prawns, \textit{Metapenaeus macleayi} and eastern king prawns, \textit{Penaeus plebejus} encountered. While reducing the posterior circumference to 100 meshes marginally improved selectivity, both of the novel square-mesh codends were the most effective designs in selecting significantly larger prawns across a smaller range of sizes and releasing up to 99% more fish than the conventional diamond-mesh codend with the 200 mesh posterior circumference. The results are discussed in terms of the influences of the geometry of the various codends on their performances and the importance of examining simple changes to codend meshes as a means for augmenting bycatch reduction from penaeid prawn trawls.

© 2003 Elsevier B.V. All rights reserved.

Keywords: Selectivity; Shrimp; Gear technology; Square-mesh codends; Bycatch reduction

1. Introduction

In New South Wales (NSW), Australia, estuarine otter trawling occurs at four locations, involves up to 247 small vessels \textgt;\textlt;10 m in length\textlt; and is valued at approx. $\text{A} 7$ million per annum. Fishers target penaeids and mostly school prawns, \textit{Metapenaeus macleayi}, but also catch and discard a diverse assemblage of unwanted small fish, cephalopods and crustaceans (collectively termed bycatch) (Liggins and Kennelly, 1996; Liggins et al., 1996). Concerns over the mortality of large numbers of juveniles of commercially important species of fish led to the development of physical modifications to trawls (for a review see Broadhurst, 2000) designed to reduce bycatch. This culminated in the adoption and legislation of several bycatch reduction devices (BRDs), including the Nordmøre-grid, which was designed to
partition the catch mechanically and to exclude all individuals larger than the targeted prawns. This BRD was shown to be effective in reducing up to 90% of bycatch, with no significant effects on the catches of prawns (Broadhurst and Kennelly, 1996a).

The Nordmare-grid has alleviated concerns over the potential impacts of trawling on many of the species comprising bycatch in NSW's estuarine prawn-trawl fisheries. An issue that still remains, however, concerns the unwanted capture of organisms smaller than the targeted school prawns (e.g. individuals not excluded by the Nordmare-grid) and, in particular, conspecifics considered to be too small for sale. While there is no minimum legal size for school prawns in NSW, operators in most fisheries conform to industry-recommended 'counts' which vary from approx. 150–180 prawns 500 g⁻¹ (i.e. mean individual weights of 3.3–2.7 g or mean carapace lengths, CL, of approx. 17–15 mm, respectively). There have been no formal estimates of the selectivity of the minimum legal mesh size (40 mm inside mesh opening) used in commercial trawls, but it is apparent that large numbers of prawns considerably smaller than the above optimal size are caught (Broadhurst and Kennelly, 1996a) and then discarded dead. This is considered a major waste of stocks because if these individuals were able to escape through trawl meshes, many would survive (Broadhurst et al., 2002b) and reach commercial size within a few months (Glaister, 1978).

The retention of juvenile school prawns and other very small individuals comprising bycatch is due to the materials and rigging arrangements of conventional diamond-mesh trawls. Like many penaeid-trawl fisheries throughout the world, those in NSW use codends with large posterior circumferences (e.g. hanging ratios of up to 0.5) and knotted mesh made from thick twine (Vendeville, 1990; Broadhurst and Kennelly, 1996b). This substantially reduces the lateral openings of the meshes in the codend and the overall trawl selectivity (Reeves et al., 1992; Broadhurst and Kennelly, 1996b; Lowery and Robertson, 1996; Lök et al., 1997).

Some of the simplest ways to increase selectivity, therefore, are to reduce the fishing circumference of the codend (i.e. increase the hanging ratio) and/or open meshes by orientating them on the bar so that they are square shaped. These sorts of modifications have successfully been applied in many fish- and crustacean-trawl fisheries (e.g. Suuronen and Millar, 1992; Thorsteinsson, 1992; Lök et al., 1997; Stergiou, 1999) and more recently in an Australian penaeid-trawl fishery (Broadhurst et al., 1999b, 2000). For example, in Gulf St. Vincent, Broadhurst et al. (1999b) showed that compared to a conventional diamond-mesh codend, those made entirely with square meshes and comprising narrow circumferences significantly reduced the bycatch of small fish and unwanted juvenile western king prawns, *Penaeus latisulcatus* with no concomitant loss of commercial catch. The improved selectivity for the target-sized western king prawns was attributed to a greater probability of small individuals encountering openings in the narrow square-mesh codends and escaping.

