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Improving tori line performance in small-vessel longline fisheries

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Johanna Pierre[1], Dave Goad[2], Igor Debski[3] and Kirstie Knowles[3]

[1]JPEC Ltd, [2]Vita Maris Ltd, [3]Department of Conservation

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Abstract

Tori lines are one of the most thoroughly tested seabird bycatch mitigation measures available, and have been proven effective in reducing seabird bycatch. The objective of this project was to develop improved tori lines which are specifically optimised for safe and effective use on small longline vessels. We conducted trials on land and on four different smaller longline vessels at sea. Tori line designs were tested at a range of vessel speeds to emulate the setting speeds used across the smaller-vessel longline fisheries of interest. Our primary measure of effectiveness was aerial extent, and tests confirmed that a number of different tori line designs delivered satisfactory aerial extents (of 70 m or more). Predictably, increasing tori line deployment height and vessel speed increased the aerial extents delivered. The most challenging component of the tori line design to refine was the in-water section, required to provide drag. However, as a broad rule-of-thumb, where the in-water section of a tori line delivers 15 kg of drag, satisfactory aerial extent should be achievable. This has important implications for small-vessel tori line specifications, such as those provided in CMM 2015-03 to mitigate the impact of fishing for highly migratory fish stocks on seabirds.

Introduction

Tori lines are one of the most thoroughly tested seabird bycatch reduction measures available, and have been proven effective in reducing seabird bycatch in both trawl and longline fisheries (Bull 2007, 2009; Løkkeborg 2011; Melvin et al. 2014). For surface longline vessels less than 35 m in length, best practice has been recognised as a single tori line with an aerial extent of 75 m or more, attached so the tori line is approximately 7 m high over the vessel stern. Brightly coloured streamers may be short or long, or both. It is recommended that short streamers are attached at 1 m intervals along the aerial extent, and long streamers at 5 m intervals (ACAP 2016).

While some New Zealand operators of small pelagic longline vessels successfully deploy tori lines on a regular basis, others report concerns about the safety of tori lines or do not consider that current best practice specifications are operationally feasible. In this study we conducted trials on land and on four different smaller vessels at sea, to explore tori line designs and materials appropriate for use during demersal and pelagic longline fishing methods. We structured our approach by vessel speed, which broadly correlates with small-vessel longline fisheries targeting different species, and focus reporting here for pelagic longline vessels (full results are reported in Pierre & Goad 2016). We also provide guidance on tori line designs and materials for smaller longline vessels, and trouble-shooting techniques to improve tori line performance.

Internationally, maintaining tori line coverage of longline hooks until the longline reaches a depth of 10 m has become a common performance measure (e.g., Papworth 2010). However, the distance astern at which fishing gear reaches that depth was highly variable in our focal fisheries (e.g. Pierre et al. 2015), so we used a key minimum performance criterion that tori lines must maintain an aerial extent of at least 70 m astern longline vessels.

Methods

At the outset of the project, a workshop was held with vessel operators. This identified a number of key issues that affect the operational feasibility, safety and efficacy of tori lines on small longline vessels:

- vessel setting speed
  Pelagic longliners set gear in the 6 – 8 knot range.
- attachment height
  Given the variation in vessel designs amongst the smaller vessel bottom and surface longline fleets, a range of attachment heights may require consideration, e.g. 5 m - 9 m above the sea surface. This range encapsulates the best practice recommendation of 7 m (ACAP 2016).
- attachment method
  Again, with the diversity amongst vessel layouts and the variable extent of above-deck attachment opportunities, exploring simple and practical attachments applicable to tori lines deployed on vessels with a range of designs was considered important.
- storage
  Tori lines are prone to tangling when not deployed. This creates issues on re-deployment. Therefore, a convenient and effective storage method is important to facilitate their safe and effective use.
- weight
  The weight of tori lines must be offset by sufficient drag to effectively achieve aerial extent. Heavier tori lines require more drag to maintain the same aerial extent than a lighter tori line would. More drag makes tori lines more difficult to retrieve after line-setting is complete.
- use of one or two weak links
  Tori lines can become tangled and caught up on fishing gear, leading to fishing activities being interrupted and potentially causing safety issues. Incorporating one or more weak links into tori lines provides known break-points, should the tori line come under undue tension. Having one weak link incorporated at the deployment point was the preferred approach, given this would result in the tori line breaking away from the vessel during setting.

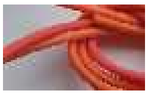
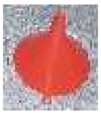
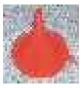
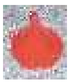
A number of materials for constructing tori lines were identified (Table 1), with consideration that these materials be cost effective and ideally off-the-shelf, already readily accessible to fishers (e.g., from gear suppliers in ports). In the course of conducting land and sea trials, we found that commercially available streamer materials were not fit for purpose for smaller vessel tori lines. For example, existing materials were too heavy (necessitating a large amount of drag) or too expensive. Therefore, the project team worked with Beauline International Ltd to manufacture a light, bright-coloured streamer material suitable for tori lines on smaller vessels. Four test materials were produced in orange, with variable tensile strengths, breaking strains and wall thicknesses (these were identified as T061 – T064 by the manufacturers). The weights of these products were around half of the 9-mm diameter Kraton-type material, at 18 – 25 gm^{-1} compared to 38 gm^{-1} respectively. We also explored the manufacture of custom solid polyethylene plastic cones in two sizes. These were custom-manufactured by Supply Services Ltd (Mt Maunganui, New Zealand) and cost NZD 460 for 100 small cones and NZD 670 for 50 large cones.

