SCIENTIFIC COMMITTEE
EIGHTEENTH REGULAR SESSION

ELECTRONIC MEETING
10 – 18 August 2022

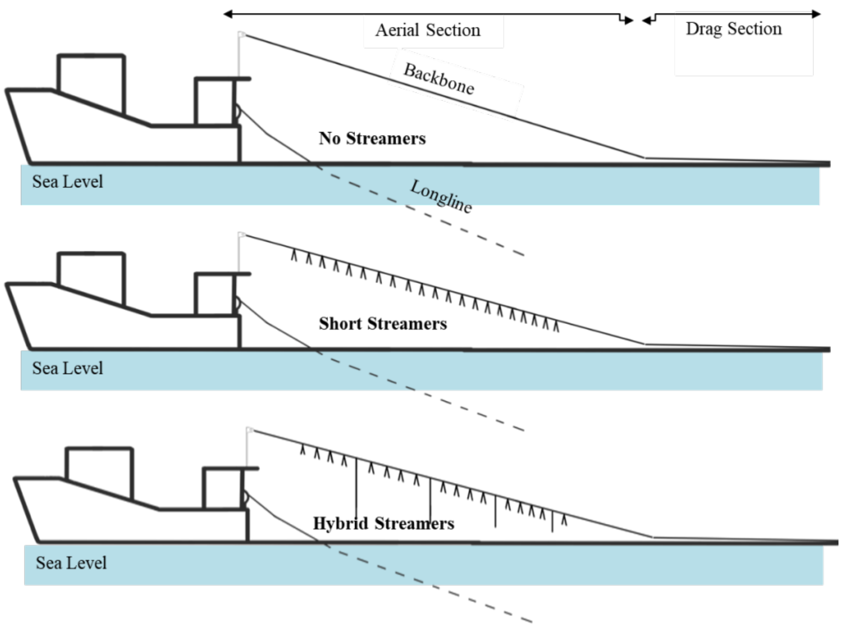
Practicality and Efficacy of Tori Lines to Mitigate Albatross Interactions in the Hawaii Deep-set Longline Fishery

WCPFC-SC18-2022/EB-IP-14

E. Gilman[1], H. Naholowaa[2], A. Ishizaki[3], M. Chaloupka[4],
C. Brady[5], M. Carnes[6], S. Ellgen[5], J. Wang[7], E. Kingma[8]

[1] Pelagic Ecosystems Research Group; The Safina Center
[2] Western Pacific Regional Fishery Management Council (Contractor)
[3] Western Pacific Regional Fishery Management Council
[4] Ecological Modelling Services Pty Ltd
[5] National Marine Fisheries Service Pacific Islands Regional Office
[6] Joint Institute for Marine and Atmospheric Research (Former Affiliation)
[7] National Marine Fisheries Service Pacific Islands Fisheries Science Center
[8] Hawaii Longline Association

Practicality and Efficacy of Tori Lines to Mitigate Albatross Interactions in the Hawaii Deep-set Longline Fishery



January 2021

Western Pacific Regional Fishery Management Council
1164 Bishop Street, Suite 1400, Honolulu, Hawaii

A report of the Western Pacific Regional Fishery Management Council
1164 Bishop Street, Suite 1400, Honolulu, Hawaii 96813 USA

Prepared by Eric Gilman[1], Holly Ann Naholowaa[2], Asuka Ishizaki[3], Milani Chaloupka[4], Colby Brady[5], Mathew Carnes[6], Sarah Ellgen[5], John Wang[7], Eric Kingma[8]

[1]Pelagic Ecosystems Research Group; The Safina Center
[2]Western Pacific Regional Fishery Management Council (Contractor)
[3]Western Pacific Regional Fishery Management Council
[4]Ecological Modelling Services Pty Ltd
[5]National Marine Fisheries Service Pacific Islands Regional Office
[6]Joint Institute for Marine and Atmospheric Research (Former Affiliation)
[7]National Marine Fisheries Service Pacific Islands Fisheries Science Center
[8]Hawaii Longline Association

This report may be cited as follows:

Gilman, E., Naholowaa, H.A., Ishizaki, A., Chaloupka, M., Brady, C., Carnes, M., Ellgen, S., Wang, J., Kingma, E. 2021. Practicality and Efficacy of Tori Lines to Mitigate Albatross Interactions in the Hawaii Deep-set Longline Fishery. Western Pacific Regional Fishery Management Council. Honolulu, Hawaii, 48pp.

Published in the United States by the Western Pacific Regional Fishery Management Council

ISBN: 978-1-944827-77-9

Contents

FIGURES

TABLES

ACKNOWLEDGEMENTS

The project team thanks the Hawaii longline vessel owners, captains and crew members who participated in the project and shared their experiences with building their own seabird deterrents, especially those who took part in the Phase 1 and Phase 2 trials: F/Vs Janthina, St. Marianne, St. Damien, Queen Diamond 2, Queen Alina, Golden Phoenix, and Hawaii Ocean. We also thank David Goad (Vita Maris, New Zealand), Daisuke Ochi and Haruka Hayashi (National Research Institute of Far Seas Fisheries Shimizu Laboratory, Japan Fisheries Research and Education Agency) for their expert input provided at the September 2019 tori line workshop, and Sean Martin (Pacific Ocean Producers) for providing workspace to build the tori lines. This project was funded by the NOAA Cooperative Research Program through NOAA and Council Award NA15NMF4410066, the Joint Institute for Marine and Atmospheric Research, and the Pacific Islands Fisheries Science Center.

EXECUTIVE SUMMARY

The Hawaii deep-set longline fishery incidentally interacts with seabirds, primarily Laysan (*Phoebastria immutabilis*) and black-footed (*P. nigripes*) albatrosses. Following a successful introduction of a suite of seabird mitigation measures in 2001, black-footed albatross interactions have increased in the fishery over the past decade. The Western Pacific Regional Fishery Management Council (Council), at its 174th Meeting in October 2018, recommended that the National Marine Fisheries Service (NMFS) support the development of tori lines (also known as streamer or bird-scaring lines) and other alternative seabird bycatch mitigation measures. At its 176th Meeting in March 2019, the Council additionally recommended the development of draft minimum standards for tori lines. In 2019, the Council, Hawaii Longline Association, NMFS Pacific Islands Fisheries Science Center and NMFS Pacific Islands Regional Office implemented a cooperative research project to conduct a tori line demonstration and experiment in the Hawaii deep-set longline fishery. The project assessed the practicality of alternative tori line designs, determined the effect of tori line use on albatross interaction risk, and developed recommendations for tori line minimum standards. The project findings inform revisions to the Hawaii deep-set longline fishery seabird mitigation measures, expand the body of literature on tori line efficacy in longline fisheries, and highlight the potential for electronic monitoring (EM) systems to monitor variables that significantly explain seabird bycatch risk in longline fisheries.

Demonstration of Alternative Tori Line Designs

The project team comprising of the report authors reviewed tori line designs used in various longline fisheries, obtained input from Hawaii fishers, explored possible materials, and examined design configurations suitable for the Hawaii longline fishery. To aid in this process, the Council convened a workshop in September 2019 with New Zealand and Japanese tori line experts who provided valuable input in the design of tori lines for smaller vessels such as those used in the Hawaii longline fishery. The project team developed five candidate aerial section designs, determined the most appropriate drag section materials and design, and developed a suitable tori line attachment pole. The project team conducted land trials to determine the amount of drag required for various potential aerial section designs and lengths. Emphasis was placed on light-weight, streamlined designs with minimal potential for tangles to improve the practicality and safety of tori line use.

Alternative tori pole materials were assessed. After testing fiberglass and galvanized steel poles for tori line attachment, stainless steel, which had only a negligible amount of flex, was determined to better withstand at-sea environments than the fiberglass or galvanized steel pole. Eight alternative drag section designs were considered for inclusion in at-sea trials. Each design was evaluated to determine if it was suitable at providing the requisite drag to achieve the target aerial section length and practicality for deployment and for minimizing the risk of entanglement with fishing gear. One drag section design was selected over the others due to its superior performance and practicality for retrieval and coiling for storage.

One-day at-sea demonstrations using five tori line designs were conducted on seven Hawaii longline vessels. Three aerial section designs were tested: (a) short streamers; (b) hybrid streamers (mix of short and long streamers); and (c) streamerless. During each of the demonstrations, the five designs were assessed for the time it takes to deploy and retrieve the tori line, and whether the tori line was consistently maintained over the area where baited hooks are typically cast. So that the demonstrations could be conducted near port, where longline fishing is prohibited, the demonstrations were conducted without deployment of fishing gear, and therefore an assessment of entanglement risk with fishing gear was not conducted. Captain and crew were also asked to provide input on the operational practicality and which of the five designs they preferred, based on the ease of installation, and practicality for deployment, retrieval and storage.

Captains and crew expressed the highest preference for tori line designs with short streamers, with an aerial extent of 40 m or 50 m, due to their ease of deployment and retrieval, and having sufficient amount of streamers to deter seabirds from sinking baited hooks. Captains predicted that the long streamers used in the hybrid design would be more effective at deterring seabirds foraging close to the vessel stern than the short streamer design, but the long streamers made it the heaviest design to retrieve. The streamerless design was least favored by captains and crew because they believed that the design would be less effective at reducing seabird interactions than the designs with streamers.

A tori line design with short streamers with a 50 m-long aerial section was selected for inclusion in the Phase 2 controlled experiment. This design was selected based on captain and crew feedback from Phase 1, because the design produced a sufficient aerial extent to cover the area with sinking baited hooks, and because it meets line specifications of the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC).

Tori Line Experiment

A controlled experiment assessed the efficacy of a tori line at reducing albatross catch risk when used during setting operations in combination with required seabird bycatch mitigation measures (branchline weighting, blue-dyed fish bait, offal and spent bait discharges). A Bayesian modelling workflow accounting for the experimental tori-line sampling design was used to model statistically the albatross interactions (attempts to contact baited hooks, contacts with baited hooks, captures) recorded using an EM system. Albatrosses contacts were about 3 times (95% highest posterior density interval [HDI]: 1-7) less likely, and attempts about 2 times (95% HDI: 1-4) less likely when tori-lines were deployed than in sets without a tori line. Albatrosses were also marginally less likely to be captured in sets with tori lines but the sample size (10 captures) was far too small to support any meaningful inference.

The experimental design did not support strong inference about the efficacy of the other employed seabird bycatch mitigation measures but it was apparent that neither blue-dyed bait nor offal discharges was helpful in reducing albatross interactions in this specific trial. While findings suggest that discharging offal and spent bait during setting was associated with higher seabird catch risk, it is unclear whether discharging caused the higher bird interaction rates or vice versa. Crew may have discharged offal or spent bait in response to observing high seabird interactions. Whether offal discharging increases long-term seabird attendance, affects seabird behavior, such as increasing short-term scavenging and competitive behavior, increasing seabird catch rates, is a research priority.

There was no apparent effect of deployment of a tori line on the distance astern of seabird interactions with terminal tackle relative to sets with no tori line. Both sets with and without a tori line had over half of interactions occur within 10 m of the stern. Of observed attempts and contacts, 99.7% occurred within 50 m of the vessel stern, and over half of interactions were within 10 m. These results suggest that there would be limited conservation gain from tori lines with aerial coverage longer than the 50 m-long design used in the experiment for this fishery. In other areas of the world, a relatively small number of deep-diving seabird species access baited hooks at depth and bring the baited hook to the surface where other, larger species may become hooked on the terminal tackle. These types of secondary interactions likely do not occur in the Hawaii longline fishery as the primary species that interact with the fishery are the shallow-diving black-footed and Laysan albatrosses .

The study provided proof of concept that an EM system can be designed to collect variables that significantly explain seabird catch risk, including some seabird bycatch mitigation methods, environmental variables and seabird scan counts.

1. INTRODUCTION

The Hawaii deep-set longline fishery incidentally interacts with seabirds, primarily Laysan (*Phoebastria immutabilis*) and black-footed (*P. nigripes*) albatrosses (Gilman et al., 2008, 2016). Following the introduction of seabird bycatch mitigation regulations in the Hawaii deep-set longline fishery in 2001, there was a 67% significant reduction in the standardized seabird catch rate based on data through 2007 (Gilman et al., 2016). Due to a combination of increasing temporal trends in fishing effort and in black-footed albatross catch rates, seabird catch levels have gradually risen over the past decade in the Hawaii deep-set longline fishery, with more significant increases observed since 2015 (Gilman et al., 2016; NMFS, 2020; WPRFMC, 2020). The rise in black-footed albatross catch rates may have been due to variability in the temporal and spatial distribution of fishing effort and an increase in the number of albatrosses attending Hawaii longline vessels, possibly in response to variability in ocean productivity in the north Pacific Ocean linked to inter-annual and decadal climate cycles and to climate change (Gilman et al., 2016; Wren et al., 2019).

In 2017, the Council held a workshop exploring the causes of the black-footed albatross interactions in 2015-2016. In 2018, the Council held a second workshop to review seabird mitigation requirements and the best scientific information available for the Hawaii longline fishery and identified priority mitigation measures suitable for the Hawaii longline fishery, potential changes to seabird measures, and research needs to inform future changes to seabird measures (Gilman and Ishizaki, 2018). Numerous gear technology methods have been demonstrated to significantly reduce seabird catch rates in pelagic longline fisheries, including combinations of: night setting, branchline weighting designs, side setting, bird curtains, blue-dyed bait, underwater setting devices, hook shielding devices, and tori lines (Gilman et al. 2005, Hall et al. 2017, ACAP 2019, WPRFMC 2018).

Workshop participants identified deterrents such as tori lines to be a high priority for further research and development due to its potential to provide an effective alternative to blue-dyed bait. A tori line, initially developed by Japanese tuna longline fishers (Brothers et al., 1999), is a line with streamers that is towed from the stern of the vessel as crew set baited hooks. The forward movement of the fishing vessel creates drag on the streamer line, so that a section of the line is in the air above the sea surface. This aerial portion of the streamer line, as the name suggests, can have streamers attached at various intervals to contribute to keeping seabirds from baited hooks.

Tori lines were previously tested in the Hawaii longline fishery in the late 1990s, which found that they were effective in reducing seabird contact rates with bait and gear (McNamara et al., 1999; Boggs, 2001). However, these early studies also identified issues with practicality and crew safety resulting from tori line entanglement with gear. The Council considered inclusion of tori lines in the seabird mitigation measures in 1999 and again in 2004, but to date tori lines have not been included as an option for the Hawaii longline fishery.[1]

[1] The Council initially recommended including towed deterrents such as tori lines and towed buoys as part of its original seabird mitigation action in 1999 in which vessels would have been required to use two out of six mitigation measures. However, tori lines were not part of the seabird mitigation measures implemented in 2001 because the measure was not included in the Terms and Conditions in the 2000 Biological Opinion developed by USFWS. The Council again recommended requiring the use of tori lines as part of stern-setting measures when it developed the side-setting option in 2004, but later modified its recommendation in 2005 to remove tori lines from the proposed modifications in part due to the limited number of studies to inform construction and operating performance standards of using tori line systems in the Hawaii longline fishery.

There have been several studies on the efficacy of various tori line designs in pelagic longline fisheries (Yokota et al., 2011; Melvin et al., 2013, 2014; Pierre et al., 2016; Domingo et al., 2017; Sato et al., 2012, 2013, 2016; Katsumata et al., 2019; Jiminez et al., 2020). The five tuna regional fisheries management organizations (RFMOs) have measures in place that either require or include tori lines as a seabird bycatch mitigation option in designated areas (ICCAT, 2011; IATTC, 2012; IOTC, 2012; WCPFC, 2018; CCSBT, 2020). Tori lines are recommended in combination with other measures by the Agreement on the Conservation of Albatrosses and Petrels (ACAP, 2019). A few countries require tori line use in pelagic longline fisheries (e.g., Japan Ministry of Agriculture, Forestry and Fisheries. 2008; Uruguay Direccion Nacional de Recursos Acuqticos, 2015; New Zealand Ministry for Primary Industries, 2018; South Africa Department of Agriculture, Forestry and Fisheries, 2019).

Following the 2018 workshop, the Council, at its 174th Meeting in October 2018, recommended that the NMFS provide support for research and development for alternative seabird bycatch mitigation measures with a high priority placed on tori lines. The Council, at its 176th Meeting in March 2019, additionally recommended identification of draft minimum standards for tori lines.

In 2019, the Council, Hawaii Longline Association, NMFS Pacific Islands Fisheries Science Center and NMFS Pacific Islands Regional Office implemented a cooperative research project to conduct a tori line demonstration and experiment in the Hawaii deep-set longline fishery. The project developed draft tori line minimum standards, assessed the practicality of alternative tori line designs and determined the effect of tori line use on albatross interaction risk. The project was divided into two phases. The goals of Phase 1 were to: (a) identify potential tori line designs based on industry input, expert advice, existing international standards and guidelines for tori lines; (b) conduct land trials; and (c) conduct at-sea trials. Five different tori line prototype designs were tested during at-sea demonstrations to determined vessel operators' perspectives on practicality and design preferences.

To determine the suitability of including tori lines as an additional option for the Hawaii deep-set longline vessels to comply with seabird bycatch requirements, Phase 2 conducted a controlled experiment of a single tori line design with short streamers that assessed the effect of tori lines on albatross risk of interacting with terminal fishing tackle. The study also observed the distance astern that Laysan and black-footed albatrosses interacted with baited hooks during setting to inform what tori line aerial coverage is appropriate for the Hawaii deep-set longline fishery. An EM system was employed to collect data for the experiment, demonstrating the capability of EM to collect several data fields of some conventional human observer program that significantly explain seabird catch risk (Emery et al., 2018; Gilman et al., 2019). Findings inform revisions to the Hawaii deep-set longline fishery seabird mitigation measures, expand the body of literature on tori line efficacy in longline fisheries, and highlight the potential for EM systems to be used to monitoring variables that significantly explain seabird bycatch risk in longline fisheries.

2. PHASE 1 - DEMONSTRATION OF ALTERNATIVE TORI LINE DESIGNS

Tori lines are designed to be used on stern setting vessels to mitigate seabird interactions during setting operations. Stern setting vessels in the Hawaii longline fishery have been testing variations of towed deterrents prior to this study, and those stern setting vessels with EM cameras were first approached to participate in the study. Most vessels that participated in the study had previous experience deploying towed deterrents during setting operations but had limited experience with using tori lines. Vessels that had deployed tori lines in the past experienced problems due to the weight of the line when retrieving it, and snagging due to long streamers and swivels getting caught on gear.

All three initial tori line designs were based on results from Katsumata et al. (2015, 2016, 2018, 2019), Goad (2017), Pierre et al. (2016), Sato et al. (2012), and Melvin et al. (2013), along with anecdotal information from fishermen in the Hawaii longline fishery and project team members' prior experiences as observers on Hawaii longline vessels. Expert input was also obtained through a Council-sponsored workshop in September 2019 with tori line experts from New Zealand and Japan with specific experience designing tori lines for small longline vessels to aid in the refinement of designs suitable for the Hawaii longline fishery. Emphasis was placed on light-weight, streamlined designs with minimal potential for tangles to improve the practicality and safety of tori line use during commercial fishing operations.

All tori line designs were created, and refinements made, during pre-Phase 1 planning. Both aerial and drag sections were addressed separately during the pre-Phase 1 planning; drag section prototypes were created and drag needed was measured out at sea. Aerial extent prototypes were measured on land, and the aerial section drag needed was paired with the drag prototype that was most preferred by fishermen. Once the aerial and drag section designs were selected, Phase 1 demonstrations were conducted to test complete tori line prototypes out at sea during day trials with participating stern setting vessels, and information gathered on practicality and efficacy of each tori line prototype tested.

