Conservation Services Programme Project MIT2014-02: Improving tori line performance in small-vessel longline fisheries

Final Report

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Abstract

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. Despite the efficacy of this mitigation measure, there is ongoing controversy around the benefits of tori line usage in some New Zealand fisheries, particularly amongst the operators of smaller longline vessels. 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, to explore tori line designs and materials appropriate for use during bottom and surface longline fishing methods. Tori line designs were tested at a range of vessel speeds (from 2.7 – 7 knots) to emulate the setting speeds used across the smaller-vessel longline fisheries of interest. Tests confirmed that a number of different tori line designs delivered aerial extents of 70 m (our key performance criterion). 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, an aerial extent of 70 m should be achievable. We provide recommendations on tori line designs to be tested in a broader range of weather conditions than was encountered during our trials and under real fishing conditions. We also recommend tori line use as part of mitigation strategies for small-vessel longliners that include effective line-weighting.

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Introduction

Amongst New Zealand commercial fisheries, small vessel longline fisheries have been identified as presenting particularly high risks to seabird populations due to incidental captures, and associated uncertainties in capture estimation (Richard and Abraham 2013, 2015). A suite of tested and effective mitigation measures provides a strong foundation for the deployment of bycatch reduction strategies on small longline vessels (e.g., Bull 2007; Løkkeborg 2011). In recent years, mitigation strategies used on smaller longline vessels (< 28 m in overall length) have been characterised and refined (Goad et al. 2010; Goad 2011; Pierre et al. 2013, 2014a, 2014b). Variation amongst vessels (e.g., in vessel design) and in the characteristics of fishing operations (e.g., setting speed) is such that to ensure efficacy and safety, mitigation measures must often be tailored to individual vessels and gear types deployed.

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 demersal longline vessels, the use of single or paired tori lines has been documented to reduce seabird catch. Best practice is identified as a tori line 150 m in length, attached such that the tori line's height above water at the vessel stern is approximately 7 m. Paired streamers are attached to the tori line backbone, 5 m apart and reaching the sea surface (ACAP 2014a). 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, again 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 2014b).

Despite the demonstrated efficacy of tori lines and their inclusion in regulation (New Zealand Government 2010, 2014), there is ongoing controversy around the benefits of tori line usage amongst some New Zealand fishers, particularly those operating smaller longline vessels. While some operators successfully deploy tori lines on a regular basis, others report that concerns about the safety of tori lines discourage them from using this mitigation measure. Some do not consider that operationally feasible tori line designs are effective in reducing seabird captures. Further, some fishers do not believe that the levels of seabird captures occurring in smaller vessel longline fisheries warrant the use of tori lines (Goad et al. 2010; Goad 2011; pers. obs.; J. Cleal, pers. comm.).

To contribute to the resolution of these issues, the overall objective Conservation Services Programme (CSP) project MIT2014-02 was to develop improved tori lines which are specifically optimised for safe and effective use on small longline vessels (CSP 2014). In this report, we describe trials conducted on land and on three different smaller vessels at sea, to explore tori line designs and materials appropriate for use during bottom and surface longline fishing methods. We structure our approach by vessel speed, which broadly correlates with small-vessel longline fisheries targeting different species. We also provide guidance on tori line designs and materials for smaller longline vessels, and trouble-shooting techniques to improve tori line performance.

Our key minimum performance criterion was that tori lines must maintain an aerial extent of at least 70 m astern longline vessels. This was developed through considering regulatory requirements for surface and bottom longline vessels (New Zealand Government 2010, 2014), international best practice guidance (ACAP 2014a, 2014b), and what might be operationally feasible for smaller vessel operations. 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 (Goad et al. 2010; Goad 2011; Pierre et al. 2013, 2014a).

Methods

Workshop

At the outset of the project, a workshop was held to consolidate the project team's approach, with input from vessel operators. Specifically, the objectives of the workshop were to:

- identify potential issues relating to the use of tori lines on smaller longline vessels, in terms of tori line performance, barriers to implementation, and safety
- compile ideas on effective construction and design for small-vessel tori lines that are considered likely to address these issues, and,
- identify next steps, including the outline of an at-sea programme, to develop tori line designs for smaller-vessel longline fisheries.

Key issues identified that affect the operational feasibility, safety and efficacy of tori lines were:

- vessel setting speed
  Bottom longline vessels are captured in the 2 – 6 knot range, and surface longliners in the 6 – 8 knot range. Both bottom and surface longline vessels could be setting at around 6 knots.
- attachment height
  Given the variation in vessel designs amongst the smaller vessel bottom and surface longline fleets (Appendix 1), 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 2014a, 2014b).
- 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 (although this can be ameliorated by decreasing vessel speed). Therefore, for smaller vessels where deployment and retrieval are likely to be conducted by hand by a single crew member, a lighter tori line is preferred.
- 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.

With these issues in mind, the research approach was developed, including on-land and at-sea testing.

New materials

Our ideal was to construct tori lines using cost effective off-the-shelf materials, already readily accessible to fishers (e.g., from gear suppliers in ports). However, this was not possible for all construction components. To achieve the deployment height required to deliver target aerial extents for tori lines, a pole system was required where vessels did not have an appropriate attachment point (Appendix 1). The project team worked with Kilwell Sports Ltd (Rotorua, New Zealand) to develop a suitable pole attachment. The pole had to be sufficiently light to be readily handled by individual fishers and also strong enough to safely and effectively support the forces the tori line generated (e.g. drag). Two pole setups were trialled. First, the team acquired three test poles, each 3 m in length, and two joining spigots from Kilwell. The poles were factory seconds and cost approximately $100 each. The poles were joined using epoxy with the fibretube spigots supporting the join. Tubes had a 42 mm external diameter and a wall thickness of 2.5 mm. When preliminary testing showed that the strength of the first test pole was insufficient (see Results), the team worked with Kilwell to create a stronger and less flexible fibretube pole. The second pole was 52 mm in external diameter with 4 mm thick walls. Two 3-m long sections of pole were joined using epoxy and an internal spigot, to create one 6-m long pole from which tori lines were suspended. This custom-manufactured system (i.e. two poles and the joining spigot) cost $400.

In the course of conducting land and sea trials (below), the project team 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 (Table 1), 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.

Finally, the team tested a range of readily available objects that could be added to the in-water section of tori lines to create sufficient drag to deliver the aerial extent desired. To facilitate manual retrieval of tori lines on small vessels, a larger number of smaller objects was preferred to create drag, compared to fewer large objects. Experience with off-the-shelf materials prompted the team to explore manufacture of solid polyethylene plastic cones in two sizes (Table 1). These were custom-manufactured by Supply Services Ltd (Mt Maunganui, New Zealand) and cost $460 for 100 small cones and $670 for 50 large cones.

