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Benefits of conventional anterior codend meshes turned 90° in an Australian trawl fishery are limited to an improved quality of *Neoplatycephalus conatus*

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Turning conventional diamond-shaped meshes 90° ('T90') in trawl extensions or codends is a simple modification for consistently increasing lateral openings and has improved size selection in several European fisheries. Here we investigate the effects of an industry-instigated cylinder of T90 meshes in the anterior codend of a trawl fished in the Great Australian Bight. Compared to the traditional codend (~5.4 m long) comprising a 93.5-mm stretched mesh opening (SMO) and double 4.1-mm-diameter twine throughout, the new T90 configuration comprising ~3 m of the same mesh turned 90° in the anterior section did not significantly affect catches of any discarded or retained species, or sizes of the primary target, deepwater flathead, *Neoplatycephalus conatus*. The only significant impact of T90 was a slightly improved quality of deepwater flathead (determined by the 'quality index method'), attributed to some release of abrasive debris from the codend. The absence of any effects of the T90 mesh on selection might reflect the small mesh size relative to most key species and the thick twine which probably negated some of the anticipated increases in lateral mesh openings. The results reiterate the need to match the mesh perimeter to the sizes of the key target prior to efforts at maximising lateral openings (*via* various established technical options), but nevertheless imply the benefits of T90 mesh may extend beyond selection.

KEYWORDS

bycatch reduction device, catch quality, fish trawl, selectivity, T90

Introduction

Demersal fish trawling is among the world's most common fishing methods, responsible for ~25% of the total ocean harvest (~98 m t; Pauly et al., 2020), but owing to poor selectivity, also ~30% of global discards (Pérez Roda et al., 2019). Concerns over the cascading effects of discard mortalities have evoked numerous efforts at improving fish-trawl selectivity, usually by modifying codends because this is where most selection occurs (Kennelly and Broadhurst, 2021).

Ideally, codend mesh openings should match the size/shape of the smallest targeted species. However, conventional diamond meshes ('T0') have inconsistent openings, which reach a maximum of ~35% of the stretched mesh opening (SMO) immediately in front of the catch, but then taper forward to 15%–25% of SMO (Robertson, 1986; Robertson and Stewart, 1988). Such variability often produces less-than-ideal size selection.

There are simple options for improving lateral mesh openings in codends. One method is to attach so-called 'lastridge' ropes along the codend/extension, usually at ~70%–95% of the total stretched length, forcing meshes to remain open (Robertson and Stewart, 1988; Ingólfsson and Bronkholf, 2020). Other methods are to turn some, or all, meshes in the codend to either 45° ('T45') or 90° ('T90') which forces wider and consistent lateral openings (Robertson and Stewart, 1988; Moderhak, 1997).

While effective, there are operational issues with alternative mesh orientations. Specifically, compared to T0 meshes, T45 meshes can distort and are weaker, while T90 meshes can eventually assume a diamond shape (although strength remains) (Madsen, 2007). Installing lastridge ropes along codends/extensions comprising either T45 (Broadhurst et al., 1999b) or T90 meshes (Einarsson et al., 2021) has minimised the above operational issues in crustacean trawls, implying utility among fish trawls, although there have been few studies (Kennelly and Broadhurst, 2021).

Anecdotal industry reports from an Australian fish-trawl fishery in the Great Australian Bight (10 fishing licences) suggest that compared to traditional codends comprising ~94-mm T0 mesh throughout (~55 meshes long × 100 meshes in circumference), substituting the anterior ~56% of the codend with four panels of the same 94-mm mesh turned 90° and with shortened lastridge ropes (by 17%) improves selection for the key target, deepwater flathead, *Neoplatycephalus conatus* (typically >35 cm TL). Further, by allowing sand and small abrasive debris to escape the codend, the T90 mesh reportedly reduces dermal damage to fish and improves their quality and price. However, no formal trials have been done to test either of the above assertions. The aims here are to address the deficit and test a four-panel, T90 anterior codend section with lastridge ropes against the traditional T0 codend.