2.1. Tori Line Design Development

2.1.1. Materials Used to Construct Tori Lines

Table 1 identifies the materials used to develop the tori line and pole tested in the design phase and in Phase 1 demonstrations. Most materials used were locally available in Hawaii through hardware stores, and fishing supply stores.

Table 1. Materials used to test and create the tori line and pole setup.

Material	Size	Color	Supplier
12-Strand Braided Dyneema line (AS-78)	3 mm	Red	West Marine
Monofilament Nylon	27 and 36 kg test	Clear	POP Fishing and Marine
3-Strand Twisted Polypropylene line	1.2 cm	Blue/green	POP Fishing and Marine
12-Strand Braided Blue Steel line	6 mm	Blue/Green	POP Fishing and Marine
Plastic Sheeting	6 mil cut into strips	Black	Home Depot
Plastic Packing Straps	12.7 mm x .031 mil	Black	POP Fishing and Marine
Plastic Tubing	6 mm diameter	Orange	Beauline NZ*
Stainless Steel Swivel	6.6 mm	Silver	POP Fishing and Marine

Waxed lashing twine	1 roll	White	POP Fishing and Marine
Stainless Steel Tuna Clip	1 Bag	Silver	POP Fishing and Marine
Marine Grade Heat Shrink Wrap	9.5 mm, 12.7 mm, and 19 mm diameters	Solid Pink and Black colors	POP Fishing and Marine (Pink), Home Depot (Black)
Black Electrical Tape	3M Temflex19mm x 18.3mm x .177mm	Solid Black	POP Fishing and Marine
Duct Tape	Craftzilla Assorted color craft tape (6 pack) 50.8 mm x 9 m	Assorted Colors	Amazon.com
Fiberglass Pole (2-piece)	4.3 m x 2.0 cm thick	White	Five Oceans Seven Seas
Galvanized Steel Pole[2]	3.0 m x 2.54 cm thick	Silver	Home Depot
Stainless Steel Pole	3.2 cm thick SCH40S TP 316 sleeve, and 2.5cm thick SCH40S TP 316 tori pole. Cut to various lengths.	Silver	Zapsteel Custom Machine LLC

* Tubing options were also available from POP, but were more expensive and required longer order fulfillment time.

2.1.2. Vessel Gear Configuration

Gear configuration information was taken from each of the four vessels participating in the Phase 2 field trials to determine estimated gear sink rates. Table 2 summarizes the gear configuration aboard each of the four vessels. Vessels used 15/0 round, flat, or a combination of round and flat circle hooks with a ≤ 10 degree offset in their gear setup. Hook widths were found by taking the width of ≥ 12 hooks total, spread across each of the hook boxes being used. Since all four vessels had 5 hook boxes, we took 3 hook measurements via caliper from each of the 5 hook boxes. The hook widths were predominantly between 4.4 and 4.5 mm, with some outliers in the 4.2-4.3, and 4.6 range.

Table 2. Summary of gear configurations found aboard participating vessels. The mode was taken for weights, and averages were taken for gear measurements.

Vessels	Gear Configuration Table				Leader Length	Leader Material
	Swivel Weight	Hook Width	Branch line Length	Branch line Material		
C	45 g	4.4 mm	9.8 m	Monofilament Nylon	0.6 m	Wire
E	45 g	4.4 mm	12.56 m	Monofilament Nylon	0.5 m	Wire
F	45 g	4.5 mm	11.9 m	Monofilament Nylon	0.6 m	Wire
G	45 g	4.4 mm	13.4 m	Monofilament Nylon	0.6 m	Wire

All vessels used a combination of 2.0-2.1 mm wide monofilament branch line attached to a 1.5 mm metal leader line with a 45 g swivel. Branch line lengths varied from vessel to vessel. Vessel C's branch line measurements varied from 9.5 – 9.9 m in length, with the mode being 9.8 m; vessel E's branch line measurements varied from 12.1 – 13.0 m in length, with the mode being 12.7 m; vessel F's branch line measurements varied from 11.7 – 12.3 m in length with the mode being 11.9 m; vessel G's branch line measurements varied from 11.5 – 14.0 m, with the mode being 13.5 m. Leader length was also taken to determine total length of the line being deployed. Vessel C's leader length varied from 0.5 - 0.6 m, with the median value being 0.6 m; vessel E's leader length stayed constant at 0.5 m; vessel F's

[2] Both two-piece fiberglass pole and galvanized steel pole were tested, but were not selected. Please refer to Section 2.1.5 (Tori Pole Design) and Section 2.2 (Preliminary Dockside Testing to Determine Required Drag) for details.

leader length stayed constant at 0.6 m; and vessel G's leader length varied between 0.5 - 0.6 m, with the median value being 0.6 m.

All vessels reported using Sanma (Saury) for bait on tuna trips, and bait length and weight were taken from all four vessels participating in Phase 2 of the project. Bait size ranged from 24.1 - 31.8 cm in length, and weighed from 81.6 g – 120.5 g.

2.1.3. Aerial Section – Backbone and Streamer Configurations

Previous research by Pierre et al. (2016) found that Dyneema (Supermax) was the best backbone material to use for the aerial portion of the tori line, because it does not hold energy and requires the least amount of drag to achieve needed aerial extents. One of the main goals in designing the line was to keep the aerial extent as light as possible to reduce amount of drag needed, while being able to achieve the needed aerial extent to deter Laysan and black-footed albatrosses as well as sooty shearwaters[3] from diving for casted baited hooks. Dyneema is a light hollow braid that is hydrophobic that allows for easy retrieval when wet, is easy to pull plastic sheeting (streamers) through, and requires the least amount of drag to achieve aerial extents in comparison to nylon monofilament and ashaway braided cord (Pierre, 2016).

During the September 2019 tori line workshop with experts from both New Zealand and Japan, the experts discussed that, in their experience, the tori line backbone should be a bright color but the specific color type and hue was unimportant. The experts noted that the degree of streamer flapping was important, and that streamers that blew more in the wind deterred birds more effectively than the color of the streamers or backbone. Ultimately, the project team chose a red backbone color based on its visibility on the EM playback.

Three streamer design configurations for the aerial section were selected for Phase 1 demonstrations based on research (Goad, 2017; Katsumata et al. 2015, 2016, 2018, 2019; Melvin et al. 2013; Pierre et al. 2016; Sato et al. 2012), along with observer recollections of albatross behavior, and captain recommendations. The three configurations were short streamers, hybrid streamer, and streamerless. The short streamer design used 100 cm long short streamers fed through the backbone to create two 50 m long streamers spaced a meter apart throughout the line. The hybrid streamer design featured orange tubing spaced every 5 m apart starting 2.5 m behind the vessel's stern, in addition to 100 cm long short streamers fed through the aerial extent backbone to create two 50 cm long streamers spaced 1 meter apart. The streamerless design was comprised solely of the backbone material. Fig. 1 shows a generalized illustration of the three streamer configurations. A red, 3 mm AS-78 (dyneema) braid was used for the backbone for all tori line designs tested during Phase 1, which is available at a reasonable price[4] from local retailers.

[3] Limited numbers of the deeper diving sooty shearwater have been observed in the deep-set fishery. For annual interactions and estimated numbers of seabird interactions see the WPRFMC annual safe report (2020).
[4] Red 1/8" AS-78, or dyneema, was purchased at West Marine for the price of $.30/foot in 2019.

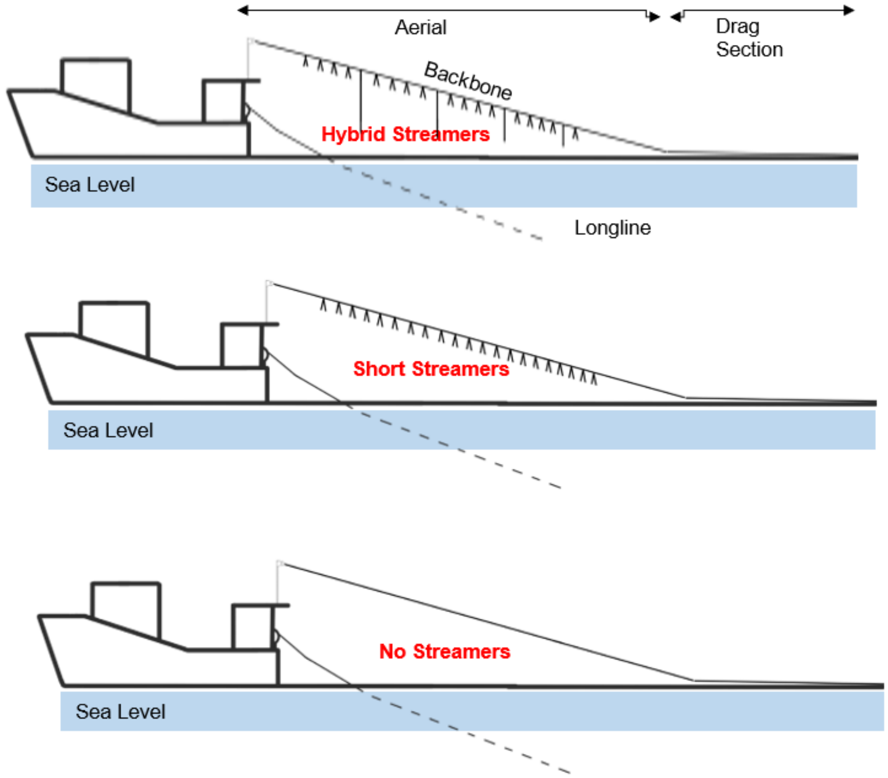


Figure 1. Three tori line designs used in the study (hybrid streamers, short streamers, and streamerless): aerial extent lengths tested was 60 m across all three designs; with an additional short streamer line designs measuring 40 m and 50 m in length.

Short streamers were cut at 100x5 cm strips and fed in through the hallow braid to create two 50 cm streamers. Short streamer color was not a defining factor in deterring birds (Goad, 2017), so black material readily available from a hardware store was selected. The black tape used for short streamer material in the New Zealand study required frequent replacement due to breakage (David Goad, pers. comm.), so the thickest black sheeting available at a reasonable price from local retailers was used. Fig. 2 contains photos of attachment styles for the orange tubing and black plastic streamers.

The long streamers for the hybrid design used ultraviolet coated 5 mm orange tubing, which were tied along the aerial extent of the backbone using waxed lashing twine and taped over with black electrical tape. Drag sections for this line were still much longer than the other two design types due to weight of the orange tubing itself, and number of long streamers lashed along the aerial extent backbone.

Streamers for the short streamer and hybrid designs started 2.5 m from the attachment point to avoid tangles or snagging from casted gear catching on the streamers or aerial extent backbone, but to remain close enough to deter seabirds from flying near the vessel's stern. These two tori line designs were also designed with the last 20 m of aerial section having no streamers to minimize entanglement with floating buoys meeting the lower portion of the tori line during the set.

A schematic diagram of the final tori line design selected for the Phase 2 trials is shown in Fig. 3.

Figure 2. Pictures showing how each streamer type was attached to the tori line backbone. Black short streamers fed in through the hollow 3 mm red dyneema backbone, and the rubber tubing lashed on and then sealed with pink marine grade shrink wrap attached to the aerial extent backbone via heat gun, and then wrapped with electric tape to prevent possible snags at the edges.

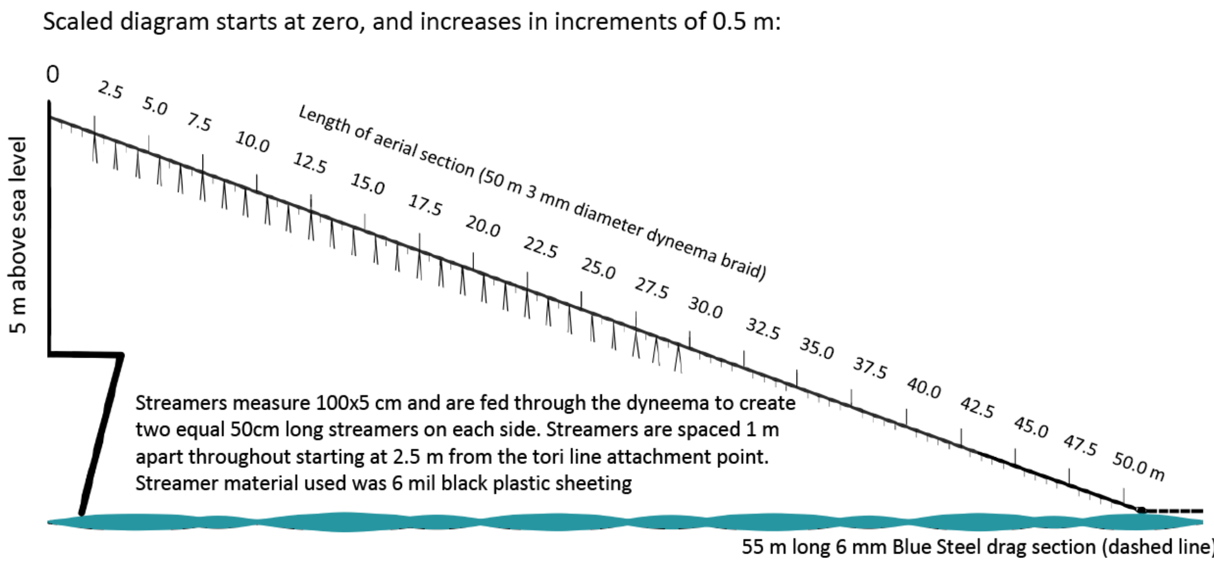


Figure 3. Schematic diagram showing the tori line design that selected for the Phase 2 trials. Vessel setting speeds of 6.0 knots produced the needed 6.23 kg of drag to keep this tori line design taut.

2.1.4. Drag Section

The aerial section was attached to the drag section in the most streamlined way possible. Advice given from experts during the September 2019 tori line workshop noted that tori lines should be created as light-wieght and streamlined as possible to avoid possible snagging with gear. An eye splice attached both the aerial portion and drag portion to a 6 mm stainless steel swivel, and heat shrink wrap was placed over the swivel and eye on both ends to create a more streamlined joint. Both ends of the shrink wrap were taped over with electrical tape to minimize any possible snagging (Fig. 4).

Figure 4. The two-step process taken to join the aerial and drag components. Step 1 consisted of creating the joints via swivel and eye splice, and step 2 involved sealing the joint with shrink wrap, a heat gun, and electrical tape to minimize the possibility of snagging.

Drag section designs were created to provide maximum drag required to keep the aerial section taut, while also being a simple and light design that minimizes chances of entanglement with fishing gear during setting operations. These design factors were based on conversation with captains in the Hawaii longline fleet regarding drag section materials, who noted the need for light and smooth drag sections that can be pulled up quickly by the crew, and do not snag on fishing gear. Some captains who had experience making drag sections preferred deploying long sections of mono, while others deployed torpedo floats or pieces of cloth tied into the monofilament line to create the drag needed to keep their aerial sections taut. When creating the drag sections for this project, we looked for light, waterproof, and snag-proof materials that would create a good amount of drag in the water but be relatively easy to retrieve when the vessel is idling.

Drag section materials tested were a 6 mm 12-strand polyolefin Blue Steel braid that has superior resistance to UV, and a 1.2 cm 3-strand polypropylene twist line. Both drag materials had selectively placed packing straps in three of the designs, and no packing straps in the fourth design. All eight designs were tested out at sea at lengths ranging from 20 m to 80 m during the drag trials for crew handling practicality, and to determine how much drag is created for each length and style combination. Table 3 outlines the different drag designs created to test during the pre-Phase 1 drag trials.

Table 3. Drag section design materials and configuration to be tested in the water at average vessel setting speed for the Hawaii longline fishery.

Design #	Rope	Configuration
1	6 mm Blue Steel braid	3 plastic packing straps woven in every 5m
2	6 mm Blue Steel braid	1 plastic packing straps woven in every 3m
3	6 mm Blue Steel braid	1 plastic packing straps woven in every 1m
4	6 mm Blue Steel braid	No packing straps
5	1.2 cm poly twist	3 plastic packing straps woven in every 5m
6	1.2 cm poly twist	1 plastic packing straps woven in every 3m
7	1.2 cm poly twist	1 plastic packing straps woven in every 1m
8	1.2 cm poly twist	No packing straps

2.1.5. Tori Pole Design

Tori pole heights were determined by measuring the height of the vessels tori attachment point starting at the waterline on the vessels stern hull, to the top of the bait shed; and then subtracting the 5 m height requirement by the measured height of the vessels tori attachment point. This process was done for all participating vessels, and poles were cut to various heights needed to achieve the 5 m tori attachment requirement as outlined in the WCPFC and IATTC minimum tori line requirements. Vessels' deck layout designs did not show much variability, and all vessels were able to use the same pole setup except for one vessel who attached the tori line to outriggers located mid vessel.

Three materials were tested for the tori pole: a two-piece fiberglass pole, a galvanized steel pole, and a marine grade stainless steel pole (Fig. 5). A stiff one-piece fiberglass pole option was used in tori line research conducted in the Japanese longline fishery (Katsumata et.al. 2015, 2018, 2019) and Goad (2017); but proved to be expensive, and hard to source. A two-piece, 4.5 m total length fiberglass pole was found at a local retailer, and tested during preliminary dockside testing, but the pole displayed too much flex when line was being pulled taught. Ordering more rigid fiberglass poles from Japan was considered, but lead time and cost deterred the team from pursuing a more rigid fiberglass pole.

Figure 5. Fiberglass tori pole flexing with the 60 m short streamer line (left), and 316 Sch.40 marine grade Steel pole flexing with the 60 m short streamer line (right).

The 4.5 m galvanized steel pole was also tested, and performed well during preliminary land-based testing without any bending or hocking. However, galvanized steel is likely to rot and rust out at sea, if left untreated. Treatment of galvanized steel was considered but decided against given captain and fabricator preference for using and installing marine grade steel poles instead of galvanized steel.

Tori poles used in Phase 1 and Phase 2 (Fig. 6) were fabricated with schedule 40, marine grade stainless steel (316) at varying heights needed to achieve the 5 m attachment height above sea level. Each pole featured a 0.6 mm flange with four 0.6 mm bolt holes attached to a 3.2 cm thick sleeve with a weep hole at its base to release seawater and prevent possible corrosion. All tori poles were cut to the appropriate height needed to achieve the required 5 m and held in the sleeve with an adjustable lockdown nut located at the top of the sleeve. Actual tori poles were constructed with the same material and featured a curved equilateral triangle at the top of the pole with a steel eye for attaching the tori line weak link.

Vessel captains liked the poles lightness, simplicity, and ease of installation. All captains thought that installing the tori pole on the port side bait shed roof was a good location to keep the line up and away from the crowded deck space. Fig. 7 shows photographs of the tori pole attached on participating vessels, and Table 4 shows the pole heights in relation to the vessel's height above sea level. A line with two eye splices at each end was used to elongate the tori in the event of a vessel attaching the tori line mid vessel. This ensured that the prescribed tori line length would be flown over where baited hooks were being cast.

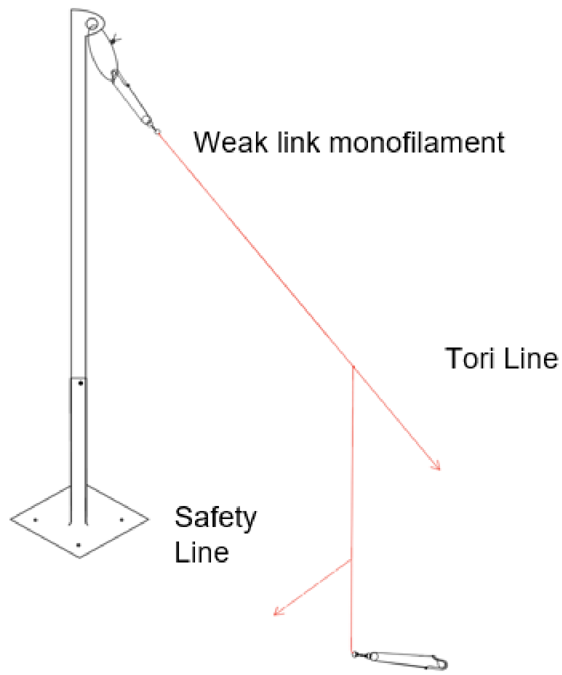


Figure 6. Diagram showing how the weak link, safety line, and tori line are assembled, and how the pole is constructed. The tori line is snapped on to weak link monofilament nylon above that is tied around the steel eye via blood knot. The safety line is attached to tori via eye splice, and snapped on to the vessel at the other end in case the weak link breaks.