On-land testing

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. We considered three deployment heights (5 m, 7 m and 9 m), achieved using three joined 3-m long fibretube poles of 42 mm in diameter. The base of the pole was held inside a 1 m steel tube, with 500mm of the pole inserted into the tube. When testing deployment heights of 7 m and 9 m, a rope loop was added to provide extra support for the pole. This was tied loosely to a support strut behind the tori pole at approximately 5 m height.

We also tested three backbone materials (3 mm diameter Dyneema rope, 3 mm monofilament nylon, 3.1 mm Ashaway albacore braid), two streamer configurations of equal weight (single streamers of 9-mm diameter Kraton-type material or double streamers of 10-mm diameter trawl braid every 2.5 m and every 5 m), and examined the effects of adding variable numbers of shark clips (often used to attach streamers) to the tori line backbone (Table 2). Streamers started at 5 m in length, and were progressively shortened along the tori line backbone with 0.5 m the shortest streamer attached.

With each different tori line design and deployment configuration, we used a set of 50 kg Salter spring scales to record the drag required to maintain the aerial extent of the test tori line at 40 m, and thereafter at 10 m intervals up to 80 m. We also tested the drag that the support poles and a standard 4.7 m game fishing outrigger pole (which had a lighter wall thickness and tapered from 45 mm to 22 mm outside diameter) could sustain before bending to close to breaking point.

To assess the weather-resistance (e.g., UV tolerance) of streamer materials, sections of each of the manufactured materials (T061 – T064) and 9-mm Kraton-type material were exposed to ambient weather conditions in Tauranga from December 2015 to June 2016. Colour and texture (i.e. product degradation) were then assessed.

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	

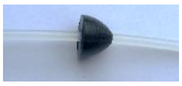
Nuts	M12 size, weighing 13 g	
Small manufactured plastic cones	20 mm diameter at their widest point, 15 mm long, with 5 mm central hole	
Lumo lead caps	12 mm diameter at base, 15 mm long	
Large manufactured plastic cones	50 mm diameter, 75 mm long with 10 mm central hole	
Polystyrene cotton reel float	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

At-sea testing

Vessel speeds

At sea, we structured our testing approach in accordance with vessel speeds used during setting in smaller-vessel longline fisheries. Past work on smaller inshore vessels highlighted wide ranges in setting speed across target species and vessel lengths. For example, setting speeds of 2.2 – 5 knots have been documented on vessels targeting snapper, 1.8 – 5.1 knots on vessels targeting bluenose and 2.6 – 4.1 knots on vessels targeting ling (Goad et al. 2010; Goad 2011; Pierre et al. 2013). Setting speeds on smaller surface longline vessels tend to be faster, at 6 – 8 knots (Pierre et al. 2015).

Preliminary drag testing

Having completed on-land testing, the in-water elements of the tori line (the 'drag section') were explored in calm sea conditions (Table 3). The focus of this testing was on the drag produced in-water by a range of materials and designs. Therefore, deployment height was removed as a factor during this testing. The trial drag sections were deployed from the test vessel attached to a rope. The drag sections were immersed entirely, and the separate rope was maintained in the air and towed from approximately 1.5 m above the vessel stern. This provided consistency for comparing the drag achieved by the different designs tested. Drag was measured aboard the vessel, using either of two sets of spring scales at the vessel end of the rope attached to the trial drag section. Drag at 2.6 knots, 4.2 knots, and 6.5 knots was recorded.

Dimensions and images of materials used for drag testing are shown in Table 1. All materials used in drag testing are commercially available except the flutterboard. This device was created by Brian Kiddie, a fisher based in Tauranga, for use as a bird deterrent astern his own bottom longline vessel. Others have since also made flutterboards for their own use.

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

Vessel-based trials

Four fishing vessels were used as platforms for at-sea testing of tori line designs and construction materials. For trials, tori lines were clipped into a variable tension link (Figure 1, the yellow rope is the tori line), which was itself attached to a continuous loop of Ashaway braid. This continuous loop was attached to the top of the deployment pole and lower down, meaning that the tori line could readily be raised and lowered from the deck, at deployment and retrieval. (This approach to hoisting a tori line has been called the “flagpole method” (Hibell 2003)). A lazy line (the lower blue rope in Figure 1) anchored the tori line to the vessel, should it be released by the link. The link was made for the trials and could be tightened to hold up to 25 kg of drag. By providing a point for breakaway, weak links help ensure the safety of tori lines at sea where they can become entangled in the longline. If the weak link gives way because the tori line is tangled in the longline on setting, the tori line can be retrieved at hauling with the rest of the gear. The weak link also preserves the pole, should undue tension arise. (While this variable tension link performed well for the trials, a simpler approach to the weak link is preferred for normal fishing operations).

Figure 1. The variable tension link used during at-sea tori line trials.

Each vessel-based test was conducted at a range of vessel speeds, to emulate the diversity of setting speeds used on small bottom and surface longliners. The same testing approach was used on all vessels. 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. On the vessel, each test commenced with measuring the drag provided by the in-water section of the tori line. This was undertaken similarly to the preliminary drag testing described above. That is, the drag section was immersed entirely, while a set of Salter 50 kg spring scales was attached to the backbone of the tori line (which was held out of the water). The drag was measured in kilograms at a range of vessel speeds. Then, the scales were removed, and the tori line was let out completely. 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.

Trial 1: The FV Royal Salute

This trial was conducted off Tauranga on 20 December 2015. The trial focused on testing a tori line constructed from commercially available materials already in use on fishing vessels, or relatively cost effective to obtain from suppliers. The flutterboards were the exception to this, and were included as they are already in use by a number of smaller longline vessels in FMA1, and are therefore of interest for this project. The focus of this trial was bottom longline fishing, and tori lines were tested at vessel speeds of 2.7 knots, 4 knots and 6 knots.

This trial involved deploying tori lines from a pole comprising two 3 m sections of fibretube obtained from Kilwell Sports Ltd. The two 3-m sections were glued together using epoxy, and the join was supported by an internal spigot. The tube was 42 mm in overall diameter with a wall thickness of 2.5 mm. The pole was attached to the vessel using a 1-m long steel support tube close to the vessel stern. Rope stays were tied from the pole to another point on both vessels, to support it further. Tori lines were deployed at 6 m above the vessel deck – approximately 6.5 m above the sea surface.

A 70-m tori line backbone was constructed from 3-mm yellow Dyneema (Table 1). Streamers attached to this backbone were 9-mm diameter Kraton-type material (Table 1). We attached single streamers with cable ties at distances of 2.5 m apart to optimise streamer weight and the likely efficacy of the tori line. Single streamers provide no redundancy should one break. However, spacing streamers more frequently along the line should provide a better curtain effect than more typical double streamers at 5-m spacings. Building on preliminary drag testing, we selected nine in-water sections to provide drag at the end of this test tori line backbone (Table 4). Performance was documented as described in previously.

