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# No deleterious circumference effects for T90 codends in an Australian fish trawl targeting tiger flathead, *Platycephalus richardsoni*

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In an attempt to improve the selectivity of Australian fish trawls targeting tiger flathead, *Platycephalus richardsoni* (≥28 cm total length), the utility of four-seam codends with shortened lastridge ropes and comprising 71-mm meshes turned 90° (T90) hung at the narrowest and widest coherent circumferences was compared against a traditional 91-mm diamond-mesh (T0) codend. Significant effects of codend configuration were limited to an increase in the catches of another commercially important species, latchet, *Pterygotrigla polyommata*, by both T90 codends, and greater escape of some small tiger flathead from the wide 71-mm T90 codend than from the 91-mm T0 codend. Notwithstanding a need to investigate slightly larger T90 mesh sizes for the fishery, the data imply that unlike most codend configurations, circumference does not negatively affect selection in the stated designs and might not require future regulation.

KEYWORDS
bycatch, selectivity, T90, fish trawling, discard

## Introduction

In Australia, the most economically important fish-trawl fishery is the southeastern "Commonwealth trawl sector" (CTS; valued at ~$40 million), which involves ~30 vessels towing single-rigged trawls with a minimum legal stretched mesh opening (SMO) of 90 mm in the codend and retaining up to ~120 commercial species (~20 targeted), among which the platycephalid tiger flathead, *Platycephalus richarsoni*, dominates catches and is also one of the smallest-sized (Broadhurst et al., 2023). Vessels also discard non-commercial catches comprising >280 species and 40%–60% by weight of the total catches—an upper rate almost double the global average (Pérez Roda et al., 2019).

All targeted species are managed by quota, but tiger flathead is the only one with a legislated minimum legal total length (MLTL), currently 28 cm TL, which corresponds to a girth of ~130 mm, or the perimeter of a ~65-mm mesh (Hunt et al., 2014). While the girths of all 28-cm TL tiger flathead are considerably smaller than the perimeter of the legislated 90-mm mesh, it is well established that conventional diamond-shaped meshes (termed "T0") in trawl codends often have very narrow lateral mesh openings (Kennelly and Broadhurst, 2021). Key affecting factors include, but are not limited to, the twine diameter (Sala et al., 2007), codend circumference (Graham et al., 2009), towing speed (Sala et al., 2007), and catch weight (O'Neill et al., 2008). Interactions between factors typically mean T0 codend meshes open to ~0.25–0.35× the SMO and, therefore, have to be much larger than the girths of fish at MLTL to maintain appropriate selectivity (Graham et al., 2009).

To reduce lateral mesh openings in 90-mm SMO codends and retain legal-sized tiger flathead, CTS trawlers legally use up to 8-mm-diameter (Ø) single or 6-mm Ø double braided twine. However, these conventional configurations likely produce considerable variability in mesh openings (Kennelly and Broadhurst, 2021). Two simple methods of maintaining consistent lateral mesh openings in codends (to approach 0.5× the SMO) are to turn some or all meshes either 45° ("T45" or square mesh; Sala et al., 2008) or, more recently, 90° (T90; Wienbeck et al., 2011), and/or include shortened ropes ("lastridge" ropes; Ingólfsson and Brinkhof, 2020) down the sides of a codend to reduce tension on the netting. Notwithstanding considerable species-specific variability, slightly smaller sizes of T90 mesh in codends constructed with four seams and shortened lastridge ropes can select fish over narrower size ranges than larger, conventional T0 meshes (without these design modifications; Kennelly and Broadhurst, 2021).

Despite improved consistency in lateral mesh openings, similar to T0 codends, there will be influencing factors affecting T90. In particular, there remains limited information on the effects of circumference on T90 codend performances, although increasing circumference reduces the selection of T0 codends, and less so for T45 codends (Kennelly and Broadhurst, 2021). The relatively few studies assessing T90 codends have tested treatments across various circumferences, including at 50% (Wienbeck et al., 2011), 60% (Einarsson et al., 2021), 66% (Digre et al., 2010; Cheng et al., 2020; Robert et al., 2020; Broadhurst et al., 2022), 80% (Kopp et al., 2018), 85% (Ingólfsson and Brinkhof, 2020), and 100% (Lomeli et al., 2017; Sola and Maynou, 2018) of the stretched circumference of the conventional T0 codends. Most of these T90 codends did not have shortened lastridge ropes (but see Einarsson et al., 2021; Broadhurst et al., 2022).