We conducted a series of tests on land, to investigate the performance of the aerial sections of tori lines at a range of deployment heights and using different construction materials and designs (Table 2). This was followed by at-sea testing, where we structured the trials according to vessel setting speed. Setting speeds on smaller pelagic longline vessels tend to be 6 – 8 knots (Pierre et al. 2015). The at-sea tests focussed on the in-water elements of the tori line (the 'drag section') in calm sea conditions and the drag produced by a range of materials and designs (Table 3).

Four fishing vessels were used as platforms for at-sea testing of tori line designs and construction materials, with trials at setting speeds relevant to pelagic longline fisheries being performed on three of those vessels (vessels A, B and C). Prior to going to sea on each vessel, a trial programme was developed with a prioritised set of tori line designs for testing at prescribed vessel speeds. This was then added to during testing, as more and less effective constructions were documented. Tables 4-6 describe the tori line designs tested on vessels

A-C, respectively, at setting speeds of 6-8 knots. On the vessel, each test commenced with measuring the drag provided by the in-water section of the tori line using a set of Salter 50 kg spring scales attached to the backbone of the tori line (which was held out of the water). The drag was measured in kilograms. At each nominated vessel speed, the aerial extent of the tori line was measured using a marked rope deployed from the vessel stern. Wind speed and direction, swell and sea state (Beaufort), and the course of tori lines astern the vessel (i.e. how well the tori lines tracked a straight line) were also recorded for each test. Photographs and digital videos were taken to show the tori line deployed, any bending in the pole to which it was attached, and the track and any splash created by the in-water section. Further details are described by Pierre & Goad (2016).

Table 1. Construction materials and dimensions for the tori line trials documented in this report.

Material	**Dimensions**	**Image**
Dyneema (aerial section)	3 mm diameter, 70 m long	
Kraton-type material (streamers)	9 mm diameter	
Plastic tubing (streamers) T061 – T064	5 mm diameter	
Trawl braid	10 mm diameter	
Large gillnet floats	92 mm long, 59 mm maximum diameter	
Small gillnet floats	80 mm long, 50 mm maximum diameter	
Large funnel	150 mm long, 115 maximum diameter	
Medium funnel	140 mm long, 96 maximum diameter	
Small funnel	105 mm long, 75 mm maximum diameter	
Large road cone (used with a polystyrene float inside)	890 mm long, 370 x 370 mm base	
Medium-sized road cone (used with a polystyrene float inside)	440 mm long, 280 x 280 mm base	
Small road cone	300 mm long, 210 x 210 mm base	

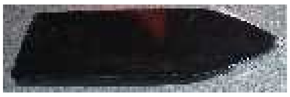
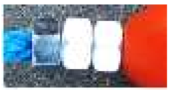
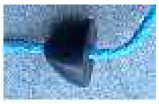
		
Large flutterboard	740 mm long, 320 m wide, 35 mm deep	
Small flutterboard	670 mm long, 200 mm wide, 40 mm deep	
Nuts	M12 size, weighing 13 g	
Small manufactured plastic cones	20 mm diameter at their widest point, 15 mm long, with 5 mm central hole	
Lumo lead caps	12 mm diameter at base, 15 mm long	
Large manufactured plastic cones	50 mm diameter, 75 mm long with 10 mm central hole	
Polystyrene cotton reel float	Maximum diameter 240 mm, minimum diameter 140 mm, 400 mm long	
Monofilament	5 mm diameter	

Table 2. Preliminary testing conducted to determine the drag required to achieve aerial extents of 40 m, 50 m, 60 m, 70 m, and 80 m, given a range of tori line designs and construction materials. (Shark clips were 11cm long and weighed 10 g).

Deployment height	**Backbone material**	**Streamer configuration**
5 m	Dyneema (3 mm)	Every 5.0 m
	Monofilament (3 mm)	Every 5.0 m
	Ashaway albacore braid (3.1 mm)	Every 5.0 m
7 m	Dyneema (3 mm)	Every 5.0 m
	Monofilament (3 mm)	Every 5.0 m
	Ashaway albacore braid (3.1 mm)	Every 5.0 m
9 m	Dyneema (3 mm)	Every 5.0 m
	Monofilament (3 mm)	Every 5.0 m
	Ashaway albacore braid (3.1 mm)	Every 5.0 m
Additional designs tested:		
7 m	Dyneema (3 mm)	Every 2.5
		Every 5 m + 10 shark clips
		Every 2.5 m + 10 shark clips
		Every 2.5 m + 17 shark clips

Table 3. Preliminary testing conducted to determine the drag delivered by different materials that could comprise the in-water section of a tori line.

Design #	Rope	Road cone	Gillnet floats	Funnels	Flutterboard	Configuration
1	50 m					
2	50 m	1 large				Rope with cone at terminal end
3	50 m	1 small				
4	2 x 25 m	3 small				1 cone – 25 m rope – 1 cone – 25 m rope – 1 cone
5	2 x 25 m		10 small			25 m rope then second 25 m length with floats 2.5 m apart
6	50 m		20 small			Rope with floats evenly spaced
7	2 x 25 m		10 small			25 m rope then second 25 m length with floats 2.5 m apart
8	50 m		20 large			Rope with floats evenly spaced
9	2 x 25 m			10 small		25 m rope then second 25 m length with funnels 2.5 m apart
10	2 x 25 m			10 medium		
11	2 x 25 m			10 large		
12	2 x 25 m			10 small, 10 large		25 m rope with 10 small funnels 2.5 m apart, then 25 m rope with 10 large funnels 2.5 m apart
13	2 x 25 m				3 small	1 flutter board – 25 m rope – 1 flutterboard – 25 m rope – 1 flutterboard
14	50 m				1 small	Rope with flutterboard at terminal end
15	25 m			10 small		Rope with funnels together at terminal end
16	2 x 25 m	2 small 1 large	30 small			1 small cone – 25 m rope with 10 small equally spaced floats – 1 small cone – 25 m rope with 10 small equally spaced floats – 1 large cone

Table 4. In-water sections prepared to trial on tori lines deployed from vessel A at setting speeds relevant to pelagic longline fisheries.