Materials and methods

The experiment was done in the Great Australian Bight, Australia (33.12°S; 128.06°E to 33.27°S; 129.40°E), during 6 consecutive days and nights from 1 December 2021 using a trawler (35 m and 500 Kw) rigged with a conventional, single two-seam trawl (41-m headline, with nominal 152- and 120-mm SMO in the wings and body) attached to 20- and 200-m bridles and sweeps and spread by steel V-otter boards. The posterior body (100 meshes in the transverse direction–T) was configured to enable different extensions (larger-mesh section connecting the codend to the body) and codend sections (i.e., smaller-meshed bag where the catch accumulates) to be attached (below). The vessel had a Scanmar trawl monitoring system to measure otter-board spread, a Lowrance global positioning system (GPS) to record distance and speed over the ground (SOG), and a Furuno echo sounder for fishing depth.

Codends tested

Two identical extension sections, a T0 codend and a partial T90 codend, were each constructed from the same panels of braided knotted netting (green polyethylene; PE), which were measured for 15 replicate samples of SMO and twine diameter (Ø) to the nearest 0.1 mm using a purpose-built gauge and Vernier callipers, respectively (Figure 1). Both extensions and codends were the same total lengths and comprised four panels (with four lastridge ropes). The extensions had mean mesh sizes (± SE) of 105.5 ± 0.4 mm SMO (3.9 ± 0.0 mm Ø twine) and measured 24.5 meshes in the normal direction (N) and 100 T creating T0 meshes (Figure 1). Each extension had lastridge ropes (for strength) made from 24-mm Ø twisted polypropylene (PP) and the same lengths as the stretched meshes (Figure 1). A 3.4-m length of rope (4.0-mm Ø PP) was secured at one end of the last row of meshes in each extension to secure these to the posterior trawl body.

The two extensions were attached to either a traditional 'T0' or new 'T90' codend, both made from 93.5 ± 0.3 mm SMO with double 4.1 ± 0.0 mm Ø twine (Figure 1). The T0 codend measured 54.5 N × 100 T and had four lastridge ropes the same as those for the extensions (at the panel junctions) (Figure 1A). The T90 codend had a posterior section (24.5 N × 100 T) identical to the T0 codend but a different anterior section: comprising T90 (50 T × 66 N). Four lastridge ropes (16-mm Ø Dyneema^{TM}) extended throughout the codend and were 83% of the stretched T90 length (or ~60% of the traditional T0 SMO) in that section, and the same length as the T0 codend in the posterior section (Figure 1B).

