Minimizing Nordmøre Grid Bar Spaces in an Australian Penaeid Fishery

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Introduction

Concerns about penaeid-trawl discard mortality, and especially juveniles of important fish stocks, have led to various resolution strategies (Hall and Mainprize, 2005). Excluding closures, the most common approach has been to locate bycatch reduction devices (BRD) anterior to the trawl codend (Broadhurst, 2000).

One of the most effective BRD is the Nordmøre grid, which comprises separated bars (e.g., 20–100 mm) and is installed at angles of approximately 30°–48° in the extension section

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ABSTRACT—The effects of reducing bar spaces in a generic Nordmøre grid used in an Australian penaeid-trawl fishery were investigated within an objective of maximising bycatch reduction while maintaining target catches. Compared to a conventional Nordmøre grid with 20 mm bar spaces, those with 16 and 18 mm bar spaces maintained the retained weights of school prawns, Metapenaeus macleayi, *and with no effects on size selectivity, but caught incrementally lower weights of total fish, which for the 16 mm grid was significant (mean reduced by ~26%). The results imply that Nordmøre grid bar spaces can be reduced to a size approaching the width of the largest penaeids with no commercial impacts.*

of trawls, with or without an anterior guiding panel and either a horizontal or triangular escape exit at the top (Isaksen et al., 1992; Broadhurst et al., 1996; Brewer et al., 1998; Silva et al., 2012). Intuitively, the performance of the Nordmøre grid should be strongly affected by the bar spaces relative to the sizes of the penaeids and unwanted bycatch. However, few studies have been published in the primary literature that test for any association between bar spacing and catches in penaeid trawls (but see Silva et al., 2012).

One penaeid-trawl fishery in which the Nordmøre grid has been successfully implemented, but for which there are no formal data assessing variations among bar spaces, occurs in estuaries in New South Wales (NSW), Australia. This fishery involves 115 small trawlers (mostly <10 m and 110 kW) diurnally targeting school prawns, *Metapenaeus macleayi* (all <25 mm carapace length; CL) mostly during the Austral summer for annual catches of 400 t per annum valued at almost AUD $3 million. A Nordmøre grid with 20 mm bar spaces was adopted by many fishermen 25 years ago and was shown to reduce total bycatch by >70% while maintaining catches of school prawns (Broadhurst et al., 1996). The 20 mm bar spacing was chosen based on school prawns being similar in size to those in European fisheries (*Pandalus borealis*) (Isaksen et al., 1992). However, the appropriateness of this spacing has never been tested. Our aim here was to assess the effects on target and bycatch species when bar spaces are reduced to a size approaching the maximum carapace thickness of the largest school prawns.

Methods

The work was done in the Clarence River (lat. 29° 27S, long. 153°12'E), NSW, Australia using one commercial double-rigged otter trawler (10 m) fishing across sand (2–20 m depth) over six days. The trawls used were identical four-seam Florida Flyers[1] (7.35 m headlines) made from 42 mm stretched mesh opening (SMO) polyethylene (PE) netting (1.2 mm diameter–Ø twisted twine) (Fig. 1a). The trawls were attached to 2.89 m sweeps and cambered otter boards (1.07 × 0.76 m; 54 kg) and had extension sections made from 41 mm SMO PE netting (1.3 mm Ø twisted twine) measuring 75 N × 100 T (Fig. 1b). Each extension section had a guiding panel (28°) terminating at the base of an inverted tombstone-shaped aluminium frame (402 × 602 mm and 10 mm square bar) secured at an angle of 45° and with an opening in the top of the codend (Fig. 1b). Conventional codends (120 × 75 B) made from square-shaped mesh (27 mm SMO and 1.3 mm Ø braided polyamide twine hung on the bar) were attached to the extension sections behind the aluminium frame (Fig. 1b).