Greater clarity on the effects of the circumference of T90 codends is required considering there are few studies and at least some species-specific effects. For example, doubling the circumference of T90 codends without lastridge ropes decreased size selection for Atlantic cod, *Gadus morhua* (Wienbeck et al., 2011; Veiga-Malta et al., 2019), but had no effect on bogue, *Boop boops* (Ilkyaz et al., 2017). Given the above, here we sought to test the hypothesis of no differences in the relative size and species selection of a conventional T0 codend and two new smaller-meshed, four-seam T90 codends at two circumferences and with shortened lastridge ropes when targeting tiger flathead in the CTS. Specifically, the T0 codend comprised conventional ~91-mm SMO, while the T90 codends were made from ~71-mm SMO—chosen to approach the approximate girth of 28-cm TL tiger flathead—and were constructed with circumferences of ~66 and 100% that of the stretched T0 codend.

## Materials and methods

The experiment was done off Ulladulla, New South Wales (37.35°S; 150.46°E) between 12 April and 1 August 2023 using the 23-m "FV Francesca". Onboard equipment included a Notus trawl-monitoring system to measure otter-board spread and a Lowrance global positioning system (GPS) to record the distance travelled and speed over the ground (SOG). The Francesca fished a conventional two-seam trawl body (42-m headline length) made from knotted, braided polyethylene (PE) twine, comprising 104- to 146-mm SMOs throughout and attached to 24-m bridles, 274-m sweeps (20-mm Ø rope), and 600-kg steel otter boards (Broadhurst et al., 2023). A lengthener (extension) made from nominal 104-mm T0 mesh (3.5-mm Ø twine) and measuring 100 meshes in the normal direction (N) and 130 meshes in the transverse direction (T) was attached posterior to the trawl body to facilitate swapping three codends (below; Figure 1). The lengthener had two 6-m lengths of 16-mm Ø braided polyamide ropes sewn along the side seams at the same length as the stretched meshes to distribute the load of the four shortened lastridge ropes on the T90 codends described below.

### Codends

Three new, short lengthener and codend sections were constructed from green, braided (PE) netting (Figure 1). During construction, all netting was measured for 20 replicate SMOs to the nearest 0.5 mm using a purpose-built gauge and twine Ø (nearest 0.1 mm) using Vernier calipers. The short lengtheners were identical and made from a mean SMO ( ± SE) of 90.6 (0.2)-mm T0 mesh (3.4 ± 0.1-mm twine Ø) measuring 30 N × 130 T and were attached to one of three codends that differed in their mesh sizes, twine diameters, and/or circumferences (Figures 1A-C).

The first codend design was the conventional "91-mm T0" and was made from 90.6 (0.2)-mm mesh (6.2 ± 0.1-mm Ø twine) and measured 30 N × 100 T (Figure 1A). The second and third codends comprised the same 70.9 (0.2)-mm mesh made from 3.6 (0.1)-mm-diameter twine turned 90° and were constructed from four panels with 16-mm Ø Dynema® lastridge ropes attached at the junction of each (17% shorter; Broadhurst et al., 2022) (Figures 1B, C). Both codends measured 49 meshes long, but one ("narrow 71-mm T90") had 86 meshes in circumference (i.e., 66% of the 91-mm T0 codend circumference; Figure 1B), and the other ("wide 71-mm T90") measured 130 meshes in circumference (i.e., 100% of the 91-mm T0 codend circumference; Figure 1C). For the T90 codends, the lastridge ropes were paired into two bridles at the short lengthener on each side and then shackled to the ropes running along the main