We then evaluated the effects of using lighter streamer configurations along the Dyneema backbone. For this test, an in-water section comprising 20 repeating sections (of one funnel-three nuts-one float-three nuts) spaced equally along 50 m of 10-mm diameter trawl braid was used. Aerial extent was compared at a vessel speed of 4 knots with three different streamer arrangements: single 9-mm Kraton-type streamers spaced at 2.5-m intervals, and single 5-mm diameter custom-manufactured plastic tubing (T064) streamers starting at 5 m long and progressing to 0.5 m long, attached to the tori line backbone using cable ties at 2.5 m and 5 m intervals. Again, performance was determined as described above.

Table 4. In-water sections prepared to trial on tori lines deployed from the FV Royal Salute. For images of components of in-water sections, see Table 1.

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
4	(3) plus 120 nuts added as weight (3 nuts on each side of each float)
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
7	(5) + (6)
8	Large road cone
9	(5) followed by one large flutterboard
10	Medium-sized road cone – 25 m rope – medium-sized road cone – 25 m rope – large road cone
11	360-mm diameter surface longline float covered in trawl netting
12	200 m 3-mm diameter monofilament
13	400 m 3-mm diameter monofilament

Trial 2: The FV Moonshadow

This trial was conducted off Greymouth on 3 March 2016. Tori lines were tested at vessel speeds of 3.5 knots, 5 knots and 7 knots (two setting speeds appropriate to small-vessel bottom longliners, and one to small-vessel surface longliners, respectively), and deployed at 6 m above the sea surface. One tori line ((7) in Table 5) was also tested at these vessel speeds at a deployment height of 7 m to assess how much aerial extent was achieved. In addition to 7 knots emulating the setting speed of small-vessel surface liners, testing included tori line constructions that were less likely to get caught in fishing gear – an especially important consideration for surface lining operations, when fishing gear can remain close to the surface for significant distances astern.

The trial used a custom-made fibretube pole manufactured by Kilwell Sports, that was thicker and stronger than those previously used. The 6-m long pole was 52 mm in overall diameter with a wall thickness of 4 mm. It comprised two 3-m sections joined with an internal spigot. The pole was held in position on the vessel against the deck railing with three hose clamps. Insulation tape under the hose clamps reduced the likelihood of abrading the tube.

For this trial, the vessel's own tori line was deployed first, with aerial extent determined. Next, a tori line similar to those used on smaller vessel longliners targeting ling was deployed, with drag and aerial extent measured. Third, a tori line backbone comprising a 70 m length of yellow Dyneema backbone with single streamers of 5-mm plastic tubing spaced at 3.5 m apart was deployed with a series of different in-water sections (Table 5).

As described above, drag and aerial extent were determined using scales and a marked rope deployed from the vessel stern. Wind speed and direction, swell and sea state, and the course of tori lines astern the vessel (i.e. how well the tori lines tracked a straight line) were recorded for each test.

Table 5. Tori line designs deployed from the FV Moonshadow during at-sea testing off Greymouth. For images of components of in-water sections, see Table 1.

Tori line	Description
1	Vessel's own – packing strapping and 3.5 mm faded fluoro plastic noodle streamers, at varying distances. Streamers mostly shorter. One 6" float as terminal object.
2	Exemplar of small vessel ling longline tori line – 70 m of 6 mm Dan 3 strand backbone, 15 5-m long single 3.5 mm fluoro plastic noodle streamers on the first 52 m of the tori line backbone, 15 m 12 -mm diameter rope with 6" float as in-water section
	• *70-m yellow Dyneema backbone with single 5-mm orange plastic streamers (attached using cable ties) every 3.5 m plus:*
3	50 large gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid
4	100 m of 5 mm diameter monofilament plus (3)
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)

As for trials conducted on the FV Royal Salute, the variable tension link was used during the trials on the FV Moonshadow to attach tori lines to the deployment pole (Figure 1).

Trial 3: The FV Coastal Rover

Following work on the FV Moonshadow, the project team wanted to further address tori line designs for lower and higher setting speeds – that is, speeds more characteristic of bottom longline vessels targeting bluenose, and surface longliners. To this end, tests on the FV Coastal Rover were conducted at speeds of 2.7, 3.5, 4, 6 and 7 knots off Tauranga on 11 April 2016.

At-sea procedures were broadly similar to the previous trials. That is, for each tori line deployed, drag delivered by the in-water sections was first determined using Salter scales. After drag testing, the tori line was deployed as a whole and its aerial extent measured with a marked rope. Weather conditions were also recorded. Most deployments occurred at 6 m from the sea surface. One design (5) was also tested at heights of 3, 4, and 5 m to investigate the effect of deployment height on aerial extent (Table 6).

Tori lines were deployed from the 52-mm diameter fibretube pole as on the FV Moonshadow. The pole was lashed to the gantry for the trials. A 70 m backbone of yellow Dyneema comprised the aerial section of the tori line, with single streamers of 5-mm diameter orange plastic tubing (T064) attached at 3.5 m intervals, starting at lengths of 5 m and progressively shortening to 0.5 m.

Trial 4: The FV Kotuku

One subsequent trial of drag was conducted on the FV Kotuku, following the FV Coastal Rover trip. This trial measured the drag of a 97 m length of 8-mm diameter braided polyester rope with 115 knots along it, at a vessel speed of 3.5 knots (Table 6). The testing procedure was as described above. This test was conducted based on feedback from the skipper of the FV Odyssey, a bottom longliner targeting ling.

Table 6. Deployments of tori lines and in-water drag sections from the FV Coastal Rover (Test 1 – 15) and FV Kotuku (Test 16) during at-sea testing off Tauranga. For images of design components, see Table 1.

Design tested	Description	Speeds tested (kn)	Heights tested (m)
	• *70-m yellow Dyneema backbone with single 5-mm orange plastic streamers (attached using cable ties) every 3.5 m plus:*		
1	50 large manufactured plastic cones along 50 m of 10-mm trawl braid	2.7, 4	6
2	(1) followed by large road cone	2.7, 4	6
3	(1) followed by polystyrene cotton reel float	2.7, 4	6
4	(1) followed by 3 large flutterboards	2.7, 4	6
5	50 small gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid followed by a large road cone	2.7, 4, 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	3.5, 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	3.5, 7	
12	(5)	2.7, 4, 6	5
13	(5)	2.7, 4, 6	4
14	(5)	2.7, 4, 6	3
	• *In-water drag section only*		
15	100 m length of 8 mm diameter 3-braid rope	3.5, 6	-
16	97 m length of 9 mm diameter braided rope with 115 knots	3.5	-

Development of recommendations for tori line usage

Determining which tori line designs and construction materials may be most appropriate to recommend for use in small-vessel longline fisheries required considering:

- 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 surface longline fisheries, tangling is a particular risk 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 surface-lining operations.