One problem with the codends examined during this work, however, was a reported variability in performance during extreme catches. Because the meshes were square shaped and codend circumference was narrow, large catches could not expand laterally and often became wedged in the posterior section of the codend, making it difficult to remove when the codend was retrieved and the draw-strings were opened. Conversely, during hauls with very small catches, square meshes have been observed to convolute over a large proportion of the posterior section of the codend (Robertson, 1986) reducing the number of mesh openings and therefore the selectivity.

We addressed the potential for the above effects in the present study by designing a new square-mesh codend that included a circular panel of square-shaped mesh instead of the traditional draw-string and laterally located zippers to release the catch through the sides of the codend. Our specific objectives in this work were to quantify the selectivities and efficiencies of two of these new square-mesh designs (made from 20 mm mesh hung on the bar and with different circumferences) and two conventional diamond-mesh codends (with posterior sections hung at ratios of 1.0 and 0.5, respectively) for catches and bycatches in a typical NSW estuarine penaeid-trawl fishery.

2. Materials and methods

This study was done on commercial prawn-trawl grounds in Lake Woolooweyah (part of the Clarence River estuary in NSW: 29°26'S, 153°22'E) in March
2002 using a chartered commercial prawn trawler (10 m in length). Two Florida Flyer trawls each with a headline length of 7.32 m were rigged in a standard twin-gear configuration (one on each side of the vessel) and towed at 1.2 m s\(^{-1}\) over a combination of sandy and mud bottoms in depths ranging from 1 to 3 m. Both trawls contained aluminium Nordmøre-grids with bar spaces of 20 mm (for details on rigging see Broadhurst and Kennelly, 1996a). Zippers (Burachi S146R, 1.45 m in length) were attached immediately posterior to the Nordmøre-grids to facilitate changing of the codends. The length of these zippers was based on the expected fishing circumference of the anterior section of a conventional diamond-mesh codend and calculated assuming a fractional mesh opening (Broadhurst et al., 1999b) of 0.35 × the circumference in number of meshes × the stretched mesh length (see Ferro and Xu (1996) for definitions of mesh size).

2.1. Codends examined

Six codends were constructed: two conventional diamond-mesh designs, two square-mesh designs and two appropriate controls (i.e. made from diamond- and square-shaped mesh, respectively, with mesh sizes approx. ≤50% of the treatment codends (Wileman et al., 1996). All codends were made from dark netting and had a total length and maximum anterior fishing circumference of approx. 2.40 and 1.45 m, respectively. The first and second codends, termed the 200 and 100 diamond codends, represented conventional designs and were made entirely of 40 mm (unless stated otherwise, all mesh sizes refer to diamond mesh opening, see Ferro and Xu (1996) for definitions) knotted polyethylene mesh netting (≤3 mm diameter twisted and braided twine) (Fig. 1A and B).

Both codends had identical anterior sections that were 33 meshes in length and 100 meshes in circumference (Fig. 1A and B). Their posterior sections were both 25 meshes in length but had circumferences of 200 and 100 meshes, respectively (Fig. 1A and B). The third codend, termed the diamond control, was made from 20 mm knotless polyamide netting (2.5 mm diameter braided twine) and had a circumference of 200 meshes throughout (i.e. an approximate fishing circumference of 1.45 m) (Fig. 1C). All three diamond-mesh codends were rigged with conventional draw-strings to close their posterior sections.

The fourth and fifth codends, termed the non-tapered and tapered square codends, were made entirely from 20 mm knotless polyamide netting (2.5 mm diameter braided twine) that was hung on the bar (i.e. the meshes were orientated so that they were square shaped) (Fig. 1D and E). The non-tapered square-mesh codend had a circumference of 110 bars throughout (Fig. 1D), while the tapered square-mesh codend had a circumference of 110 bars at the start of the anterior section that was reduced to 54 bars at the end of the posterior section (i.e. a 50% reduction in fishing circumference) (Fig. 1E). It was hypothesised that this taper would increase the probability of prawns encountering open meshes and therefore the selectivity of the codend (see Section 1). The sixth codend, termed the square control, was made entirely from 6 mm (mesh opening or 7 mm mesh length) knotless polyamide netting (1.5 mm diameter braided twine) hung on the bar and without a taper (Fig. 1F). To maintain symmetry, all three square-mesh codends were constructed in two sections; each section comprising upper and lower panels sewn together with opposite knot directions (see also Broadhurst et al. (1999b) for construction details) (Fig. 2). Appropriate-sized circular panels of square-shaped mesh were attached to the ends of the posterior sections of the three square-mesh codends and, instead of a conventional draw-string, zippers (Burachi S146R, 0.3 m in length) were attached to each of the lateral seams to allow removal of the catch (Fig. 2). It was thought that this would improve selectivity by maintaining codend geometry and mesh openings.

