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Title:

Adaptive bycatch reduction in penaeid trawls via rapid adjustments to headline height

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Reducing bycatch by changing headline height

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Adaptive bycatch reduction in penaeid trawls via rapid adjustments to headline height

Abstract Penaeid trawling is among the world's least selective fishing methods; a characteristic that has evoked spatial closures being implemented in some fisheries if certain bycatch limits are exceeded. For decades, considerable work has been done to develop modifications to penaeid trawls that reduce unwanted bycatches, with most focussed at the posterior section (i.e. codend). More recently, efforts have examined ways to prevent bycatch entry into trawls entirely—via modifications to anterior components. This study assessed the utility of proactively lowering the headlines of Australian penaeid trawls, using clips at the otter boards, to 68 and 54% of their conventional height, and demonstrated mean total bycatch reductions (by weight) of 69 and 79%, respectively, with no effects on the targeted Metapenaeus macleayi (Haswell). The results provide insights into the location and behaviour of various species in the water column preceding capture, and support a simple and easy method for regional fishers to use in situ to avoid excessive bycatch and associated fishing closures. More broadly, the data support ongoing efforts in other penaeid-trawl fisheries to reduce bycatches via similar, rapid adjustments to anterior components, depending on species-specific behaviours during capture.

KEYWORDS: bycatch reduction, headline height, penaeid trawls

1 | INTRODUCTION

For several decades, efforts to reduce bycatch have usually involved researchers developing solutions that are then trialled in fisheries, modified and eventually implemented as regulations (Kennelly, 2007; McHugh et al., 2017). Such work has resulted in a plethora of bycatch reduction devices (BRDs), as well as fishing industries that have become well-versed in their benefits and applications. A more current priority is to develop modifications that allow fishers to adjust gear selectivity quickly while at sea. Such modifications would be very successful in reducing overall bycatch (i.e. absolute quantities) because they would facilitate rapid implementation according to spatio-temporal variations in catches. They could also have utility under management regimes that involve bycatch limits—where excessive bycatches can lead to fishing closures (Little et al., 2015).

Penaeid trawls are one of the world's least selective fishing gears, catching large quantities of non-targeted fish and other organisms; the mortality of which is considered wasteful (Alverson et al., 1994; Kelleher, 2005). Despite decades developing various operational and technical modifications to reduce bycatch and/or discard mortality (reviewed by Broadhurst, 2000; McHugh et al., 2017) significant issues remain throughout many penaeid-trawl fisheries. Most developments have involved modifications at or near the codend, comprising grids or strategically positioned panels and meshes under the (mostly untested) assumption of minimal escape mortality (for reviews, see Broadhurst, 2000; Broadhurst et al., 2006; McHugh et al., 2017). Relatively less work has focused on anterior modifications to trawls. The argument her is that by developing modifications that stop bycatch from entering trawls, escape mortalities will be prevented, presumably with concomitant benefits for stocks.

While it is well known that higher headlines in fish trawls increase the capture of some fish (Fujimori et al., 2002), only a few studies have assessed the utility of reducing headline height to decrease bycatches in penaeid trawls (e.g. Broadhurst et al., 2013; 2016). The available work demonstrates a need to achieve sufficient headline height to maximise the capture of penaeids stimulated upwards by the ground gear, whilst lowering it sufficiently to minimise catches of fish and/or cephalopods (Stender and Barnes, 1994; Eayrs, 2002; Madhu et al., 2015). For example, Hines et al. (1999) compared high (3.7 m) and low (0.9 m, 24% lower) headline heights in skimmer trawls and, while the latter caught less total bycatch (by ~14%), catches of brown shrimp, *Farfantepenaeus aztecus* (Ives) were also significantly reduced (by up to 39%). By contrast, Johnson et al. (2008) observed 50% fewer fish in low- (0.8 m) than high- (1.2 m, 33% higher) opening otter trawls, with no significant differences in catches of school prawns *Metapenaeus macleayi* (Haswell), although swept area was not quantified and may have confounded comparisons. Broadhurst et al. (2016) assessed the utility of knot orientation (which affects panel lift and therefore headline height) and observed fewer catches (standardised to per ha trawled) of fish (by up to 67%), but also fewer school prawns (by 26%) in the lower-height trawl.

