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Engineering and catch implications of variable wing-end spread on a penaeid trawl

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ABSTRACT

The importance of wing-end spread on the performance of a generic penaeid trawl was assessed to investigate the potential for confounding effects when comparing modified anterior sections designed to improve selectivity and fuel efficiencies. Two identical beam-and-sled assemblies were configured to allow two identical trawls (7.35 m headlines and footropes) to be adjusted to spread ratios (defined as wing-end spread ÷ headline length) of 0.5, 0.6, 0.7 and 0.8 and deployed ($n = 30$ each) in a double rig across the same depth, current, towing speed and duration. Increasing spread ratio significantly increased drag (by up to 16%), without affecting absolute catch weights. However, when standardised to per ha trawled, significantly fewer targeted school prawns (*Metapenaeus macleayi*) and total bycatch by weight were retained in the wider-spread trawls. The significant reductions in standardised catch with increasing spread ratio were hypothesised to reflect either: (i) slightly reduced ground gear contact and headline heights offsetting the greater swept areas; or perhaps more likely (ii) steeper wing angles which increased the probability of mesh encounters and escape for school prawns and were less efficient for herding fish. Future research comparing modified trawl bodies should focus on maintaining similar spread ratios to minimise confounding effects. Similar logic applies to surveys using penaeid trawls to obtain relative abundance estimates.

1. Introduction

Penaeid trawling occurs throughout the inshore waters of >25 tropical and temperate countries around the globe, and is very important to local economies (Vendeville, 1990; Gillett, 2008). While a plethora of trawls and configurations are used, owing to their small mesh sizes (typically 30–50 mm; Vendeville, 1990) and benthic contact, virtually all are characterised by the common key environmental issues of (i) poor size and species selectivity for slow swimming animals (and associated unaccounted fishing mortality) and (ii) high fuel intensity (Kelleher, 2005; Gillett, 2008).

Historical recognition of these two issues has led to various attempts at their resolution (e.g. Sumpton et al., 1989; Andrew et al., 1991; Broadhurst et al., 2000, 2012a,b, 2013a,b). However, by far most relevant work has focused on the first issue and involved retrospectively installing so-called ‘bycatch reduction devices’ (BRDs) in the posterior sections of trawls (reviewed by Broadhurst, 2000 and Broadhurst et al., 2006). In many cases, BRDs have considerably improved selectivity and reduced unwanted mortalities (Broadhurst et al., 2006), but because the catch comprises only a very small percentage of the total system drag of penaeid trawls there are few, if any, effects on drag (and therefore fuel intensity).

One method by which cumulative improvements in selectivity, along with reductions in drag can be concomitantly addressed is via larger-scale modifications to the anterior sections of penaeid trawls—although this requires understanding of the key influencing factors and their often complex, interactive effects (Sterling, 2005; Broadhurst et al., 2012a,b, 2013a,b). Potentially important factors include, but are not limited to the: number of trawls (i.e. single- or multi-net systems; Andrew et al., 1991; Broadhurst et al., 2013a,b); body and frame-line tapers (Conolly, 1992; Broadhurst et al., 2012b); mesh size, twine diameter and material (Sumpton et al., 1989; Broadhurst et al., 2000); and for otter trawls, sled and otterboard design (Sterling and Eayrs, 2010; Broadhurst et al., 2012a). In many cases, substantial changes to just one of these parameters will concomitantly affect both selectivity and drag.

Because penaeid-trawl systems are dynamic and most are laterally spread by hydrodynamic forces on otter boards, variations to the above parameters often have an ancillary impact on the horizontal opening of the trawl, which can be discussed in relative

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terms as the 'spread ratio' (wing-end spread ÷ headline length). Depending on the penaeid trawl and spreading mechanism, target spread ratios typically range between 0.50 and 0.85 (Sterling, 2005).

Very little scientific work has been published assessing the effects of spread ratio on penaeid-trawl performance. However, like for other benthic trawls, within any configuration, spread ratio could vary according to a plethora of technical and environmental factors including the towing speed, current, sea conditions, bottom type, warp length and fishing depth (Wathne, 1977; Engås and Godø, 1989; Fujimori et al., 2005; von Szalay and Somerton, 2005; Weinberg and Kotwicki, 2008). Studies with benthic fish trawls have identified that even subtle variations in spread ratio can alter geometry sufficiently to ultimately affect standardised (e.g. per swept area) catches (e.g. Rose and Nunnallee, 1998; von Szalay and Somerton, 2005; Weinberg and Kotwicki, 2008) and drag (Sala et al., 2008). Any similar impacts of spread ratio for penaeid trawls are of concern because these could confound comparisons of conventional and modified anterior sections, thereby making it difficult to ascribe causality to the fixed effects of interest.

Owing to complex interactions of the various factors listed above, isolating spread-ratio effects on trawl catches and drag is very difficult. One method is to use beam-and-sled assemblies and secure trawls at various treatment spread ratios, while keeping all other important parameters as constant as possible. Further, by maintaining the same weight and area of the beam-and-sled assembly, any differences in drag can be directly attributed to spread-ratio effects on trawl geometry. We sought to use this approach at one location in south eastern Australia. Specifically, for a generic, locally used trawl, we replaced the conventional otter boards with a beam-and-sled assembly and tested the hypothesis of no effects of 0.5, 0.6, 0.7 or 0.8 spread ratios on the catches of the targeted penaeids (school prawns, *Metapenaeus macleayi*) and unwanted teleosts and also drag, among similar environmental (depth and substratum) and technical (towing speed, current and warp length) conditions.