2.2. Experimental procedure

The four treatment codends were compared against their respective controls in independent, paired hauls. In each paired comparison, the particular treatment and control codend being tested were attached posterior to the Nordmøre-grids (Fig. 2) in the twin-rigged trawls and towed simultaneously. The position and order of each codend was determined randomly and they were used in normal commercial hauls of 30 min duration between 0700 and 1400 h each day. Two replicate tows of each test codend against its control were done on each day, providing a total of 20 replicate hauls for each comparison over 10 days.
After each tow, the two codends being tested were emptied onto a partitioned tray. Prawns and all individuals of commercially important species comprising bycatch were separated by species. Following removal of a subsample (see below), school prawns were further separated (by the skipper of the vessel) into either commercially retained or discarded categories. The following categories of data were collected for each tow: the weight of total prawns; the weight of total school prawns and a subsample (250 prawns from each codend) of their lengths (to the nearest 1 mm CL); the number of total school prawns (estimated from the subsample); the percentage (by weight) of discarded school prawns; the total weight, number and sizes of eastern king prawns, *Penaeus plebejus*; the weight of total bycatch; the number of all commercially important species comprising bycatch and the sizes of commercially important fish; and the numbers of non-commercial species. Approximately 500 school prawns were collected from several randomly selected hauls during the experiment and 110 eastern king prawns collected after the experiment was completed. These individuals were separated by sex and then weighed and measured in the laboratory.
Fig. 2. The location of the Nordmare-grid in a prawn trawl and the panel assembly for the square-mesh codends.

to the nearest 0.1 g and 0.1 mm CLs, respectively. These latter samples and measurements were taken to facilitate accurate determination of length/weight relationships for school and eastern king prawns.

2.3. Statistical analyses

An orthogonal, two-factor analyses of variance (ANOVA) model was used to test the hypotheses of no differences in catches between the four treatment codends. In these analyses, codend type and days were considered fixed and random factors, respectively. The effect of days was considered multiplicative and so catch data for replicate hauls that had sufficient numbers of each variable (i.e. at least 1 individual in at least 10 replicates) were ln(x + 1) transformed. All transformed data were tested for heterocedasticity using Cochran’s test and then analysed by ANOVA. To increase power for the main effect of codend type, where the interaction term was non-significant at P < 0.25, it was pooled with the residual (Winer, 1971). Significant differences detected in these analyses were investigated using Student–Newman–Keuls (SNK) multiple comparisons.

Linear regressions of log wt (g) against log CL (mm) were fitted separately for male and female school and eastern king prawns and then compared intraspecifically using appropriate analysis of co-variance (ANCOVA). These analyses failed to detect significant intraspecific dimorphism in the weight/length relationships across the range of sizes examined (see Section 3). The selectivity estimates for the various treatment codends described below were therefore done irrespective of sex.

Size-frequencies of individuals of species caught in sufficient quantities were combined across all tows and logistic and Richards selection curves fitted to these data using maximum likelihood. These
fits used the estimated-split SELECT model for trouser trawls (Millar and Walsh, 1992) and were implemented using the free software package R and selectivity functions downloaded from http://www.scitec.auckland.ac.nz/~greebie/selectware/R. Model fits were assessed by visual examination of deviance residuals and by comparing model deviances and associated degrees of freedom with a chi-squared distribution (Millar and Fryer, 1999). When the individual tows had sufficient data, model deviances and standard errors of parameter estimates were adjusted for over-dispersion (due to between-haul variation) using the replicate estimate of dispersion (Millar and Fryer, 1999). This was calculated by summing the deviances that resulted from fitting the combined-tows selection curve to the data from each individual tow, and dividing by the appropriate degrees of freedom. Wald statistics were calculated for pairwise differences between codends in the estimated parameter vectors (length at 50% retention, $L_{50}$ and selection range, $SR$) (Kotz et al., 1982). These have an approximate chi-squared distribution (2 d.f.) under the hypothesis of no difference in true $L_{50}$'s and SRs of the two codends being compared.