2.1.6. Practicality to Install

For purposes of the trials, tori poles were temporarily secured to the vessel using hose clamps or discarded line, securing the pole to the existing railings near the aft of the vessel. This allowed captains and owners to try out the tori pole and line before permanently attaching the pole setup onto their vessels. Project personnel provided prefabricated poles and holders to captains who then installed them on their vessels. Each pole holder featured a horizontal pad with 4 holes for the captain to have the option of either bolting or welding the holder onto the vessel at a later date. Captains and owners were very supportive of the suggested placement of the tori line setup at the top of their bait sheds (Fig. 7). Placement kept the tori line box and the safety line generally out of the way. The placement of the tori poles was based on which side the bait was thrown by crew during setting (e.g., if bait were thrown on the port side, poles were installed between the location of the line shooter and the port rail so bait would be covered as it were dragged toward the mainline coming from the shooter). If the vessel did not have a bait shed, or different placement were needed, an alternative was to place the pole on the second level mid deck. During Phase 1, one vessel used an existing structure to attach the tori line instead of a tori pole. All vessels in Phase 2 used a tori pole. Table 4 summarizes the vessels' tori line attachment point height above sea level, and pole height needed to achieve the 5 m WCPFC and IATTC minimum requirements.

Figure 7. Tori line pole installation locations on vessels involved in study.

Table 4. Summary of vessels' attachment point height above sea level, and pole height needed to achieve the 5 m WCPFC and IATTC minimum requirements for flying a tori line.

Vessel Name	Vessel Phase Participant	Attachment Height Above Sea Level (w/o pole)	Pole Height Needed to Achieve 5 m Minimum Requirement
Vessel A	Phase 1	2.9 m	2.1 m
Vessel B	Phase 1	4.1 m	0.9 m
Vessel C	Phase 1-2	3.3 m	1.7 m
Vessel D	Phase 1-2	3.8 m	1.2 m
Vessel E	Phase 1	3.5 m	1.5 m
Vessel F	Phase 1-2	2.4 m	2.6 m
Vessel G	Phase 1-2	3.3 m	1.7 m

2.1.7. Tori Line Weak Link

Tori line weak links favored by captains and crew was clear weak monofilament line tied around the pole eye (Fig. 6). Weak link monofilament was offered to crews at 27, and 36 kg test weights to accommodate differing preferences amongst vessel captains and crew. Captains and crew preferred having a simple weak link over a more complicated weak link design. Tori lines were snapped onto the weak link via tuna clip.

2.1.8. Attachment to Vessel in the Event of a Snag

Safety lines of varying lengths were created based on findings from Goad et al. (2017) to keep the tori line attached to the vessel in the event of a snag breaking the weak link. The safety line was created with the 3 mm AS-78 line, cut at various lengths to accommodate different vessel setups, and was fashioned with two eyes at each end: one eye to attach the safety line to the tori line, and another eye attached to a stainless steel snap clipped onto the vessel in the event of the tori line breaking away from the pole (Fig. 6). The design was suggested by captain and crews involved in the project. Participating crews were also observed pulling the safety line down in order to reach the actual tori line, thus making the tori line easier to retrieve it at the end of the set.

2.2. Preliminary Dockside Testing of Aerial Section Designs to Determine Required Drag

Drag needed to maintain different aerial section designs at different lengths were tested on land. Land tests were conducted at Oahu, Hawaii. Marine grade stainless steel pole attachment heights were situated to be a total height of 5m above ground, to match IATTC and WCPFC tori line minimum requirements. Varying distances from the pole were marked with colored duct tape at 10 m intervals from 40 to 80 m lengths. Each line was then set a certain distance from the attachment point and pulled taught with a Dr. Meter digital spring scale to determine the drag amount needed. Drag readings were taken for each of the four designs tested, at different lengths. Table 5 illustrates the findings from our land-based tests to find drag needed for each design at each length.

The fiberglass pole was deemed unsafe while testing the 60 m hybrid and short streamer designs. The fiberglass pole was not stiff enough for the project's intents and purposes and flexed significantly when the tori line was pulled taught. Pole recoil in the event of a snag during setting operations also posed a significant drawback, and captains noted that pole recoil as a possible safety issue out at sea.

Based on further discussions with captains, information on general time-depth recorder sink rates within the fishery (Gilman, pers. comm. 2020), and observations out at sea, aerial section lengths between 40-60 m were selected for further testing in Phase 1. These lengths were determined to be sufficient to cover the area of potential Laysan and black-footed albatrosses interactions, which represent most of the interactions in the Hawaii longline fishery. Aerial section lengths of 70-80 m were not tested further due to very low catch rates of shearwaters throughout the year in the Hawaii longline fishery, which minimizes the need for preventing secondary attacks from deeper-diving species (see Section 3.3.3 for additional discussion).

Table 5. Aerial section drags needed (kg) to keep line taut for each length and design combination.

Length of Aerial Section	Drag needed for each aerial section design			
	Short Streamer 1m	Long Streamer 5m	Modified Streamer (short 1m and long 5m combined)	Streamerless
40m	4.26	8.45	11.87	3.31
50m	6.23	9.8	13.03	3.84
60m	8.475	12.5	13.79	4.79
70m	12.52	13.88	14.7	5.06
80m	14.85	16.2	16.28	5.54

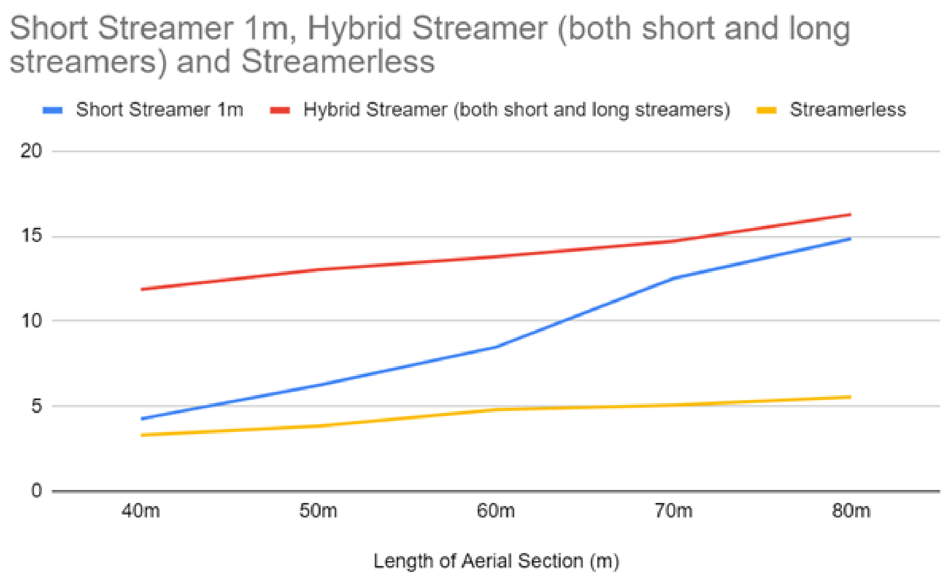


Figure 8. Drag weight (kg) needed for each aerial design section at the prescribed lengths.

2.3. At-sea Testing of Various Drag Designs for Practicality and Drag Amount Created

Drag sections were tested at sea to measure drag amount created by each design. Testing was conducted at the average vessel setting speed of 6.6 knots (kn), in Beaufort 02 conditions. The vessel speed, however, varied from 5.6-7 kn depending on wind, waves, and current during the cruise. Drag designs were tested at 20 m to 80 m lengths, and length markers were taped off along each drag design at 10 m intervals. Drag design lengths were measured with a spring scale attached to the drag section via Diamond braid line with carabiners clipped on at both ends. Drag produced varied +/- 2(kg) for each tested drag section, and median drag readings for each tested design are logged in Table 6. Median drag amounts varied from 13.0 kg to 1.2 kg across all tested designs.

During the drag trials, it was noted that crew had an easier time handling and coiling the polyolefin Blue Steel braid over the three-strand twist polypropylene line (Fig. 9a). Out of the four Blue Steel braided sections, design 3 proved to be the most cumbersome to coil and let out due to plastic packing strap edges poking crews' hands when pulling the line in. Design 4 was the easiest to coil back but created the least amount of drag. Designs 1 registered the most drag for lengths 80-70m, but gains were minimal amounting to 2.6kg more than the 80m section registering the smallest drag amount. The gap between drag 1 and 4 diminish as the lengths lessened and designs 1-4 registered approximately the same amount at the 60m length. Designs 5-8 using the three-strand twist polypropylene line did not perform well due to the line twisting in the water (Fig. 9b-c). Crew noted that design 5 twisted more at longer lengths, and less at shorter lengths. However, the twisting of drag designs 5-8 made it difficult for crew to coil the line back in and created twists in the Diamond braid line attached to it (Fig. 9d). The captain also noted that the three-strand polypropylene twist line used on designs 5-8 created more turbulence on the water than designs 1-4 using the polyolefin Blue Steel braided line.

Design 4 was most liked because it was a smooth line that minimized the possibility of gear snagging due to having no packing straps woven in it and was comfortable to handle. Three extra measurements for design 4 (90, 100, and 110 m) were taken to achieve the drag needed for the hybrid streamer line.

The captain and crews preferred the 6mm polyolefin Blue Steel braid over the 1.2 cm poly twist line, and preferred design 4 to designs 1-3 because it was easier to handle when deploying and retrieving the line. Designs 1-3 created more drag at longer lengths, but captain and crews were willing to deal with a little more line than having to grab around the plastic packing straps when retrieving the tori line.

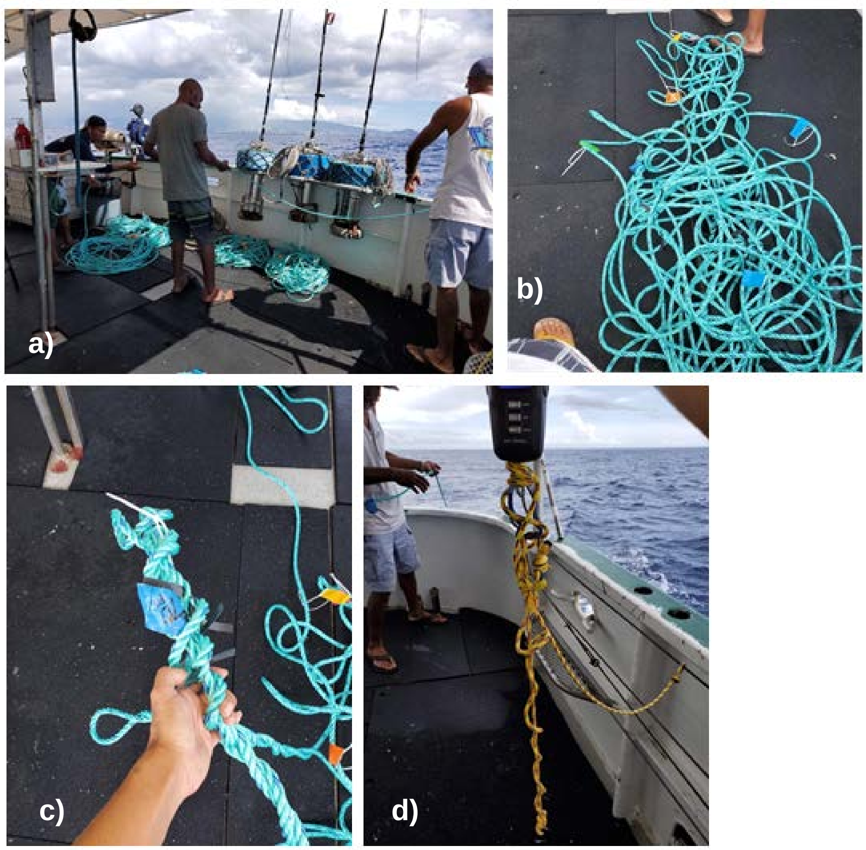


Figure 9. Photographs of the at-sea drag design testing: a) designs 1-4 (using braided polyolefin Blue Steel line) coiled on deck; b) twist three-strand twist polypropylene line (used for designs 5-8) on deck; c) twisting of drag design 5; and d) twisting of the polypropylene line affected the Diamond braid attached to the drag design via carabiner clip.

Table 6. Drag section design type, lengths tested, and amount of drag (kg) created per each type tested aboard vessel A. Length and designs to be used with the 5 different tori lines highlighted in orange. See Table 3 for description of each design.

Drag (kg)	Length in (m)						
Design #	**80m**	**70m**	**60m**	**50m**	**40m**	**30m**	**20m**
1	10.8	8.6	6.2	5.2	3.3	2.2	1.3
2	9.2	7.5	6.2	5.5	4.1	2.5	1.2
3	9.0	7.5	6.0	5.0	3.6	2.6	1.4
4	8.2	6.9	6.2	5.0	3.9	2.5	1.3
5	13.0	12.5	8.2	7.5	4.7	3.6	1.7
6	11.5	10.0	9.0	6.3	4.0	3.0	1.6
7	12.3	10.0	9.2	7.8	5.8	3.6	2.0
8	10.5	8.6	7.5	6.0	4.6	3.3	1.7

Design #	110m (est)	100m	90m
4	~14.7	12.5	10.3

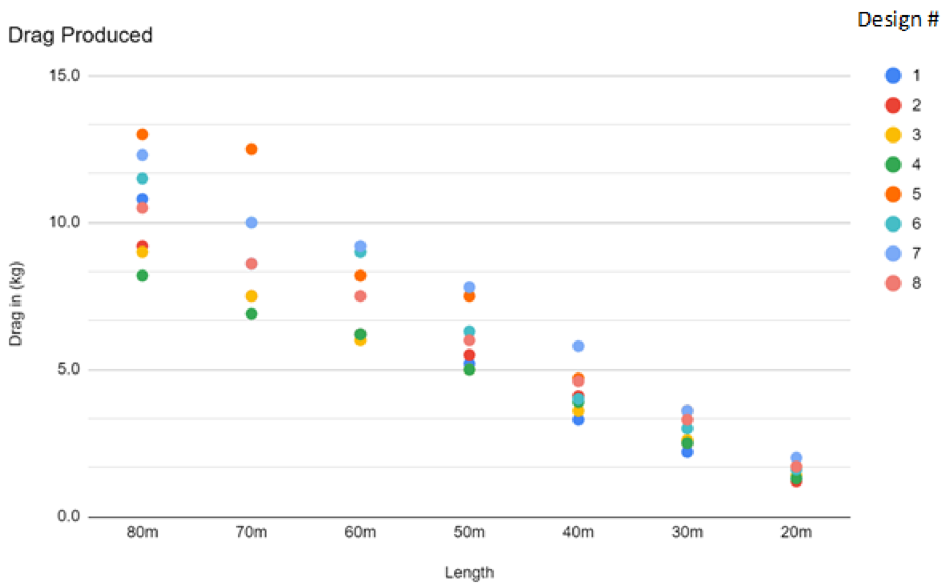


Figure 10. Drag produced by each of the eight drag section designs.

2.4 Phase 1 One-day At-Sea Demonstrations

Five aerial section designs and drag length combinations were selected for the Phase 1 one-day at-sea demonstrations (Table 7). Seven vessels participated in the demonstrations, with four additional vessels interested but unable to participate due to COVID-19 restrictions. Pole installations for Phase 1 at-sea trials were completed on all of the seven participating vessels, with the exception of one vessel who had their own attachment point mid vessel. Each vessel tested all five designs, and participating captains and crews provided feedback on the practicality. The one-day demonstrations were conducted without deployment of fishing gear so that the trips could be conducted near port, where longline fishing is prohibited. The demonstrations therefore did not include an evaluation of entanglement risk with fishing gear.

Table 7. Summary of tori lines selected for the Phase 1 At-Sea Demonstrations.

Design Number	Aerial Extent (m) / design type	Drag Section (m) / design number
1	40 / Short Streamer	50 / 4
2	50 / Short Streamer	60 / 4
3	60 / Short Streamer	80 / 4
4	60 / No Streamer	50 / 4
5	60 / Hybrid Streamer	110 / 4

2.4.1. Practicality to deploy

All five tori line designs were tested on time it takes to deploy and retrieve the line, aerial extent, length of submerged drag section, and whether the tori line was consistently maintained over where baited hooks were being cast. There was not a significant difference in retrieval and deployment times across all tested designs, but there was a significant difference in retrieval times between vessels pulling in the line while running, and while idling. Vessel A's retrieval times were taken while the vessel was moving at 6.8 kt, while the other vessels were in idle. Vessel A's crew found it very taxing to pull in the lines while the vessel was in motion, and later discussions regarding tori line retrieval showed that captains were willing to put the vessel in idle to pick up the lines.

Table 8. Vessels A-G deployment and retrieval times during the Phase 1 trials. Times highlighted in orange were longer due to tangles when deploying the line. Vessel A's retrieval time was measured as the vessel was moving at setting speed of 6.8 kt, while the other vessels retrieval speeds were taken when the vessel was at idle.

		Vessel						
Design	**Times**	**A***	**B**	**C**	**D**	**E**	**F**	**G**
1	Deployment	1:54	1:11	2:09	:53	:48	:35	:38
	Retrieval	2:59	2:14	2:34	2:05	1:37	2:13	1:42
2	Deployment	2:20	3:40	5:20	1:39	:40	:41	:50
	Retrieval	3:14	2:24	1:31	2:25	3:03	3:03	2:13
3	Deployment	2:55	1:53	3:19	1:59	1:04	1:04	:54
	Retrieval	4:28	2:40	2:48	2:38	2:57	2:57	2:04
4	Deployment	1:54	1:22	1:24	:49	:54	1:13	:49
	Retrieval	2:59	2:39	3:03	2:05	1:50	2:48	2:23
5	Deployment	2:27	4:40	1:48	2:30	1:04	:48	1:03
	Retrieval	8:46	2:40	4:22	4:02	2:58	3:54	2:56

* Retrieved at setting speed

Crews were able to deploy and retrieve all tested designs in a timely manner but commented that they had to exert more energy to pull in the longer lines that had more streamers and longer drags, like designs 3 and 5.

Aside from vessel A, tori lines were let out while the vessel was running at setting speed, and then pulled in while the vessel was in idle. Crews were equipped with Atlas 451 gloves to increase grip and comfort when pulling in the red AS-78 aerial extent backbone. Vessels A and B had tightly coiled their lines upon retrieval, and the tight coils cinched the streamers, causing the tori line to form tangles upon the next deployment. This problem was addressed by having the crew flake the line into the bin instead of making compact coils, which eliminated in-bin tangling in the subsequent Phase 1 trials.

Design 5 was the heaviest to pull in, which deterred crews from that design. However, captains did like the longer streamers to deter seabirds foraging close to the vessels stern and remain open to trying a hybrid streamer design with a shorter aerial section length. Design 4 was the captains and crews least favorite because of the lack of streamers: all captains noted that streamers were a very important component of the tori lines ability to deter seabirds, adding that the aerial extent backbone should be undulating instead of rigid if used without streamers. All captains and crew liked designs 1 and 2 mainly because they were easy to deploy and retrieve, while also having streamers to deter seabirds from going after the sinking baited hooks.