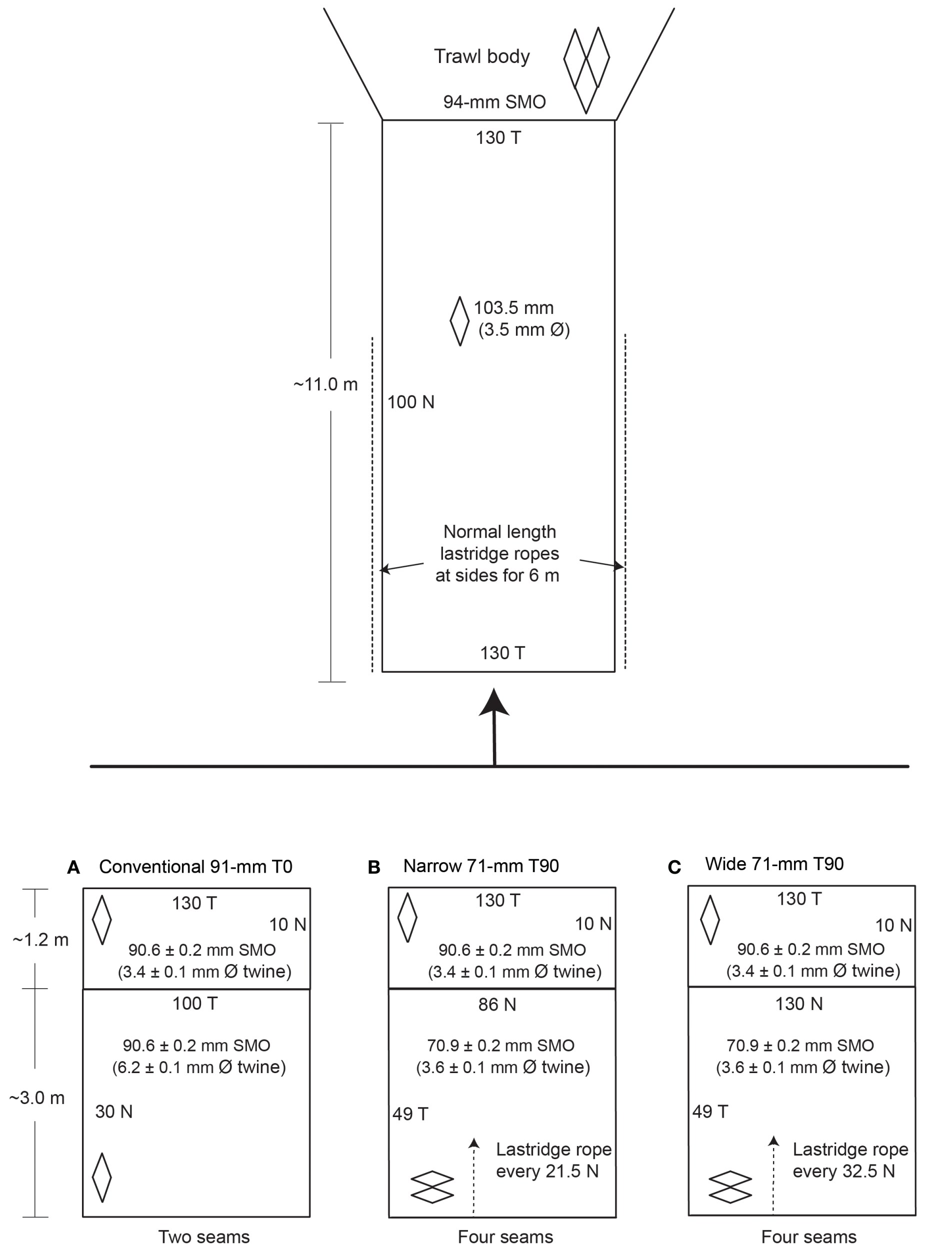


FIGURE 1
Diagram of the main trawl lengthener and short lengtheners attached to the **(A)** conventional 91-mm T0 codend, and **(B)** narrow and **(C)** wide 71-mm T90 codends. SMO, stretched mesh opening; T, transversals; N, normals; Ø, diameter.

lengthener when the codends were secured by lacing lengtheners together with 4-mm Ø polyamide rope.

## Experimental design and data collected

The three codends were alternately fished on the trawl in an attempted blocked design mostly comprising three deployments with two codends tested on each fishing day, and with two replicates of each codend every 2 days. Prior to deployment, the tested codend was attached, and the trawl was deployed across fishing grounds randomly selected from available options on each day according to weather conditions and encompassing the same depth ranges across replicate treatments.