Unlike some retroactively fitted BRDs, varying headline height can be a relatively simple procedure which, if successful in reducing bycatch whilst maintaining catches of the targeted penaeids, may provide fishers with a simply way to adjust their fishing practices quickly and in response to high or low abundances of problematic species. This paper assesses the utility of such a system in an Australian estuarine penaeid-trawl fishery (which is subjected to variable spatio-temporal closures evoked by excessive bycatches), by testing the effects of three different headline heights on bycatch and targeted penaeids, whilst keeping all other parameters constant in a paired-tow experimental design.

2 | METHODS

2.1 | Experimental design

This study was done in Lake Wooloweyah, Australia, using a local trawler (10 m and 89 kW) fishing in ≈1.5–2.0 m across homogenous sand/mud substrata. The vessel was equipped with a Notus trawl monitoring system (to measure wing-end spread) and a Lowrance global positioning system (GPS) to record the distance trawled and speed over the ground (SOG). The trawler had 8-mm diameter (Ø) stainless warps and 10-m bridles (6-mm Ø stainless wire) on two hydraulic winches and attached to paired sets (i.e. double rig) of stainless-steel cambered otter boards (53.0 kg; 1.08 × 0.73 m; 0.79 m^2) (Fig. 1a).

Each otter board had conventional headline, ground-gear and foot-rope attachment points at the trailing edges. For the experiment, a 0.73-m length of 8-mm Ø chain was attached along the trailing edge of each otter board to provide multiple attachment points (i.e. at any of the chains links) for the headline (Fig. 1b). The headline attachments included: (1) the conventional ‘high’ attachment at 71 cm above the ground chain; (2) a ‘medium’ attachment at 48 cm (or 68%) above the ground gear; and (3) a ‘low’ attachment at 38 cm (or 54%) above the ground gear (and slightly above the midpoint of the otter board to maintain stability of the board; Fig. 1b). Snap clips that fit through the attachment points were shackled to 2.93-m sweeps and then to the ground gears, foot-ropes and headlines of two identical conventional trawls. The trawls comprised nominal 41-mm mesh (stretched mesh opening) throughout, 1N3B body tapers and rolled-rope ground gear with lead weights. All trawls were attached to extension sections (100 T × 30 N of nominal 40-mm mesh; with 28-mm bar spaced Nordmøre-grids installed) and codends (120 × 75 B; made from nominal 27-mm mesh hung on the bar).

At the start of the first day, each trawl was randomly assigned to a vessel side (i.e. otter-board pair) and the ground-gear and foot-rope sweeps were shackled to the otter boards (Fig.

1b). The headline heights were randomly assigned to compare the conventional high (71 cm) against each of the medium (48 cm) and low (38 cm) headline heights, and the latter two against each other (i.e. all three possible combination of configurations) in alternate, simultaneously paired 30-min deployments and with the paired Notus trawl sensors attached at the wing ends. The trawls were always deployed using 9.9 m of bridle (i.e. within ≈5 m of the vessel stern). The two trawls were swapped from side-to-side at the beginning and halfway through each trawling day, while the paired Notus sensors were swapped between trawls at the start of each day. A total of fourteen deployments of each headline-height configuration were done, with seven paired comparisons of each of the three possible combinations of configurations.

The technical data collected during each deployment included the total distance trawled (defined as otter boards on and off the bottom and obtained from the plotter and net monitoring system), SOG, and the averaged wing-end spreads (in m; recorded every 1 min for 15 min on alternate sides of the vessel). The depth of fishing and distance of the trawls behind the vessel remained constant. Collected biological data included the total weights of school prawns and bycatch, the numbers of each bycatch species, and total lengths (TL rounded to the lower 0.5 cm) of any teleosts caught. Random samples of school prawns were placed into plastic bags and transferred to the laboratory, where 100 individuals were measured (carapace length; CL rounded to the lower 1 mm) and weighed. The latter data were used to estimate the total numbers of school prawns caught during each deployment.