3. Results

ANOVA failed to detect any significant differences in weights of prawns for the main effect of codend (Fig. 3A, B, E and Table 1). Significant $F$ ratios were detected for the number of total school prawns caught and the percentage discarded, weight of bycatch and the number of bycatch species, king prawns, southern herring, whitebait, pink-breasted siphonfish and bottle squid (Table 1). SNK tests failed to detect any significant order among codends for the number of total school prawns, although incrementally fewer were caught in the 100 diamond, tapered square and non-tapered square codends, respectively (Fig. 3C). Compared to the 200 diamond codend, all other designs caught significantly less bycatch (means reduced by between 31 and 51%) and fewer southern herring (by 56–82%), whitebait (by 75–99%) and pink-breasted siphonfish (by 42–94%) (Fig. 3G, I–K). The two square-mesh codends similarly caught significantly fewer bycatch species, whitebait, pink-breasted siphonfish and bottle squid than the 100 diamond codend (means reduced by between 34 and 98%) (Fig. 3H, J, K and N), while proportionally fewer school prawns were discarded from the non-tapered square codend than all other designs (Fig. 3D). Several variables had significant $F$ ratios for the main effect of days, but no interactions were detected (Table 1).

The sizes of school and eastern king prawns caught ranged from 3 to 22 mm CL. ANCOVA failed to detect significant differences in regression coefficients or elevations between regressions of log wt and log CL for male (log wt = 2.903 log CL – 6.668, $r^2 = 0.93$, $n = 178$) and female (log wt = 2.922 log CL – 6.942, $r^2 = 0.94$, $n = 296$) school prawns and male (log wt = 2.939 log CL – 7.282, $r^2 = 0.96$, $n = 55$) and female (2.964 log CL – 7.326, $r^2 = 0.93$, $n = 50$) eastern king prawns. Common regressions were calculated as log wt = 2.917 log CL – 6.919 for school prawns and log wt = 2.925 log CL – 7.234 for eastern king prawns. Because of these results, selectivity analyses were done irrespective of sex.

School prawns, eastern king prawns and southern herring were caught in sufficient quantities in all codends to permit attempts at modelling their selectivity. Large numbers of whitebait were also retained in the 100 and 200 diamond codends, however, convergence errors occurred during analyses, precluding any estimation of model parameters. Similar results occurred for southern herring from the 200 diamond codend and were attributed to a lack of selectivity by these codends for small fish (i.e. they had similar size distributions as those in the control codend, Fig. 4). Selectivity models were fitted for school and eastern king prawns for all codends, although for the 200 diamond codend, these models were not significantly different from the null model (i.e. no selectivity at $P > 0.05$) and so were not presented.

In all cases where selectivity models converged, there was no significant reduction in deviance associated with using a Richard's curve ($P > 0.05$), except for school prawns caught in the tapered square codend. However, this was only marginally significant ($P > 0.04$) and so, to maintain consistency, the simpler logistic model was used throughout. All model fits showed no significant disequilibrium in fishing efficiency (i.e. parameter $P = 0.05$, Table 2) for school and eastern king prawns between the paired codends ($P > 0.05$). The $P$ for herring was similar in both
Fig. 3. Differences in mean catch (+S.E.) between the 200 diamond, 100 diamond, tapered square and non-tapered square codends: (A) weight of total prawns, (B) weight and (C) number of total school prawns, (D) percentage of school prawns discarded, (E) weight and (F) number of eastern king prawns, (G) weight of bycatch and numbers of (H) bycatch species, (I) southern herring, (J) whitebait, (K) pink-breasted siphonfish, (L) catfish, (M) Ramsey’s perchlet, (N) bottle squid and (O) silver biddy. Shaded histograms represent significant F ratios. > and = indicate the direction of these differences determined by SNK tests.
Reducing the discarding of small prawns  Project No. 2001/031