Three grids were constructed so that they could be easily inserted into, and removed from, the two aluminum frames (Fig. 1b). All grids were made from identical materials (10 and 12 mm Ø aluminium rod bars and frames) and had the same external dimensions (400 × 600 mm) but different numbers of bars (and therefore spaces): 12 (19.69 mm; conventional grid); 13
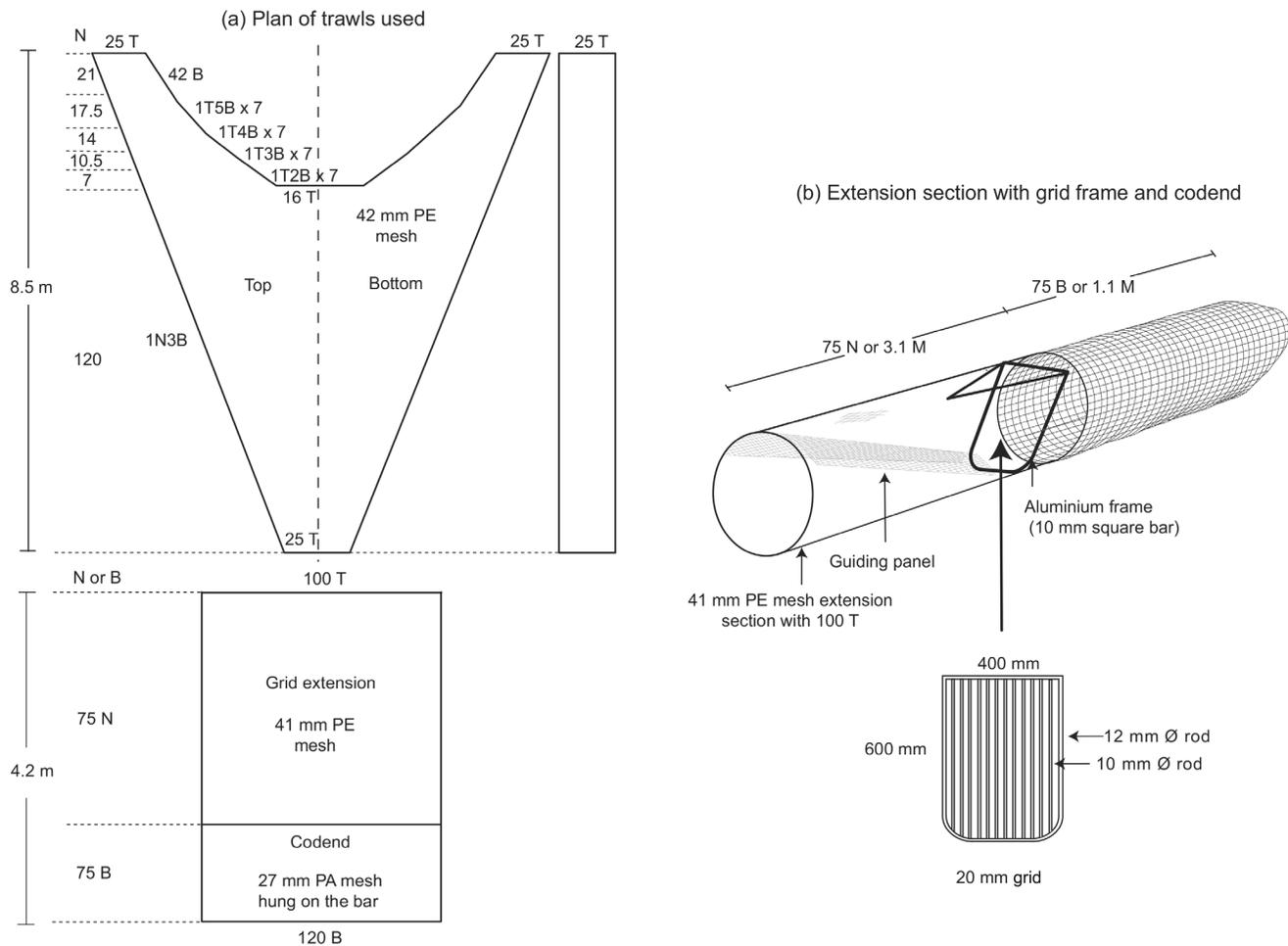
Figure 1.—The (a) trawls used and (b) extension section with grid frame (and 20 mm grid) and square-mesh codend (PE: polyethylene; PA: polyamide; Ø: diameter).