2.2 | **Data analyses**

Data describing engineering and catch variables were analysed in linear mixed models (LMM) with 'headline height' considered fixed, while 'trawls', 'Notus sensors', 'vessel sides' and 'days' and the interaction between 'deployments' and days were included as random terms. Engineering variables were analysed raw. Speed over the ground was considered as a covariate in the LMM for wing-end spread and assessed based on the lowest value for Akaike's information criterion (AIC; Akaike, 1974). Data for school prawns, total bycatch and other species caught in sufficient numbers for individual analysis were considered both as (1) absolute and (2) standardised to per ha trawled using the swept area of the trawl (calculated by average wing-end spread × distance trawled). In both cases, data were log-transformed so that differences between gears were modelled to act multiplicatively. The significance of gear configuration was determined using a Wald F-test and any significant differences were subsequently explored using the Benjamini-Hochberg-Yekutieli procedure to control the false discovery rate (FDR). Models were fitted using ASReml in R 2.15.3 (The R Project for Statistical Computing; http://www.r-project.org/).

To determine if lowering the headline had an effect on school prawn size-selectivity, a length-dependant catch-comparison analysis (SELNET; Herrmann et al., 2012) was conducted following the methodology of Krag et al. (2015) and including recent model improvements developed by Herrmann et al. (2017). Each combination of headline heights was analysed separately. One thousand bootstrap repetitions were performed to calculate the Efron 95% Confidence Intervals (CI; Efron, 1982) for the modelled catch comparison curves using a double bootstrap method (Millar, 1993). The quality of the model fits was assessed on the basis of the fit-statistics: p-value, deviance and degrees of freedom (Wileman et al., 1996).

3 | RESULTS

Fourteen deployments of each headline-height configuration were done during three days, with seven paired comparisons of each of the three possible combinations of configurations. It took ≈1 minute to change headline heights among trawls and deployments. Nineteen species were caught, and while catches were low, they were all within the range of conventional deployments (Table 1).

There were no significant differences in trawl wing-end spread and distance and area trawled due to reducing headline height, although the means increased slightly (LMM, $p > 0.05$; Table 2). Including SOG in the LMM for wing-end spread produced a lower AIC, but the covariate was not significant ($p > 0.05$). There were no stability problems with the otter boards attached to the lower headline heights.

There were similarly no effects of headline height on the absolute or standardised (per ha trawled) numbers or weights of school prawns (LMM, $p > 0.05$; Table 2; Fig. 2a,b). However, there was a trend for the trawl with the conventional high headline height to catch more school prawns (for both predicted absolute and standardised mean weights and numbers by ≈1.1 to 1.2 × that caught by the lower heights; Fig. 2a; Tables 2 and 3).

The three modelled length-dependent catch-comparison curves fitted the experimental data (4–25 mm CL) well, and only the model for the conventional versus medium headline had poor fit statistics (p-value < 0.001; deviance = 42.29; dof = 14). After inspecting the residuals, the poor fit statistics were attributed to overdispersion in the length classes at the limit of the sampled range, providing confidence in applying the model. The analysis showed no significant differences in the catches of school prawns for any of the length classes represented for any comparison of headline height.