A broader consideration supporting tori line usage was storage prior to deployment and after retrieval. The project team explored the use of reels and bins in this regard.

Results

On-land testing

Deployment height

The drag required to achieve tori line aerial extent decreased with increasing deployment height, as shown in Figure 2. 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 3). 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.

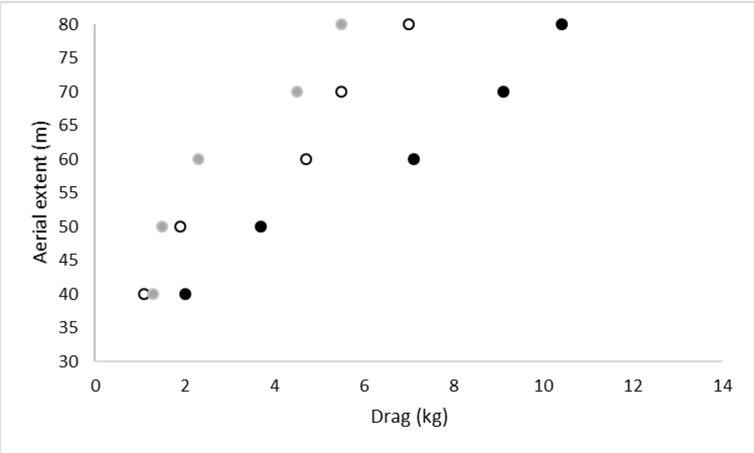


Figure 2. Drag required to achieve tori line aerial extents of 40 – 80 m at deployment heights of 5 m (black), 7 m (open circles) and 9 m (light grey), when 3 mm Dyneema backbone was used with streamers placed every 5 m along the line.

Figure 3. 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.

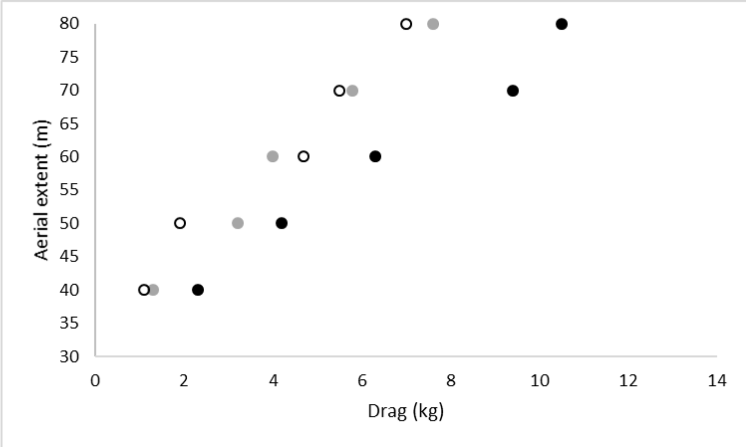


Figure 4. Drag required to achieve tori line aerial extents of 40 – 80 m using three different backbone materials: monofilament (black), Dyneema (open circles), Ashaway albacore braid (light grey) at a deployment height of 7 m.

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 5). 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.

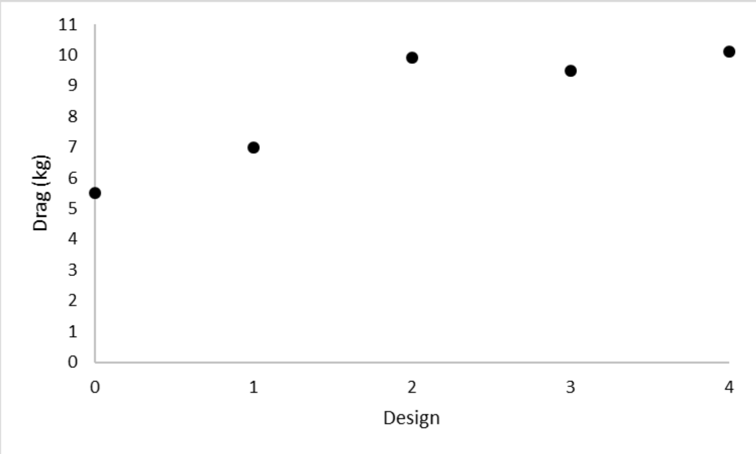


Figure 5. Drag required to provide 70 m aerial extent for a tori line with a 3 mm Dyneema backbone deployed at 7 m high, with different combinations of streamers and shark clips attached. Design 0: streamers at 5 m intervals; 1: streamers at 5 m intervals and 10 shark clips attached; 2: streamers at 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.

Of the streamer materials left in ambient weather conditions for seven months, the 9-mm diameter Kraton-type material faded most (Figure 6). The lengths of T061 – T064 retained their colour. There was no noticeable change in strength amongst any of the streamer materials over time.

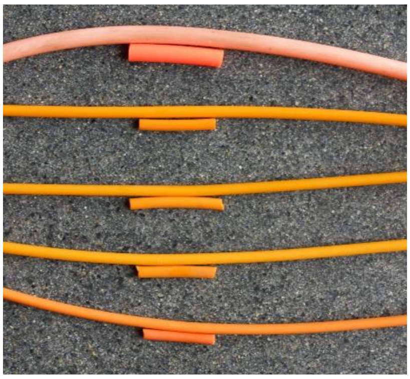


Figure 6. Five streamer materials after seven months exposure to ambient exterior conditions. The small segments are the same materials pre-exposure. The 9-mm diameter Kraton-like material is at the top, and T061 – T064 are in order from the second to top to the bottom of the figure.

At-sea testing

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 7). 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 required to achieve the required aerial extent.

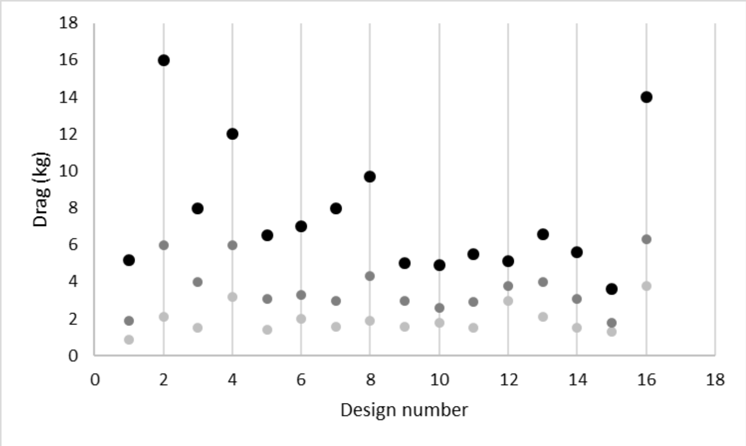


Figure 7. Drag generated from an in-water section of rope with various objects attached, at approximately 2.6 knots (light grey), 4.2 knots (dark grey dots) and 6.5 knots (black dots). Configurations of the in-water section are described in Table 3.