(17.57 mm); and 14 (15.73 mm) bars. These treatments were termed the 20, 18, and 16 mm grids, respectively.

The narrowest bar space (16 mm) was chosen to be slightly wider than the maximum carapace thickness of the largest school prawns, and based on established morphological relationships between CL and maximum carapace width (CW) and height (CH) derived for individuals (5–25 mm CL) in the Clarence River by Broadhurst et al. (2004). Both CW and CH were deemed important because the orientation of school prawns during passage through the grid remains unknown. Following an absence of sexual dimorphism, common regressions were cal-

culated as CH = 0.638CL-0.766 and CW = 0.511CL-0.496; which for a 25 mm CL individual provides maximums of 15.18 and 12.28 mm, respectively (Broadhurst et al., 2004).

For every deployment (4–8 per day), the 20 mm grid was randomly allocated to one of the paired trawls and secured within the aluminum frame (using cable ties). Either the 16 or 18 mm grids were then alternately secured to the remaining trawl. The two trawls were simultaneously deployed for standard commercial durations of 60 min. The grids were then reordered as above for subsequent deployments. Over six days fishing, we completed 17 replicate paired deployments of

both the 16 and 18 mm grids against the conventional 20 mm grid.

Catches were separated and the total weight of school prawns recorded. All bycatch species and approximately 500 g of school prawns were transferred to a laboratory. School prawns were counted, weighed, and a subsample (n = approximately 100) measured for CL (to the nearest 1 mm) and used to calculate the total weight and mean CL per deployment. Fish were separated by species, counted, weighed, and measured (total length; TL to the nearest 0.5 mm).

Data for the numbers and weights of catches were separately analyzed using linear mixed models (LMM's). Prior
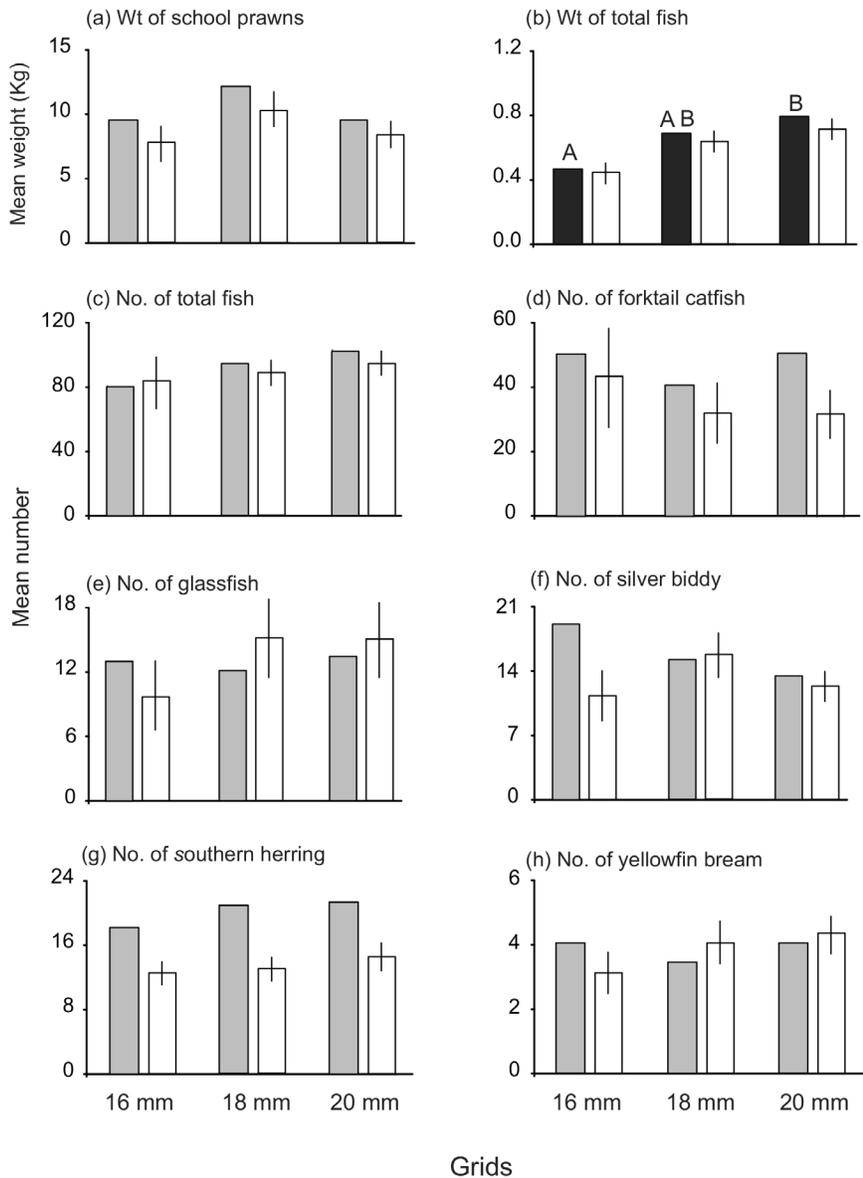
Figure 2.—Differences in predicted (shaded) and raw (±SE, white) mean catches between grids for the (a) weight of school prawns, *Metapenaeus macleayi*, (b) weights and (c) numbers of total fish, and the numbers of (d) forktail catfish, *Arius graeffei*, (e) glassfish, *Ambassis jacksoniensis* and *A. marianus*, (f) silver biddy, *Gerres subfaciatus*, (g) southern herring, *Herklotsichthys castelnaui*, and (h) yellowfin bream, *Acanthopagrus australis*. Letters above the weight of total fish indicate the direction of differences detected in false-discovery-rate pairwise comparisons for the significant fixed effect of bar spaces in linear mixed models (black histograms; $p < 0.05$).