Technical data collected included otter-board spread, start and end times of the deployments (otter boards on and off the bottom), total distance trawled, and SOG. At the end of each deployment, catches were emptied onto a confined area of the deck with a known volume and the total weight was estimated. Individuals of target and by-product species were separated and placed into 55-L boxes before weighing and counting. The remaining bycatch, including individuals of commercially important species smaller than the desired sizes, were sorted, and abundant non-commercial discards were counted and weighed. Subsamples of key species were measured to the nearest 0.5 cm TL.

## Data analyses

The hypothesis of no differences in SMOs and twine Øs between codends was analyzed using a linear model (LM). Data describing otter-board spreads were analyzed using a linear mixed model (LMM) comprising the fixed effects of "codend", "depth", and "SOG", and the random effect of "days". Depth and standardized ($ha^{-1}$ trawled) log-transformed catch variables were also analyzed with LMMs when data were >0 (log-transformed to act multiplicatively), or if the data were 0, generalized linear mixed models (GLMMs) with the Tweedie distribution were used. These models had codend and days as fixed and random effects, respectively. Any significant effects between the three codends were explored using false discovery rate (FDR) pairwise tests.

Generalized additive modeling (GAM) was used to fit relative size selectivity curves to scaled-up data (by deployment subsampling) for tiger flathead and abundant discarded species among each of the three possible pairings of the codends (Supplementary Material). This catch-comparison analysis was implemented using the SELECT R package, which includes bootstrap functionality to incorporate between-haul variability (Millar, 2021). A permutation test was used (1,000 resamples) to test for no TL effects due to codend configuration (i.e., relative selectivity is the same for all TLs; Broadhurst et al., 2022). Analyses were done in R (R Core Team, 2021).

# Results

The SMOs and twine Øs were significantly different between codends, with the 91-mm T0 codend having larger meshes (mean ± SE of 90.6 ± 0.2) and twine Øs (6.2 ± 0.1) than the T90 codends (LM and FDR, $p < 0.05$), which were identical (pooled means of 70.9 ± 0.2 and 3.6 ± 0.1 mm) (LM, FDR, $p > 0.05$). During 14 days at sea, we completed 12, 13, and 14 replicate deployments of the 91-mm T0, and narrow and wide 71-mm T90 codends over durations of 0.91 to 4.55 h and SOGs of 1.5 to 2.0 $ms^{-1}$. There was no significant difference in otter-board spreads (112.9 ± 2.2 m) of the trawl when attached to the three codends or the depths (102.2 ± 6.9 m) and areas (161.6 ± 10.4 ha) trawled (LMM, $p > 0.05$). Nevertheless, catches were standardized to $ha^{-1}$ trawled. Otter-board spread was significantly and positively associated with depth and SOG (LMM, $p < 0.01$).

The total catch was 28 t, of which 18.5 t (66%) was discarded, including ~7 t of elasmobranchs (Supplementary Table 1). More than 110 species were caught, but 13 comprised ~70% of the total, and these formed the analyses of species selection (Table 1).

## Species selectivity

Significant codend effects were limited to the numbers and weights of retained latchets $ha^{-1}$, which, while caught in low numbers (i.e., in only 2 hauls of the T0, but 13 hauls of the T90 codends), had mean catches that were similarly greater in the narrow (0.06 ± 0.04 and 0.07 ± 0.04 $ha^{-1}$) and wide 71-mm T90 codends (0.08 ± 0.03 and 0.02 ± 0.01 $ha^{-1}$) than in the 91-mm T0 codend (0.0003 ± 0.0002 and 0.001 ± 0.0008 $ha^{-1}$) (LMM and FDR $p < 0.05$, Table 1, Supplementary Material). Although not significant, the *p*-values for the number of retained and weights of discarded tiger flathead were 0.06 and 0.09, and with a trend of more retained in the narrow 71-mm T90 codend than the other two designs (Table 1, Supplementary Material). Similar non-significant differences were observed for several other variables, including the total retained and discarded weights (Table 1).