Vessel-based trials

Trial 1: The FV Royal Salute

On the FV Royal Salute, 23 separate tests were conducted: five at 2.7 knots, 11 at 4 knots, and seven at 6 knots. Wind strength ranged from 10 – 15 knots and swell height was 0.2 m during testing.

At 2.7 knots, aerial extent delivered by the tori lines tested ranged from 45 – 70 m, with drag from 4.5 – 12 kg (Figure 8). The tori pole flexed under the drag of all tori lines (i.e. including at the lowest level of drag of 4.5 kg). With the three large flutterboards (tori line 6 in Figure 8), the tori line tracked a straight line path best. Other designs were more prone to being blown downwind, however these other designs delivered superior aerial extent. The large road cone (tori line 8 in Figure 8) generated a small amount of splash, more so than the other designs tested.

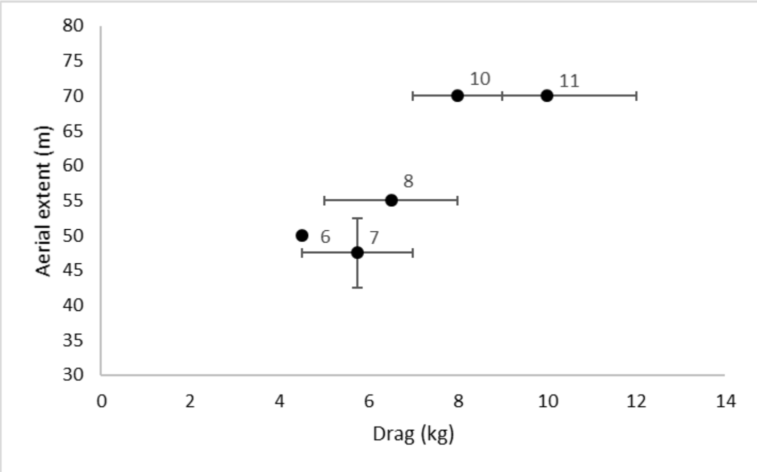


Figure 8. Drag and aerial extent delivered by the six tori line designs tested at 2.7 knots on the FV Royal Salute. Error bars show ranges in drag or aerial extent where the in-water section did not deliver consistent drag. Numbers adjacent to points refer to the construction of the in-water section (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.

At 4 knots, the drag produced by in-water sections 1, 2, and 3 was insufficient to warrant a full trial using the tori line backbone, as these sections generated drag of only 2, 3 and 1.8 kg respectively. Five other in-water sections were tested using the 70 m Dyneema backbone with single 9-mm diameter Kraton streamers attached at 2.5 m intervals, and these generated aerial extents from 50 – 70 m at associated levels of drag of 2.7 – 13 kg (Figure 9). Where the drag created by in-water sections was inconsistent (i.e., tori lines for which y-axis error bars are shown in Figure 9), more streamer movement was created due to the drag object bouncing along through the water. Concomitant intermittent sagging of the tori line backbone also occurred. 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. Similar to trials conducted at 2.7 knots, the tori pole flexed as drag as applied to it. Tori lines 7 and 8 delivered the most splash of those tested at 4 knots (Figure 10).

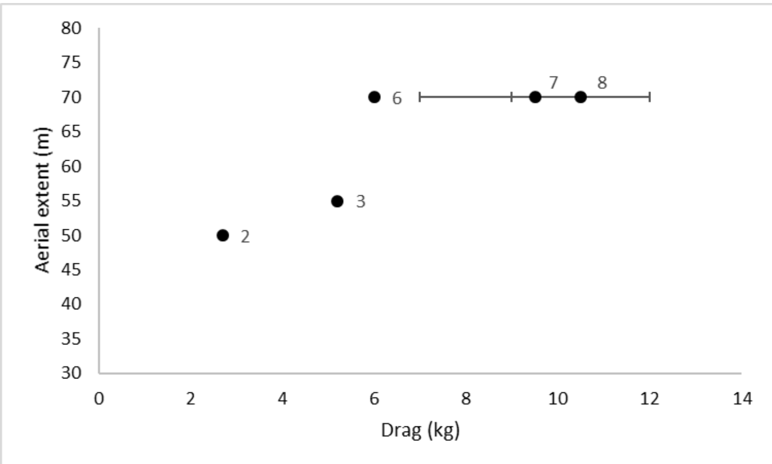


Figure 9. Drag and aerial extent delivered by the tori line designs tested at 4 knots on the FV Royal Salute. Error bars show ranges in drag or aerial extent where the in-water section did not deliver consistent drag. Numbers adjacent to points refer to the construction of the in-water section (Table 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.

Figure 10. 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 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 in-water sections were tested at 2.7 and 4 knots, using the 70 m Dyneema backbone with single 9-mm diameter Kraton streamers attached at 2.5 m intervals. These delivered aerial extents of 55 – 75 m at associated levels of drag of 5.8 – 9.5 kg (Figure 11). 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. For example, tori line design 1 with 55 m of aerial extent was tested in 5 knots of wind and maintained a straight course astern the vessel. In contrast, tori line 5 was tested in winds of 10-15 knots, and blew downwind 6-10 m. Its aerial extent was 65 m.

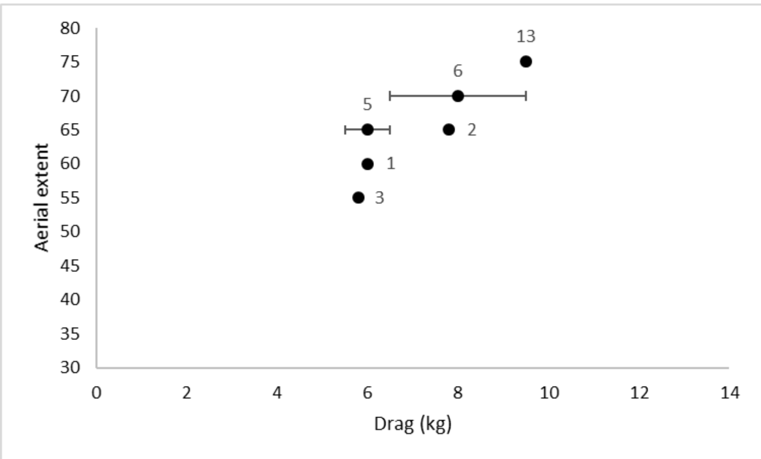


Figure 11. Drag and aerial extent delivered by the tori line designs tested at 6 knots on the FV Royal Salute. Error bars show ranges in drag or aerial extent where the in-water section did not deliver consistent drag. Numbers adjacent to points refer to the construction of the in-water section (Table 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.

