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Comparing three conventional penaeid-trawl otter boards and the new batwing design

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ABSTRACT

Three experiments were conducted to compare the engineering and catching performances of a hydrodynamic otter board termed the 'batwing' (comprising a sled-and-sail assembly, configured to operate at 20° angle of attack – AOA and with minimal bottom contact) against three conventional designs (termed the 'flat-rectangular', 'kilfoil' and 'cambered' otter boards) with AOAs between ~30 and 40°. Experiments involved paired penaeid trawls (7.35-m headlines). The first experiment compared the batwing otter boards against all other designs (using 41-mm mesh trawls). In experiment 2, the batwing was tested against the flat-rectangular design (with 32-mm mesh trawls). In experiment 3, the batwing and flat-rectangular otter boards were towed without trawls to facilitate estimates of their partitioned drag. Overall, compared to the conventional otter boards, the batwings had up to ~86 and ~18% less bottom contact and drag, respectively. Among the conventional otter boards, the trawls spread by the cambered design caught up to 13% more school prawns *Metapenaeus macleayi* attributed to their greater solid profile. No significant differences were detected among catches of fish in the trawls spread by the various otter boards. The results reaffirm that because otter boards contribute towards a large proportion of total system drag (estimated here at up to ~56%), their appropriate configuration is essential to maximise the fuel efficiency of penaeid-trawl systems.

1. Introduction

Penaeids are targeted throughout the world's tropical and temperate regions; mostly using small fishing vessels (<25 m) towing multi-net trawl systems that are laterally spread by paired hydro vanes, called 'otter boards' (Kelleher, 2005; Gillett, 2008). While there is considerable variety among otter-board designs, all encompass a substantial proportion of the entire trawling system weight to ensure sufficient seabed contact, and are orientated at an angle to the tow direction (termed the angle of attack – AOA). The water moving over otter boards creates hydrodynamic forces that horizontally open penaeid trawls to spread ratios (SR) typically 0.6–0.8 of their total headline length. The drag component of such hydrodynamic forces has been hypothesised to account for up to 30% of the total-system drag (Sterling, 2000).

At a broad level, the most common otter boards are simple flat, rectangular designs – although more hydrodynamically complex cambered variations are also popular (Seafish et al., 1993). Irrespective of design subtleties, the majority of otter boards are rigged to have AOAs between 30 and 40° (Seafish et al., 1993; Sterling, 2000). Operating conventional otter boards at such high AOAs helps to maintain their stability, which keeps the other trawl components at optimal efficiency (Patterson and Watts, 1985). Even slight reductions in AOA below this range can result in operational issues, manifesting as reduced stability and possibly lost effective fishing time (Patterson and Watts, 1985; Seafish et al., 1993). In an attempt to overcome such issues, a more recent prototype termed the 'batwing' otter board was developed by Sterling and Eayrs (2010) to remain at a constant 20° AOA, and with robust stability achieved through its unique rigging strategy (see Methods Section).

Although not extensively quantified (but see Patterson and Watts, 1985, 1986), compared to conventional designs, otter boards such as the batwing that have low AOAs should have relatively lower drag for the same spreading force and therefore require less fuel to tow. Calculating the extent of any such fuel reductions is complex. It is well established that the fuel consumed during trawling is proportional to the thrust applied by the trawler, if propeller efficiency remains constant (Prado, 1990). However, the

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assumption of a proportional relationship between drag reductions and fuel savings remains approximate because many factors affect efficiency, including propeller loading.

Globally, it is becoming imperative to reduce fuel usage in many fisheries including demersal trawling, which has some of the greatest fuel-to-catch ratios, with fuel accounting for 30% of a trawl operator's total costs in developed countries (Suuronen et al., 2012). In fact, in Australia, trawlers use at least 55% of their fuel while trawling (with the rest used during travelling between trawl grounds and operating electrical equipment), and are operating close to their profitability threshold (Thomas et al., 2010; Wakeford, 2010).

Beyond drag/fuel savings, a potential concomitant benefit of lowering otter-board AOA is reduced benthic contact for any given length (i.e. ~1.5% for each degree the AOA is lowered), and subsequently fewer associated impacts. For example, an otter board ~1 m long deployed at 40° AOA will impact the bottom for ~64 cm, while at 20° its contact will be reduced to ~34 cm. Even slight reductions in impacts are potentially beneficial, considering that otter boards leave the most discernible track marks from trawl configurations (Caddy, 1973; Kaiser et al., 2002). However, from a catching perspective, one concern with minimising otter-board bottom contact is that a lower AOA could reduce substrate disturbance and negatively affect catches because penaeids mostly reside in the substratum (Broadhurst et al., 2012, 2013a; McHugh et al., 2014). Further, otter boards are known to herd fish (Wardle, 1989), either through visual or tactile stimuli, and so even subtle variations in their design and AOA might influence species selection by the trawl.

Despite the above, there have been very few formal studies of the effects of otter boards on the engineering and catching performances of penaeid trawls (but see Broadhurst et al., 2012, 2013b). The main aim of this study was to address this shortfall by quantifying the catches and fuel efficiency (measured as least drag) associated with three conventional otter-board designs and the batwing (with its relatively less bottom contact) in one Australian fishery targeting school prawns, *Metapenaeus macleayi*. A secondary aim was to use an approach involving removing the trawls and just towing the otter boards (separated by wire stays) to quantify their contribution towards total system drag for the tested trawls, so the benefits of future refinements to otter-board design and their AOAs can be established.