## Relative size selectivity

Sufficient size data were collected for tiger flathead and the abundant discard, round-snouted gurnard, *Lepidotrigla mulhall* (but not for latchet), to permit analyses. Significant TL effects were limited to tiger flathead caught in the wide 71-mm T90 vs. the 91-mm T0, whereby the GAM cubic spline showed the former codend retained proportionally fewer small fish and especially those <30 cm TL (permutation test, $p < 0.05$; Figure 2A). In contrast, the proportions of tiger flathead retained in the other two codend pairings and for round-snouted gurnard across all three paired comparisons remained consistent for all TLs (Figures 2B-F).

# Discussion

The data contribute toward the few studies exploring the effects of T90 codend circumference (Wienbeck et al., 2011; Veiga-Malta et al., 2019) and address the dearth of information describing any such effects in the presence of shortened lastridge ropes—which appear to help homogenize selection. While the tested 71-mm SMO minimally impacted tiger flathead catches, both T90 codends similarly retained more of another small by-product species, and without significantly affecting the weight of total discards. These findings support future directions for assessing generic T90 codends in fish trawls, and for maximizing their selective performances in the CTS.

It is difficult to rationalize mesh size and/or configuration in a multispecies fishery with different sizes and/or morphologies of fish because optimizing selection for one species invariably negatively or positively affects others (Broadhurst et al., 2023). Here, we aimed to improve size selection for tiger flathead using 71-mm mesh (~20% smaller than the conventional 90-mm mesh) that was slightly larger than the approximate girth of fish with 28 cm TL. However, this mesh was probably too small, although the almost significant differences for numbers and weights ($p$ = 0.06 and 0.09) and significant TL effects between the wide 71-mm T90 and conventional 91-mm T0 codends imply some small tiger flathead were able to escape more easily. Perhaps of greater importance is that, because there were no significant differences in any size or species selection between T90 designs, unlike for T0 codends (Graham et al., 2009), any increase in T90 mesh size could occur

TABLE 1 Summaries of significance from mixed-effects models testing for the effects of "codend" (91-mm T0 vs. narrow and wide 71-mm T90) on the numbers and weights of key retained and discarded species/groups, and mean catches (± SE).

| Variable | Codend | 91-mm T0 | Narrow 71-mm T90 | Wide 71-mm T90 |