Of the three trials conducted at a vessel speed of 4 knots to assess the effects of streamer weight, drag and aerial extent did not vary detectably. Drag was measured at 9 – 11 kg, and aerial extent was 70 m for all three streamer configurations. However, the tautness of the tori line astern the vessel did vary. The lightest streamer configuration (T064 streamers spaced at 5-m intervals) sagged the least, and the heaviest design tested with 9-mm diameter Kraton streamers spaced at 2.5 m, sagged the most. Sag in the tori line design with T064 streamers spaced at 2.5 m intervals was intermediate to the two extremes.

Trial 2: The FV Moonshadow

On the FV Moonshadow, 30 trials of tori lines deployed from 6 m above the sea surface were conducted at three different vessel speeds: ten at 3.5 knots, nine at 5 knots, and eight at 7 knots. Further, three tests (one at each of the three vessel speeds) were conducted using a deployment height of 7 m, to explore the amount of extra drag that a greater deployment height created. Wind strength was 0.5 – 5 knots and swell height was 0.2 m during all testing on this vessel. All tori lines tracked a straight line course during trials.

Testing commenced with the vessel's own tori line, which delivered 30 m of aerial extent at 3.5 knots, up to 60 m at 7 knots. The second design tested – an exemplar of the tori line design used on smaller longline vessels targeting ling – performed similarly, with 35 m of aerial extent at 3.5 knots. With only 4 kg of drag delivered by the 6-inch diameter float used at the terminal end of the tori line, the performance of this design would improve significantly with more drag applied.

For the other tori line designs (designs 3 – 10 in Table 5), trials at 3.5 knots delivered aerial extents of 50 – 65 m at drag weights of 2.5 – 7 kg (Figure 12). Tori line design 8 delivered the most drag and the most aerial extent at 3.5 knots, using 100 m of 5-mm diameter monofilament line followed by 50 large-size custom-manufactured solid polyethylene cones. Designs 3, 10 and 5 were the next best performers in terms of aerial extent, all delivering 60 m (Figure 12).

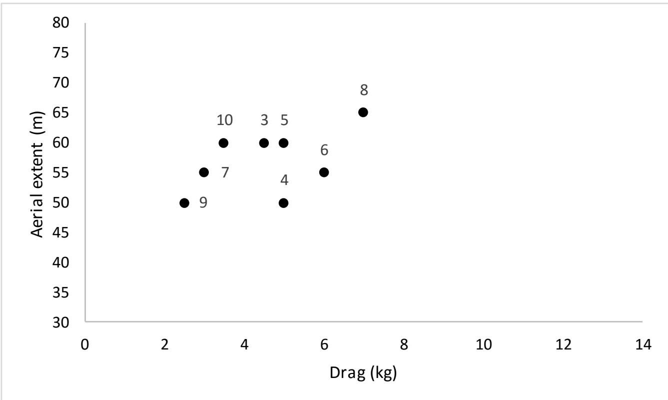


Figure 12. Drag and aerial extent delivered by the tori line designs tested at 3.5 knots on the FV Moonshadow. Numbers adjacent to points refer to the construction of the tori line (Table 5). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals.

At vessel speeds of 5 knots, the vessel's own tori line delivered 50 m of aerial extent. The other tori line designs tested provided 65 – 75 m. Drag ranged from 5 – 13 kg. Design 8 provided the most aerial extent (Figure 13). The large plastic cones comprising the in-water section of tori line designs 7 and 8 started to plane over the water surface and ride up out of the water at 5 knots, generating splash. In comparison, the smaller manufactured cones (design 9) remained in the water, generating some splash but less than the larger polyethylene cones.

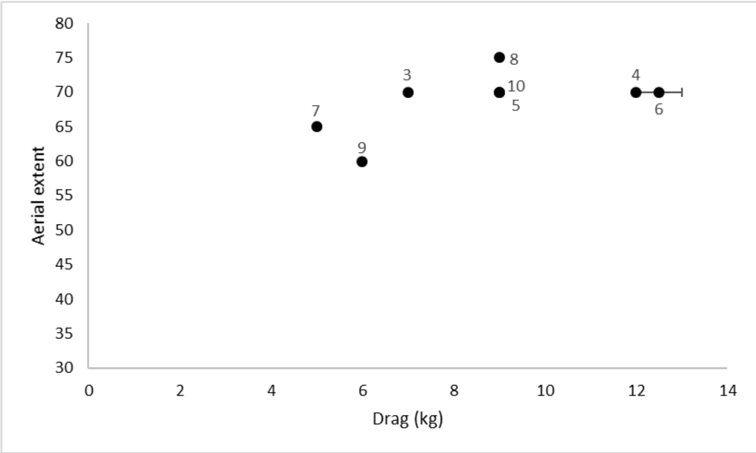


Figure 13. Drag and aerial extent delivered by the tori line designs tested at 5 knots on the FV Moonshadow. Numbers adjacent to points refer to the construction of the tori line (Table 5). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals.

At 7 knots, the vessel's own tori line provided 60 m of aerial extent. As at 5 knots, 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 (Figure 14). This happened so quickly that the associated changes in drag could not be measured effectively.

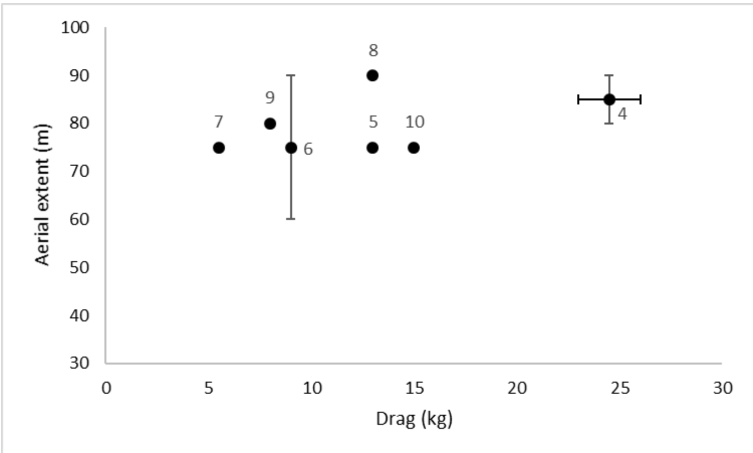


Figure 14. Drag and aerial extent delivered by the tori line designs tested at 7 knots on the FV Moonshadow. Numbers adjacent to points refer to the construction of the tori line (Table 5). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals.

At the three vessel speeds under which testing was conducted on the FV Moonshadow, we compared the aerial extents attained by tori line design 7 at deployment heights of 6 m and 7 m above the sea surface. At 7 m, the aerial extent this design delivered was 60 m, 70 m and 75 m for 3.5, 5 and 7 knots respectively. Therefore, at the two lower speeds, increasing the tori line deployment height by 1 m achieved a commensurate increase in aerial extent of 5 m. However, at 7 knots, deployment heights of both 6 m and 7 m provided 75 m of aerial extent.