2. Methods

The work was done during February and March 2013 in Lake Wooloweyah (29°26 S 153°22 E), New South Wales, Australia using a local double-rigged trawler (10 m and 89 kW) fishing in ~2 m across sandy and mud substrata. The trawler had separate winches; each attached to ~80 m of 8 mm diameter–Ø stainless warp and 40 m bridles (6 mm Ø stainless wire). The trawler was equipped with a: global positioning system (GPS; Lowrance); hull-mounted sum log (EchoPilot, Bronze Log+); and load cells and associated data logger (Amalgamated Instrument Company; model no's PA6139 and TP4). The load cells were attached to the bridles (which were always deployed to 12 m) on each side of the vessel to measure their tension.

2.1. Trawls, beam assembly and fishing

Two identical conventional trawls were constructed from nominal 41 mm (stretched mesh opening–SMO) mesh (1.25 mm Ø twisted polyethylene-PE twine), and had headlines and footropes that measured 7.35 m (Fig. 1). The headline length and SMO were chosen based on the legislated requirements for this fishery (maximum headline and minimum SMO of 7.50 m and 40 mm respectively). Both trawls were rigged with a single 150 mm Ø float in the centre of the headline and had identical extension sections (100 transversal meshes–*T* × 30 normal meshes–*N* of nominal 41 mm PE mesh, and 2 mm Ø twine) with Nordmøre-grids (28 mm bar spacing) installed and codends (120 × 75 bars–*B*) made from nominal 27 mm polyamide (PA) mesh (1.25 mm Ø twine) hung square (Broadhurst et al., 2012b, Fig. 2). Prior to use, the trawl bodies, extensions and codends were measured (*n* = 15 for each section) for their SMOs using a local purpose-built gauge.

The trawls were deployed behind two independent 6 m long beam-and-sled assemblies on each side of the vessel (Fig. 2a). Each assembly was constructed so that the beams were positioned above the headlines of the trawls on top of the sleds (0.76 × 1.07 m), which could be horizontally positioned and pinned at different widths (3.68, 4.41, 5.15 and 5.88 m) according to the four treatment spread ratios of 0.5, 0.6, 0.7 and 0.8 (effectively providing wing-end angles of 14°, 21°, 29° and 39°; Fig. 2b).

At the start of each fishing day, the sleds on each beam (on each side of the vessel) were adjusted to a different treatment spread ratio and used in three 40 min deployments, after which the trawls were swapped from side-to-side for a further three 40 min deployments. The two load cells were alternated from side-to-side after each deployment. Over ten days, we attempted 30 replicate deployments of the trawls configured to each spread ratio, with an even distribution between sides of the vessel.

2.2. Data collected and analyses

The technical data collected during each deployment included the: (i) warp tension (kgF) for each configuration (recorded at 1 min intervals from the load cells); (ii) the total distance (m) trawled (sleds on and off the bottom–obtained from the GPS); and (iii) speed over the ground (SOG) and through the water (STW; both in $\mathrm{m\,s^{-1}}$). The drag of the trawls was assumed through the horizontal component of the tension vector for the warp aft of the vessel. System drag is proportional to warp tension while the declination angle of the warp is constant (i.e. constant warp length and water depth).

Biological data collected at the end of each deployment included the: total weights of school prawns and bycatch; numbers of each bycatch species; and total lengths (TL in mm) of the most abundant teleosts (except forktail catfish, *Arius graeffei*—owing to their spines). Random samples of ~500 g of school prawns were placed into plastic bags and transferred to the laboratory, where they were measured (carapace length–CL in mm), weighed and counted. These latter data were used to estimate the total numbers caught during each deployment.

The hypothesis of no differences in the mesh sizes within the two trawl bodies, extensions or codends was tested in a linear model (LM). Within each experiment, the remaining data were analysed in linear mixed models (LMMs), with some standardised prior to analyses. The numbers and weights of catches were analysed per 40 min deployment, and also standardised to per ha trawled using the swept area of the foot rope (calculated by the known wing-end spread × the distance trawled). In both cases, data were then log-transformed so that predicted effects would be multiplicative. All other data, including the mean CL and the number of school prawns per 500 g (a local industry measure; Broadhurst and Millar, 2009) drag and area and distance trawled were analysed in their raw form.

All LMMs included 'spread ratio' as a fixed effect, while 'trawls', 'sides' and 'days' and the interactions between 'deployments' and days and between sides and days were included as random terms. For the LMM assessing drag, 'load cells' were included as an additional random term while additional fixed covariates included 'SOG', 'STW' and 'flow' (calculated as the speed of the current in the direction of travel and defined as SOG–STW). The most parsimonious model was chosen based on the lowest value for a penalised log-likelihood in the form of the Akaike's information criterion. All models were fitted using either the lmer function from the lme4 package or ASReml in the *R* statistical language, with the significance of spread ratio determined using a Wald *F*. Upon obtaining a significant effect of spread ratio, the differences were subsequently