In-water section	Description
1	20 large gillnet floats along 50 m of 10-mm diameter trawl braid
2	(1) plus 120 nuts added as weight (with 3 nuts on each side of each float)
3	20 small gillnet floats along 50 m of 10-mm diameter trawl braid
5	20 repeating sections of one medium funnel-three nuts-one small gillnet float-three nuts, along 50 m of 10-mm diameter trawl braid
6	3 large flutterboards at each end and the centre of a 50 m length of 10-mm diameter trawl braid
13	400 m 3-mm diameter monofilament

Table 5. Tori line designs deployed from vessel B at setting speeds relevant to pelagic longline fisheries. . In-water sections described in the table were attached to an aerial section comprising a 70-m yellow Dyneema backbone with single 5-mm orange plastic streamers (attached using cable ties) every 3.5 m.

Tori line	Description
4	100 m of 5 mm diameter monofilament plus 50 large gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid
5	50 small gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid
6	100 m of 5 mm diameter monofilament followed by a 360-mm diameter float covered with net
7	50 large manufactured plastic cones along 50 m of 10-mm trawl braid
8	100 m of 5 mm diameter monofilament followed by (7)
9	100 small manufactured plastic cones spaced equally along 100 m of 5 mm diameter monofilament
10	100 m of 5 mm diameter monofilament followed by (9)

Table 6. Deployments of tori lines and in-water drag sections from the vessel C at setting speeds relevant to pelagic longline fisheries. In-water sections described in the table were attached to an aerial section comprising a 70-m yellow Dyneema backbone with single 5-mm orange plastic streamers (attached using cable ties) every 3.5 m

Design tested	Description	Speeds tested (kn)	Heights tested (m)
5	50 small gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid followed by a large road cone	6	6
6	200 m of 5 mm diameter monofilament	6, 7	6
7	100 small manufactured plastic cones spaced equally along 100 m of 5 mm diameter monofilament	6, 7	6
8	100 lumo lead caps spaced equally along 100 m of 5 mm diameter monofilament	6, 7	6
9	100 m of 5 mm diameter monofilament followed by (7) followed by one medium-sized road cone	7	6 6
10	100 m of 5 mm diameter monofilament followed by one medium-sized road cone	6, 7	6
11	100 m of 5 mm diameter monofilament followed by 50 small gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid	7	
12	(5)	6	5
13	(5)	6	4
14	(5)	6	3

To determine which tori line designs and construction materials may be most appropriate to recommend for use in small-vessel longline fisheries we considered:

- setting speeds at which designs were most effective,
- aerial extent achieved,
- simplicity of design and construction,
- propensity for tangling,
- ease of deployment and retrieval,
- cost efficacy, and,
- availability of materials.

For pelagic longline fisheries, tangling is a particular concern given the proximity of the gear to the sea surface along the entire length of the tori line. Therefore, tangling assumed greater importance when developing recommendations on design attributes of tori lines for pelagic longliners compared to demersal longliners.

Results

Deployment height

The drag required to achieve tori line aerial extent decreased with increasing deployment height, as shown in Figure 1. Across all treatments tested, the maximum drag required to deliver 80 m of aerial extent at deployment heights of 5 – 9 m was 16.5 kg, at 5 m high for a monofilament backbone. The minimum drag required to achieve 80 m aerial extent at these deployment heights was 5.5 kg, at a 9 m deployment height for a Dyneema backbone.

The fibreglass poles used to suspend tori lines tested flexed as increasing drag was applied to achieve increasing aerial extents (Figure 2). The rope loop used to support the tori pole at the 7 m and 9 m deployment heights was effective. That is, when the pole flexed, it did so above this loop. While tori poles were more difficult to handle when tori lines were attached at 9 m high, poles still effectively sustained the drag required to deliver aerial extents of 80 m. One pole broke when 30 kg of drag was applied to it. This is almost twice the maximum drag required to achieve an 80 m aerial extent for any of the designs tested.

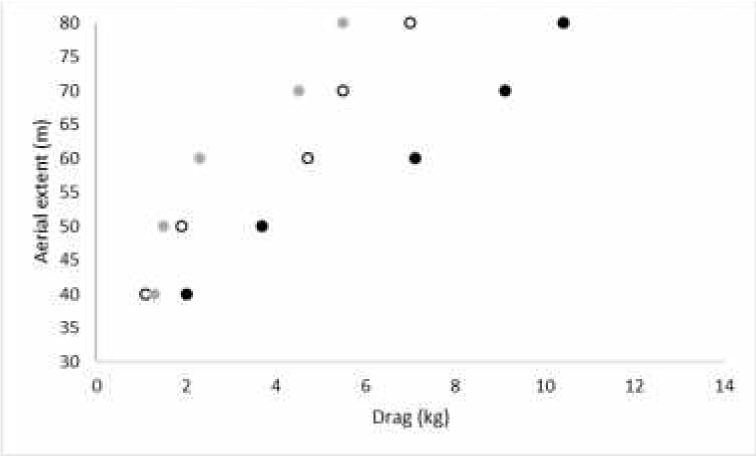


Figure 1. Drag required to achieve tori line aerial extents of 40 – 80 m at deployment heights of 5 m (black), 7 m (open circles) and 9 m (light grey), when 3 mm Dyneema backbone was used with streamers placed every 5 m along the line.