Design 2 was selected for the Phase 2 experimental trials because it met all the tori line requirements for the Hawaii longline fishery, and easily provided the 40 m of aerial coverage needed for Laysan and black-footed albatross interactions, as well as a 10 m buffer to accommodate possible outliers (see Section 3.3.3).

2.4.2. Practicality during set

Setting speeds for all vessels participating in the Phase 1 at-sea demonstrations varied from 6-7.7 kn, and all aerial extents plus an estimated meter or less of drag were achieved at median setting speeds with the prescribed drag amounts. Drag sections for all five designs were cut by 5 m to eliminate extra line that was unnecessary to achieve the prescribed aerial extents, and the new trialed line drag lengths were tested out at sea as part of the tori line. Aerial extents were marked in 10 m intervals starting 20 m out with colored duct tape, and tori line aerial extents were observed at speeds from 6-7.7 kn. All aerial extents were achieved at setting speeds, but the aerial extent started sagging at speeds below 6 kn.

Table 9. Summary of new tori line drag lengths for Phase 1 at-sea demonstrations. Drag lengths were trimmed by 5 m to eliminate extra line that was not needed to achieve the prescribed aerial extents.

Design Reference Number	Aerial Extent (m) / design type	Drag Section (m) / design number	Total Length (m)
1	40 / Short Streamer	45 / 4	85
2	50 / Short Streamer	55 / 4	105
3	60 / Short Streamer	75 / 4	135
4	60 / No Streamer	45 / 4	105
5	60 / Hybrid Streamer	105 / 4	165

Setting direction in relation to wind direction influenced horizontal movement of the tori line over where the baited hooks were being cast in over 40 kph winds. Tori poles were set up on the port side of the vessel to accommodate the routine north easterly winds that blow down towards the fishing grounds[5]. It did not influence the tori lines ability to track well over baited hooks when setting at 6 – 7.7 kn in winds below that, regardless of direction. When winds over 40 kph were encountered, wind direction in relation to setting direction was best when vessels were setting into the wind. The tori line tended to drift from the port side towards the middle when the wind was coming at an adjacent angle to the port side stern and drifted off course when the wind came at the same angle on the starboard side. Winds coming from the stern pushed the tori aerial section towards the stern and made it more susceptible to sagging. Wind speed[6] coupled with choppy swells caused minimal momentary sagging in the tori line, which the tori line

[5] North Easterly winds are called the trades in Hawaii. Fishermen usually set into the trades, and the placement of the tori line on the port side allows the line to remain partially over the sinking baited hooks and wake rather than off to the side if blown off course.

[6] Conditions ranged from a Beaufort 2-4

was able to recover from quickly. Fig. 11 shows three different tori line streamer design configurations being flown.

Figure 11. 105 m short streamer line being flown; 165 m hybrid streamer line being flown; 105 m streamerless design being flown during Phase 1 demostration trips with no fishing gear deployed.

All captains who experienced Laysan and black-footed albatrosses following their vessel noted that having a couple long streamers starting 2.5 m from the attachment point would deter more seabirds from making attempts near the stern of the vessel. They noted that Laysan albatross near the stern of the vessel were observed to make more attempts on baited hooks in rough weather. Some captains also noted that Laysan and black-footed albatrosses would go after baited hooks within 20 m of the vessel stern, suggesting that a shorter tori line with longer streamers may better deter Laysan and black-footed albatrosses from making attempts on cast baited hooks.

2.4.3. Practicality to Store

Crews and captains with smaller deck space liked storing the tori line in a rectangular 12-gal storage bin, because they appreciated the versatility in being able to store the small rectangular storage bin away from the deck area when not using the tori line. Vessels with larger deck space did not always mind keeping a larger bin outside to flake the line into. However, all but one vessel reported that the 12-gal storage bin was enough for flaking in the tori line. Captains liked the flexibility of being able to store the bin alongside the tori pole when the line was not in use, and storing the bin in the bait shed with other gear when not actively fishing or in bad weather. Captains on vessels with smaller less deck space also liked the lightness and smaller size of the bin, making it easy to quickly store the line away. Fig. 12 shows the bin with tori line design 2.

Figure 12. 105 m short streamer line being shown here coiled into a black plastic 12-gal bin. Captains like that the bin was small, portable, and easily stored away on vessels with limited deck space.

2.4.4. Safety Issues Encountered

Captains generally liked the tori lines lightness, construction, and durability. No tori line parts, or pole setups broke during the duration of this study. However, some captains did have suggestions for improvement. During vessel setting, some captains observed that in rough weather, streamers touching the water near the stern end of the tori line were contributing to the tori line being pulled back with more force than usual operation. In the event of the tori line being pulled too hard and breaking off, Crews were told that the tori line would still be attached to the vessel via safety line, allowing them to quickly retrieve the tori line. Crews were instructed to cut the tori line in emergencies, but were also informed they could attach the tori line snap to the mainline as it went over the vessel stern to increase the chance of recovering the tori line during haulback.

Safety lines were first created at 2.4 m length to accommodate a variety of vessel attachment point lengths. However, a safety issue was encountered on one of the vessels concerning the safety line getting snagged by a casted hook, due to the safety line length. The safety line was removed from this vessel, and shorter safety lines were made, measuring 1.3 m long to prevent any future snagging possibilities due to length. This approach worked, and no further reports of snagging with the tori line were reported. Learning from this experience, a standard safety line may not be possible, resulting in each vessel setting a custom length to accommodate their setting procedures.

2.4.5. Summary of fishers' perspectives

Captains and crew had positive experiences using the tori lines during setting operations for Phase 2 of the project. All captains liked the 50m short-streamer design (design 2) selected for Phase 2, and found the design to be light-weight, streamlined, and easily stowable. Participating vessels appreciated the thought that went into picking the materials for the tori line and pole combination. Captains liked the portability, marine grade material, and craftsmanship that went in to making the tori pole. The captains and crew were instrumental to making Phase 1 a success by offering advice and working with the team to trial different tori line materials and design types.

3. PHASE 2 - EXPERIMENT – TORI LINE EFFECT ON SEABIRD BYCATCH RISK IN THE HAWAII DEEP-SET LONGLINE FISHERY

3.1. Methods

3.1.1. Treatments

The control treatment entailed setting without a tori line, and the experimental treatment entailed setting with a tori line. The treatment used for the first set of a trip was randomly selected. All vessels set from the vessel stern. Both control and experimental treatments used the same branchline weighting designs (45 g lead-centered swivels attached about 0.6 m from the hook) leader material (wire), bait (saury, *Cololabis saira*) and hook type (15/0 circle hooks). Information on these fields, which could not be collected by the EM analyst, was collected dockside. When fishing north of 23°N, vessels were required to follow existing seabird mitigation regulations, which include blue-dyed fish bait and offal or spent bait discards during setting.

The tori line design used in the experiment is described in detail in Section 2. A 50 m-long, red, 3 mm diameter, 12-strand, single-braid Dyneema (AmSteel AS-78 Dyneema, thermoplastic polyethylene) rope was used for the aerial section of the tori line. Two 50 cm-long streamers were attached every 1 m along the aerial section, with the first streamer attached at 2.5 m from the point of attachment to the tori pole on the vessel deck, and the last streamer attached at 30.5 m, for a total of 28 streamers. The aerial section was attached 5 m above the sea surface on schedule 40, marine grade, stainless steel poles. Streamers were 50 cm-long, 5 cm-wide, 6 mm thick, black polyethylene sheeting. One 100 cm-long strip was spliced through the Dyneema rope to create the two 50 cm-long streamers. The drag section of the tori line was 55 m-long, and made of 6 mm diameter, 'Blue Steel' 12-strand polyolefin fiber rope. A weak link, using monofilament nylon (polyamide), was in between the aerial section of the tori line and the tori pole. Safety lines were incorporated to retain the tori line if the weak link broke. The aerial and drag sections were connected by splicing them onto a 6 mm stainless steel swivel, which was then covered first with heat shrink wrap and then with electrical tape.

This tori line design meets the minimum tori line design requirements of the two Pacific tuna RFMOs in whose convention areas the Hawaii deep-set longline fishery occurs (IATTC, 2012; WCPFC, 2018). The design and materials were selected based on preferences expressed by Hawaii longline fishers, local availability, cost and lessons learned from tori line trials in New Zealand and Japan (Pierre et al., 2016, Goad, 2017; Goad and Debski, 2017; Katsumata et al., 2019). The selected tori line design was also based on the estimated distance astern that Laysan and black-footed albatrosses are able to access baited hooks.

3.1.2. Electronic Monitoring System

An 8-megapixel super low lux camera (GeoVision model GV-ABL8712; GeoVision, 2019) was positioned to provide a field of view off the vessel stern (Fig. 13). The camera was set to record at 20 frames per second and imagery at 1440p resolution to ensure adequate image quality to meet monitoring objectives during setting. Two internet protocol, dome-shaped security cameras, with 3-megapixel super low lux sensors were also part of the EM system. These were positioned to provide fields of view of the processing deck and the outboard side of the rail off the hauling station to provide the ability for species identification in case the crew interacted with a rare species (Fig. 13). The dome-shaped cameras were set to record at 10 frames per second and imagery in 720p resolution to minimize data storage while capturing images of adequate quality to observe seabirds captures during the gear haulback. In Fig. 13, the green-shaded area is the field of view of one of the 3-megapixel cameras mounted to the outside of the rail with a view outside of the vessel to show catch in the water. The yellow-shaded area is from the second standard camera mounted on the roof of the forward wheelhouse to provide a view of the section of the deck where crew process landed catch. These latter two cameras were used by the EM analyst to record the species of captured seabirds retrieved during the gear haulback. The pink-shaded area is the field of view of the 8-megapixel stern-facing camera – which was mounted either inside of a bait shed from the ceiling or attached to the float cage atop the shed. The low lux sensors optimize the cameras' recording in low light conditions (minimum illumination at 0.01 and 0.003 lux for the 3 and 8-megapixel cameras, respectively). The cameras had waterproof housings and a marine sealant (3M™ Marine Adhesive Sealant) applied to increase waterproofing. The EM reviewing software *Review*, originally produced by Saltwater and now open-source (Chordata, 2019), was used to analyze the EM data.

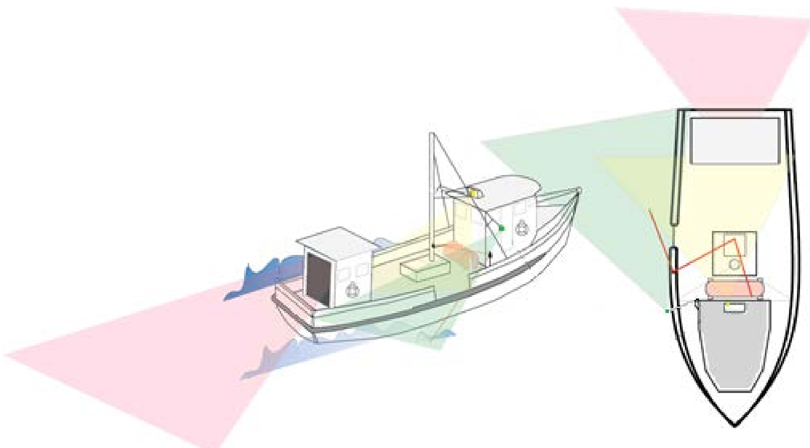


Figure 13. Fields of view of three cameras included in the EM system.

3.1.3. Data

Data fields that significantly explain seabird catch and survival risk, and fields related to individual seabird bycatch mitigation methods, were adapted from Gilman et al. (2019, 2020); Gilman and Clarke (2015); Gilman and Hall (2015); and ISSF (2015). The protocol for recording seabird attempts and contacts with baited hooks was adapted from Boggs (2001) and Gilman et al. (2003). While side setting is an additional seabird bycatch mitigation method employed in the Hawaii longline fisheries (NMFS, 2005), only stern-setting vessels were included in the study and therefore an EM data field for side- vs. stern-setting was not included.

An EM analyst collected the data fields and employed the data collection methods summarized in Table 10. The fields are organized by categories of seabird bycatch mitigation method, other gear and other fishing methods that potentially have significant effects on seabird catch and survival, response variables of seabird attempts and contacts during the set, seabird scan counts, and environmental variables that potentially have significant effects on seabird catch and survival. The EM analyst also recorded any incidences of the tori line breaking during each set.

Table 10. Data fields and collection protocols employed by the EM analyst.

Data Field	Collection Method
Seabird bycatch mitigation methods during setting	
Tori line deployed	Record 'yes' if a tori line was deployed during the entire set, from the deployment of the first to final hook; 'no' if a tori line was not deployed during any of the set; and 'partial' if a tori line was deployed during a segment but not the entire set.
Tori line aerial extent	Record the estimated length of the aerial section of the tori line to the closest meter, from the vessel stern to the first point where the tori line contacts the sea surface.
Tori line maintained over area where baited hooks enter water	At the start of the set and every hour thereafter during the set, record yes or no as to whether the aerial portion of the tori line was over the area of the sea surface where crew were setting baited hooks.
Bait dyed blue or untreated	Record yes or no as to whether baits were untreated or dyed blue.
Offal and spent bait management	Record 'no' if no offal or spent bait were discharged during the entire set, or 'yes' if offal or spent bait were discharged during the set.
Other fishing methods	
Date and time of start and end of set	Record the date and time at the start and end of the set, based on when the first and last baited hooks enter the water. Collected by the EM system using an integrated GPS.
Set duration	Record the duration of the set, calculated from the data on the date and time of day of the start and end of the set.
Latitude and longitude at the start and end of the set	Record the latitude and longitude of the vessel position when the first and last baited hooks enter the water. Collected by the EM system using an integrated GPS.
Wind direction in relation to the vessel setting direction	Record the wind direction in relation to the vessel setting direction (e.g., wind from the stern, wind from the port).
Hooks per set	Record the hooks deployed per set, estimated as the number of hooks between two floats * number of baskets set.
Seabird attempts and bait contacts during the set	
Number of seabird attempts to take bait from hooks	Record the number of species-specific seabird attempts to contact a bait attached to a hook. An attempt is when a seabird plunges underwater or completely submerges but does not contact a bait attached to a hook. A bird sitting on the sea surface looking underwater was not considered an attempt – the seabird must have conducted a submerged or partially submerged body thrust to be recorded as an attempt. Only one attempt was recorded per individual bait, regardless of whether multiple birds made attempts to scavenge the same bait or an individual bird made multiple attempts to contact the same bait. If a bait was contacted by a seabird, then attempts to contact that bait were not recorded.
Number of seabird contacts with baited hooks	Record the number of species-specific seabird contacts with baited hooks. A contact is when a seabird grasps a bait in its beak while the bait is attached to a hook. Only one contact was recorded per individual bait. If a

	seabird contacted a bait held by another bird, this was not counted as a second contact. If a bird contacted a bait held by another bird and successfully stole the bait from the other bird, this also is not counted as a second contact. If an individual bird contacted the same baited hook multiple times during separate events (i.e., the bird released the baited hook, and subsequently grasped the same baited hook in its beak), and if multiple birds contacted the same baited hook during separate events, each event was not counted as separate contacts.
Distance astern of seabird attempts and contacts	Record the distance astern that each seabird attempt and contact occurred, estimated to the meter.
Seabird captures	
Number and condition of seabirds retrieved during the gear haulback	During each haul, record the number of each species of seabird retrieved.
Seabird scan counts	
Number of seabirds, by species, attending the vessel during the set	At the start and end of the set, and every hour following the start of the set, within an area 100 m of the vessel in all directions that are within the EM stern-facing camera field of view, record a count of the number of seabirds, to the species level if possible.
Environmental variables that potentially significantly explain seabird catch risk	
Beaufort wind force scale	Following the Hawaii longline observer program protocols (NMFS, 2017), record the Beaufort scale based on the sea surface state and wave height, from Beaufort scale of 0 – surface like a mirror, 0 m wave height, to 10 – sea looks white, foam blown in dense streaks obscuring visibility, wave height between 8.8 m and 12.5 m.
Illumination	Following the Hawaii longline observer program protocols for assessing weather conditions (NMFS, 2017), record condition category (clear, partly cloudy, cloudy – one or more layers, drizzle, showers, rain, thunderstorm, rain and fog, fog and thick haze, snow or snow and rain).

The data comprise the number of seabird interactions recorded during 392,720 hooks deployed in 175 fishing sets during 17 trips by four commercial Hawaii longline fishing vessels, Golden Phoenix, Queen Alina, St. Damien and St. Marianne, undertaken between 17 February and 20 July 2020. Fig. 14 shows the study area overlaid on the estimated non-breeding distributions of the Laysan and black-footed albatrosses. Nearly all recorded seabird interactions were comprised of either the black-footed albatross or the Laysan albatross that have distributions that overlap with the Hawaii deep-set longline fishing effort (see Fig. 14), while shearwaters accounted for ca. 1% of the attempts of contacts. The two albatross species records were combined into a generic albatross category as there were insufficient data to estimate any species-specific effects.

The analysis therefore focused on the following albatross-specific interactions or response metrics: (1) number of albatross hook-caught (or "captured") on each set, (2) the recorded number of albatross attempts to attack the gear/bait for each set and (3) the recorded number of albatross contacts with the gear/bait for each set. There were too few attempts or contacts > 2 or 3 to model meaningfully (see Fig. 15) so these response metrics were more appropriately restructured as a binary or Bernoulli response (0,1) variable with the attempt rate being recoded as either 0 for no attempts and 1 for one or more attempts. The same procedure was applied to the albatross contacts data.

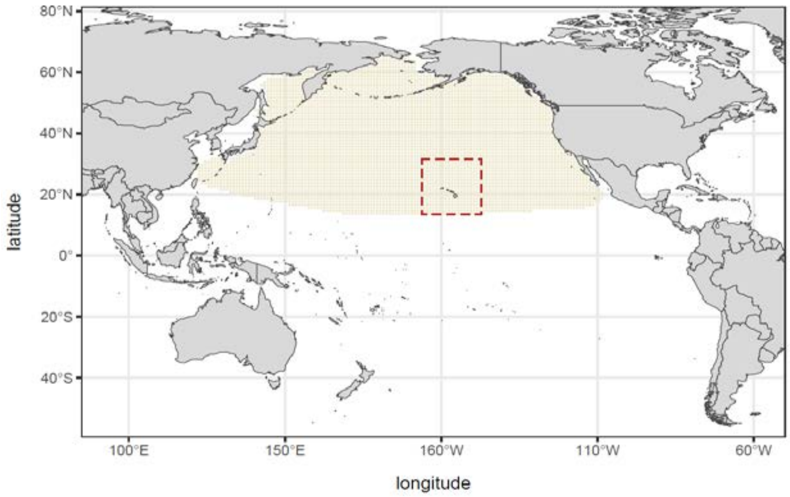


Figure 14. Study area (dashed polygon) overlayed on the combined maximum non-breeding distributions of the Laysan and black-footed albatrosses (BI and HBW, 2019).