|---|---|---|---|---|
| Retained catches | | | | |
| Total wt | Ns | 1.71 (0.42) | 1.85 (0.35) | 1.36 (0.18) |
| Wt of tiger flathead, *Platycephalus richardsoni* ≥28 cm TL | Ns | 0.20 (0.05) | 0.47 (0.08) | 0.29 (0.07) |
| No. of tiger flathead | $p$ = 0.06 | 0.50 (0.15) | 1.18 (0.21) | 0.70 (0.20) |
| Wt of eastern angel shark, *Squatina albipunctata* | Ns | 0.16 (0.12) | 0.22 (0.08) | 0.11 (0.03) |
| No. of eastern angel shark | Ns | 0.08 (0.07) | 0.04 (0.01) | 0.02 (0.01) |
| Wt of redfish, *Centroberyx affinis* | Ns | 0.07 (0.04) | 0.19 (0.07) | 0.08 (0.04) |
| No. of redfish | Ns | 0.40 (0.23) | 1.36 (0.66) | 0.48 (0.29) |
| Wt of eastern school whiting, *Sillago flindersi* | Ns | 0.21 (0.11) | 0.17 (0.09) | 0.06 (0.03) |
| No. of eastern school whiting | Ns | 3.57 (1.81) | 2.22 (1.18) | 0.89 (0.43) |
| Wt of red gurnard, *Chelidonichthys kumu* | Ns | 0.03 (0.02) | 0.07 (0.02) | 0.08 (0.04) |
| No. of red gurnard | Ns | 0.05 (0.02) | 0.13 (0.03) | 0.12 (0.05) |
| Wt of latchet, *Pterygotrigla polyommata* | ** | 0.00 (0.00) | 0.06 (0.04) | 0.08 (0.03) |
| No. of latchet | ** | 0.00 (0.00) | 0.07 (0.04) | 0.02 (0.01) |
| Wt of Gould's squid, *Nototodarus gouldi* | Ns | 0.01 (0.01) | 0.02 (0.01) | 0.01 (0.00) |
| No. of Gould's squid | Ns | 0.02 (0.01) | 0.04 (0.02) | 0.02 (0.01) |
| Wt of John dory, *Zeus faber* | Ns | 0.01 (0.01) | 0.03 (0.01) | 0.03 (0.01) |
| No. of John dory | Ns | 0.03 (0.01) | 0.04 (0.01) | 0.02 (0.01) |
| *Discarded catches* | | | | |
| Total wt | Ns | 2.63 (0.74) | 4.79 (1.74) | 1.81 (0.33) |
| Wt of round-snouted gurnard, *Lepidotrigla mulhalli* | Ns | 0.18 (0.07) | 1.19 (0.56) | 0.38 (0.12) |
| No. of round-snouted gurnard | Ns | 3.50 (1.15) | 22.48 (10.48) | 6.92 (2.16) |
| Wt of southern fiddler ray, *Trygonorrhina dumerilii* | Ns | 0.51 (0.22) | 0.75 (0.27) | 0.52 (0.25) |
| No. of southern fiddler ray | Ns | 0.17 (0.07) | 0.28 (0.08) | 0.22 (0.12) |
| Wt of tiger flathead <28 cm TL | $p$ = 0.09 | 0.02 (0.01) | 0.03 (0.01) | 0.01 (0.00) |
| No. of tiger flathead <28 cm TL | Ns | 0.17 (0.07) | 0.26 (0.07) | 0.10 (0.04) |
| Wt of redfish | Ns | 0.01 (0.00) | 0.18 (0.16) | 0.02 (0.01) |
| No. of redfish | Ns | 0.10 (0.05) | 0.45 (0.22) | 0.18 (0.10) |
| Wt of velvet leatherjacket, *Meuschenia scaber* | Ns | 0.07 (0.05) | 0.02 (0.01) | 0.02 (0.01) |
| No. of velvet leatherjacket | Ns | 0.17 (0.07) | 0.17 (0.06) | 0.16 (0.07) |
| Wt of Australian burrfish, *Allomycterus pilatus* | Ns | 0.04 (0.01) | 0.03 (0.01) | 0.03 (0.01) |
| No. of Australian burrfish | Ns | 0.08 (0.03) | 0.07 (0.02) | 0.07 (0.02) |