Figure 2. A tori pole under 20 kg of drag - more than was ever required to achieve an aerial extent of 80 m during the on-land trials.

Backbone material

Of the three materials tested, monofilament sagged and stretched the most across the three deployment heights tested (5 m, 7 m and 9 m). Monofilament also required the most drag weight to achieve aerial extents of 40 m – 80 m. The performance of Ashaway albacore braid and Dyneema was similar (Figure 3). However, Ashaway stretched more than Dyneema.

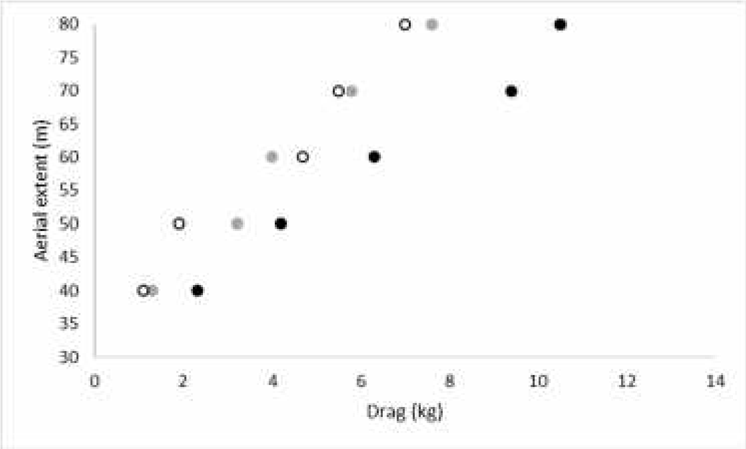


Figure 3. Drag required to achieve tori line aerial extents of 40 – 80 m using three different backbone materials: monofilament (black), Dyneema (open circles), Ashaway albacore braid (light grey) at a deployment height of 7 m.

Streamer configuration

Streamers of 9-mm diameter Kraton and similarly heavy 10-mm trawl braid added significant weight and windage to tori lines. This resulted in increased drag being required to achieve aerial extent. For example, single 9-mm diameter Kraton or double trawl braid streamers placed every 5 m along the 70 m tori line backbone generated 1 kg of weight, and 5.5 kg of drag was required to provide 70 m of aerial extent. When streamers were placed every 2.5 m along the same backbone (starting 5 m from the pole), the total streamer weight became 2 kg and the drag required to achieve 70 m aerial extent increased to 9.9 kg. The addition of up to 17 shark clips (weighing 10 g each) had minimal effect on drag requirements (Figure 4). These results highlight that lighter weight streamers should facilitate the achievement of greater aerial extents and reduce requirements for drag provision by the in-water sections of tori lines.

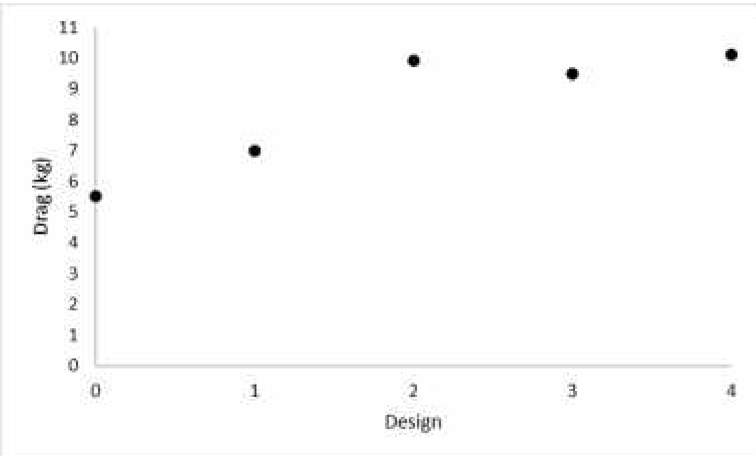


Figure 4. Drag required to provide 70 m aerial extent for a tori line with a 3 mm Dyneema backbone deployed at 7 m high, with different combinations of streamers and shark clips attached. Design 0: streamers at 5 m intervals; 1: streamers at 5 m intervals and 10 shark clips attached; 2: streamers at 2.5 m intervals with no shark clips; 3: streamers at 2.5 m with 10 shark clips; 4: streamers at 2.5 m with 17 shark clips.

Amongst streamer materials left in ambient weather conditions for seven months, the 9-mm diameter Kraton-type material faded most (Figure 5). The lengths of T061 – T064 retained their colour. There was no noticeable change in strength amongst any of the streamer materials over time.

Figure 5. Five streamer materials after seven months exposure to ambient exterior conditions. The small segments are the same materials pre-exposure. The 9-mm diameter Kraton-like material is at the top, and T061 – T064 are in order from the second to top to the bottom of the figure.

Preliminary drag testing

Across the 16 configurations of in-water sections tested, drag varied from approximately 1 kg to a maximum of 20 kg. Predictably, increasing vessel speed increased the drag provided by each design of in-water section tested (Figure 6). Large funnels provided less consistent drag than smaller funnels, as they tended to skip over the water. Inconsistent drag was provided by the road cones at higher speeds, as these dug in to the water then bounced up before digging in again.