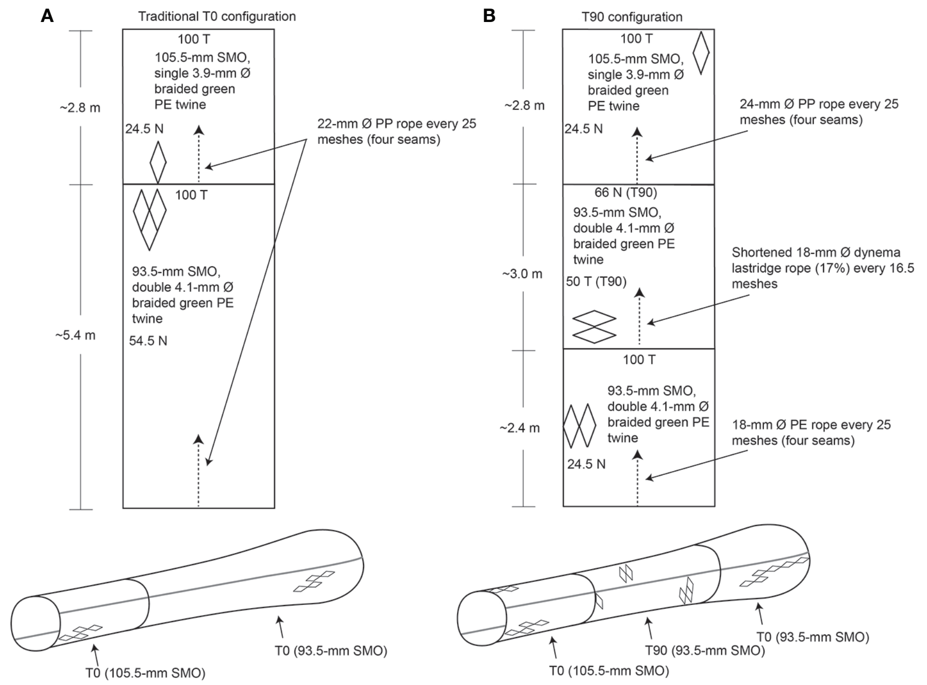

FIGURE 1
Schematic diagram of the **(A)** traditional T0 and **(B)** new T90 codends. Ø, diameter; N, normal direction; T, transverse direction; SMO, stretched mesh opening; PE, polyethylene; PP, polypropylene.

Sampling protocol and data collected

The two codend/extensions were alternately attached to the trawl and fished in pairings across similar depths and locations, providing four deployments (~3.5–5.0 h) every 24 h, during 6 days (i.e., 24 replicates). Technical data included swell height (m), fished location, distance (km) and duration (h; winch brakes on and off), otter-board spread (m); SOG (ms^{-1}), and depth (m) of the trawl. The latter three variables were logged every ~15 min to provide an average deployment^{-1}.

After retrieval, the codend was emptied into an area with a measured volume, and the total catch weight was estimated. Retained catches were separated and boxed before weighing and counting. The total weight of discarded catch (bycatch) was estimated by subtracting the retained component from the total catch. A subsample of discards was then assessed. All discards were then individually counted and weighed in the subsample and extrapolated to the total. Randomly selected subsamples of deepwater flathead (up to 115 deployment^{-1} or ~one-third of catches) were measured to the nearest 0.5-cm TL.

For most deployments, an additional 15 deepwater flathead were randomly selected (~45 to 55 cm TL) after being placed in boxes (deceased and prior to freezing) and assessed for physical damage using a version of the 'quality index method' (QIM) (Nielsen, 2005). For each sample, 11 qualitative measures (describing skin, scales, gills, fins, eyes, and wounds) were recorded and scored between 0 and 3, according to worsening severity (STable 1). The sums of the 11 scores for each fish were then used to provide a datum describing individual physical condition/quality.

Data analyses

Data for otter-board spreads and standardized (ha^{-1} trawled and log-transformed to act multiplicatively) catches (numbers and weights) were analysed using linear mixed models (LMMs). The QIM scores were approximately Gaussian and also analysed with LMMs. In all models, 'codend' was considered fixed while 'pairs' were random. Additional covariates of 'SOG' and fishing 'depth' were also assessed in the LMM assessing variability among otter-board spread, while 'total catch weight', depth, and 'tow duration' were used in the LMM assessing QIM data. The significance of terms was determined using likelihood ratio tests (Millar, 2011).

Relative size frequencies of deepwater flathead were explored for statistically significant differences between the codends by using the 'SELECT' (Share Each LEngths Catch Total; Millar, 1992) model to fit a cubic regression spline to the proportions at length of all retained fish that were retained in the trawl with the

T90 codend. This catch-comparison analysis was implemented using the SELECT R package which includes bootstrap functionality to allow for between-haul variability (Millar et al., 2004; Millar, 2021). A permutation test was also used (10,000 resamples) to assess for any statistical significance of codend configuration (Broadhurst and Millar, 2022). All analyses were done in R (R Core Team, 2021).

Results

The 24 replicate tows (3.4–5.0 h; mean ± SE of 4.8 ± 1.1 h) were at consistent SOG (3.0–3.4; 3.1 ± 0.0 ms^{-1}) and depths (112–148; 125.5 ± 3.0 m) and across comparable weather (mostly swell <0.6 m). Otter-board spread was not significantly affected by the codends tested (LMM, $p > 0.05$) but was significantly and positively influenced by fishing depth (LMM, $p < 0.05$).