**$p < 0.001$; Ns, not significant; TL, total length.
The random effect of "days" was included in all models.

with flexibility in codend circumference (i.e., 66%–100% of a conventional T0 design).

Normally, increasing codend circumference in the absence of lastridge ropes negatively affects selection in T0 codends (Graham et al., 2009) and at least some T45 (Broadhurst and Millar, 2009) and T90 (Wienbeck et al., 2011) designs. These effects occur because excessive circumferences cause meshes to convolute under strain, which blocks some openings. The catch and size data imply no such effects here. Rather, the wide 71-mm T90 codend (but not the narrow 71-mm T90) had slightly improved selection over the 91-mm T0. Possibly, because the short lastridge ropes supported the weight of the codend during fishing, the T90 meshes did not

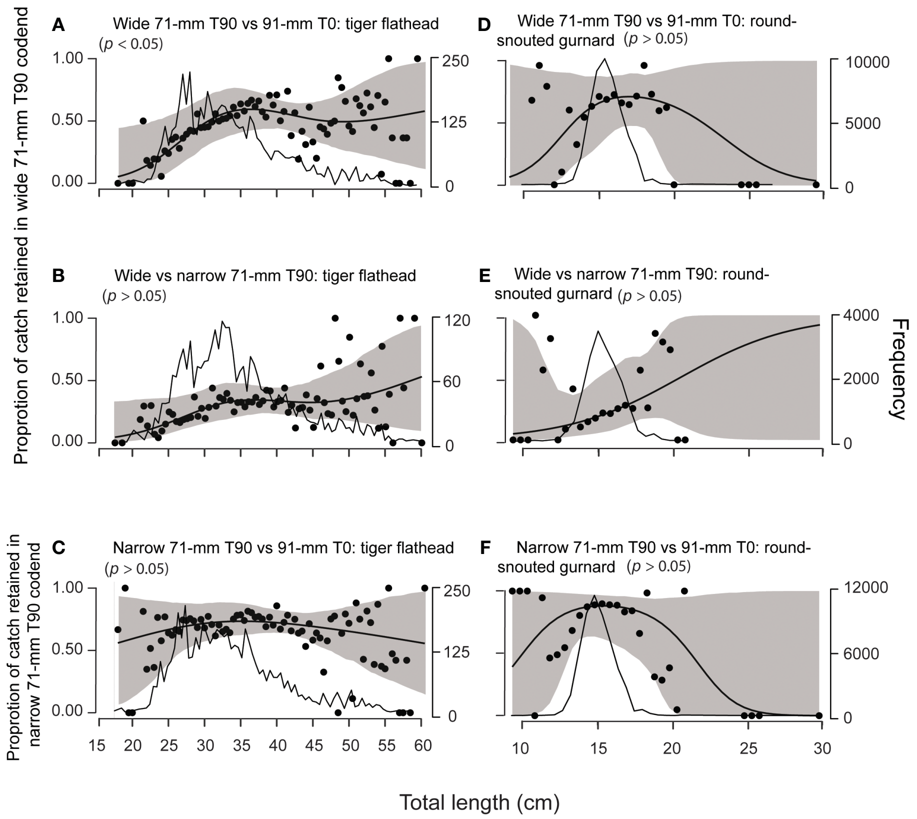


FIGURE 2
Cubic regression splines (solid lines) with 95% confidence intervals (gray) fitted to the proportions (black circles) of the combined catches (represented by continuous frequency curves) of each total length for tiger flathead, *Platycephalus richardsoni*, and round-snouted gurnard, *Lepidotrigla mulhalli*, from the **(A, D)** 91-mm T0 and wide 71-mm T90 codends that were retained in the latter, **(B, E)** narrow and wide 71-mm T90 codends that were retained in the latter, and **(C, F)** 91-mm T0 and narrow 71-mm T90 codends that were retained in the latter. The *p*-values (permutation test) for an effect of TL on relative selection are provided.

excessively convolute, and the wide 71-mm T90 codend simply provided more openings for small tiger flathead to escape.

Notwithstanding a similar general trend of relatively less total and discarded catches in the wide 71-mm T90 codend than the other designs, significance did not extend to any other variables, including catches of latchet, which was the only other species affected by the codends. Although quite low numbers were caught, and this species is of less importance than many others, latchet catches were similarly and significantly greater in both T90 codends, which may be explained by their small size and morphology. Latchet are thinner and more fusiform than tiger flathead, and many small individuals probably squeezed through the 91-mm mesh. Regardless of codend circumference, the smaller 71-mm mesh appeared more appropriate than the conventional 91 mm for latchet.

The consistent increases in catches of one by-product species, combined with evidence of a slight improvement in size selection for tiger fathead and no significant increase in discards by the 71-mm T90 codends, warrant additional work to examine similar designs with meshes between ~75 and 80 mm SMO. It might also be possible to use similar-sized T0 mesh and simply attach lastridge ropes. Greater clarity on the effects of shortened lastridge ropes as a controlled treatment is required, considering this is a very simple, inexpensive modification. Certainly, there would be minimal benefit in using T90 codends made with 75- to 80-mm mesh in the CTS without shortened lastridge ropes, because eventually meshes will distort—unless thicker twine is used but, similar to the conventional 90-mm T0 mesh codends, this would concomitantly reduce lateral openings (Kennelly and Broadhurst, 2021).

For some species in the CTS, selectivity might also be improved via additional posterior and anterior trawl modifications, and especially those used to reduce catches of some discarded elasmobranchs (which accounted for one-third of discards here). Nevertheless, there is resistance to major gear changes in many fleets and so, initially, simple options are required (Kennelly and Broadhurst, 2021). Regulating a more appropriate mesh size and/or configuration in the codends of CTS trawlers would be a coherent starting point for ongoing efforts to improve selection.

## 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 approved by Regional NSW Fisheries Animal Care and Ethics Committee (Ref no: ARA-FISH-0419 (08/06) Testing selective fishing gears in NSW commercial fisheries). The study was conducted in accordance with the local legislation and institutional requirements.

## Author contributions

MB: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. RM: Conceptualization, Data curation, Formal Analysis, Software, Visualization, Writing – review & editing.

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## Conflict of interest

The 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.2024.1341890/full#supplementary-material

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