The drag produced by most of the in-water sections tested at this stage of the project was substantially less than on-land testing showed necessary to achieve aerial extents of 80 m, particularly at slower vessel speeds. Therefore, additional work was required to develop in-water sections delivering more drag to improve the efficacy of tori lines, and to construct lighter tori lines such that less drag would be necessary to achieve the required aerial extent.

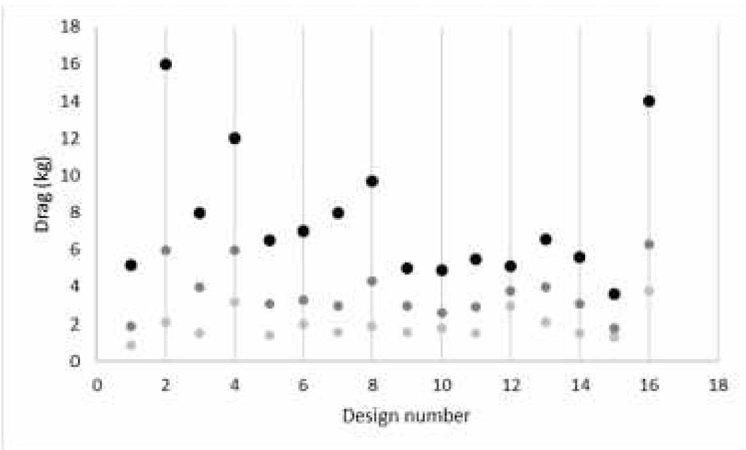


Figure 6. Drag generated from an in-water section of rope with various objects attached, at approximately 2.6 knots (light grey), 4.2 knots (dark grey dots) and 6.5 knots (black dots). Configurations of the in-water section are described in Table 3.

Vessel-based trials

Full results are reported by Pierre & Goad (2016). Here we report on test scenarios relevant to small pelagic longline vessels, with setting speeds 6-8 knots. Figure 7 shows one experimental tori line design during the trials.

Figure 7. Tori line 8 showing the large road cone comprising the in-water section and the splash it created at 4 knots. The rope used to measure aerial extent (marked with floats at 5-m intervals) is visible on the left.

Of the seven tori line designs trialled on vessel A at 6 knots, drag produced by one in-water section (12) was insufficient at 4.2 kg to progress to a full trial with the tori line backbone. The other six designs delivered aerial extents of 55 – 75 m at associated levels of drag of 5.8 – 9.5 kg (Figure 8). All tori lines tested were blown downwind, with the degree of displacement increasing with aerial extent. For example, tori line 4 with aerial extent of 50 m was displaced slightly downwind, whereas tori line 6 with 70 m aerial extent was blown 6 m downwind. Performance at 6 knots varied more than at slower vessel speeds in terms of how well tori lines tracked along a straight path astern. Assessing this was confounded by tori lines with less aerial extent being tested in calmer conditions.

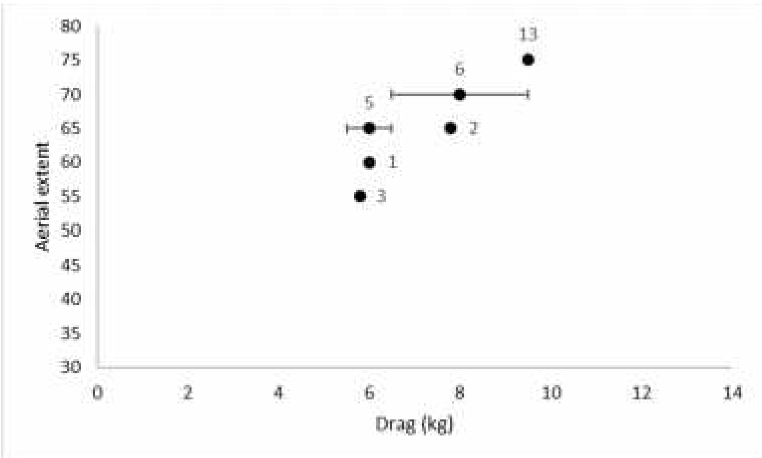


Figure 8. Drag and aerial extent delivered by the tori line designs tested at 6 knots on vessel A. Error bars show ranges in drag or aerial extent where the in-water section did not deliver consistent drag. Numbers adjacent to points refer to the construction of the in-water section (Table 4). The aerial section of all tori lines comprised 70 m of 3-mm diameter Dyneema with single 9-mm Kraton streamers placed at 2.5 m intervals.

On vessel B eight tori line trials were conducted at 7 knots (Figure 9). A further test was conducted using a deployment height of 7 m, to explore the amount of additional aerial extent created. Tori line design 8 provided the greatest aerial extent. Design 6 provided the same aerial extent at times, but there was broad variation from 60 – 90 m due to the netted float digging under, then bouncing up and over the water at these speeds (the intent of this design was to alert birds to the tori line). This happened so quickly that the associated changes in drag could not be measured effectively. A 7 m deployment height delivered an aerial extent of 75 m at 7 knots. Whilst at lower speeds the increase in tori line deployment height by 1 m achieved a commensurate increase in aerial extent of 5 m (Pierre & Goad 2016), at 7 knots, deployment heights of both 6 m and 7 m both provided 75 m of aerial extent.

