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Engineering and catching performance of five netting materials in commercial prawn-trawl systems

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ABSTRACT

High-strength netting trawls have less drag due to the opportunity to use thinner twine. In prawn/shrimp trawl systems, where large otter boards spread the trawls to high spread ratios, further substantial drag reduction should occur due to the reduced size of otter boards required. Here we conducted two comparative experiments with commercial prawn trawls made from five respective netting materials including standard polyethylene (PE), high tenacity PE and three examples of Ultra High Molecular Weight (UHMW) PE. In the first experiment, a sequence of paired comparisons of engineering performance (drag and spread) was undertaken across all trawls individually connected to one of three pair of different size otter boards; in all cases codends were left open to avoid catch size confounding the measurements. In the second experiment, catch and selectivity performances were assessed by towing the five trawls simultaneously in a five-rig system, with location in the system randomly varied. The trawl-board combination with the best engineering performance for each high-strength material produced a range of drag reduction compared to the best combination for the standard PE trawl: ~12% for high tenacity PE and ~19–21% for the three UHMW PE trawls. The high-strength netting trawls caught larger prawns compared to the standard PE trawl, possibly due to (i) increased twine flexibility allowing smaller prawns to escape, and (ii) greater flow of water through the trawl causing increased catch efficiency for larger, more mobile prawns. A strong negative result was the large amount of bycatch for most high-strength netting trawls—it was concluded that this was driven in part by low fishing line tension, exacerbated by higher operating spread ratio. Some evidence was obtained that this could be mitigated by applying layback to the headline.

1. Introduction

The performance of prawn/shrimp trawl systems is assessed in relation to three desirable goals: high fuel efficiency, successful retention of target catch, and low collateral environmental impact (McHugh et al., 2016). Concern about fuel efficiency creates close attention to drag of the trawl system (for a given speed), but when combined with the goal for maximum prawn catch interest shifts towards minimising the drag per unit of swept area rate, so measuring the lateral span of the system is very relevant (Sterling, 2005). Catching performance is also driven by catch efficiency, the proportion of prawns in the path of the trawl that are captured (Eayrs, 2003), and selectivity measures how catch efficiency varies between species and size classes within species. The ideal outcome is to catch the animals that make up marketable seafood products, but allow all other animals (bycatch) to escape while also causing no physical impacts to the natural environment.

Fuel accounts for up to 50% of fishing business expenditure (Parker et al., 2015), and towing the trawl gear consumes ~55% of the fuel used, depending on distance to the trawl ground and the fuel used for refrigeration et cetera (Wakeford, 2010). In prawn trawling substantial drag reduction and corresponding fuel savings occur with the use of high order multi-trawl systems, where a number of smaller trawls are used instead of a lesser number with an equivalent combined headline length (Broadhurst et al., 2013). Further, in Australia eco-efficient trawl gear (W-trawl and batwing otter boards) have recently been developed, producing up to ~30% drag (and hence fuel) reduction and a substantial reduction in seabed impact (Balash and Sterling, 2014).

A widespread approach for drag reduction in netting structures is to minimise twine area via using larger mesh size (Rotherham et al., 2008) and/or thinner twines (Sumpton et al., 1989). For plane sheets of netting, drag is dependent on netting area, trawl speed, solidity, Reynolds number, and incident angle of flow; and it is affected by netting-surface roughness (Fridman, 1973; Tsukrov et al., 2011;

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Table 1
Netting construction and geometry specifications.

Retail name	Construction properties	Effective twine diameter [mm]	Mesh size (normal × transverse) [mm]	Knot size (normal × transverse) [mm]
Polyethylene (PE)	twisted 24 ply single knot	1.68	52.1 × 49.7	5.24 × 4.32
Ultracross Dyneema	1.1-mm braided knotless	1.28	51.0 × 51.0	1.9 × 1.9
Hampidjan Dynex	1.0-mm braided double knotted	1.26	50.25 × 42.05	6.8 × 3.3
Euroline Premium Plus	1.0-mm braided single knot	1.40	52.06 × 49.51	5.12 × 4.12
Van Beelen Spectra	1.0-mm twisted single knot	1.10	53.7 × 51.95	3.5 × 3.1

Enerhaug et al., 2012; Klebert et al., 2013) and by twine bending stiffness (Gansel et al., 2012); with the same relationships also applying to high-strength netting materials (Kumazawa et al., 2012; Zhou et al., 2015). In trawl systems, the total netting drag of a trawl can be generally assumed to be the combined drag of the netting panels exposed to flow at respective angles of attack (Reid, 1977). At zero angle of attack the drag of a netting sheet is relatively low and not tightly dependent on twine area; thus in shrimp trawl models, Spectra (Ultra High Molecular Weight Polyethylene; UHMW PE) netting having 33% less twine area (due to thinner twine) delivered a substantial 28% drag reduction compared to polyamide (PA). The drag reduction was somewhat less than the twine area reduction because a large proportion of the netting in a prawn trawl is nearly parallel to the flow and twines are partially shadowed (Goudey, 1992).