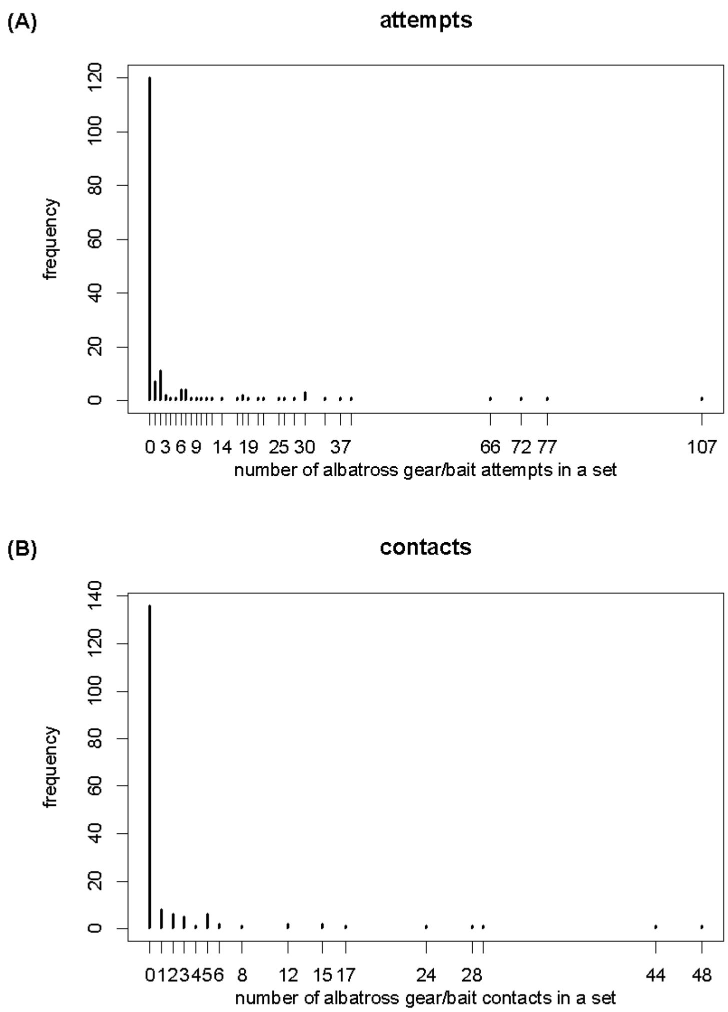


Figure 15. Summary of albatross interactions for each of the 175 sets. (Panel A) shows frequency of albatross attempts with the gear/bait for each set. (Panel B) shows frequency of albatross contacts with the gear/bait for each set.

3.1.4. Experimental Design

The longline set is the fundamental sampling unit or blocking factor (Bergh et al., 1990; Jensen et al., 2018) that is nested within trip, which is itself nested within vessel. Thus the sampling design comprises 3 crossed random-effects: set, trip and vessel. This multilevel or hierarchical random-effects structure needs to be accounted for in any statistical modelling of the estimated tori-line effect on seabird bycatch rates. The trial also comprised 2 other seabird bycatch mitigation measures or treatments: (1) strategic offal discharge and (2) blue-dyed bait (Gilman et al., 2005; Gilman et al., 2016). Some but not all control and experimental treatment sets also used blue-dyed fish bait and discarding offal or spent bait during setting. Of 83 control treatment sets, 31 used blue-dyed bait, 12 used both blue-dyed bait and offal/bait discards, and 40 did not use blue-dyed bait or offal/bait discards. Of 93 sets using the experimental treatment, 32 used blue-dyed bait, 16 used blue-dyed bait and offal/bait discards, and 45 did not use blue-dyed bait or offal/bait discards.

The trial comprises 3 treatments: (1) tori-line, (2) offal discharge and (3) blue-dyed bait. The 3-treatment experimental design is summarized in Fig. 16, which shows the $2^3 = 8$ possible treatment arms if this was a fully factorial study design. Two of the 8 arms are not possible here because offal only occurred in conjunction with the blue-dyed bait treatment (Fig. 16), which results in a partially nested or partially clustered experimental design (Baldwin et al., 2011; Candlish et al., 2018).

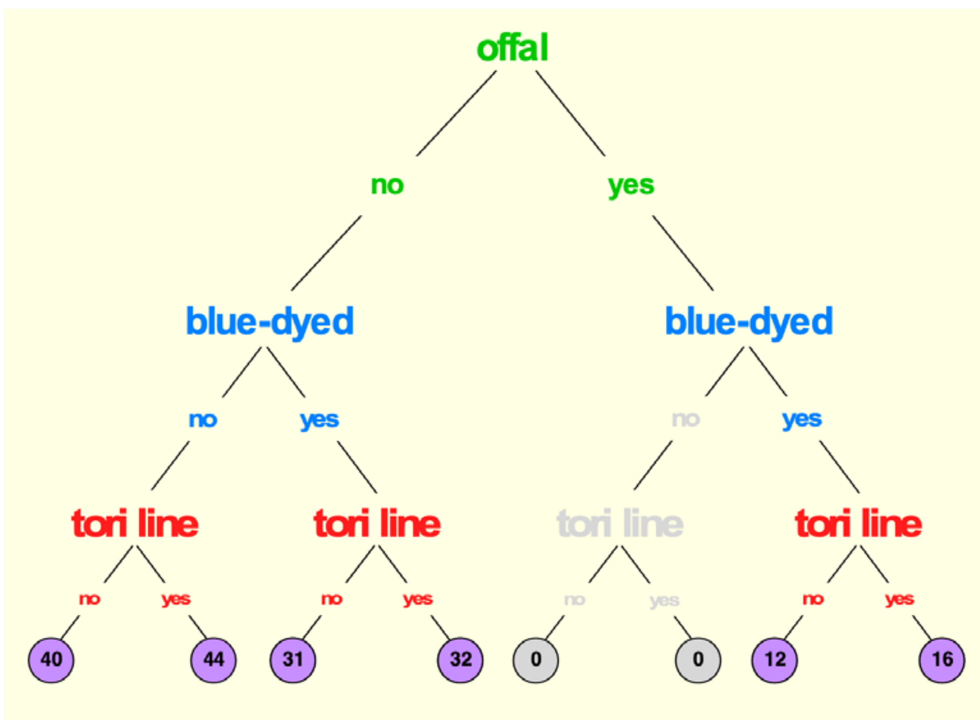


Figure 16. Experimental design to evaluate the effect of tori lines as a seabird bycatch mitigation measure in the Hawaii-based deep-set pelagic longline fishery given the co-application of 2 other mitigation measures (offal discard, blue-dyed bait). Terminal nodes show the number of sets completed for each of the $2^3 = 8$ potential treatment combinations. Nodes with zero sets shows those treatment arms that did not occur in this study and hence leads to a partially nested rather than a fully factorial study design. Total sets completed was 175.

The partially nested design adds a complication that needs to be accounted for in any subsequent statistical modelling of the estimated tori-line effect on seabird bycatch rates. This was done here by creating a 3-category factor cluster as follows: 1 = [offal=="no" & blue=="no"], 2 = [offal=="no" & blue=="yes"], 3 = [offal=="yes" & blue=="yes"]. So, there was no level that includes offal discharge but not blue-dyed bait.

3.1.5. Statistical Modeling Approach

3.1.5.1. Albatross captures

There were only 10 albatrosses captured (hooked) in the 175 sets: 5 black-footed albatrosses and 5 Laysan albatrosses These data are too few to warrant any comprehensive statistical analysis other than some robust form of summary. So, the median posterior albatross capture rate and the highest posterior density interval (HDI) was summarized by sampling from a binomial likelihood with a Bayes-Laplace prior (Tuyl et al., 2008) using the binom R package (Dorai-Raj, 2014). Specifically, the number of sets with at least 1 capture for those sets with or without tori-lines deployed were sampled from a binomial likelihood with 1000 simulation trials, which were then summarized as the median and highest posterior density intervals (80%, 95%) using the tidybayes package for R (Kay, 2020a) and stat_halfeye() function from the ggdist package for R (Kay, 2020b).

The posterior ratio (and 95% HDI) based on the 1000 trials for the 2 densities was then used to assess any apparent difference between the capture rate for sets deployed with or without tori-lines. The posterior ratio summary was also included in the observed capture summary plot. The ggplots2 (Wickham, 2016) and colorspace (Zeileis et al., 2020) packages for R were used for the summary graphics while the patchwork package for R (Pedersen, 2020) was used for the multi-panel arrangements.

3.1.5.2. Observed albatross attempt and contact summaries

The median posterior albatross attempt rate (at least one albatross attempt to attack the gear per set) and the HDI was summarized by sampling from a binomial likelihood with a Bayes-Laplace prior (as used above for the albatross captures). Specifically, the number of sets with at least 1 attempt at the gear/bait for those sets with or without tori-lines deployed were sampled from a binomial likelihood with 1000 simulation trials. Those trials were then summarized as the median and the 80% and 95% HDIs. The same procedure was then applied to the contact rate (at least 1 albatross contact per set). These are simple summaries of the apparent tori-line effect for the 2-response metrics, but without accounting for any potentially informative covariates or predictors. That approach is outlined in the next section to estimate the contact or attempt rates conditional on informative predictors relevant at the longline set level.

3.1.5.3. Modelling the albatross attempt and contact rates

The statistical modelling approach was based on a Bayesian inference workflow (Gabry et al., 2019) using spatially-explicit generalized additive mixed regression structured models (geoGAMM: Fahrmeir & Lang, 2001, Kammann & Wand, 2003) with an appropriate response-specific likelihood for the various forms of interaction rate data (see Gilman et al., 2018 and Gilman et al., 2020 for recent fishery related examples).

Here the response metrics are now binary data (for example: 0 = no attempts, 1 = at least one attempt to attack the gear/bait) and so are sampled from a Bernoulli probability distribution and so appropriately modelled using a regression model with Bernoulli likelihood — which is a special case of a binomial likelihood but now with a single trial (Congdon, 2003).

Specifically, geoGAMMs with Bernoulli likelihood were fit to the albatross interaction data (ATTEMPT = at least 1 albatross attempt to attack the gear, CONTACT = at least 1 albatross contact with the gear) while accounting for potentially informative predictors using the Stan computation engine (Carpenter et al, 2017) via the brms interface (Bürkner, 2017). All models were implemented using weakly informative regularizing priors (Lemoine, 2019) and so prior predictive graphical summaries were used to assess the adequacy of the priors used (Gabry et al., 2019).

The predictors included hooks per set (as a nonlinear effect rather than just as an offset: see Davies & Jonsen 2011 for discussion of nonproportional effort scaling), wind speed, cloudiness (overcast or not), `offal blue-dyed bait` cluster, nonlinear mean density of seabirds attending the vessel and specific set geolocation. The offal-blue-dyed-bait cluster covariate helps account for the partially nested design issues summarized in Fig. 16.

Cubic smoothing splines (Wood, 2016) were used to account for possible nonlinear functional form of the covariates such as hooks per set (the longline fishing effort metric). The structured spatial effect of the individual set geolocations was estimated in the geoGAMMs using a 2D Gaussian Process structure (Gelfand & Schliep, 2016, see Gilman et al., 2020b for a recent fishery related example).

The random effect structures (intercepts-only) included in the geoGAMMs were the identity of the 17 trips and the identity of the 4 vessels to account for any correlated or trip- and/or vessel-specific heterogeneity in the interactions rates not accounted for by the other predictors. The 3-category cluster variable was included as a either a fixed effect or a random effect — if as a random effect then this form was used as suggested by Candlish et al (2018): (0+tori|cluster), where tori indicates whether tori-lines were used or not.

Model selection was based on leave-one-out cross-validation metrics to estimate any comparative difference in expected predictive accuracy between the various models fitted such as whether to include an explicit spatial effect or not or whether including a vessel-specific random effect was necessary (Vehtari et al., 2017). The weight of evidence in favor of one model over any other candidate models was also assessed using Bayesian stacking, which is the Bayesian analogue of model averaging (Yao et al 2018).

The posterior samples for all models were sourced from 4 chains and 12000 iterations after a warmup of 2000 iterations per chain. Therefore, the posterior for each estimate comprised 10,000 samples or draws that were used to derive the uncertainty intervals (HDIs or highest posterior density intervals: Kruschke & Liddell, 2018) using the tidybayes package for R (Kay, 2020a). Convergence diagnostics such as effective posterior sample size and the Gelman-Rubin statistic (Rhat<1.01) reflected convergence of all Bayesian models used here (Gelman and Hill, 2007). Further evaluation of the best-fit-model was then assessed using graphical posterior predictive checks (Gabry et al., 2019). All inference was then made using the best-fit model.

In any experimental setting it is important to be able conclude that there was an effect, when there really was an effect. And it is equally as important to be able to conclude that there was no effect, when there was in fact no effect. This can be done using indices of existence and significance in a Bayesian setting (Makowski et al., 2019). A probability statement about the *existence* of a particular effect and its direction, such as tori-line effects, can be determined with those 10,000 draws using the probability of direction metric proposed recently by Makowski et al. (2019) — also known as the maximum probability of an effect.

The *significance* (rather than just existence) of any such effect (or parameter estimate) was then assessed using the HDI+ROPE approach (Kruschke & Liddell, 2018). The region of practical equivalence (ROPE) has been proposed as a robust procedure to determine the significance of a meaningful effect in a Bayesian setting using the posterior draws from the best-fit model along with the calculated 95% highest posterior density interval of those draws (Kruschke & Liddell, 2018). An appropriate ROPE range or "null hypothesis" region for a regression model with Bernoulli likelihood has been defined by Kruschke & Liddell (2018) as [-0.18,0.18].

The decision rule is that if the HDI lies entirely outside the ROPE then reject the "null hypothesis" that samples are the same or equivalent (Kruschke & Liddell, 2018). If the HDI is lies entirely within the ROPE then accept the "null". Otherwise, the decision to reject or accept is "undecided". This is called the HDI+ROPE decision rule (Kruschke & Liddell, 2018). Kelter (2020) suggested recently that using a 100% HDI based on the entire posterior distribution (aka full ROPE) could be used for a more robust decision. The existence and significance metrics were derived here using the BayestestR package for R (Makowski et al., 2019).

Finally, the estimated effects summaries based on the best-fit conditional regression models were then adjusted for variable sample size of the treatments using the marginal means approach (Searle et al., 1980, Lenth, 2016) and implemented using the emmeans package for R (Lenth, 2020). The ggplots2 (Wickham, 2016) and colorspace (Zeileis et al., 2020) packages for R were used for all summary graphics while the patchwork package for R (Pedersen, 2020) was used for all multi-panel arrangements.

3.2. Results

3.2.1. Effects on Albatross Interactions

3.2.1.1. Captures

The modelled statistical summary of albatross captures for sets deployed with and without tori lines is shown in Fig. 17. The modelled interaction rates estimate that ca. 7% of sets had at least one hooked albatross. Albatrosses were marginally less likely to be captured when tori-lines were deployed, but the 80% and 95% HDIs completely overlapped, indicating that there was no difference in capture rates. The sample size in this trial of only 10 albatross captures (5 black-footed, 5 Laysan) was far too small to support any further meaningful inference.

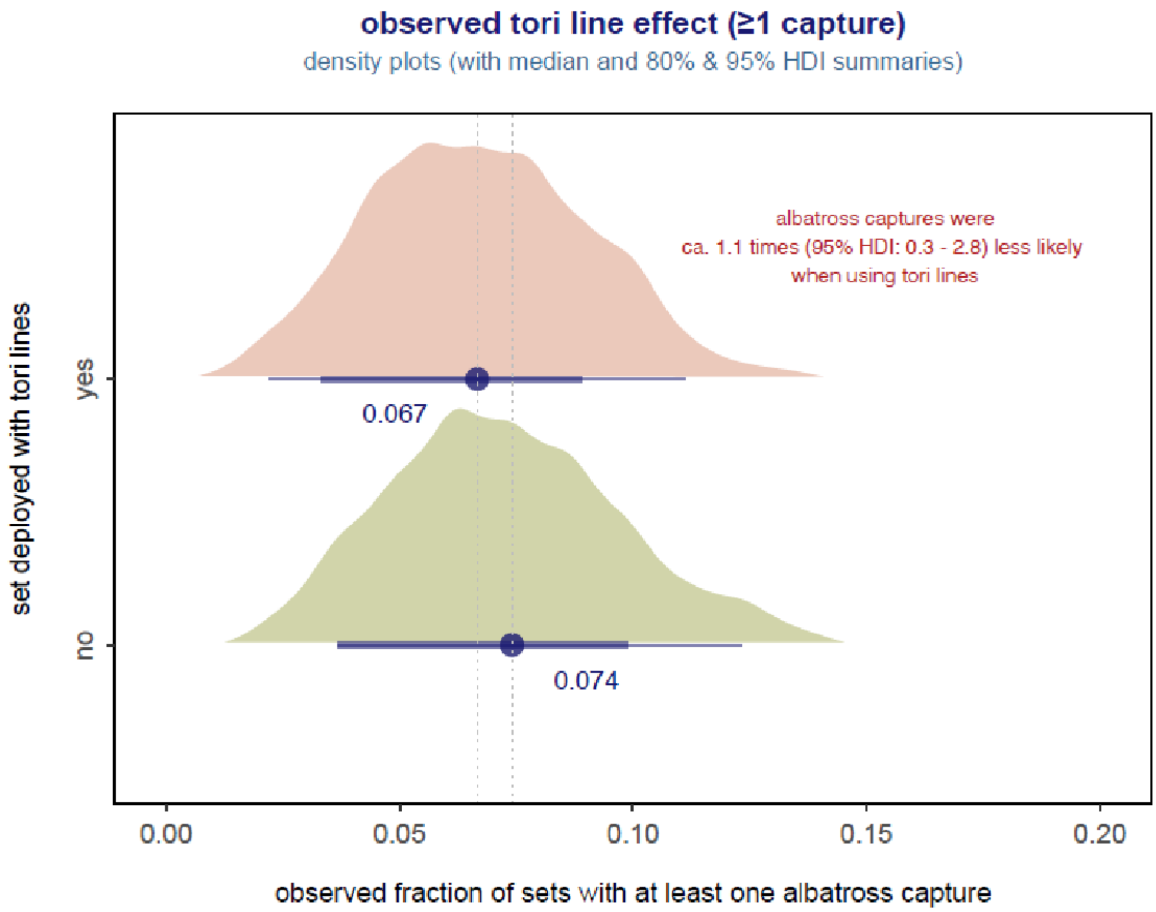


Figure 17. Summary of 10 albatross captures on the 175 longline sets. Colored polygon shows the density distribution summary of the 1000 simulations for the sets deployed with or without tori-lines, solid dot = median estimated of the density polygon (estimate also shown as a numeric label), thick horizontal line below each polygon shows the 80% highest posterior density interval for the density polygon while the thin horizontal line is the 95% HDI.

3.2.1.2. Attempts and contacts

Strong inference is possible using the Bayesian structured modelling workflow that comprised (1) prior predictive checks to assess the adequacy of the priors used for (2) a robust statistical model accounting for experimental design constraints and potential predictors of interaction rates other than the tori-line treatment effect and then followed by (3) posterior predictive checks of the adequacy of the statistical model(s) fitted to the interaction data.

A summary of some of the potentially informative predictors for all the geoGAMMs fitted to the albatross interaction data is shown in Fig. 18. The top panel shows the significant seabird density effect where it is apparent that albatross contact rate increased nonlinearly with increasing seabird density. The residual spatial effect is shown in the bottom panel where it is apparent that contact rates varied considerably over the region that the 175 sets were deployed — importantly model selection based on leave-one-out cross-validation (LOOcv) and the Bayesian stacking suggest that the spatial effect was a significant effect and had relevant for any model inference.