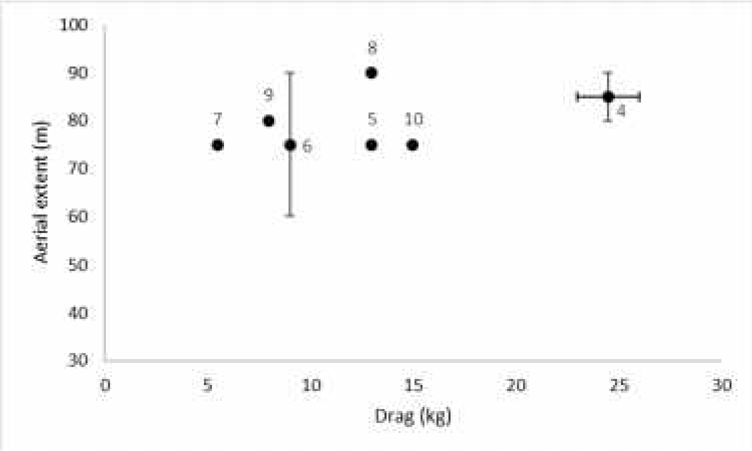


Figure 9. Drag and aerial extent delivered by the tori line designs tested at 7 knots on vessel B. Numbers adjacent to points refer to the construction of the tori line (Table 5). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals.

On the vessel C trials were undertaken at 6 and 7 knots. All tests except three were conducted at deployment heights of 6 m above the sea surface. The three additional tests were conducted on one design (tori line 5 in Table 6) at heights of 5, 4, and 3 m above the sea surface. All tori lines achieved aerial extents of 60 m or greater, and at 7 knots, tori line 9 stood out in terms of achieving both significantly greater aerial extent and drag compared to the other designs (100 – 120 m aerial extent and 25 – 30 kg drag; Figure 10).

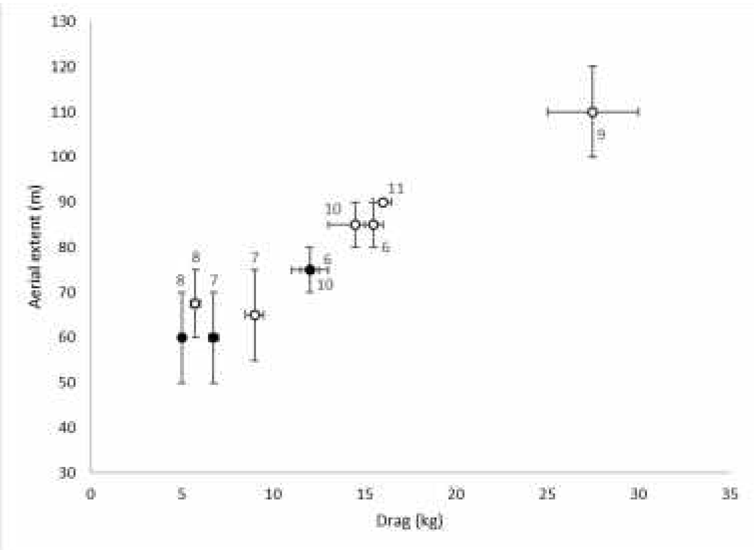


Figure 10. Drag and aerial extent delivered by the tori line designs tested at 6 (black circles) and 7 (open circles) knots on vessel C. Numbers adjacent to points refer to the construction of the tori line (Table 6). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals. Ranges likely result in part due to swell action during trials.

As expected, increasing deployment height broadly increased the aerial extent achieved by the test tori line. However, the extent of this increase varied and there was overlap between aerial extents achieved in the different trials (Figure 11).

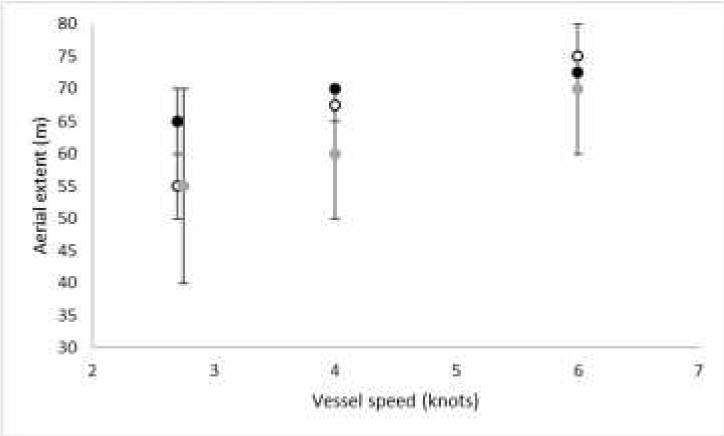


Figure 11. Aerial extent delivered by a tori line tested at deployment heights of 5 m (black circles), 4 m (open circles) and 3 m (grey circles) above the sea surface on vessel C. The aerial section of the tori line comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals. Ranges likely result from swell action during trial conditions.

Throughout the at-sea trials undertaken, we also considered storage options for tori lines. Three options were identified: reels, fish bins and re-purposed plastic drums (e.g. empty plastic 44 gallon drums, lashed onto deck railing). Fish bins were the least preferred option. They did not store tori lines as neatly as the drums, therefore tangling could occur between retrieval and the next deployment. Reels worked well for storing the monofilament sections of the tori lines tested. However, appropriately-sized reels suitable for use in the marine environment were not widely available or cost effective (quoted prices were upwards of NZD 1,000). Where monofilament sections are used in tori lines (e.g. as the in-water section), deploying from fence or hose reels may be the most cost effective option. These reels would be expected to degrade however and would need replacing over time. Plastic drums or smaller plastic washing baskets worked well for storing rope sections of tori lines. When retrieved, rope was coiled into the drum, with the in-water section coming in last, making it appropriately positioned for deploying first at the next set. In terms of the attachment of the tori line pole to the vessel, placement of the pole was, as expected, determined by vessel structure. The poles that we used in these trials were attached in different ways on three test vessels, and all attachment methods worked well (e.g., Figure 12).