In total, 58.5 t (>63 species) was caught, of which 19.1 and 39.4 t were retained and discarded, respectively; however, 74% of the latter was wide stingaree, *Urolophus expansus* (STable 2). Nine retained and three discarded species (92% of total catches) were caught in sufficient quantities to test for effects on their catches due to codends, but there were no significant differences among any of their weights or numbers (LMM, $p > 0.05$; Table 1).

Similarly, the permutation test established that the proportion of the total catch (combined over the T0 and T90 codends) of deepwater flathead (32.5–80.0 cm TL, but mostly 40.0–50.0 cm TL) caught in the T90 codend did not depend on TL. That is, there was no significant difference in the size selection of deepwater flathead due to codend (p = 0.7; Figure 2).

The only significant effect of codend was restricted to log-transformed QIM scores for deepwater flathead ($p < 0.05$). The parsimonious model eliminated effects of total catch or SOG and revealed a significantly lower score among those fish caught in

TABLE 1 Summary of catches (and their totals) tested in mixed-effect models assessing the importance of codend configuration and the means ± SE ha^{-1} trawled separated for the T0 and T90 codends.

Variable		Mean (± SE) ha^{-1} trawled	
Retained catches	**Total amount**	**T0 codend**	**T90 codend**
Wt of total	19,123.8	1.85 (0.15)	1.87 (0.18)
Wt of deepwater flathead, *Neoplatycephalus conatus*	6,910.0	0.74 (0.03)	0.59 (0.06)
No. of deepwater flathead	9,006	0.97 (0.07)	0.78 (0.09)
Wt of latchet, *Pterygotrigla polyommata*	3,213.9	0.27 (0.10)	0.33 (0.13)
No. of latchet	12,342	1.05 (0.45)	1.24 (0.56)
Wt of gummy shark, *Mustelus antarcticus*	1,995.8	0.23 (0.10)	0.20 (0.07)
No. of gummy shark	691	0.09 (0.05)	0.06 (0.02)
Wt of ocean jacket, *Nelusetta ayraudi*	1,624.5	0.17 (0.06)	0.15 (0.08)
No of ocean jacket	2,904	0.27 (0.10)	0.31 (0.18)
Wt of bight redfish, *Centroberyx gerrardi*	954.6	0.09 (0.04)	0.10 (0.05)
No. of bight redfish	681	0.06 (0.02)	0.08 (0.04)
Wt of ornate angelshark, *Squatina tergocellata*	951	0.08 (0.01)	0.10 (0.03)
No. of ornate angelshark	114	0.01 (0.00)	0.01 (0.00)
Wt of yellowspotted boarfish, *Paristiopterus gallipavo*	946.5	0.09 (0.03)	0.09 (0.02)
No. of yellowspotted boarfish	594	0.06 (0.02)	0.06 (0.02)
Wt of red gurnard, *Chelidonichthys kumu*	506.5	0.04 (0.01)	0.06 (0.02)
No. red gurnard	688	0.06 (0.02)	0.08 (0.03)
Wt of knifejaw, *Oplegnathus woodwardi*	253.4	0.02 (0.01)	0.03 (0.01)
No of knifejaw	289	0.03 (0.01)	0.03 (0.01)
Discarded catches			
Wt of total	39,439.8	3.25 (0.83)	4.72 (1.68)
Wt of wide stingaree, *Urolophus expansus*	29,118.0	2.12 (0.72)	3.84 (1.67)
No. of wide stingaree	47,484	3.43 (1.16)	6.22 (2.68)
Wt of jackass morwong, *Nemadactylus macropterus*	287.7	0.02 (0.01)	0.03 (0.01)
No. of jackass morwong	637	0.06 (0.02)	0.06 (0.02)
Wt of latchet, *Pterygotrigla polyommata*	5,960.7	0.64 (0.29)	0.53 (0.12)
No. of latchet	23,874	2.37 (0.97)	2.29 (0.52)

Random blocking effects for all models included 'pairs of deployments'. Weights (Wt) in kg. All variables were Ns at $p > 0.05$.