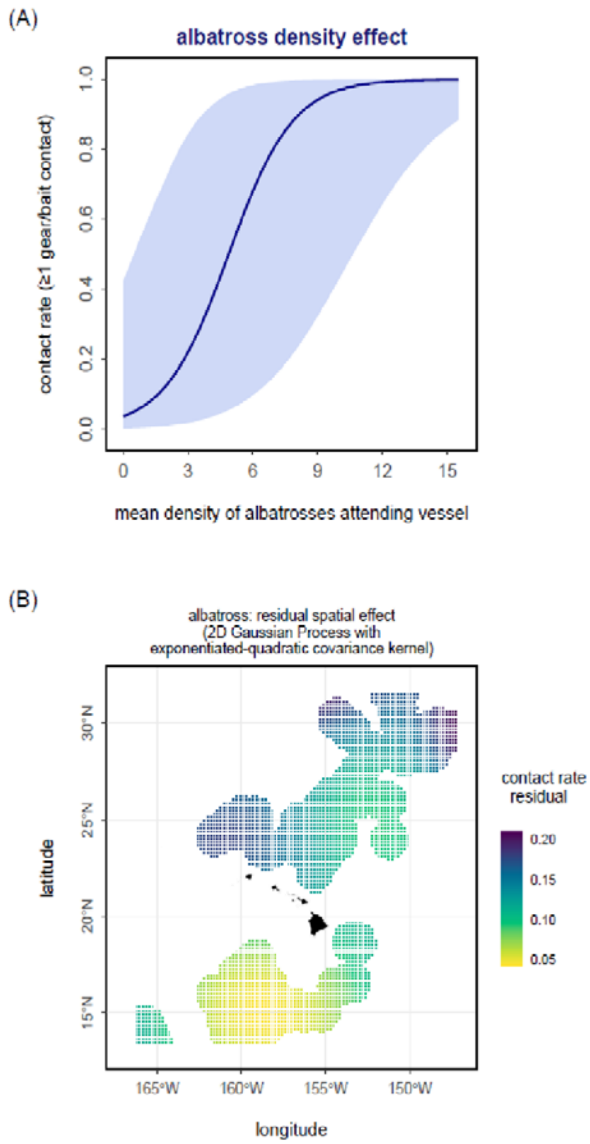


Figure 18. Estimated functional form for 2 continuous predictors included in the best-fit geoGAMM to estimate albatross contact rate conditional on potentially informative predictors. Panel A shows the nonlinear functional form for the estimated effect for the density of seabirds attending the vessel: solid curve = median effect, shaded polygon = 95% credible interval. Panel B shows the residual spatial effect from an albatross contact rate geoGAMM. Black polygons show the main Hawaiian Islands.

On the other hand, LOOcv and Bayesian stacking metrics suggested that inclusion of the vessel-specific random effects was not necessary but that trip-specific random effects were — but there was little difference in model fit using vessel, set and trip as random effects but the best-fit model included trip-specific effects only. So, the best-fit GAMMs selected for inference for either the attempt or contact rates excluded the vessel- and set- specific random-effects and used only trip-specific random-effects. The best-fit geoGAMMs identified by the LOOcv and Bayesian stacking metrics fitted the interaction data well. All inference is now based on those best-fit geoGAMMs and in all models the tori-line treatment effect conditional on all other predictors was significant statistically. That key finding is explored in further detail next.

For attempts, Figs. 19 and 20 show the existence and significance of the modelled conditional tori-line effect based on the posterior draws from the best-fit attempt rate geoGAMM. Specifically, Fig. 19 shows that the tori-line effect had a 0.995 probability of being negative while Fig. 20 shows that the tori-line effect was statistically significant using either the full (100%) HDI+ROPE or the 95% HDI+ROPE metric. The estimated offal-blue-dyed-bait cluster-specific effect was equivocal for the specific `offal=no + bluedye=yes` effect but significant for the `offal=yes + bluedye=yes` effect that also had a 0.978 existence probability of being positive (Fig. 19). Similarly, for contacts, not shown, based on the posterior draws from the best-fit contact rate geoGAMM. the tori-line effect had a 0.994 probability of being negative and the tori-line effect was statistically significant based both on the full (100%) HDI+ROPE and the 95% HDI+ROPE metric. The estimated offal-blue-dyed-bait cluster-specific effects were equivocal although the specific `offal=yes + bluedye=yes` effect had a 0.969 existence probability of being positive and hence associated with a higher contact rate rather than reducing the rate.

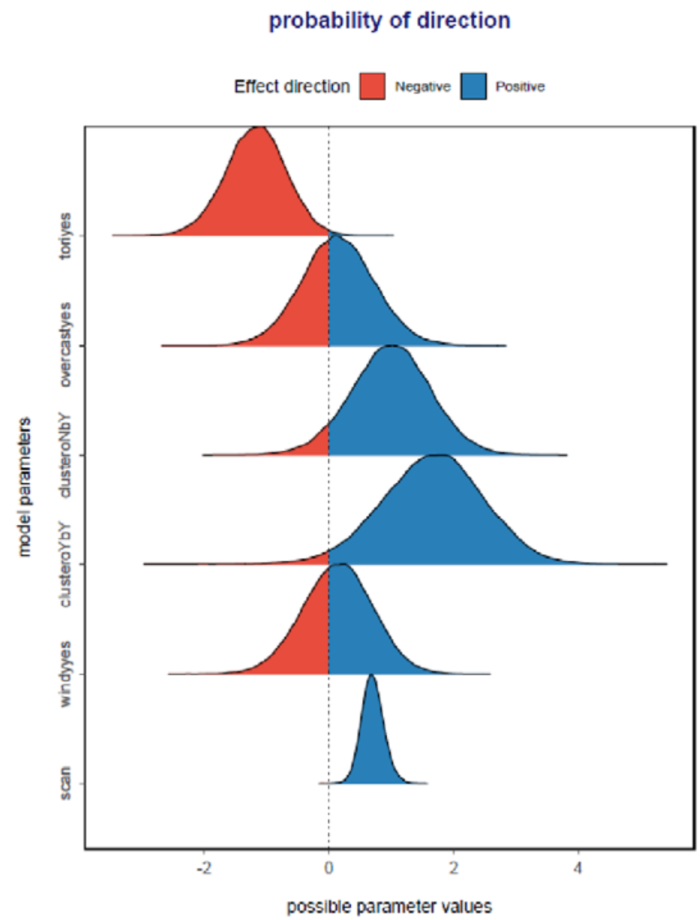


Figure 19. Probability of direction plot for selected parameters estimated from the best-fit GAMM for the albatross bait/gear attempt rate. Polygons show the density summary of the posterior draws and colored given the estimated direction (positive or negative) of the effect or parameter. The proportion of the polygon that does not include zero is a statement about the probability of the proposed direction of the effect.

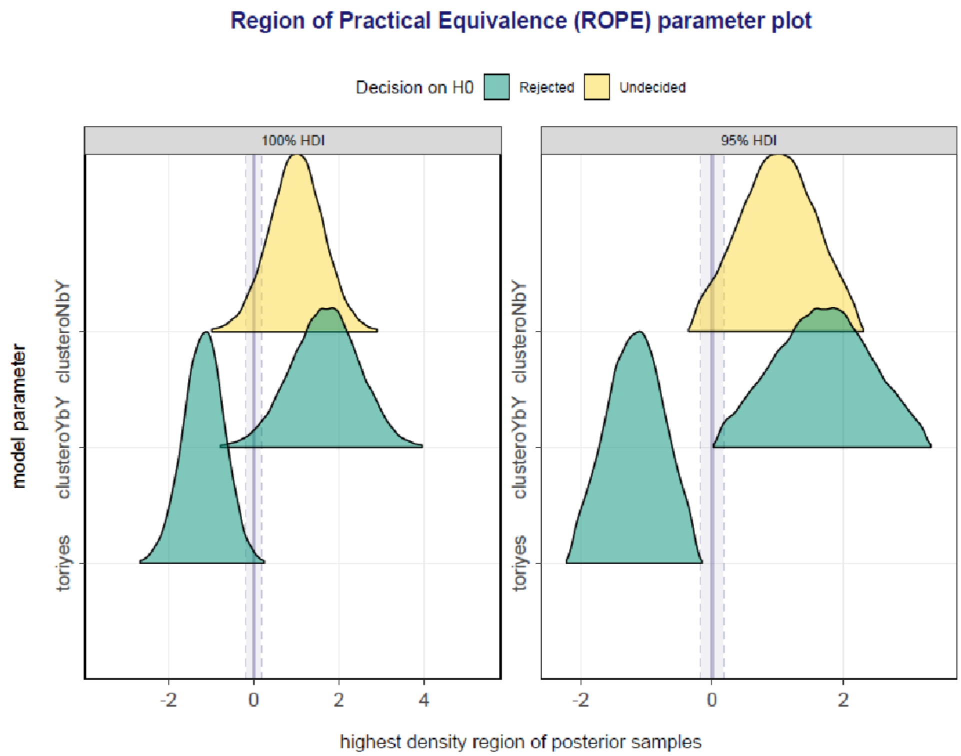
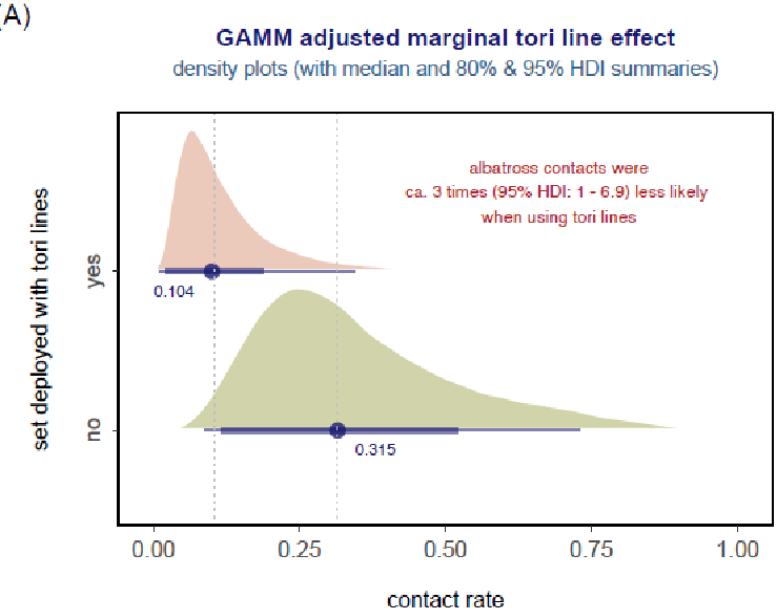


Figure 20. ROPE-based summary of the significance of the tori-line and offal - blue-dyed bait cluster effects derived from the best-fit GAMM for the albatross bait/gear attempt rate. The left panel shows the effects given a ROPE based on a 100% highest posterior density interval. The right panel shows the effects given a ROPE based on a 95% highest posterior density interval. Green polygon indicates a significant effect.

Fig. 21 shows the estimated marginal means for the tori-line effect for the albatross contact rate sourced from the posterior draws from the best-fit conditional geoGAMM. The top panel shows the estimated marginal means density distribution for the sets with and without tori-lines where it is apparent that albatrosses were ca. 3 times (95% HDI: 1-7) less likely to contact the gear/bait when tori-lines were deployed. The bottom panel summarizes the same predicted effect as in the top bottom but now the summary is conditioned on the offal-blue-dyed-bait cluster level. Again, contact rate is predicted to be lower on sets with tori-lines deployed and that this effect difference increases with 1 or 2 co-applied mitigation measures — contact rates were highest when the sets were deployed with both offal and blue-dyed bait but that co-application of tori-lines for those sets moderated that undesirable effect.

As with contacts, Fig. 22 shows the estimated marginal means for the tori-line effect for the albatross attempt rate sourced from the posterior draws from the best-fit conditional geoGAMM. The top panel shows the estimated marginal means density distribution for the sets with and without tori-lines where it is apparent that albatrosses were ca 2 times (95% HDI: 1-4) less likely to attempt to attack the gear/bait when tori-lines were deployed. The bottom panel summarizes the same predicted effect as in the top bottom but now the summary is conditioned on the offal-blue-dyed-bait cluster level. Again, the attempt rate is predicted to be lower on sets with tori-lines deployed and that this effect difference increases with 1 or 2 co-applied mitigation measures — attempt rates were highest when the sets were deployed with both offal and blue-dyed bait but that co-application of tori-lines for those sets moderated that undesirable effect. Importantly, it was apparent that even deploying sets with blue-dyed bait and not offal discharge also increased the albatross attempt rate that was again moderated by co-application of tori-lines.

(A)



(B)

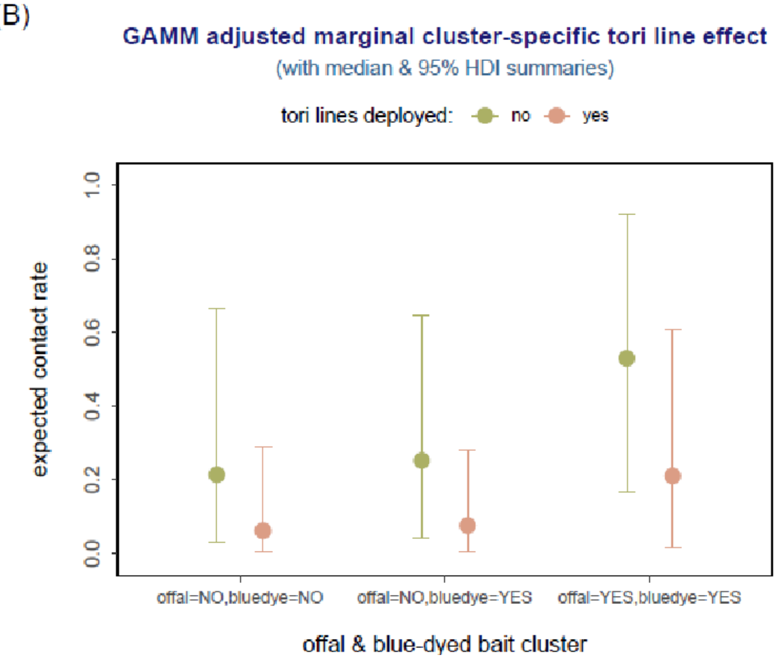
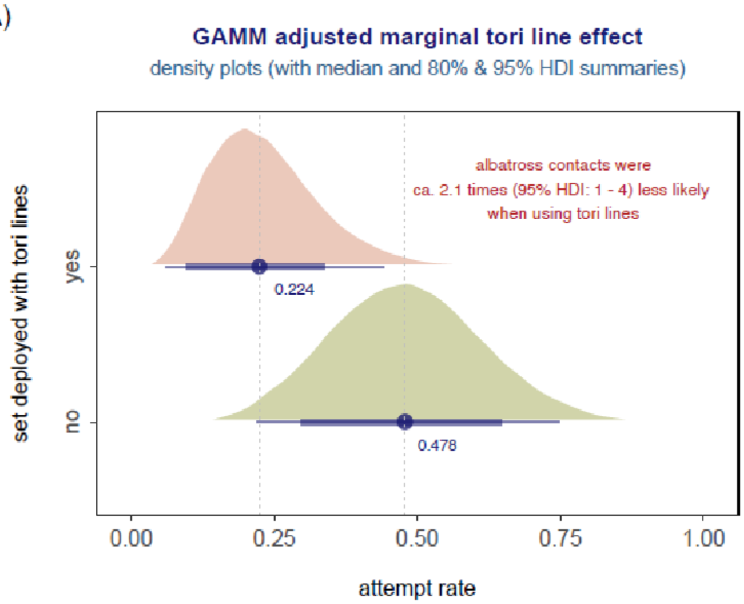


Figure 21. Summary of the estimated marginal mean tori-line effect derived from the best-fit GAMM for the albatross bait/gear contact rate. Panel A shows the estimated tori-line effect. Panel B shows the estimated tori-line effect conditional on offal-blue-dyed-bait treatment cluster. Colored polygon shows the density distribution summary, solid dot (+ numeric label) = median estimated of the density polygon, thick horizontal line below each polygon shows the 80% highest posterior density interval for the density polygon while the thin horizontal line is the 95% HDI.

(A)



(B)

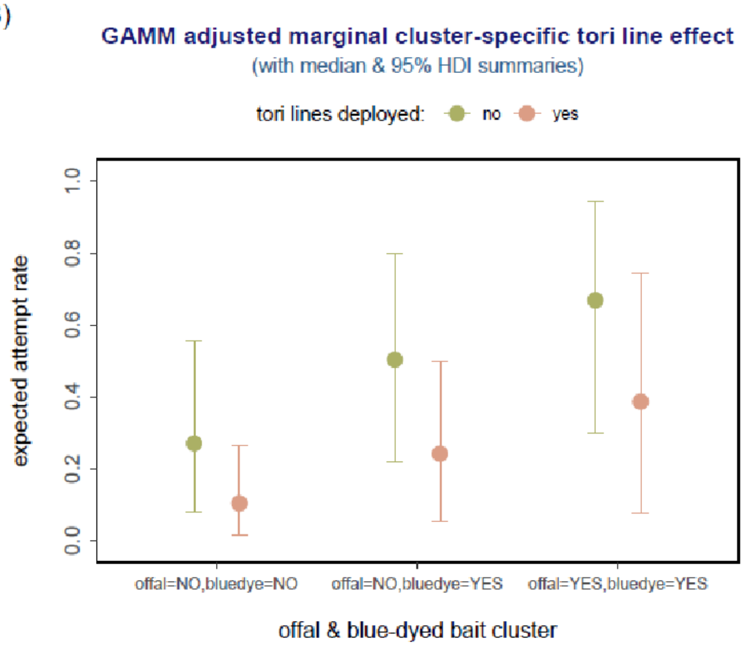


Figure 22. Summary of the estimated marginal mean tori-line effect derived from the best-fit GAMM for the albatross bait/gear attempt rate. Panel A shows the estimated tori-line effect. Panel B shows the estimated tori-line effect conditional on offal-blue-dyed-bait treatment cluster. Coloured polygon shows the density distribution summary, solid dot (+ numeric label) = median estimated of the density polygon, thick horizontal line below each polygon shows the 80% highest posterior density interval for the density polygon while the thin horizontal line is the 95% HDI.

3.2.2. Distance Astern, Secondary Interactions

Table 11 summarizes the distance astern of attempts and contacts by Laysan and black-footed albatrosses, with and without a tori line deployed. The EM analyst did not observe any secondary interactions.

Table 11. Frequency of the distance astern that black-footed and Laysan albatrosses' attempts and contacts occurred, with and without a tori line.

Distance astern range (m)	No tori line		Tori line		Cumulative % of total
	Attempts and contacts	Cumulative %	Attempts and contacts	Cumulative %	
0-5	310	31.4	61	27.5	30.7
6-10	271	58.9	60	54.5	58.1
11-15	153	74.4	40	72.5	74.0
16-20	108	85.3	14	78.8	84.1
21-25	61	91.5	8	82.4	89.8
26-30	32	94.7	9	86.5	93.2
31-35	30	97.8	13	92.3	96.8
36-40	14	99.2	5	94.6	98.3
41-45	6	99.8	3	95.9	99.1
46-50	1	99.9	6	98.6	99.7
51-55	0	99.9	3	100.0	99.9
76-80	1	100.0	0	100.0	100.0

3.2.3. Operational Practicality

During the experiment, there was one incident of the tori line's safety line entangling with gear. There were no incidents of tori lines breaking. No safety issues were raised by the fishermen related to deploying and retrieving the tori line.

3.3. Discussion and Conclusions

3.3.1. Tori Line Effect on Seabird Catch Risk

The findings here that use of a tori line during setting significantly reduced albatross interactions is consistent with previous studies on the efficacy of various tori line designs in pelagic longline fisheries (Yokota et al., 2011; Melvin et al., 2013, 2014; Pierre et al., 2016; Domingo et al., 2017; Sato et al., 2012, 2013, 2016; Katsumata et al., 2019; Jiminez et al., 2020), including two previous tori line experiments conducted in Hawaii longline fisheries (McNamara et al. 1999, Boggs 2001). The addition of a tori line to existing concurrently-used seabird bycatch mitigation methods, including branchline weighting, would very likely result in substantial reductions in albatross catch risk.

3.3.2. Offal and Spent Bait Discharge Effect on Seabird Catch Risk

Findings suggest that discharging offal and spent bait during setting might exacerbate and not mitigate seabird catch risk. This is consistent with findings from a study in a demersal longline fishery that higher quantities of offal discharges had higher white-chinned petrel catch rates (Delord et al., 2005).

However, it is unclear whether discharging caused the higher bird interaction rates or vice versa. Crew may have discharged offal or spent bait in response to observing high seabird interactions.