to analyses, the numbers and weights of catches were log-transformed so that differences between bar spaces were modeled to act multiplicatively rather than additively. The mean individual mass and mean CL of school prawns per deployment were analyzed in their raw form. All models included "bar spaces" as fixed, while "trawls", "days", and the interaction between "deployments" and days were random. The significance of bar spaces was determined using a Wald *F*-test. Predicted mean numbers and weights were obtained by back-transforming log-predictions from the LMM's, and any significant differences were subsequently explored using the Benjamini-Hochberg-Yekutieli procedure to control the false discovery rate (FDR) (Benjamini and Yekutieli, 2001). Both the predicted and raw (±SE) means of interest were graphed.

For individual species, the proportion of the total paired catch (for each length class) retained in the trawl with the 20 mm grid was calculated. A curve was fitted to these proportions under the assumption that the grids had logistic selection. Geometric similarity was assumed so the selection curves scaled proportional to the bar spacing. Curves were fitted using maximum likelihood, with over-dispersion correction to allow for between-haul variability (Millar et al., 2004).

Results

In total, during the 34 paired tows across six days, 496 kg of school prawns (5–25 mm CL) and 44 kg of fish (or 4,447 individuals) were caught. The fish included more than 13 species, but only five species/groups were caught in sufficient quantities (>95% of the total) to permit analyses (Fig. 2).

There were no significant differences between the 16, 18, and 20 mm grids for the mean (± SE) CL's (14.35 ± 0.30, 14.40 ± 0.30, and 14.42 ± 0.29 mm CL) of school prawns or their individual mass per deployment (LMM, P > 0.05, Table 1, Fig. 2a). Selection curves were attempted for school prawns; but the null hypothesis of no relationship between the proportion and the CL's of school prawns was accepted for bar spaces (P > 0.1, Fig. 3a).