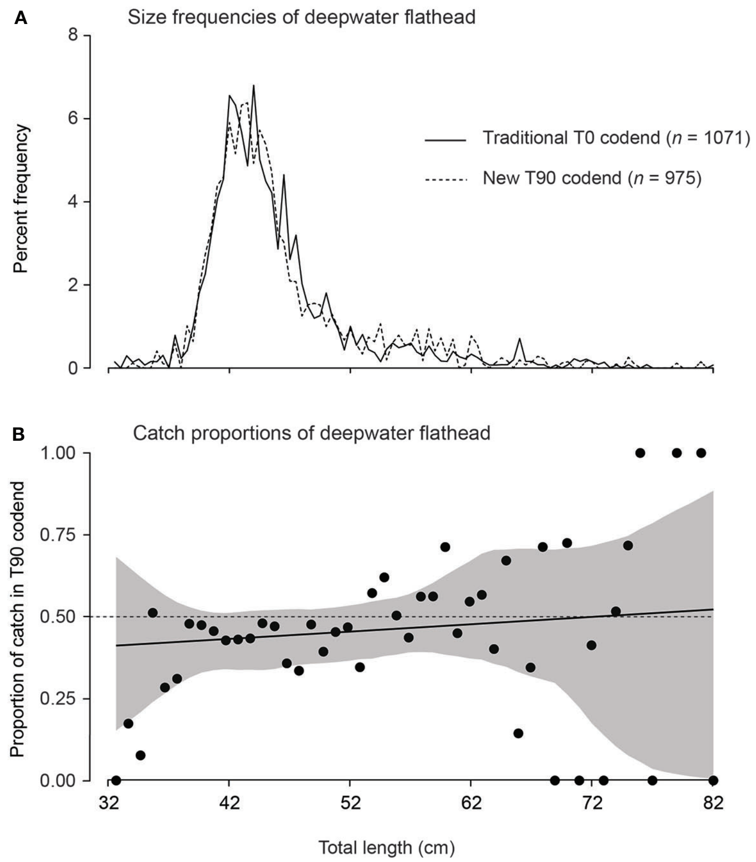

FIGURE 2
(A) Relative size-frequency plots for deepwater flathead, *Neoplatycephalus conatus*, retained in the traditional T0 and new T90 codends, and **(B)** plot of catch proportions with 95% confidence intervals designated by the shaded area and the horizontal dashed line marking 50% retention.

the T90 codend (predicted mean ± SE of 0.3 ± 0.01) than conspecifics in the T0 (0.2 ± 0.01). This result was due to slightly fewer cuts and a more natural belly colour (STable 1).

Discussion

The data here contribute toward ~20 primary literature studies since 1997 assessing T90 codends or part thereof (Kennelly and Broadhurst, 2021) and represent one of the few efforts outside European trawl fisheries (but see Lomelli et al., 2017; Cheng et al., 2020). However, contrary to general consensus, turning conventional meshes 90° in the anterior section (55%) of the codend here did not improve any species selection or size selection for deepwater flathead. Rather, significant effects were limited to a marginal improvement in fish quality. These outcomes can be discussed by considering the sizes of the abundant species and likely low selectivity of existing mesh—either as T0 or T90—but potentially improved movement of water through the latter meshes. Assuming validity of these suppositions, the data can then be used to suggest future modifications.