Discharging offal from processed catch, spent bait and dead discards away from setting and hauling operations may draw scavenging seabirds' attention away from where baited hooks are available and reduce seabird catch rates during that fishing operation, as demonstrated in some studies in pelagic and demersal longline fisheries (Cherel et al., 1996; McNamara et al., 1999). However, this might be a short-term effect. Based on research conducted in trawl fisheries, increased time between offal discharge events and retention of offal reduces the number of seabirds attending vessels (Abraham et al., 2009; Pierre et al., 2010, 2012). The lower the seabird density attending vessels, the lower the seabird catch risk (Gilman et al., 2005; Abraham et al., 2009). Retention might also reduce competitive seabird scavenging behavior and foraging intensity, reducing capture risk (Delord et al., 2005; Gilman et al., 2016). Hawaii longline fishery may be unique in requiring 'strategic' offal discharge during setting or hauling as the only option for managing offal discharge. The seabird measures of the two Pacific Ocean tuna RFMOs define 'management of offal discharge' as either (a) not discharging offal during setting or hauling, or (b) discharging offal only from the opposite side of the vessel from where setting or hauling is occurring (IATTC, 2012; WCPFC, 2018) and we are not aware of domestic fisheries management systems that implement option b other than in the Hawaii longline fisheries. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (2018) prohibits offal and discard discharging during setting in longline fisheries, consistent with the recommendations of Agreement on the Conservation of Albatrosses and Petrels (ACAP, 2019). Whether offal discharging increases long-term seabird attendance, affects seabird behavior, such as increasing short-term scavenging and competitive behavior, increasing seabird catch rates, is a research priority.

3.3.3. Distance Astern Where Albatrosses Are Susceptible to Capture – Tori Line Aerial Length

Laysan and black-footed albatrosses have limited diving capacities, typically only making body thrusts to reach prey near the surface. Kezama et al. (2019) observed that black-footed albatrosses made dives to a mean depth of 0.6 m (± 0.2 m 95% CI), and reached a maximum depth of 2.5 m. Unlike in other regions, secondary interactions during setting, where relatively small species of deep-diving seabirds access baited hooks at depth and bring the baited hook to the sea surface where larger seabird species are then able to access the terminal tackle and become captured (Jiminez et al. 2012; Melvin et al., 2014), is not known to occur in Hawaii longline fisheries (Gilman et al., 2016, 2020a).

To estimate the distance astern that the tori line needs to protect longline baited hooks from primary interactions with Laysan and black-footed albatrosses, we assumed that: (a) Laysan and black-footed albatrosses can access baited hooks within the upper 2.5 m of the surface, (b) a vessel setting speed of 3.6 m/s (7 knots), and (c) the baited hook sink rate is 0.5 m/s, which is about half the sink rate estimated by Brothers and Gilman (2006) for the prevalent branchline design used in the Hawaii fishery (a 15/0 circle hook baited with saury with a 45 g weight attached 0.6 m from the hook was estimated to have a sink rate of 1 m/s). A baited hook would, most of the time, be out of reach of Laysan and black-footed albatrosses in 5 seconds following contact with the sea surface, by which time the vessel would have moved 18 m forward. If crew throw a baited hook 10 m astern, then a tori line would need to protect 28 m astern. This does not account for variability in baited hook sink rates, such as due to different environmental conditions of wind and surface current velocity, when crew throw baited hooks into the prop turbulence, and when tangles cause tension in the mainline to bring baited hooks back up to the sea surface. With the tori line attached 5 m above the sea surface, and a 50 m-long aerial section, the horizontal distance covered by the aerial section extends about 49.7 m astern, which might enable protecting baited hooks during the rare events when baited hooks are available substantially further astern than the estimated 28 m threshold.

The empirical observations were consistent with the theoretical estimate. Almost all of the observed seabird interactions occurred within 50 m of the vessel. The 49.7 m horizontal distance protected by the tori line's aerial section covered 99.7% of the observed distances astern of attempts and contacts by Laysan and black-footed albatrosses. Given that more than half of the seabird interactions occurred very close to the vessel, within 10 m, this highlights the importance of protecting baited hooks with streamers on the tori line in this area. With only 0.3% of interactions occurring beyond 50 m of the vessel stern, there would be limited conservation gain from tori lines with aerial coverage longer than the design used in the experiment. The EM analyst, however, may have had lower certainty estimates of seabird interactions the further astern the interaction occurred (e.g., see McElderry et al., 2011). There was no apparent effect of deployment of a tori line on the distance astern of seabird interactions with terminal tackle relative to sets with no tori line. Both sets with and without a tori line had over half of interactions occur within 10 m of the stern. Using longer streamers on the tori line near the vessel, where the aerial section is relatively high above the sea surface, could improve the tori line's efficacy at reducing seabird interactions in this area. However, the hybrid tori line design with longer streamers close to the stern used in the Phase 1 demonstration trials required a longer drag section than the short streamer design, which made the tori line heavier and more difficult for crew to retrieve.

3.3.4. EM System Meeting Seabird Bycatch Monitoring Objectives

The study provided proof of concept that an EM system can be designed to collect variables that significantly explain seabird catch risk. This included the employment of some of the seabird bycatch mitigation methods that were used during setting in the study (tori lines including streamer line position in relation to baited hooks, blue-dyed bait, offal management), but not branchline weight amount or distance from the hook (leader length), consistent with previous assessments of EM system capabilities (Ames et al., 2005; Piasente et al., 2012; Pierre, 2018; Gilman et al., 2020). The EM system was also capable of enumerating seabirds to the species level during scan counts, which was similarly achieved in some previous EM trials (McElderry et al., 2011; Piasente et al., 2012) but not others (McElderry et al., 2004, 2011), and the environmental factors Beaufort wind force scale and cloud cover. All sets were made during the daytime. Nighttime setting might prevent the EM analyst from consistently or accurately collecting some of these variables (Ames et al., 2005; Piasente et al., 2012). During night, seabird scan count estimates might be more accurate when using thermal or infrared night-vision cameras (Gilman et al. 2019). We explored but determined it was not feasible for the EM analyst to accurately estimate the relative hue, value and chroma of bait due to variable lighting conditions. Hue refers to the type of color, chroma the strength or colorfulness, and value or luminance the brightness (Zeileis et al., 2019). It was also not feasible for the EM analyst to estimate the duration that baits soaked in blue dye prior to setting due to the camera field of view not covering the area of the deck where crew dye baits. After the project was finished, the bullet cameras (GV-ABL8712) used to record the stern of the vessel were severely corroded. Future projects should stick to a dome camera with similar image capabilities

3.3.5. Conclusions and research priorities

Consistent with findings from tori line experiments in other pelagic longline fisheries (Yokota et al., 2011; Melvin et al., 2013, 2014; Pierre et al., 2016; Domingo et al., 2017; Sato et al., 2012, 2013, 2016; Katsumata et al., 2019; Jiminez et al., 2020), as well as two previous studies in the Hawaii longline fishery (McNamara et al. 1999, Boggs 2001), the findings from this study indicate that a short streamer tori line significantly reduces the risk of albatross interactions in the Hawaii deep-set longline fishery. Findings also suggest that discharging offal and spent bait during setting might exacerbate and not mitigate seabird catch risk. However, it is unclear if crew discharged offal and bait in response to periods with high bird interactions, or if the high bird interactions was a result of the discharging. This is a research priority. The study also determined that, in this fishery, a 50 m-long tori line aerial section protects close to 100% of the area where seabird interactions are most likely to occur. With over half of observed interactions occurring within 10 m of the vessel stern, this highlights the importance of protecting bait hooks in this area. Modifications to the tori line design trialed in this study by adding streamers and using longer streamers close to the vessel stern could improve the tori line's seabird bycatch mitigation efficacy, but could reduce practicality. Furthermore, alternative colors and materials for the streamers might increase seabird mitigation efficacy (Delord et al., 2005). The EM system was employed to collect data for the experiment, demonstrating the capability of EM to collect several data fields of some conventional human observer program that significantly explain seabird catch risk in pelagic longline fisheries (Emery et al., 2018; Gilman et al., 2019). Findings contribute to informing revision of seabird mitigation measures required in the Hawaii deep-set longline fishery to curb the recent increase in the rate and magnitude of seabird captures, expand the body of literature on tori line efficacy in longline fisheries and highlight the potential for EM systems to be used to monitoring variables that significantly explain seabird bycatch risk in longline fisheries.

4. RECOMMENDATIONS FOR TORI LINE MINIMUM STANDARDS FOR THE HAWAII DEEP-SET LONGLINE FISHERY

Tori line designs tested in Phases 1 and 2 of this project were based on experiences in similar fisheries (Katsumata et al. 2015, 2015, 2018, and 2019; Goad 2017; Pierre et al. 2016; Sato et al. 2012; Melvin et al. 2013), expert advice, and existing international standards and guidelines. The short streamer design with 50 m aerial section selected for Phase 2 meets existing specifications under the two RFMOs applicable to the Hawaii deep-set longline fishery, the WCPFC and IATTC (Table 12).

Under the current WCPFC measure (WCPFC, 2018), when fishing north of 23° N., vessels of all sizes can use a long streamer tori line design that meets the following specifications:

- Minimum length: 100 m
- Must be attached to the vessel such that it is suspended from a point a minimum of 5m above the water at the stern on the windward side of the point where the hookline enters the water
- Must be attached so that the aerial extent is maintained over the sinking baited hooks
- Streamers must be less than 5m apart, be using swivels and long enough so that they are as close to the water as possible
- If two (i.e. paired) tori lines are used, the two lines must be deployed on opposing sides of the main line [sic]

Otherwise, vessels can opt to use a short streamer tori line design. For vessels ≥ 24 m total length, the short streamer design specifications are:

- Must be attached to the vessel such that it is suspended from a point a minimum of 5m above the water at the stern on the windward side of a point where the hookline enters the water
- Must be attached so that the aerial extent is maintained over the sinking baited hooks
- Streamers must be less than 1m apart and be 30 cm minimum length
- If two (i.e., paired) tori lines are used, the two lines must be deployed on opposing sides of the main line

And for vessels < 24 m total length, the short streamer design specifications are:

- Must be attached to the vessel such that it is suspended from a point a minimum of 5m above the water at the stern on the windward side of a point where the hookline enters the water
- Must be attached so that the aerial extent is maintained over the sinking baited hooks
- If streamers are used, it is encouraged to use the streamers designed to be less than 1m apart and be 30cm minimum length
- If two (i.e., paired) tori lines are used, the two lines must be deployed on opposing sides of the mainline.

Under the current IATTC measure (IATTC, 2011), when fishing north of 23° N., plus the area bounded by the coastline at 2°N, west to 20°N-95°W, south to 15°S-95°W, east to 15°S-85°W, vessels ≤ 20 m length overall are not required to employ seabird bycatch mitigation measures. Vessels > 20 m length overall can use tori line design that meets all of the WCPFC long streamer design, plus one additional specification of: "If the tori line is less than 150 m in length, must have a towed object attached to the end so that the aerial extent is maintained over the sinking baited hooks." Otherwise, vessels > 20 m length overall can use a 'light streamer' tori line design with the following specifications:

- Minimum length of tori line: 100 m or three times the total length of the vessel
- Must be attached to the vessel such that it is suspended from a point a minimum of 5 m above the water at the stern on the windward side of a point where the hookline enters the water
- Must be attached so that the aerial extent is maintained over the sinking baited hooks
- Streamers must be less than 1m apart and be 30 cm in minimum length

- If two (i.e. paired) tori lines are used, the two lines must be deployed on opposing sides of the main line

Table 12. Tori line standards when fishing north of 23° N under seabird measures of IATTC (2012) and WCPFC (2018).

	WCPFC			IATTC	
	Long Streamer	**Short Streamer (large vessels)**	**Short Streamer (small vessels)**	**Long Streamer**	**Light Streamer**
Required	No	No	No	No	No
Vessel size	Any size	≥24 m	<24 m	>20 m	>20 m
Minimum length	100 m	n/a	n/a	100 m	100 m or 3x the total length of the vessel
Attachment point	5 m above water at stern on windward side of where hookline enters water			5 m above water at stern on windward side of where hookline enters water	
Minimum Aerial Extent	Over sinking baited hooks			Over sinking baited hooks	
Streamer length	Long enough to be as close to the water as possible	30 cm minimum length	Optional: if used, 30 cm minimum length encouraged	Long enough to be as close to the water as possible	30 cm minimum length
Minimum Streamer Distance	< 5 m apart	< 1 m apart	Optional: if used, <1 m apart encouraged	< 5 m apart	< 1 m apart
Towed Object Required	No	No	No	If tori line is <150 m in length	No
Two tori lines	Optional: If used, must be deployed on opposing sides of mainline			Optional: If used, must be deployed on opposing sides of mainline	
Swivels required	Yes	No	No	Yes	No

Minimum tori line standards for the Hawaii deep-set fishery would need to be consistent with the two RFMO measures if tori line is used as one of the measures to meet international compliance. See WPRFMC (2019), *Considerations for Developing Draft Minimum Standards for Tori Lines in the Hawaii Longline Fishery*, for summaries of tori line measures of other tuna RFMOs, the CCAMLR (for demersal longline), national measures, and the Agreement on the Conservation of Albatrosses and Petrels. Additional considerations of relevance to the Hawaii longline fisheries are discussed in WPRFMC (2019). A subset of these previously identified considerations that could inform Hawaii tori line specifications based on this project's experiences are described here.

Tori Line Length

The tori line should have an aerial extent that covers a distance astern where baited hooks are accessible to Laysan and black-footed albatrosses. A theoretical estimate of this distance for the deep-set fishery is 28 m astern (see Section 3.3.3 for details). Observations from the EM analyst during the Phase 2 experiment were that: (a) the 50 m aerial section (which translates into 49.7 m of horizontal distance covered when the tori line is attached at 5 m height at vessel stern) covered 99.7% of the observed distances astern of attempts and contacts by Laysan and black-footed albatrosses; and (b) over half of seabird interactions occurred within 10 m of the stern. With only 0.3% of interactions occurring beyond 50 m of the vessel stern, there would be limited conservation gain from tori lines with aerial coverage longer than the design used in the experiment.

The total length of the tori line is a function of the aerial section length and design, which in turn determine the length of the drag section (see Section 2). Specifying minimum total length in addition to aerial section length could aid in assessing compliance through dockside assessment. Minimum aerial section length could also be assessed by EM systems, for example, if two stern-facing cameras are used, or if identification marks are added to the tori line backbone at specified distances astern (e.g., see Ames et al., 2005; Piasente et al., 2012; Pierre, 2018).

The 105 m long tori line used in the Phase 2 experiment (50 m aerial section with a 55 m Blue Steel braided rope drag section) would comply with the minimum length specification under the IATTC, which requires that the total length either be 100m or three times the vessel length. Vessels operating under the Hawaii longline limited entry permit have a maximum length of 101ft (30.8 m), such that a 90 m minimum total length could ensure consistency with international measures.

Height of tori line attachment point to vessel

For this project, tori lines were attached to a pole located near the vessel stern with an attachment point at 5m above the sea surface. This configuration worked well for maintaining the desired aerial extent and is consistent with WCPFC and IATTC specifications. Because tori poles or other structures to attach the tori line to the vessel may be located forward from the vessel stern, specifying the minimum height of the tori line at the stern would not be feasible to assess dockside. However, assuming that the tori line is mounted to the vessel close to the vessel stern, if the height above the sea surface at the point of the tori line attachment to the vessel is at least 5 m, then the height of the tori line at the stern will be only slightly shorter and not likely affect the length of the aerial portion of the tori line. Minimum standards could specify that if the tori line is attached within, for example, 2 m of the vessel stern, then the height of the tori line at the point of attachment to the pole must be at least 5 m above the sea surface, otherwise, if the point of attachment is > 2 m from the stern, then the point of attachment to the tori pole must be 5.5-6 m above the sea surface.

Specifications for Streamers

Tori line design used in Phase 2 had two 50cm streamers attached every 1 meter, consistent with WCPFC and IATTC specifications that call for streamers to be less than 1m apart and be 30 cm in minimum length. The Phase 2 tori line design attached the first streamer within 2.5 m of the attachment point. Findings from the experiment were that > 30% of seabird interactions occurred within 5 m of the stern. Using longer streamers on the aerial section of the tori line close to the vessel stern might also increase the seabird deterrence efficacy of the tori line. However, due to longer streamers affecting the overall tori line weight, additional design improvements should take into consideration fishermen preferences for ease of use. As the short streamer design was effective at reducing interactions, a minimum standard with short streamer specifications consistent with WCPFC and IATTC would be sufficient.

Tori line placement on windward side of a point where the hookline enters the water, maintained over the sinking baited hooks

These two specifications are part of the WCPFC and IATTC measures. Specifying the placement of the tori line on the windward side of where hook enters the water, and the position of the tori line in relation to baited hooks, could be accomplished by making the tori line position to be adjustable to run along both the port and starboard side of the mainline depending on the wind direction in relation to the vessel's setting direction. Alternatively, if this is deemed to be too restrictive, as it does go beyond the minimum specifications of WCPFC and IATTC, then the tori line may be attached to a pole or an existing structure on the vessel in a static position so that the tori line would run along either the port or the starboard side of the mainline. For this project, tori pole placement was determined based on the side that crew threw the bait during setting operations (e.g., if bait were thrown on the port side, poles were installed between the location of the line shooter and the port rail so bait would be covered as it were dragged toward the mainline coming from the line shooter).

Type approval process

An alternative to specifying minimum standards for tori lines would be to establish a type approval process for tori lines that meet minimum performance standards. This approach may encourage innovation by fishermen by allowing use of their own tori line design after being evaluated through an established approval process. Once multiple tori line designs have been approved, fishermen would also have a choice of approved tori line designs. The approval process along with the performance standards for evaluation would need to be developed.

Other Considerations Not Recommended for Inclusion in Minimum Standards for the Hawaii Deep-set Longline Fishery

- **Materials**: Specifications for tori line materials would be suited for inclusion in design guidelines, which could include recommended materials that have been trialed and demonstrated to be practical and effective. While the use of towed objects at the end of the drag section has been found to increase entanglement risk with longline gear, we do not recommend prohibiting the use of towed objects. Design guidance based on the experience of this project include the following:
  - Aerial section should use material that is light-weight, does not absorb water, does not hold energy, and does not tangle easily. This project used ultra high molecular weight polyethylene, known as dyneema or spectra, but other similar materials may be available or become available in the future. Monofilament material should not be utilized for the aerial section due to sagging concerns thereby reducing aerial coverage, nor should monofilament be used for drag sections as substantially more material is needed to create the amount of necessary drag.
  - Drag section should use braided material that does not tangle easily, does not absorb water, material that floats, and have a design that minimizes chances of tangles.
  - Tori poles should be made of solid material that do not flex (marine grade stainless steel is recommended for safety and durability purposes). Specifically, fiberglass poles should not be utilized. Alternatively, tori lines can be attached to a sturdy fixed point on the vessel.
- **Breakaways**: Specifying the use of breakaways as part of the minimum standards/regulations is not recommended as it does not affect the efficacy of the design, but could be recommended as it improves the practicality of the design.
- **Extreme weather**: No exemption is recommended for extreme weather conditions where use of a tori line might be unsafe. Vessels could plan for this situation by having an alternative seabird bycatch mitigation method available to use if they determine that using the tori line would not be safe. During the Phase 2 trips, there were some sets in high wind/rough conditions where the fishers found the tori line used in the trials could be deployed safely.

5. REFERENCES

Abraham, E., Pierre, J., Middleton, D., Cleal, J., Walker, N. Waugh, S. 2009. Effectiveness of fish waste management strategies in reducing seabird attendance at a trawl vessel. Fish. Res. 95, 210–219

ACAP. 2019. ACAP Review and Best Practice Advice for Reducing the Impact of Pelagic Longline Fisheries on Seabirds. Agreement on the Conservation of Albatrosses and Petrels, Hobart, Australia.