2. Methods

Three experiments were completed in the Clarence River, New South Wales, Australia, during May 2013 using a local penaeid trawler (10 m and 89-kw) fishing in ~4–18 m water-depth across mud and sand substratum. The trawler had 8-mm diameter (Ø) stainless warps and 40-m bridles (6-mm Ø stainless wire) on a double-drum, hydraulic, split winch. The trawler was also equipped with: a fuel monitor (Floscan series 9000); global positioning system (GPS; Lowrance); hull-mounted sum log (EchoPilot, Bronze Log+), warp-attachable load cells and associated data logger (Amalgamated Instrument Company; model nos PA6139 and TP4); and a portable acoustic, trawl-monitoring system with paired wing-end distance sensors (Notus Trawlmaster System; Model no. TM800ET; see Broadhurst et al., 2013a for details). All monitoring equipment was calibrated prior to starting the experiments.

2.1. Trawls and otter boards tested

Four trawls were constructed – two identical replicates of two similar designs (Fig. 1). The first two trawls (termed A and B) were conventionally mandated designs for the fishery, and comprised a mean stretched mesh opening (SMO) ± SE of 41.43 ± 0.11 mm (n = 20 meshes in each trawl) and 1.2-mm Ø twine, with a side taper of 1N3B and were used in experiment 1 (Fig. 1). Owing to the small sizes of prawns encountered (see Results Section), the third and fourth trawls (labelled C and D) used in experiment 2 were made from smaller 31.61 ± 0.08 mm SMO (n = 20 meshes in each trawl) and 0.8 mm Ø twine, and with a side taper of 1N5B (Fig. 1). All four trawls were rigged with identical Nordmøre-grids and square-mesh codends made from 27.37 ± 0.10-mm SMO (n = 20 meshes in each trawl) polyamide mesh hung on the bar and had 2.89-m sweeps (6-mm Ø wire) attached at their wing ends, terminating in snap clips to facilitate attachment to the otter boards.

Four otter-board pairs were tested, all with 100 mm baseplates (Fig. 2). The first otter board represented a standard design used nationally and internationally, and comprised a mild-steel frame with marine-grade plywood inserts and was termed the 'flat-rectangular' (52.5 kg, 1.39 m × 0.61 m, solid area of 0.77 m^2; Fig. 2a). The second design ('kilfoil') was constructed entirely from galvanised mild steel and had three 270 mm-wide cambered vertical foils in a rectangular frame (63.0 kg, 1.25 m × 0.63 m, solid area of 0.58 m^2; Fig. 2b), while the third ('cambered') had a single, cambered foil over its entire length and was made from stainless-steel plate (53.0 kg, 1.08 m × 0.73 m, 0.79 m^2; Fig. 2c).

The fourth design was the batwing and comprised a main sled made from mild and stainless steel, and a polyurethane (PU) sail set on a stainless-steel boom and mast (60.7 kg, 1.12 m × 1.23 m, 0.74 m^2) configured to remain at a 20° AOA (Fig. 2d). The batwing foil was designed to act like an independent kite with a single longitudinal connection to the trawl system via a heavy main sled made from a combination of mild and stainless steel (Fig. 2d). The batwing was configured so that the heavy sled baseplate was aligned to the tow direction, while the sail had a stable AOA and rode on a polyurethane flap designed to pass lightly over the seabed on a layer of pressurised water (similar in concept to the skirt on a hovercraft).

To ensure the same trawl wing-end height during fishing, vertical upper sweep attachment bars were welded to the tops of the flat-rectangular and kilfoil designs to match the heights of the cambered and batwing otter boards (Fig. 2). All otter boards were rigged at their industry-standard AOAs, and to achieve the same trawl wing-end spreads (see Results Section).

2.2. Experiment 1 – Four pairs of otter boards with trawls

In the first experiment, the four otter boards were tested against each other in paired comparisons. On each fishing day, one of the six possible otter-board combinations was attached to each side of the vessel. The 41-mm trawls (A and B) and sweeps were clipped to the otter boards, while the Notus paired sensors were attached to the trawl wing ends. After two replicate deployments, the trawl-monitoring equipment (Notus sensors and load cells) were swapped from side-to-side, but the trawls remained. After four replicate deployments, both the trawls and the trawl-monitoring equipment were swapped from side-to-side. After six deployments, just the trawl-monitoring equipment was swapped again. In total, each of the four otter-board pairs were deployed across three alternate replicate days, with eight replicate 30-min deployments for each treatment on each day (providing a total of 24 deployments).

2.3. Experiment 2 – Two pairs of otter boards with trawls

To obtain more data over a broader range of conditions (and especially longer tow durations more representative of conventional operations), just the flat-rectangular and batwing otter boards were compared. On each of four days, pairs of the two otter boards were alternately attached to each side of the vessel, and clipped to the sweeps attached to the 32-mm trawls. The smaller-mesh trawls were used to remove the possibility that confounding