Figure 12. The tori pole attachment, and tori line storage drum, shown in context and close up on.

Recommended tori line specifications

The series of trials conducted on land and at sea confirmed that a variety of tori line designs delivered aerial extents of 70 m or more, our key minimum performance requirement. The most challenging component of the tori line design to refine was the in-water section, required to provide drag. Predictably, increasing tori line deployment height and vessel speed increased the aerial extents delivered. With this basic performance metric addressed, considering optimal tori line designs and materials for the operational environment aboard smaller vessel longliners is required.

Tori line construction

Pole

The 52-mm diameter fibretube pole used during the trials performed extremely well, and this design is recommended for further testing where vessels do not have other structures from which to suspend their tori lines. The pole was strong, did not flex significantly when supported by stays, was relatively light given its length, and could be easily attached to existing vessel structures. The pole was custom-produced for this project, which increased its cost (NZD 500). However, to make poles in production runs of five (with this stock held by a distributor ideally located port-side) would provide cost savings of around 10%.

Backbone

Of the three backbone materials we tested, the Dyneema and Ashaway albacore braid both performed better than monofilament. Monofilament backbone stretched and sagged the most of the three materials. Given its properties and performance characteristics, Dyneema was preferred overall. Dyneema has a number of attributes contributing to its suitability for tori lines, for example, it floats, and does not absorb water, stretch, or twist. It is also extremely durable and resistant to abrasion. Ashaway is less durable, absorbs water and stretched more than Dyneema. Dyneema is slightly more expensive than Ashaway braid (NZD 0.99 compared to NZD 0.71 per metre, respectively). Fibres that do not twist may mean that tori line backbones perform better in bad weather (if streamers do not get wound around the backbone as much as they might when a twisting backbone fibre is used). Alternative approaches to reducing twisting have included the incorporation of swivels into tori line backbones (e.g. McNamara et al. 1999). However, these increase the complexity and cost of the tori line.

At the pole-end of the tori line backbone, the incorporation of a weak link is recommended. In case of undue tension (e.g., caused by tangling), this will break, freeing the tori line from the pole and allowing it to be safely carried astern the vessel while setting continues. Weak links are therefore recommended both for safety and operational reasons. The simplest weak link is a loop of monofilament line or rope of low breaking strain (lower than the tori line backbone, and the fishing gear). Rubber washers have also been recommended (Keith 1999). More complex links (such as the variable tension link developed for this project) can also be developed and tailored to a diversity of fishing operations, but are not functionally necessary for day to day fishing operations.

Streamers

In terms of performance of the streamers themselves, we did not identify any issues with the 9-mm Kraton or the 5-m diameter T064 material. However, with maintaining drag effectively being a key issue for small-vessel tori lines, we consider that lighter streamer materials are preferable. Smaller diameter streamer materials will also generate less windage than chunkier streamers, further reducing the drag necessary to keep tori lines on-course. Building on the custom production of the T061 – T064 materials undertaken for this project, Beauline International is exploring stocking the T062 product (one of the materials produced for this project) to address the need for a lighter weight streamer material for smaller-vessel longline operations. T062 weighs 19 gm^{-1} in contrast to the 9-mm diameter Kraton-like material at 38 gm^{-1}. Respective costs are approximately NZD 1.50 m^{-1} compared to NZD 3.00 m^{-1}. In addition to its lighter weight and lower cost, this material maintained its colour better than the 9-mm diameter Kraton-like material. However, if line-setting (and therefore tori line use) only occurs at night, colour retention may not be a significant performance issue.

The streamer materials used in this project did not create noise or blow around unpredictably in the wind, as other materials can (e.g., holographic tape, small plastic flags or plastic bait-box strapping), and some fishers report that the noise and unpredictable movement of streamer materials contributes to their efficacy (e.g., Goad et al. 2010; FV Moonshadow crew, pers. comm.). While the efficacy of tori lines with a mix of short and long streamers has been explored quantitatively (e.g., Sato et al. 2012), any specific effects of including flashy or flappy materials between more traditional longer lengths of streamer material have not (e.g., Melvin et al. 2009). While it is flashy, readily available holographic tape (also known as ‘irri-tape’) may not be durable (Melvin et al. 2009), so gains in efficacy would be offset by the requirement for replacement as the holographic coating wears off.

Fishers also reflected that tori line streamers were not operationally feasible when deployed to the sea surface close to the vessel stern. This is because of the extreme risk of tangling and has also been reflected from larger vessel surface longline fisheries (Melvin et al. 2009). Therefore, to reduce operational issues, attaching shorter streamers at 5 – 10 m astern and no streamers for the first 5 m is recommended. Where pelagic longline gear is not weighted, attaching long streamers from distances further astern may be considered preferable from an operational perspective.

In-water section (drag)

Optimising the height at which tori lines are deployed and the drag required to achieve satisfactory aerial extent are the two most critical components of tori line design relating to efficacy and operational performance. In both bottom and surface longline fisheries, in-water sections need to provide drag while not creating unacceptable risks of tangling with fishing gear (e.g. floats and hooks). For example, crew on one test vessel did not support the use of a series of gillnet floats to provide drag on a tori line due to tangling risks. Similar tangling issues have been reported in other longline fisheries (Melvin et al. 2009; Løkkeborg 2011).