In terms of the operational practicality of all tori line designs, feedback from the crew aboard the FV Moonshadow was that they would be reluctant to deploy any design with components that increased the risk of the tori line tangling with the fishing gear (including the floats attached to the longline backbone), despite any potential efficacy in deterring seabirds. Crew did not support the use of multiple gillnet floats along the in-water section of the tori line for this reason. Crew endorsed the concept of the monofilament “spacer” section attached aft of the aerial section and prior to any other in-water components. This spacer section provided more opportunity (time and greater distance astern) for the longline to sink before there was any potential to become tangled with the tori line. In addition, the spacer section also provided some drag on the tori line, thereby reducing the amount of drag that the in-water section had to deliver. However, use of the spacer section also meant that the tori line took longer to retrieve due to its length.

Trial 3: The FV Coastal Rover

On the FV Coastal Rover, 34 trials were conducted. Trials were undertaken at five vessel speeds: 2.7, 3.5, 4, 6 and 7 knots. At speeds of 2.7 – 4 knots, tori line designs were aimed at bottom longliners. At higher vessel speeds of 6 and 7 knots, surface longline operations were the focus. Therefore, not all designs were tested at all speeds (Table 6). 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. During all tests, wind strength ranged from 2 – 5 knots and swell height was 0.5 – 1 m. All tori lines tested aboard the FV Coastal Rover tracked a straight line course during trials.

At speeds of 2.7 – 3.5 knots, the performance of all tori lines tested was very similar, in terms of aerial extent obtained (65 – 70 m). Drag varied more significantly, from around six to almost 12 kg (Figure 15). At 4 knots, this was also the case, with aerial extents varying 5 m or less, while drag fluctuated from 12 – 23 kg (Figure 16).

Increasing vessel speed increased both drag and aerial extent amongst tori line designs explored for surface lining operations (Figure 17). 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).

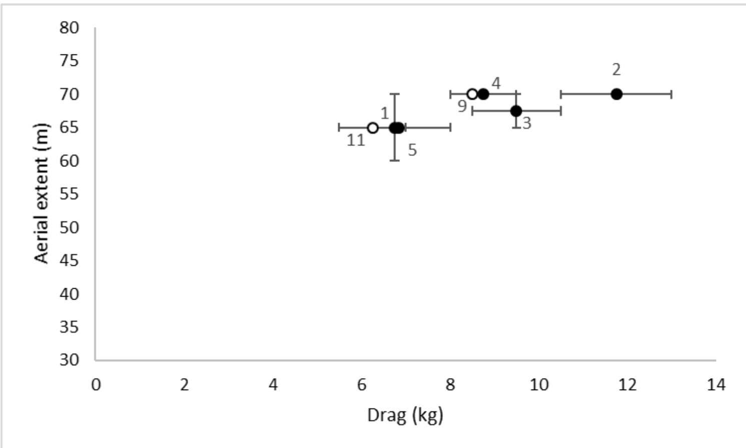


Figure 15. Drag and aerial extent delivered by the tori line designs tested at 2.7 (black circles) and 3.5 (open circles) knots on the FV Coastal Rover. Numbers adjacent to points refer to the construction of the tori line (Table 6). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals. Ranges likely result from swell action during trials.

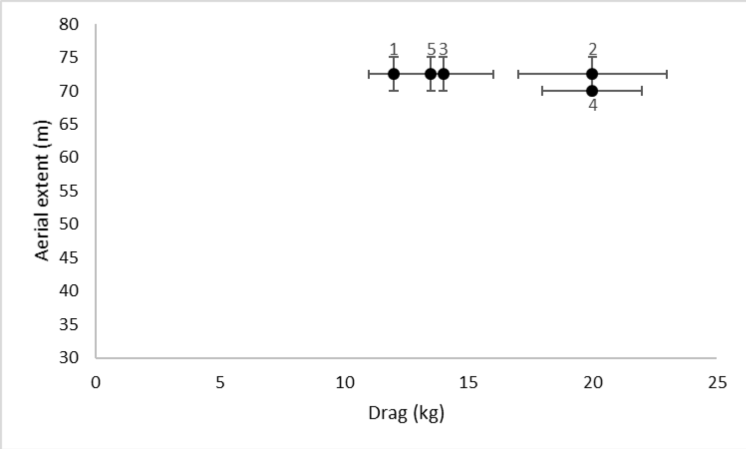


Figure 16. Drag and aerial extent delivered by the tori line designs tested at 4 knots on the FV Coastal Rover. Numbers adjacent to points refer to the construction of the tori line (Table 6). The aerial section of all tori lines shown here comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals. Ranges likely result from swell action during trials.

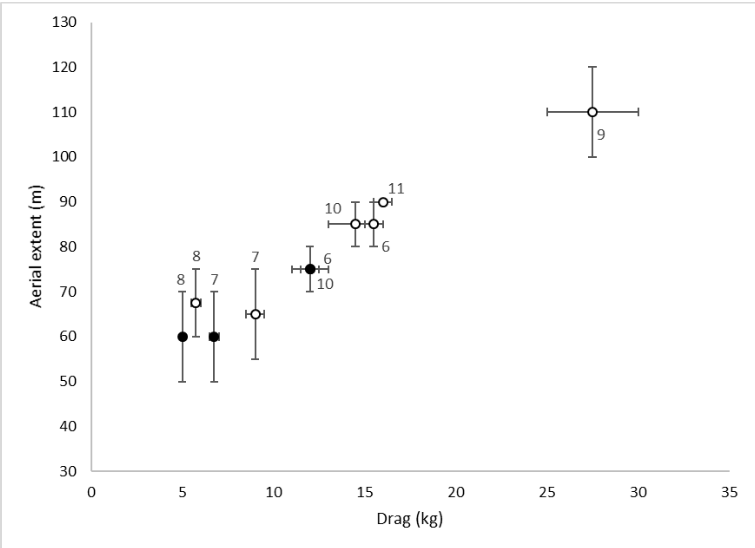


Figure 17. Drag and aerial extent delivered by the tori line designs tested at 6 (black circles) and 7 (open circles) knots on the FV Coastal Rover. Numbers adjacent to points refer to the construction of the tori line (Table 6). The aerial section of all tori lines shown here comprised 70 m of 3-mm 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.