Forktail catfish, *Arius graeffei*, was the dominant bycatch (47% of the total and 5.0–10.0 cm TL), followed by glassfish, *Ambassis jacksoniensis* and *A. marianus* (16%; 4.5–10.0 cm TL), silver biddy, *Gerres subfaciatus* (15%; 3.5–15.5 cm TL), southern herring, *Herklotsichthys castelnaui*

| Item	Wald *F*
Wt of school prawns	2.37
Mean CL of school prawns	0.16
Mean individual mass of school prawns	0.68
Wt of total fish	3.44[1]
No. of total fish	1.80
Wt of forktail catfish, *Arius graeffei*	0.95
No. of forktail catfish	1.54
Wt of glassfish, *Ambassis jacksoniensis* and *A. marianus*	0.56
No. of glassfish	0.23
Wt of southern herring, *Herklotsichthys castelnaui*	1.21
No. of southern herring	0.38
Wt of silver biddy, *Gerres subfaciatus*	1.05
No. of silver biddy	2.14
Wt of yellowfin bream, *Acanthopagrus australis*	0.80
No. of yellowfin bream	0.63

[1]$P < 0.05$
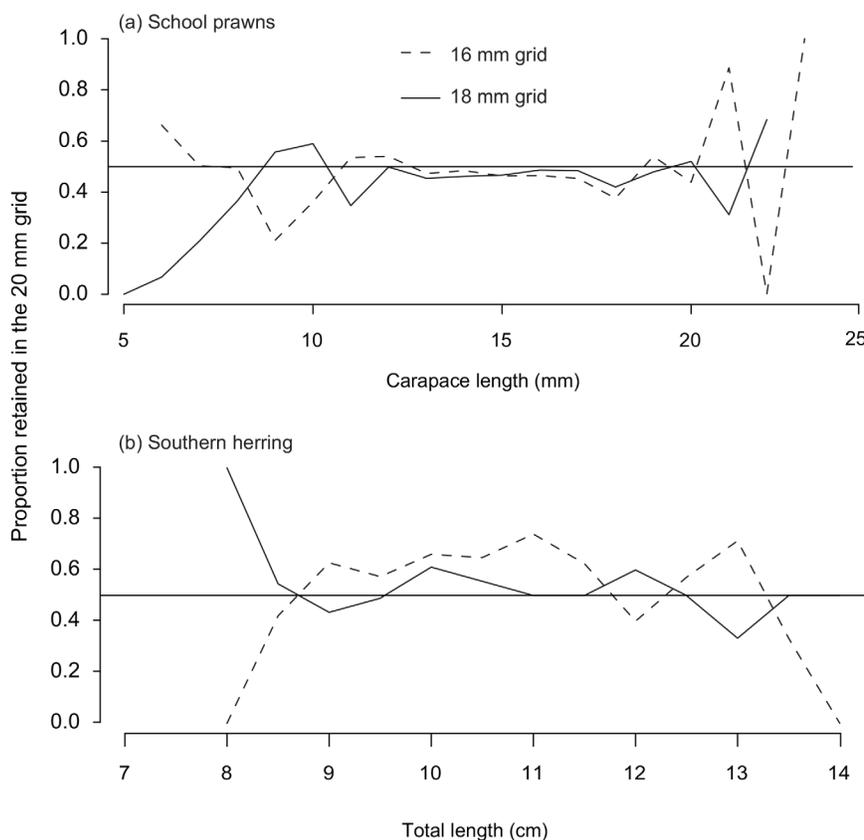
Figure 3.—Plots of the proportions of (a) school prawns, *Metapenaeus macleayi* and (b) southern herring, *Herklotsichthys castelnaui* at encountered sizes retained in the 20 mm grid during paired comparisons with the 16 and (dashed lines) 18 mm grids (solid lines).