From a prawn-size selectivity perspective, in an Australian field experiment catch from a monofilament PA trawl contained fewer small prawns compared to a conventional 'folded multifilament' PE trawl of the same mesh size and larger twine diameter (Sumpton et al., 1989). However this result was not confirmed by Broadhurst et al. (2000), who found no difference in catch performance between trawls where only twine diameter was different, but an increase in mesh size and twine thickness caused significant reduction in small prawns and fish bycatch (where bycatch is all catch other than commercial species), while retaining equivalent quantities of targeted prawns.

There have been some negative comments from commercial trials of multifilament UHMW PE netting, including knot slippage in a demersal trawl (Sala et al., 2008), and also a greater propensity for bycatch-fouling and gear tangling during trawl deployment and hauling (because of low twine bending stiffness). However, UHMW PE twines generally have good resistance to breakdown by sunlight (UV radiation), seawater absorption, abrasion, and cutting.

Breaking-load tests of netting samples made from UHMW PE (commercially known as Ultracross Dyneema, Spectra and Dynex) and high tenacity PE (Euroline Premium Plus (Prem.Plus)) demonstrated equal or greater strength for thinner 'high-strength' netting compared to traditional 24-ply PE netting in traditional (T0) and 90° rotated (T90) mesh orientations (Sterling and Eayrs, 2010). But for T45 orientation, joint construction rather than the material's molecular structure determined the netting strength (mesh stability). Flume-tank resistance tests on five prawn-trawl models constructed from standard PE and high-strength netting (Ultracross and Prem.Plus in T0, and Dynex in T0 and T90) showed significantly less drag for the high-strength materials, which was generally proportional to the associated twine area (Balash and Sterling, 2012). Specifically, the single-knot material (Prem.Plus) showed less drag reduction compared to knotless (Ultracross Dyneema), and the double-knot material (Dynex) produced more-limited drag reduction owing to the knot's restriction to mesh opening in the transverse direction and the corresponding increase in netting solidity.

Unlike demersal fish trawls, prawn trawls have short sweeps (connection wires between the otter boards and trawl), operate at high spread ratio, and have wings at a large angle of incidence to the direction of tow. Such a configuration requires relatively large otter boards, which have substantial drag of ~1/3 the total drag for the prawn-trawl system including the vessel (Balash and Sterling, 2012). Any drag reduction of the netting part of the trawl system (e.g. due to thinner twine) then implies that smaller otter boards are required to spread the trawl and this results in further drag reduction. To assess the extent of the combined drag reduction, here we performed a sequence of paired engineering comparisons for commercial trawls constructed from a range of traditional and high-strength netting materials in conjunction with otter boards of three sizes. This was followed by separate catching trials where all trawls were towed simultaneously in a five-rig system.

2. Methods

2.1. The commercial trawls

Five standardised commercial trawls were designed and constructed from five respective netting materials (Table 1, Fig. 1) with equal headline length, lead-a-head (horizontal forward extension of the top panel), and gape (the ratio of the width of the trawl mouth, measured in meshes (T), to the depth of the trawl mouth, measured in points (N)). Two departures from perfect standardisation were: (i) the Dynex trawl had a greater number of meshes in the T-direction because of Dynex's lower lateral mesh size (a result of its double-knot construction limiting T-direction mesh opening), and (ii) the Spectra trawl was a four-seam trawl (with side panels) as modified from an existing trawl due to limited availability of that material.

Each netting body was attached via dropper chains (180-mm long and separated by 600 mm) to a stainless-steel ground chain (10-mm Ø medium link). In response to the estimated variation of hydrodynamic forces between the trawls (from the preceding flume-tank study by Balash and Sterling (2012)), gravity forces (applied by the dropper chains) were kept in scale by varying the weight of the dropper chains between each case to achieve similar fishing line height and to produce a standardised seabed contact. Specifically, a heavy dropper was used for the PE trawl, medium for the Prem.Plus and Dynex, and light for the Ultracross and Spectra trawls. Further, the Ultracross trawl was hung on neutrally buoyant 6-mm Dyneema lines instead of stainless wire to reduce the gravity force acting on the trawl's framelines.

2.2. Engineering trials

Comparative engineering performance trials (drag and spread) were undertaken over five days within Rainbow Bay, north of Double Island Point, in Queensland, Australia. A 15-m trawler, FV CKing, was double rigged with a single trawl spread by a pair of otter boards on each side of the vessel.

Three sizes of kilfoil-design otter boards were utilised in the trials (Table 2, Fig. 2). Trawl and otter board combinations were randomly selected to produce a schedule of 22 paired comparisons between 15 possible trawl-board combinations. These paired comparisons were then reordered to minimise the number of required board changes because they are difficult and dangerous to accomplish at sea. The number of instances for each trawl was biased towards the otter board combination that was deemed likely to be more efficient (Table 3).