Among seven bycatch species caught in sufficient quantities for analyses, all but two were significantly affected by the main effect of headline height in the LMMs, which also meant total bycatches were strongly affected ($p < 0.05$; Table 2 and Fig. 2). Irrespective of absolute or standardised catches, compared to trawls fished at the conventional high headline height, those with the medium and low heights retained similarly and significantly less weights (predicted means reduced by up to 69 and 79%, respectively) and numbers (by 57 and 66%) of total bycatch and numbers of southern herring Herklotsichthys castelnaui (Ogilby) (by 81 and 92%) and tailor Pomatomus saltatrix (L.) (by 81 and 84%) (LMM and FDR, $p < 0.001$; Table 2; Fig. 2b,c,g). For silver biddy Gerres subfasciatus Cuvier and yellowfin bream Acanthopagrus australis Günther, there were no differences in absolute or standardised numbers between the trawls rigged at the conventional and medium headline heights (LMM and FDRs, $p > 0.05$; Table 2; Fig. 2f,h), but fewer were caught in the low headline trawl (LMM and FDR $p < 0.05$; Table 2; Fig. 2f,h) (by 53 and 64%, respectively).

The only species that showed a contrasting result was pink-breasted siphonfish Siphamia roseigaster (Ramsey & Ogilby) (per ha trawled) with significantly more caught when trawls were rigged at the low headline height (LMM and FDR $p < 0.05$; Table 2; Fig. 2e). Catches of toadfish Tetractenos glaber (Fréminville) and squid Uroteuthis sp. were not affected by headline height (LMM, $p > 0.05$; Table 2; Fig. 2d,i).

4 | DISCUSSION

There were two obvious and quite positive outcomes from this experiment. First, reducing headline height reduced the bycatch of small fish in this fishery without greatly affecting school prawn catches; and second, the quickly adjustable system facilitated rapidly moving the headline from one configuration to another, without affecting trawl performance.

According to the results, it would appear that some of the bycaught species frequently encountered in this fishery (e.g. Liggins & Kennelly, 1996) orientate higher in the water column (or are herded there, or quickly swim there as the trawl approaches) than others, and the mostly benthic school prawns (Ruello, 1973; Coles, 1979). Such individuals therefore avoided entering the net when the headline was lowered. More specifically, because the medium headline configuration excluded the same numbers of southern herring and tailor as the low headline, individuals of these species must have been relatively high in the water column. By comparison, other fish, like silver biddies and yellowfin bream, may have been slightly lower in the water column since only the low headline reduced their numbers. Toadfish and squid, on the other hand, did not respond to either reduction in headline height and were likely either orientated closer to the bottom, or were not strong enough swimmers to respond to the trawl and rise up and over the headline.

By contrast, for the very small pink-breasted siphonfish, the opposite result to that for other species was detected, with greater standardised catches in the lower headline configuration than the conventional or medium-height configurations. Because size has been demonstrated to be strongly negatively correlated to fish swimming ability (Wardle, 1989), the result for pink-breasted siphonfish may simply reflect their very small size (all <5.5 cm TL) and relatively poor swimming ability than the larger species above (mostly all >6–23 cm TL).

Although adjustable headline heights should have broad applicability in many penaeid-trawl fisheries, it is important to note that there are various technical and environmental considerations when developing this concept. First, the trawl used did not have headline floats or kites, and fisheries that use these may not see the same magnitude of reductions observed here due to confounding effects of maintained buoyancy of the headline—although, intuitively, such fisheries may realise species-selectivity benefits simply by removing such devices. Second, the trawl did not have any ‘lead-a-head’ (i.e. whereby the top panel extends anterior to the bottom panel), and the bycatch reduction observed due to lowering the headline may be affected when a lead-a-head is used. Third, weather, and especially current intensity and direction, could affect the stability of otter boards with low headline attachment points. Fourth, the quite shallow water in the lake in which the experiment was done may have affected fish escaping over the headline (e.g. due to greater visibility; Broadhurst et al., 2015). While many other penaeid-trawl fisheries similarly operate in shallow water and during the day, further work should examine the effects of headline height in deeper-water fisheries and/or at night. Finally, no significant increase in swept area was observed with a reduction in headline height, although the means were incrementally greater. Such a positive relationship might be expected, simply because a lower angle of netting would reduce drag and allow the trawl to open wider. Under some circumstances, this could affect catches of penaeids (Broadhurst et al., 2016; 2017).