Table 1

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Weight of total prawns</th>
<th>School prawns</th>
<th>King prawns</th>
<th>Bycatch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>Discarded (%)</td>
<td>Weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weight</td>
<td>No.</td>
<td>Weight</td>
</tr>
<tr>
<td>Days</td>
<td>9</td>
<td>3.94**</td>
<td>3.89**</td>
<td>2.49*</td>
<td>1.67</td>
</tr>
<tr>
<td>Codends</td>
<td>3</td>
<td>1.03</td>
<td>0.99</td>
<td>3.08**</td>
<td>9.49*</td>
</tr>
<tr>
<td>Interaction</td>
<td>27</td>
<td>1.68</td>
<td>1.73</td>
<td>1.73</td>
<td>0.942d</td>
</tr>
<tr>
<td>Residual</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of southern herring</td>
<td></td>
<td>No. of whitebait</td>
<td>No. of PBSF</td>
<td>No. of fork-tailed catfish</td>
<td>No. of Ramsey's perchlet</td>
</tr>
<tr>
<td>Days</td>
<td>9</td>
<td>1.22</td>
<td>1.50</td>
<td>3.39**</td>
<td>0.81</td>
</tr>
<tr>
<td>Codends</td>
<td>3</td>
<td>18.24**</td>
<td>218.50**</td>
<td>58.28**</td>
<td>1.01</td>
</tr>
<tr>
<td>Interaction</td>
<td>27</td>
<td>0.992d</td>
<td>0.932d</td>
<td>1.029d</td>
<td>0.392d</td>
</tr>
<tr>
<td>Residual</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*All data were ln(x + 1) transformed with the exception of percentage of discarded school prawns, which were sin⁻¹(√x) transformed. p<0.05 indicates that the F ratio for the interaction was non-significant at P < 0.05 and the sums of squares pooled with the residual. The subsequent degrees of freedom (d.f.) for the main effect of codends were 3, 67. PBSF, pink-breasted siphonifish.  

* P < 0.05.

** P < 0.01.
square-mesh codends (i.e. 0.60, Table 2), but only significantly biased in the non-tapered square codend ($P < 0.01$).

The tapered and non-tapered square codends had similar logistic selection curves for school prawns (Fig. 5A and Table 2) and there were no significant differences between estimated $L_{50}$'s (10.1 and 10.3 mm, respectively) and SRs (3.2 and 3.5 mm) ($P > 0.05$; Table 2). In contrast, the 100 diamond codend had a significantly smaller $L_{50}$ (8.6 mm) and larger SR (3.9 mm) than either square-mesh codend (pairwise $\chi^2$ test, $P < 0.01$) (Fig. 5B and Table 2). All three codends had similar estimated $L_{50}$'s for eastern king prawns (10.3–10.7 mm) and although the SR for the non-tapered square codend was considerably lower than that for the other designs (i.e. 2.3 vs. 3.5 mm), it
Reducing the discarding of small prawns


Table 2

Lengths at 50% probability of retention ($L_{50}$), selection ranges (SRs) and relative fishing efficiencies ($P$), for school prawns, eastern king prawns and southern herring.

<table>
<thead>
<tr>
<th></th>
<th>School prawns</th>
<th>Eastern king prawns</th>
<th>Southern herring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L_{50}$ (cm)</td>
<td>100.0 (0.50)</td>
<td>ns</td>
</tr>
<tr>
<td>100 diamond codend</td>
<td>8.60 (0.30)</td>
<td>10.30 (0.50)</td>
<td>ns</td>
</tr>
<tr>
<td>SR</td>
<td>5.90 (0.60)</td>
<td>5.90 (0.50)</td>
<td>ns</td>
</tr>
<tr>
<td>$P$</td>
<td>0.51 (0.01)</td>
<td>0.52 (0.03)</td>
<td>ns</td>
</tr>
<tr>
<td>Tapered square codend</td>
<td>10.1 (0.20)</td>
<td>10.70 (0.70)</td>
<td>8.00 (0.70)</td>
</tr>
<tr>
<td>SR</td>
<td>3.20 (0.30)</td>
<td>3.50 (1.40)</td>
<td>1.60 (0.40)</td>
</tr>
<tr>
<td>$P$</td>
<td>0.46 (0.01)</td>
<td>0.46 (0.04)</td>
<td>0.66 (0.07)</td>
</tr>
<tr>
<td>Non-tapered square codend</td>
<td>10.30 (0.20)</td>
<td>10.6 (0.30)</td>
<td>7.7 (0.40)</td>
</tr>
<tr>
<td>SR</td>
<td>3.50 (0.30)</td>
<td>3.0 (0.50)</td>
<td>1.3 (0.30)</td>
</tr>
<tr>
<td>$P$</td>
<td>0.49 (0.01)</td>
<td>0.50 (0.02)</td>
<td>0.66 (0.04)</td>
</tr>
</tbody>
</table>

*Lengths are in mm for prawns and cm for southern herring. Standard errors are given in parentheses. The null hypothesis concerning non-selectivity (ns) was not rejected for all three species from the 200 diamond codend and southern herring from the 100 diamond codend.*

was not significantly different (pairwise $\chi^2$ test, $P > 0.05$) (Table 2). The estimated selection parameters for southern herring were not significantly different between the two square-mesh codends (pairwise $\chi^2$ test, $P > 0.05$) (Table 2).