(12%; 7.5–15.5 cm TL), and yellowfin bream, *Acanthopagrus australis* (5%; 5.5–17.5 cm TL) (Table 1, Fig. 2d–h). The LMM's detected significant differences among grids for the weight of total fish (Table 1, $P < 0.01$), with FDR's revealing that the 16 mm grid caught 26% less than the 20 mm grid ($P < 0.05$), but no differences between these grids and the 18 mm grid ($P > 0.05$, Fig. 2b). The number of total fish followed a similar mean trend among grids with up to 20% fewer in the 16 than the 20 mm grid, but this was not significant (LMM, $P > 0.05$, Table 1, Fig. 2c). Similarly, there were no significant differences in the predicted mean weights or numbers of individual species (only numbers are plotted for brevity), but some were lower in the 16 mm grid (LMM, $P > 0.05$, Table 1, Fig. 2e, f). There were no differences in size selectivity among grids for any fish (southern herring graphed as an example, $P > 0.1$, Fig. 3b).

Discussion

The data presented here contribute toward the existing literature describing technical factors affecting Nordmøre grid performances in penaeid-trawl fisheries (Broadhurst and Kennelly, 1996; Brewer et al., 1998; Silva et al., 2012; Kennelly and Broadhurst, 2014). More specifically, it is clear that bar spaces can be reduced to a size close to the CH of the largest school prawns while still consistently maintaining target catches, but with some reduction in bycatch. These observations can be discussed in terms of the species caught and their morphology, possible behaviors, and orientations at the Nordmøre grid, and then used to propose other refinements.

The maintenance of school prawn catches and the lack of any relative differences in size selection as bar spaces decreased implies that irrespective of their initial contact, all individuals were quickly orientated parallel to the angled bars (to pass through) and conceivably for many, across their width because this is their narrowest dimension. A contributing factor may have been the guiding funnel, which

directed the entire catch to the base of the grid and ensured maximum exposure to the surface. In some cases, the absence (or associated design issues) of such a guiding panel could be a contributing factor in the escape of penaeids from other grids with relatively much larger bar spaces (Broadhurst et al., 2002).

Fish also would have been similarly directed to the base of the grids, and so the significant reduction in the weight of bycatch but not numbers (although means were reduced) implies a few larger individuals passed through the escape exit of the 16 mm grid. However, although not significant, the abundant species that apparently contributed towards these reductions mostly comprised individuals with dimensions much smaller than the bar spaces. Specifically, all forktail catfish were very small (5.0–10.0 cm TL), while both species comprising glassfish have maximum TL's of approximately 7 and 10 cm, respectively and widths considerably less than 16 mm. Similarly, even a 15.5 cm TL southern herring (maximum size observed here and typically present in the river) has a maximum width < 16 mm (Broadhurst et al., 2012).

Considering the above, and the lack of any evidence of size selection, it is possible that at least some small fish (across all sizes) were able to actively swim forward after detecting the narrower 16 mm bars in the grid and out of the exit—implying a behavioral response. A contributory influence may have been the proximity (<1.2 m) of the grid to the end of the codend (Broadhurst et al., 2002). Previous studies have shown that at this distance there is significant displacement of water forward that can assist small fish to maintain position (Broadhurst et al., 1999; 2002). Any such effects might have facilitated some small fish, including glassfish and southern herring, to escape via the grid opening, and might also contribute towards the consistent passage of all small fish through the anterior section of the square-mesh codend (Broadhurst et al., 2002).

The results from this study imply that as a starting point, the bar spaces in Nordmøre grids (and perhaps other similar separating grids, such as those used to reduce catches of sea turtles) can be reduced to a size approaching the maximum CW of the targeted penaeids. Doing so will not only maintain the escape of large animals (e.g., sea turtles and elasmobranchs), but might also facilitate some behavioral escape of teleosts similar in size to the penaeids and certainly mechanical separation among those individuals that are larger (often encountered at different areas and times; Broadhurst et al., 1996). The latter is an important consideration because ideally, wherever possible, a single BRD would fulfill species-selectivity requirements, and especially for small-scale fisheries with multi-trawl configurations that generally preclude incorporating complex BRD combinations. Such work warrants ongoing attention, because despite historical efforts, bycatch in many fisheries remains a global concern that still requires applied solutions (Hall and Mainprize, 2005).

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