Notwithstanding the above, because changing headline height is a simple process, such a modification provides a mechanism by which penaeid fishers can easily adapt their gear to avoid large abundances of particular species. Further, unlike for conventional, posteriorly located BRDs, changing headline height precludes many fish entering the trawl at all, thus preventing any associated mortalities. Whilst the possibility exists for fewer penaeids to be caught using lower headline heights, if realised, any such losses might be more-than-compensated by improved species selection precluding fishing closures, less damaged prawns in catches, less time spent sorting, and therefore more time spent fishing.

This work has shown the utility of lowering headline height on reducing bycatches of small fish in penaeid trawls and how such a modification can be used by fishers to quickly reduce such bycatches where and when teleosts are in large abundances. This could have substantial utility for avoiding fishing closures caused by exceeding specified bycatch limits. It is recommended that greater focus continues on developing such easily implemented solutions—and so allow fishers to be more flexible and adaptive in trying to reduce unwanted bycatches in situ.

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TABLE 1 Scientific and common names, numbers and sizes of organisms (in ascending order of abundance) caught during the experiment. Sizes were carapace length in mm for school prawns and total length in cm for fish. Na means that these species were not measured. ^economically important in other fisheries (all other species are economically unimportant).

Scientific name	Common name	Numbers	Size range
Metapenaeus macleayi	School prawn^	21 393	4.0–25.0
Herklotsichthys castelnaui	Southern herring	204	5.5–15.0
Uroteuthis sp.	Squid^	94	Na
Siphamia roseigaster	Pink-breasted siphonfish	85	2.5–5.5
Gerres subfasciatus	Silver biddy^	80	4.0–16.0
Pomatomus saltatrix	Tailor^	43	12.0–19.0
Acanthopagrus australis	Yellowfin bream^	40	8.0–23.0
Ambassis marianus Günther, 1880	Ramsey’s perchlet	24	7.0–9.5
Tetractenos glaber	Toadfish	23	9.0–14.0
Engraulis australis (White, 1790)	Australian anchovy^	17	4.0–9.0
Hyperlophus vittatus (Castelnau, 1875)	Whitebait^	13	3.0–5.5
Neoarius graeffei (Kner & Steindachner, 1867)	Fork-tail catfish	8	9.5–11.0
Pseudorhombus arsius (Hamilton-Buchanan, 1822)	Largetooth flounder^	5	9.0–18.0
Muraenesox bagio (Hamilton, 1822)	Common pike eel	3	Na
Dasyatis sp.	Stingray	3	Na

Terapon jarbua (Forsskål, 1775).	Saddleback grunter	2	9.5–12.0
Pelates sexlineatus (Quoy & Gaimard, 1824)	Six-lined trumpeter	2	8.0–15.0
Platycephalus fuscus Cuvier, 1829	Dusky flathead^	1	Na
Scomberoides tol (Cuvier, 1832)	Needleskin queenfish^	1	Na

TABLE 2 Summaries of Wald F statistics from linear mixed models (LMM) assessing the importance of the fixed effect of headline height (conventional: 73 cm, medium: 48 cm; and low: 38 cm) for explaining variability among technical and biological responses, and predicted means (and SEs where appropriate). All numbers and weights (kg) were log-transformed and analysed as absolute and standardised to per ha trawled. Random effects included 'trawls', 'sides of the vessel', 'days' and 'deployments within days' for all LMMs, and also 'paired trawl sensors' for those LMMs assessing relevant technical variables.