4. Discussion

The results illustrate the utility of simple changes in the sizes and configurations of meshes to significantly improve trawl selectivity, measured as a reduction in the unwanted bycatches of fish and small prawns. Compared to the conventional codends, both the square-mesh designs showed a general improvement in performance (Fig. 3 and Table 1). This was due to the escape of nearly all pink-breasted siphonfish and whitebait, along with large number of small individuals of species like southern herring and bottle squid (e.g. up to 82% less than the 200 diamond codend).

The magnitude of differences between the diamond and square-mesh codends was accentuated by the extremely poor selectivity characteristics of the former designs, and particularly the conventionally used 200 diamond codend. The lateral mesh openings in these codends were very narrow, and for the 200 diamond codend, these openings were essentially the same as those in the diamond control (20 mm mesh).

Although the selectivities of the tapered and non-tapered square codends were considerably less than the industry-recommended mean target size for school prawns (i.e. 15–17 mm CL), both designs did have significantly greater $L_{50}$’s and smaller SRs than the 100 diamond codend (Fig. 5A and Table 2). Further, although not significant, the non-tapered square codend similarly selected king prawns over a slightly smaller range of sizes (Fig. 5B and Table 2). These results are consistent with previous studies in fish-trawl fisheries which have shown that SRs for square mesh are generally lower than for diamond mesh (e.g. Robertson and Stewart, 1988; Halliday et al., 1999). The potential for at least some reduction in SR with increasing mesh opening is important because it means that, for the estuarine prawn-trawl fisheries of NSW, it should be feasible to use larger sizes of square mesh (e.g. possibly 23 or 25 mm mesh hung on the bar) and still retain a large proportion of commercial-sized school prawns entering the trawl.

While the improved selectivity of the tapered and non-tapered square codends can be mostly attributed to their larger and more frequent openings, the new novel design and a subsequent maintenance of geometry during fishing probably contributed to their performance. For example, when the codends were retrieved from the water the meshes were observed to remain open throughout the posterior sections, regardless of the catch volume. The posteriorly located circular panels of mesh (that replaced the traditional draw-strings) meant that all individuals entering the codend at least had opportunities to encounter open meshes. In contrast, the traditional diamond-mesh codends with draw-strings were often characterised by bunched and closed meshes and so they probably had varied lateral openings in their posterior sections. It is known that the catch in these sorts of codends tends to spread laterally and assumes a parabolic shape during fishing, effectively masking meshes anterior to the main bulk of catch (Broadhurst et al., 1999a).

Unlike the results observed by Broadhurst et al. (1999b), reducing codend circumference did not improve the selectivity of the square-mesh designs examined here. One possible explanation for this anomaly is that any potential benefits of a narrower codend diameter (e.g. in the tapered square codend) in
terms of increasing the probability of school prawns encountering open meshes may have been negated by proportionally fewer openings, owing to the size and position of the laterally located 'catch release' zippers (which occupied up to 30% of the surface area of the posterior codend circumference). The potential for this effect could easily be addressed in future modifications by positioning these zippers further forward and away from the accumulation of catch.

The work done in this experiment has shown that the minimum diamond mesh size of 40 mm used in NSW estuarine prawn trawls is entirely inappropriate for the target-sized penaeids. Further, like the results from other studies, this work has shown the potential of square-shaped mesh for significantly improving selectivity (Broadhurst et al., 1999b, 2000). Because similar sizes of diamond-shaped mesh (e.g. 40–50 mm) are used in nearly all prawn-trawl fisheries throughout Australia (but see Broadhurst et al., 1999b, 2000) to target penaeids considerably larger in size than those recorded here (e.g. Broadhurst and Kennedy, 1996b; Brewer et al., 1998; Broadhurst et al., 2002a), it is likely that these fisheries would also benefit from an examination of the effects of increasing mesh openings. Simple modifications to incorporate square-mesh codends in trawls would augment efforts to reduce bycatch in these fisheries.
Acknowledgements

This work was funded by NSW Fisheries and the Australian Fishing Industry Research and Development Corporation (Grant no. 2001/031). Thanks are extended to the Clarence River Fishermens Cooperative, Michael Wooden, Don Johnson, Allan Bodycote (Quality Trawl Nets Pty. Ltd.), Chris Gallen and Cristina Damiano for their expertise and assistance.

References