Previous studies assessing T90 throughout codends or only in anterior sections have shown increased sizes at 50% retention for various species (especially round fish including cod, *Gadus morhua*, haddock, *Melanogrammus aeglefinus*, and red mullet, *Mullus barbatus barbatus*), and often with maintained (e.g., Moderhak, 1997) or even reduced selection ranges (e.g., Wienbeck et al., 2011; Lomeli et al., 2017). Despite their name, like all platycephalids, deepwater flathead is not a 'flatfish', with congenerics having a maximum height-to-width ratio of ~0.5, which corresponds to the T90 shape (Broadhurst et al., 2006). Consequently, body shape is unlikely to have prevented small deepwater flathead from escaping. Instead, the relatively small mesh perimeter of ~187 mm clearly precluded egress of most sizes encountered, regardless of mesh orientation.

No published data are available on the morphometrics of deepwater flathead, but Broadhurst et al. (2006) showed that at maximum girths of 187 mm (mesh perimeter here), two platycephalids—the eastern blue spotted flathead, *P.*

caeruleopunctatus, and spikey flathead, *Ratabulus diversidens*—had TLs of 42.6 and 40.5 cm, respectively. These sizes are at the lower range of the deepwater flathead observed here. Potentially, if encountered, smaller deepwater flathead would escape through the T90 mesh.

Nevertheless, although not measured, several other species (especially discarded latchet, *Pterygortrigla polymnata*) were caught at sufficiently small sizes to pass through the mesh. These individuals should have had opportunity to escape, assuming the catch built up sufficiently, increasing the displacement of water forward and assisting some individuals to maintain position at the T90 cylinder (Broadhurst et al., 1999a). However, the double 4.1-mm Ø twine (thickness ~9% of the SMO) probably confounded selection (regardless of mesh orientation), considering the known negative implications of increasing twine diameter (e.g., Herrmann et al., 2013).

While there were no effects of T90 on relative size or species selection, the QIM data support the fishers' assertion of an improved physical quality of deepwater flathead (and better price). Other studies assessing similar codend changes (e.g., alternate materials or designs) to improve catch quality have shown comparable marginal (Brinkhof et al., 2021) or non-significant impacts (Tveit et al., 2019; Jensen et al., 2022). Much of the improved quality of deepwater flathead was attributed to fewer cuts/abrasions and possibly because the T90 cylinder allowed small debris to pass out of the codend, which would have been facilitated by the water displaced forward (Broadhurst et al., 1999a). Nevertheless, any explanation remains speculative and additional data are required to better quantify improvements in the landed-catch quality and temporal preservation implications due to the T90.

Conclusions

Unlike previous published studies assessing similar sizes or smaller T90 (to conventional T0) mesh in codends, we failed to show any selectivity improvements (Kennelly and Broadhurst, 2021). This anomaly might reflect research bias, where only positive effects are published, but it is also likely other gear parameters, including the small mesh size and double twine used, would have limited selection. Future research might benefit from assessing T90 in a slightly larger mesh size and/or a single twine in either the anterior section, or throughout the codend.

Beyond reducing unwanted catches of some small deepwater flathead when present, and other species, greater lateral mesh openings might further improve catch quality. However, because volume negatively affects catches through increased interactions, reducing unwanted catches of wide stingaree (~50% of the total catch) would be warranted. The small average weight (~0.6 kg) and sizes of the wide stingarees might preclude mechanical-separating grids. Anterior-trawl modifications, including changes to ground gears and/or dropout panels, might have greater utility, but will require consideration given that wide stingarees and deepwater flathead maintain similar positions on the substrate.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was reviewed and approved by the NSW DPI Animal Care and Ethics Committee (ACEC REF 08-06).

Author contributions

Credit authorship: Conceptualization (MB, RM, and IK); Data curation (MB, IK); Formal analysis (RM); Funding acquisition (MB, IK); Investigation (MB, IK); Methodology (MB, RM, and IK); Project administration (MB); Resources (MB); Software (MB and RM); Supervision (MB); Validation (MB); Visualization (MB, RM, and IK); Roles/Writing – original draft (MB); Writing – review & editing (MB, RM, and IK). All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author IK was employed by Fishwell Consulting.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.951549/full#supplementary-material

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