Technical variables	Wald F	Conventional 71 cm	Medium 48 cm	Low 38 cm
Wing-end spread (m)	1.77	4.12 (0.07)	4.18 (0.07)	4.22 (0.07)
Distance trawled (km)	0.96	2.35 (0.05)	2.32 (0.05)	2.32 (0.05)
Area trawled (ha)	0.40	0.96 (0.02)	0.97 (0.02)	0.98 (0.02)
Biological variables				
Wt of school prawns	0.72	1.09	0.99	0.94
Wt school prawns per ha	0.86	1.13	1.01	0.97
No. of school prawns	0.90	575.34	509.41	483.13
No. of school prawns per ha	0.90	543.59	456.47	481.31
Wt of total bycatch	10.29***	0.71	0.22	0.15
Wt of total bycatch per ha	10.29***	0.67	0.21	0.15
No of total bycatch	22.63***	23.69	10.17	8.14
No. of total bycatch per ha	22.62***	22.39	9.61	7.70
No. of southern herring	28.05***	8.87	1.70	1.68
No. of southern herring per ha	27.66***	8.40	0.67	0.65
No. of squid	1.05	2.07	2.85	1.99
No. of squid per ha	1.05	1.95	2.68	1.88
No. of pink breasted siphonfish	2.47	1.87	1.82	3.15
No. of pink breasted siphonfish per ha	4.84*	1.78	1.24	3.05
No. of silver biddy	3.74*	2.05	1.47	0.96
No. of silver biddy per ha	3.72*	1.93	1.40	0.91
No. of tailor	16.33***	2.32	0.44	0.36
No. of tailor per ha	16.26***	2.19	0.42	0.34
No. of yellowfin bream	4.00*	1.49	0.90	0.54
No. of yellowfin bream per ha	3.99*	1.40	0.85	0.51
No. of toadfish	0.11	0.46	0.57	0.46
No. of toadfish per ha	0.11	0.43	0.54	0.43

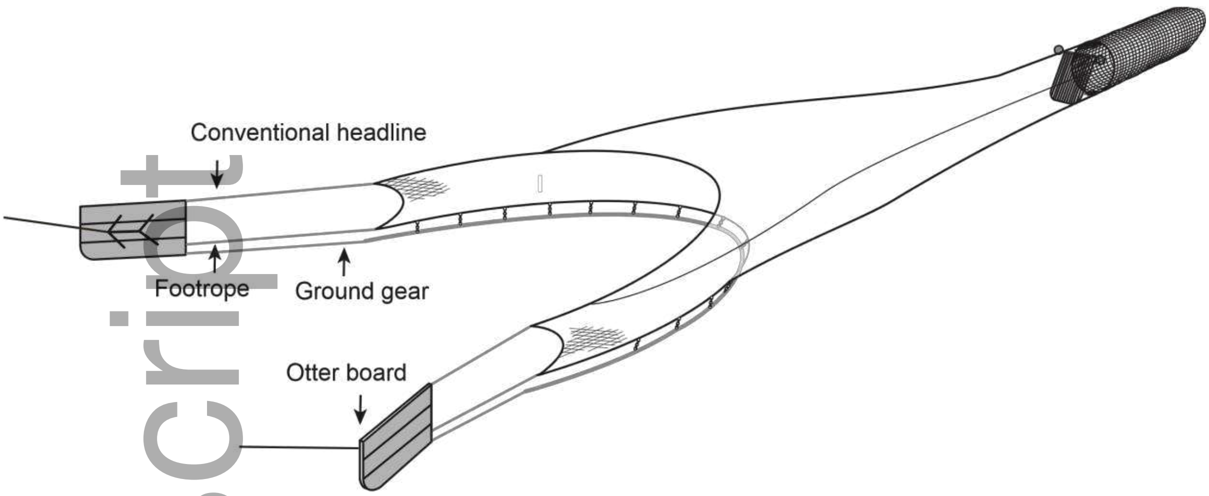
***p < 0.001; **p < 0.01; *p < 0.05

Legends to Figures.