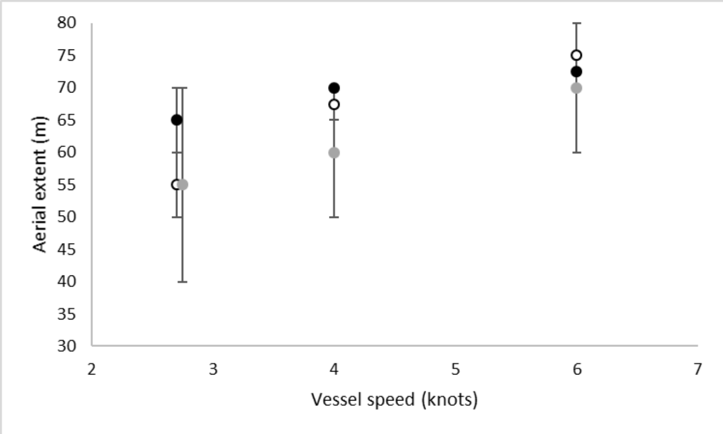


Figure 18. Aerial extent delivered by a tori line tested at deployment heights of 5 m (black circles), 4 m (open circles) and 3 m (grey circles) above the sea surface on the FV Coastal Rover. The aerial section of the tori line comprised 70 m of 3-mm diameter Dyneema with single 5-mm orange plastic (T064) streamers placed at 3.5 m intervals. Ranges likely result from swell action during trial conditions.

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 18).

Finally, the drag produced by in-water section 15 (Table 6) was 5 – 10 kg and 16 – 20 kg at 3.5 and 6 knots respectively, with variation resulting from swell conditions.

Trial 4: The FV Kotuku

Conditions during this trial (design 16 in Table 6) were similar to those in the FV Coastal Rover series. The knotted rope delivered 7.5 – 9.5 kg of drag at a vessel speed of 3.5 knots.

Tori line storage and attachment

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 $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 19).

Figure 19. The tori pole attachment, and tori line storage drum, shown in context and close up on the FV Moonshadow.

Discussion

The series of trials conducted on land and at sea confirmed that a variety of tori line designs delivered aerial extents of 70 m, 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, 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 ($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 ($0.99 compared to $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, cited in ACAP 2013). 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 at 38 gm^{-1}. Respective costs are approximately $1.50 m^{-1} compared to $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 tori lines are only used 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.

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, fishers on the FV Moonshadow 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; ACAP 2013).

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

We provide broad recommendations for developing tori line designs for each category of vessel speeds below and in Appendix 2. Recommendations are intended to be starting points from which vessel operators can refine their own approach, and include designs for operations in which fishers are more comfortable managing the risk of tori lines tangling with fishing gear (e.g. where this risk is mitigated through the use of substantial line weights), as well as for operations in which tangling is a particular concern (e.g., surface lining operations, where gear is especially close to the surface a substantial distance astern). For the designs here, we focus on construction materials available through gear suppliers.

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 – T064) 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, as described above.

2.7 – 3.5 knots

Supplying sufficient drag to maintain aerial extent at low vessel speeds is particularly challenging, especially where tangling is a concern. We propose the following designs for in-water sections for further trials, including in a range of weather conditions:

- 100-m length of 8 – 10 mm diameter rope with knots approximately 1-m apart
- 360-mm diameter surface longline float covered in trawl netting
- three medium-sized road cones at the start, middle and end of a 50 m length of 10-mm trawl braid
- 100 m of 5-mm diameter monofilament followed by one medium or large-size road cone

4 – 5 knots

In-water sections considered appropriate for further trials in this speed bracket are:

- one large road cone
- 50 small gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid followed by a large road cone
- three large flutterboards at each end and the centre of a 50 m length of 10-mm diameter trawl braid
- 100 m of 5 mm diameter monofilament, plus either 50 large gillnet floats spaced equally along 50 m of 10-mm diameter trawl braid, or a 360-mm diameter float covered with net

6 – 7 knots

In-water sections considered appropriate for further trials in this speed bracket 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

Conclusions

Over the past two decades, many designs for tori lines have been proposed (and to a varying degree tested) by fishers and bycatch mitigation practitioners (Keith 1999; Smith 2001; Bull 2007; Melvin and Walker 2008; Melvin et al. 2009; Løkkeborg 2011). 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 provides 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.

In addition to further exploring the design components suggested above under a range of weather conditions, we recommend:

- testing the efficacy of in-water sections in supporting tori line backbones longer than the 70 m backbone we used
- assessing whether including swivels in tori lines (e.g. to attach streamers to the backbone, and the in-water section to the aerial section) significantly improves tori line performance,
- testing tori line designs under fishing conditions
- investigating whether adding flashy materials that move unpredictably and create noise (e.g. holographic tape or small flags) between long streamers running to the sea surface increases the efficacy of tori lines
- quantifying whether tori line designs that generate splash are more effective as seabird deterrents
- conducting in-port and on-vessel workshops with fishermen to promote effective tori line design and to support trouble-shooting where designs are inadequate,
- working with suppliers to bed in manufacturing and sale arrangements for the new streamer materials and the deployment pole produced in this project where these are found effective on an ongoing basis,
- continuing to distribute tori line construction materials (and whole tori lines) as part of seabird liaison programmes

- supplying government fisheries observers deployed on smaller longline vessels with the fact sheet produced as part of this project, to facilitate trouble-shooting with tori lines they may encounter at sea, and,
- promulgating tori line use as part of broader mitigation strategies for small-vessel longliners that include effective line-weighting. Heavier line-weighting will reduce the distance astern that tori lines must protect.

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Appendix 1: Smaller longline vessels

Amongst New Zealand's smaller-vessel longline fisheries, vessel types can be grouped as follows:

1. Very small vessels (i.e., around 8 m or less in length) with a wheelhouse but no other significant superstructure: These vessels will be the most challenging in terms of tori line development, given their low height above water and minimal options for tori line attachment (Figure 1).
2. Vessels around 9 – 12 m in length with some metalwork above the deck: This category comprises the majority of small bottom longline vessels. The shelter deck may have a hard (fibreglass or metal) or soft (canvas) roof (Figure 2).
3. Vessels around 12 – 15 m in length that were formerly trawlers but have been converted for longlining: These vessels are the most straightforward to deploy tori lines from. This is because they have some residual gantry metalwork in place, which is robust and can be used to elevate and support tori lines (Figure 3).
4. Vessels that are 15 – 20 m in length and fish using both the bottom and surface longline methods: These vessels may have metalwork around the stern that can be used to attach and elevate tori lines (Figure 4). The deck layout at the stern may differ significantly between vessels, but all offer a number of potential options for tori line attachment.

Figure 1. A small bottom longline vessel that is low to the water and has minimal deck structure at the stern for the robust attachment and effective elevation of a tori line. Photo: D. Goad.

Figure 2. An example of a “typical” small bottom longline vessel, i.e., vessels 12-15 m in length with a shelter deck and some metalwork close to the stern. Photo: D. Goad.

Figure 3. A former trawler that has been converted for inshore bottom longlining. The residual gantry metalwork in place provides many options for the attachment of tori lines. Photo: D. Goad.

Figure 4. A vessel that fishes using both the bottom and surface longline methods, with metal shelter deck supports and a float cage near the stern. Photo: D. Goad.