We considered two solutions for in-water sections to ameliorate these issues. First, we trialled the inclusion of a “spacer” section of 100-m long 5-mm diameter monofilament between the aerial section and any object used to create drag on the terminal end of the tori line. Not only did this section increase the distance (i.e. distance over the water and depth) between fishing gear and drag object, the monofilament itself also provided drag. Second, we trialled a number of in-water sections that minimised the potential for tangling. These included, for example, lengths of monofilament, rope, knotted rope and custom-made solid plastic cones. The drag delivered was broadly comparable to other in-water constructions in many cases, demonstrating that drag “objects” are not necessary to support tori line aerial extent, particularly at higher speeds. The trade-off with both approaches was that designs reducing tangling risk resulted in a longer tori line, which consequently took more time to retrieve. Fishers will be required to decide for their operation what the optimal balance comprises between the length of in-water section versus the tangling risk.

In terms of the performance of drag objects, vessel speeds above 5 knots caused some of the drag objects tested (e.g. the road cones and the netted float) to dig in and then bounce up out of the water, thereby providing inconsistent drag, which led to intermittent sagging of the tori line (i.e. variable aerial extent). This has been reported from other work (Melvin and Walker 2008) and makes these objects less effective in delivering consistent protection of longline hooks. However, at lower speeds these objects provided consistent and effective drag.

At the outset of this project, we were particularly interested in designs for in-water sections of tori lines that created splash. However, during the project, we encountered different views on how on-water splash affected seabirds. Some practitioners considered that splash deterred seabirds, whereas others considered that splash attracted seabirds’ attention (and so could be used to focus their attention away from fishing gear). In the context of refining tori line designs, we recommend clarifying the response of seabirds to splash in relation to any effects on tori line efficacy.

Tori line designs for smaller-vessel longline fisheries

The following recommendations are intended to be starting points from which vessel operators can refine their own approach to designing an effective and practical tori line suited to their fishing operations. We include designs for operations in which fishers are more comfortable managing the risk of tori lines tangling with fishing gear, as well as for operations in which tangling is a particular concern (where gear is especially close to the surface a substantial distance astern).

For all designs, we recommend the use of an aerial section comprising a 70-m or longer backbone of 3-mm diameter Dyneema, with single streamers of 5-mm diameter plastic tubing (e.g. T062, available from Beauline International Ltd) placed at 3.5 m intervals, starting from around 5 m astern (and with the first two streamers being short to avoid tangling in fishing gear). We also recommend the use of a pole attachment as in this project where other structures are not in place for tori line attachment, to provide a deployment point for tori lines 6 m or more above the sea surface and with a weak link attaching the tori line to the pole (to protect the pole from breaking and allow retrieval of the tori line). For vessels setting at 6-7 knots the in-water sections considered appropriate are:

- a 200-m (or longer) length of 5-mm diameter monofilament
- a 100-m length of 8 - 10 mm diameter braided rope

- 100 m of 5-mm diameter monofilament plus 50 large gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid (though this option may have a relatively higher risk of tangling with gear)

If a shorter line is preferred, a towed object can be used to generate sufficient drag. A cone shaped object will reduce the likelihood of tangles (and attaching the object with a weak length of rope of monofilament would allow it to break away in the event of a tangle).

Discussion

Deploying tori lines from smaller longline vessels creates particular design challenges, e.g., the need for a dedicated mounting pole on many vessels, light construction materials, and drag such that tori lines can be retrieved by a single crew member. Some fishers may be discouraged from using tori lines given negative experiences with past deployments, potentially resulting from ineffective designs and construction materials that are not fit-for-purpose. This project provided some solutions to the design challenges of smaller vessels, and these are intended as a starting point for vessel operators to tailor tori lines to their situation. In reality, the design options are endless. Our results confirm that numerous tori line designs can deliver 70 m of aerial extent when deployed from smaller longline vessels. The amount of drag needed to deliver this aerial extent varied with vessel speeds and materials used to construct tori lines. However, as a broad rule-of-thumb, where the in-water section of a tori line delivers 15 kg of drag, an aerial extent of 70 m should be achievable. Pierre & Goad (2016) make recommendations for further research, including at-sea tests under a range of weather conditions during commercial fishing activity.

In the context of mitigating the impact of fishing for highly migratory fish stocks on seabirds in the Convention Area of the Western and Central Pacific Fisheries Commission, CMM 2015-03 provides minimum specifications for a range of mitigation options, including tori lines.

The specifications for tori lines to be used by vessels <35 m total length south of 30^{o} south (CMM 2015-03 Annex 1 1b)) is similar to some of the optimal designs found in this study, and our recommendations may assist vessel operators to find construction solutions to meet the required specifications.

However, the specifications for tori lines to be used by vessels <24 m total length north of 23^{o} north (CMM 2015-03 Annex 1 2c)) varies considerably from our optimal designs and from international best practice (ACAP 2016). Notably, the specifications do not require streamers to be used. These specifications reflect findings from trials reported by Katsumata et al (2015) who noted that tangling of the under-water section of the tori line with fishing gear was a particular concern. In our trials, concerns from fishermen on possible tangling was a major consideration in developing tori line designs for small vessel pelagic longliners. We addressed these concerns through the use of extra light weight streamer material, and in-water sections that had low risk of entanglement. We believe these design principles can apply to other small vessel pelagic longliners globally, and would result in more effective, and practical, tori line designs for reducing seabird bycatch. Designs such as those we report should be considered in the review of specifications in Annex 1 2c) of CMM 2015-03, which must be reviewed no later than 3 years from the implementation date.

Recommendations

We recommend that:

- the SC note the tori line design options reported here, developed especially for small longline vessels, and recognise that they may be useful for vessel operators to implement practical and effective tori lines to meet current required specifications.

- the SC consider these tori line designs during the review or development of any updated tori line specifications, as will be required for the review of specifications set out in CMM 2015-03.

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