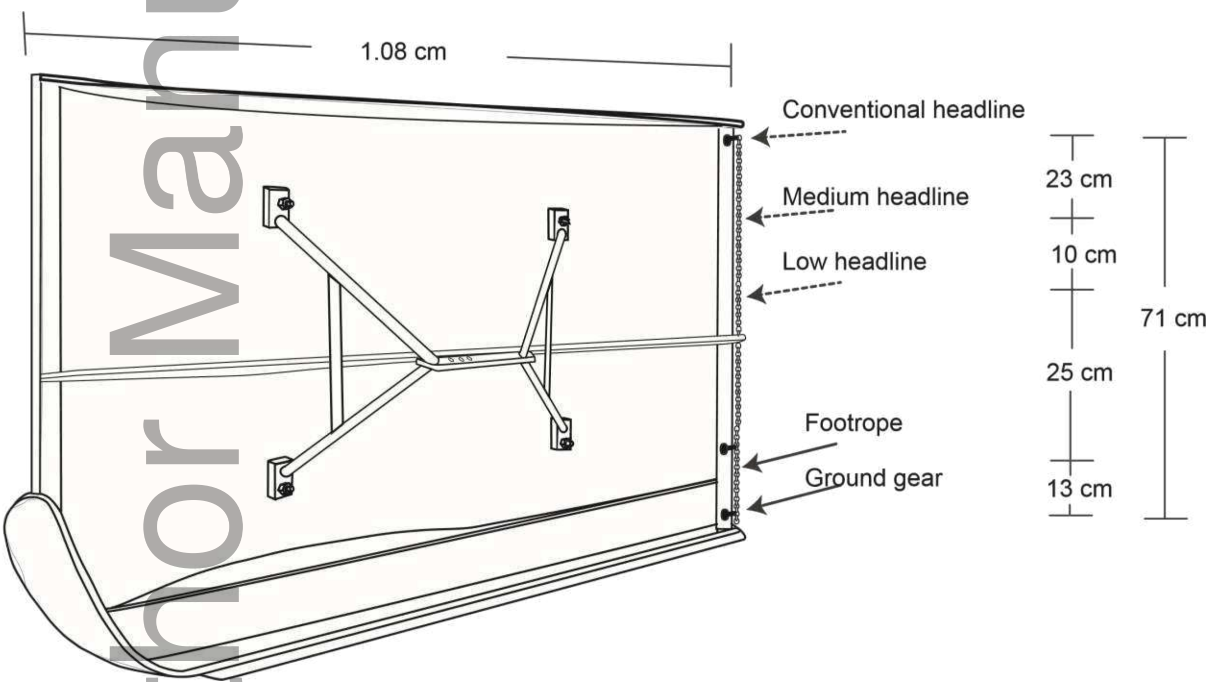
FIGURE 1 Three-dimensional diagrams of the (a) conventional-trawl configuration and (b) locations of the attachment points used at the trailing edge of the otter boards to alter headline height.

FIGURE 2 Differences in raw (+SE) and predicted mean catches trawled per ha between trawls configured at the conventional (con; 71 cm) and medium (48 cm) and low (38 cm) headline heights for the weights of (a) school prawns, Metapenaeus macleayi and (b) bycatch, and the numbers of (c) southern herring, Herklotsichthys castelnaui, (d) squid, Uroteuthis sp., (e) pink breasted siphonfish, Siphamia roseigaster, (f) silver biddy, Gerres subfasciatus, (g) tailor, Pomatomus saltatrix, (h) yellowfin bream, Acanthopagrus australis, and (i) toadfish, Tetractenos glaber. Dissimilar letters above the predicted means indicate significant differences detected in false-discovery-rate pairwise comparisons ($p < 0.05$).

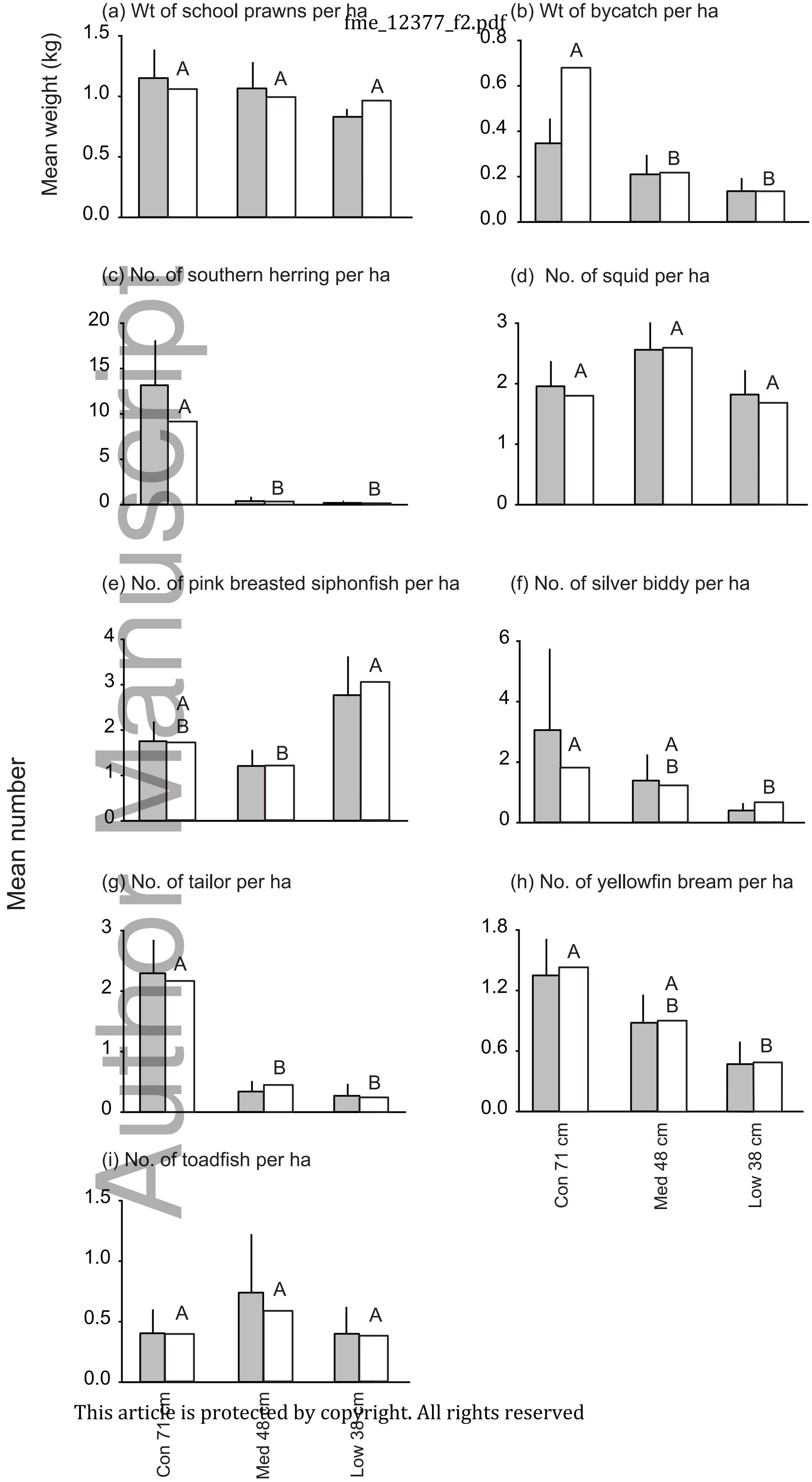
A.


Conventional headline
Footrope
Ground gear
Otter board

B.


1.08 cm
Conventional headline
Medium headline
Low headline
Footrope
Ground gear
23 cm
10 cm
25 cm
13 cm
71 cm

5


(a) Wt of school prawns per ha
(b) Wt of bycatch per ha
Mean weight (kg)
(c) No. of southern herring per ha
(d) No. of squid per ha
(e) No. of pink breasted siphonfish per ha
(f) No. of silver biddy per ha
(g) No. of tailor per ha
(h) No. of yellowfin bream per ha
(i) No. of toadfish per ha
Mean number
Con 71 cm
Med 48 cm
Low 38 cm