Ames, R., Williams, G., Fitzgerald, S. 2005. *Using Digital Video Monitoring Systems in Fisheries: Application for Monitoring Compliance of Seabird Avoidance Devices and Seabird Mortality in Pacific Halibut Longline Fisheries*. NOAA Technical Memorandum NMFS-AFSC-152. Alaska Fisheries Science Center, National Marine Fisheries Service: Seattle.

Baldwin, S., Bauer, D., Stice, E., Rohde, P. 2011. Evaluating models for partially clustered designs. *Psychological Methods* 6: 149–165.

Bergh, M., Pikitch, E., Skalski, J., Wallace, J. 1990. The statistical design of comparative fishing experiments. *Fisheries Research* 9: 143-163.

BI and HBW. 2019. *Bird Species Distribution Maps of the World*. Version 2019.1. BirdLife International and Handbook of the Birds of the World, Cambridge, UK and Barcelona, Spain.

Boggs, C. 2001. Deterring albatrosses from contacting baits during swordfish longline sets. In: Melvin E, Parish J (eds). *Seabird Bycatch: Trends, Roadblocks and Solutions*. Anchorage: University of Alaska Sea Grant. pp. 79–94.

Brothers, N., Cooper, J., Lokkeborg. S. 1999. *The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation*. FAO Fisheries Circular 937. Rome: Food and Agriculture Organization of the United Nations.

Brothers, N., Gilman, E. 2006. *Technical Assistance for Hawaii-Based Pelagic Longline Vessels to Modify Deck Design and Fishing Practices to Side Set*. Pacific Islands Regional Office, National Marine Fisheries Service, Honolulu.

Bürkner, P. 2017. brms: An R Package for Bayesian multilevel models using Stan. *Journal of Statistical Software*.

Candlish, J, Teare M, Dimairo M, Flight L, Mandefield L, Walters S. 2018. Appropriate statistical methods for analysing partially nested randomised controlled trials with continuous outcomes: a simulation study. *BMC Medical Research Methodology* 18: 105.

Carpenter B, Gelman A, Hoffman M, Lee D, Goodrich B, Betancourt M, Brubaker M, Guo J, Li P, Riddell A. 2017. Stan: a probabilistic programming language. *Journal of Statistical Software* 76: 1-32.

CCAMLR. 2018. *Minimisation of the Incidental Mortality of Seabirds in the Course of Longline Fishing or Longline Fishing Research in the Convention Area*. Conservation Measure 25-02. Commission for the Conservation of Antarctic Marine Living Resources, Hobart, Australia.

CCSBT. 2020. Resolution to Align CCSBT's Ecological Related Species Measures with those of other Tuna RFMOs. Commission for the Conservation of Southern Bluefin Tuna, Hobart, Australia.

Cherel Y, Weimerskirch H, Duhamel G. Interactions between longline vessels and seabirds in Kreguelen waters and a method to reduce seabird mortality. Biol Conserv. 1996; 75: 63–70.

Chordata, 2019. *Open Source Electronic Monitoring for Commercial Fisheries*. Available online, https://pt.chrdta.com/em/ and https://bitbucket.org/fisherieselectronicmonitoring/, accessed 6 Sept. 2019. Chordata, Juneau, Alaska.

Congdon P. 2003. *Applied Bayesian Modelling*. Wiley and Sons Ltd, UK.

Davies, T., Jonsen, I. 2011. Identifying nonproportionality of fishery-independent survey data to estimate population trends and assess recovery potential for cusk (Brosme brosme). Canadian Journal of Fisheries and Aquatic Sciences 68: 413-425

Delord, K., Gasco, N., WEimerskirch, H., Barbraud, C. Micol, T. 2005. Seabird mortality in the Patagonian toothfish longline fishery around Crozet and Kerguelen Islands, 2001-2003. CCAMLR Science 12: 53-80.

Domingo, A., Jiménez, S., Abreu, M., Forselledo, R., Yates, O., 2017. Effectiveness of tori line use to reduce seabird bycatch in pelagic longline fishing. PLoS One 12, e0184465.

Dorai-Raj S. 2014. binom: Binomial confidence intervals for several parameterizations. R package version 1.1-1. https://CRAN.R-project.org/package=binom

Emery, T., et al. 2018. The use of electronic monitoring within tuna longline fisheries: Implications for international data collection, analysis and reporting. Reviews in Fish Biology and Fisheries 4: 887-907.

Fahrmeir L, Lang S. 2001. Bayesian inference for generalised additive mixed models based on Markov random field priors. *Applied Statistics* 50: 201-220.

Gabry J, Simpson D, Vehtari A, Betancourt M, Gelman A. 2019. Visualization in Bayesian workflow. *Journal of the Royal Society Series A* 182: 1-14.

Gelfand A, Schliep E .2016. Spatial statistics and Gaussian processes: a beautiful marriage. Spatial Statistics 18 (Part A): 86-104

Gelman A, Hill J. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, New York, USA

Gelman A, Hwang J, Vehtari A. 2014. Understanding predictive information criteria for Bayesian models. Statistics and Computing 24: 997–1016

Geovision. 2019. GV-ABL8712. 8MP H.265 4.3x Zoom Super Low Lux WDR Pro IR Bullet IP Camera. Available online, http://www.geovision.com.tw/product/GV-ABL8712, accessed 4 Sept. 2019. GeoVision, Taipei.

Gilman, E., Beverly, S., Musyl, M., Chaloupka, M. 2020a. Commercial viability of alternative designs placing pelagic longline branchline weights at the hook to reduce seabird bycatch . *Endangered Species Research* 43: 223-233

Gilman, E., Boggs, C., Brothers, N. 2003. Performance assessment of an underwater setting chute to mitigate seabird bycatch in the Hawaii pelagic longline tuna fishery. *Ocean and Coastal Management* 46: 985-1010.

Gilman, E., N. Brothers, D. Kobayashi. 2005. Principles and approaches to abate seabird bycatch in longline fisheries. *Fish and Fisheries* 6: 35-49.

Gilman, E., Castejon, V.D.R., Loganimoce, E., Chaloupka, M. 2020. Capability of a pilot fisheries electronic monitoring system to meet scientific and compliance monitoring objectives. *Marine Policy* 113: https://doi.org/10.1016/j.marpol.2019.103792

Gilman E, Chaloupka M, Fitchett M, Cantrell D, Merrifield M. 2020b. Ecological responses to blue water MPAs. PLoS ONE 15(7): e0235129. https://doi.org/10.1371/journal. pone.0235129

Gilman E, Chaloupka M, Musyl M. 2018. Effects of pelagic longline hook size on species- and size-selectivity and survival. Reviews in Fish Biology and Fisheries 28: 417–433

Gilman, E., Chaloupka, M., Peschon, J., Ellgen, S. 2016. Risk factors for seabird bycatch in a pelagic longline tuna fishery. *PLoS ONE* 11(5): e0155477. doi:10.1371/journal.pone.0155477.

Gilman, E., Chaloupka, M., Wiedoff, B., Willson, J. 2014. Mitigating seabird bycatch during hauling by pelagic longline vessels. *PLOS ONE* 9(1): e84499. doi:10.1371/journal.pone.0084499

Gilman, E., Clarke, S. 2015. *Changes to WCPFC Longline Observer Bycatch Data: Proposals in Response to a Minimum Suite of Harmonized Fields for Tuna RFMOs*. EB-IP-05. Available online, https://www.wcpfc.int/node/21730, accessed 1 July 2018. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Gilman E, De Ramón Castejón V, Loganimoce E, Chaloupka M. 2020a. Capability of a pilot fisheries electronic monitoring system to meet scientific and compliance monitoring objectives. Marine Policy 113: 103792

Gilman, E., Hall, M. 2015. *Potentially Significant Variables Explaining Bycatch and Survival Rates and Alternative Data Collection Protocols to Harmonize Tuna RFMOs' Pelagic Longline Observer Programmes*. Appendix 1 to WCPFC-SC11-2015/EB-IP-05. Western and Central Pacific Fisheries Commission, Kolonia, Pohnpei, Federated States of Micronesia.

Gilman, E., Ishizaki, A. (Eds.). 2018. *Report of the Workshop to Review Seabird Bycatch Mitigation Measures for Hawaii's Pelagic Longline Fisheries.* ISBN: 978-1-944827-37-3. Western Pacific Regional Fishery Management Council, Honolulu.

Gilman E, Kobayashi D, Chaloupka M. 2008. Reducing seabird bycatch in the Hawaii longline tuna fishery. *Endanger Species Res.* 5: 309–323.

Gilman, E., Legorburu, G., Fedoruk, A., Heberer, C., Zimring, M., Barkai, A. 2019. Increasing the functionalities and accuracy of fisheries electronic monitoring systems. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29: 901-926.

Goad, D. 2017. Tori Line Designs for Small Longline Vessels. New Zealand Department of Conservation, Wellington.

Goad, D., Debski, I.2017. Tori Line Designs and Specifications for Small Pelagic Longline Vessels. WCPFC-SC13-2017/EB-WP-08 Rev 1. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Hall M, Alverson D, Metuzal K. 2000. By-catch: problems and solutions. *Mar Pollut Bull* 41: 204-219.

Hall M, Gilman E, Minami H, Mituhasi T, Carruthers E. 2017. Mitigating bycatch in tuna fisheries. Rev Fish Biol Fisher 27:881–908

IATTC. 2012. Resolution to Mitigate the Impact on Seabirds of Fishing for Species Covered by the IATTC. Resolution C-11-02. Inter-American Tropical Tuna Commission, La Jolla, USA.

ICCAT. 2011. Supplemental Recommendation by ICCAT on Reducing Incidental By-catch of Seabirds in ICCAT Longline Fishery. Recommendation 11-09. International Commission for the Conservation of Atlantic Tunas, Madrid.

IOTC. 2012. Resolution 12/06 on Reducing the Incidental Bycatch of Seabirds in Longline Fisheries. Resolution 12/06. Indian Ocean Tuna Commission, Mahe, Seychelles.

ISSF. 2015. *Report of the Tuna RFMO Expert Working Group: Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs. 27-29 January 2015, Keelung, Taiwan*. ISSF Technical Report 2015-08. International Seafood Sustainability Foundation, Washington, D.C.

Japan Ministry of Agriculture, Forestry and Fisheries. 2008. Restrictions of Fishing Gear Specified by the Minister of Agriculture, Forestry, and Fisheries, Pursuant to the Provisions of Article 20-2 of the Ministerial Ordinance Regulating Specific Fisheries Permitted by the Minister. Minister of Agriculture, Forestry, and Fisheries Public Notice No.1193, July 25, 2008. (In Japanese). Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan.

Jensen S, Schaarschmidt F, Onofri A, Ritz C. 2018. Experimental design matters for statistical analysis: how to handle blocking. Pest Management Science 74: 523-534

Jiminez S, Domingo A, Abreu M, Brazeiro A. 2012. Bycatch susceptibility in pelagic longline fisheries: are albatrosses affected by the diving behaviour of medium-sized petrels? Aquat Conserv 22:436-445

Jiminez, S., Domingo, A., Winder, H., Parker, D., Gianuca, D., Neves, T., Coelho, R., Kerwath, S. 2020. Towards mitigation of seabird bycatch: Large-scale effectiveness of night setting and tori lines across multiple pelagic longline fleets. Biological Conservation 247: 108642.

Kammann E, Wand M. 2003. Geoadditive models. Applied Statistics 52: 1-18

Katsumata N, Ochi D, Matsunaga H, Inoue Y, Minami H. 2015. At-sea experiment to develop the mitigation measures of seabirds for small longline vessels in the western North Pacific. WCPFC-SC11-2015/EB-WP-10. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Katsumata N, Okamoto K, Ochi D, Inoue Y, Matsunaga H, Minami H, Oshima K. 2016. Examination of effectiveness of seabird bycatch mitigation measures for small-scale longline vessels fishing north of 23oN specified in CMM 2015-03. WCPFC-SC12-2016/EB-WP-13. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Katsumata N, Okamoto K, Ochi D, Inoue Y. 2018. Trials of extension of horizontal aerial extent of tori line for the Japanese small longliners operating in the Northwest Pacific Ocean. WCPFC-SC14-2018/EB-IP-13. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Katsumata N, Okamoto K, Oshima K, Ochi D. 2019. Research Update about the Effective Design of Tori-line for Japanese Small-scale Fleet in the North Pacific. WCPFC-SC15-2019/EB-WP-06. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Kay M. 2020a. tidybayes: tidy data and geoms for Bayesian models. R package version 2.1.1. doi: 10.5281/zenodo.1308151

Kay M. 2020b. ggdist: Visualizations of distributions and uncertainty. R package version 2.3.0, URL: https://mjskay.github.io/ggdist/

Kelter R. 2020. Analysis of Bayesian posterior significance and effect size indices for the two-sample t-test to support reproducible medical research. BMC Medical Research Methodology 20: 88. https://doi.org/10.1186/s12874-020-00968-2

Kezama, K., Harada, T., Deguchi, T., Suzuki, H., Watanuki, Y. 2019. Foraging behavior of black-footed albatross *Phoebastria nigripes* rearing chicks on the Ogasawara Islands. Ornithological Science 18: 27-37.

Kruschke J, Liddell T (2018) The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. Psychonomic Bulletin & Review 25: 178–206

Lemoine N. 2019. Moving beyond noninformative priors: why and how to choose weakly informative priors in Bayesian analyses. Oikos 128: 912-928
Lenth R. 2016. Least-squares means: the R package lsmeans. Journal of Statistical Software 69:1–33
Lenth R. 2020. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.5.2-1. https://CRAN.R-project.org/package=emmeans
Makowski D, Ben-Shachar M, Lüdecke D. 2019. bayestestR: Describing effects and their uncertainty, existence and significance within the Bayesian framework. Journal of Open Source Software 4(40): 1541. https://doi.org/10.21105/joss.01541
McElderry, H., Beck, M., Pria, M., Anderson, S. 2011. Electronic monitoring in the New Zealand inshore trawl fishery: A pilot study. DOC Marine Conservation Services Series 9. Department of Conservation, Wellington
McElderry, H., Schrader, J., McCullough, D., Illingworth, J., Fitzgerald, S., & Davis, S. 2004. *Electronic monitoring of seabird interactions with trawl third-wire cables on trawl vessels—a pilot study*. NOAA Technical Memorandum NMFS-AFSC-147. Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle.
McNamara, B., Torre, L., Kaaialii, G. 1999. *Hawaii Longline Seabird Mortality Mitigation Project*. Western Pacific Regional Fishery Management Council, Honolulu.
Melvin, E.F., Guy, T.J., Read, L.B., 2013. Reducing seabird bycatch in the South African joint venture tuna fishery using bird-scaring lines, branch line weighting and nighttime setting of hooks. Fish. Res. 147, 72–82.
Melvin, E., Guy, T., Read, L. 2014. Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. Fisheries Research 149: 5-18.
New Zealand Ministry for Primary Industries. 2018. Fisheries (Seabird Mitigation Measures—Surface Longlines) Circular 2018. Ministry for Primary Industries, Wellington.
NMFS. 2020. *Seabird Interactions and Mitigation Efforts in Hawaii Longline Fisheries*. *2018 Annual Report.* Pacific Islands Regional Office, National Marine Fisheries Service, Honolulu.
NMFS. 2017. Hawaii Longline Observer Program Field Manual. Version LM.17.02. Pacific Islands Regional Office, National Marine Fisheries Service, Honolulu.
NMFS. 2005. Fisheries off west coast states and in the western Pacific; pelagic fisheries; additional measures to reduce the incidental catch of seabirds in the Hawaii pelagic longline fishery. US National Marine Fisheries Service. Federal Register 70: 75075–75080.
Pedersen T. 2020. patchwork: The Composer of Plots. R package version 1.1.0. https://CRAN.R-project.org/package=patchwork.
Piasente, M., Stanley, B., Timmiss, T., McElderry, H., Pria, M., & Dyas, M. 2012. *Electronic onboard monitoring pilot project for the eastern tuna and billfish fishery*. FRDC Project 2009/048. ST-IP-05. Kolonia, Federated States of Micronesia: Western and Central Pacific Fisheries Commission.
Pierre, J. 2018. *Using electronic monitoring imagery to characterize protected species interactions with commercial fisheries: A primer and review*. Lower Hutt, New Zealand: JPEC Ltd
Pierre, J., Abraham, E., Middleton, D., Cleal, J., Bird, R., Walker, N., Waugh, S. 2010. Reducing interactions between seabirds and fisheries: responses to foraging patches provided by fish waste batches. *Biol. Conserv*. 143: 2779–2788.
Pierre, J., Abraham, E., Richard, Y., Cleal, J., Middleton, D. 2012. Controlling trawler waste discharge to reduce seabird mortality. *Fisheries Research* 131: 30-38.
Pierre JP, Goad D, Debski I. 2016. Developing Tori Lines for New Zealand's Small-vessel Longline Fisheries. ACAP-SBWG7-Inf08. Agreement on the Conservation of Albatrosses and Petrels, Hobart.
Sato N, Ochi D, Minami H, Yokawa K. 2012. Evaluation of the Effectiveness of Light Streamer Tori-Lines and Characteristics of Bait Attacks by Seabirds in the Western North Pacific. *PLoS ONE* 7:e37546.
Sato, N., Minami, H., Katsumata, N., Ochi, D., Yokawa, K., 2013. Comparison of the effectiveness of paired and single tori lines for preventing bait attacks by seabirds and their bycatch in pelagic longline fisheries. *Fish. Res*. 140: 14–19.
Sato, N., Katsumata, N., Yokota, K., Uehara, T., Fusejima, I., Minami, H., 2016. Tori-lines with weighted branch lines reduce seabird bycatch in eastern South Pacific longline fishery. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* 26: 95–107.
Searle, S., Speed, F., Milliken, G .1980. Population marginal means in the linear model: An alternative to least squares means. *The American Statistician* 34: 216-221

South Africa Department of Agriculture, Forestry and Fisheries. 2019. *Section B. Permit Conditions: Large Pelagic Longline Fishery. Fishing Season: 2019/2020*. Department of Agriculture, Forestry and Fisheries, Pretoria.

Tuyl F, Gerlach R, Mengersen K. 2008. Comparison of Bayes-Laplace, Jeffreys, and other priors: the case of zero events. *The American Statistician* 62: 40-44.

Uruguay Direccion Nacional de Recursos Acuqticos. 2015. *Revision de Planes de Accion Nacional para la conservacion de Aves Marinas y Condrictios en las Pesquerias Uruguayas*. Direccion Nacional de Recursos Acuqticos, Ministerio de Ganaderia Agricultura y Pesca, Montevideo.

Van Fossen L. 2007. *Annual Report on Seabird Interactions and Mitigation Efforts in the Hawaii Longline Fishery for 2006*. Honolulu: National Marine Fisheries Service, Pacific Islands Regional Office.

Vehtari A, Gelman A, Gabry J. 2017. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing* 27: 1413–1432

Véran S, Gimenez O, Flint E, Kendall WL, Doherty P, Lebreton J. 2007. Quantifying the impact of longline fisheries on adult survival in the black-footed albatross. *J Appl Ecol.* 44: 942–952.

WCPFC. 2018. *Conservation and Management Measure to Mitigate the Impact of Fishing for Highly Migratory Fish Stocks on Seabirds*. CMM 2018-03. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Wickham H. 2016. *ggplot2: Elegant Graphics for Data Analysis*. 2nd Edition. Springer-Verlag, New York, USA.

Wood S. 2006. *Generalized Additive Models: An Introduction with R*. Chapman and Hall/CRC, Boca Raton.

WPRFMC. 2018. Appendix 5. Fact Sheets on Seabird Bycatch Mitigation Methods for Pelagic Longline Fisheries. IN: Gilman, E., Ishizaki, A. (Eds.). *Report of the Workshop to Review Seabird Bycatch Mitigation Measures for Hawaii's Pelagic Longline Fisheries.* ISBN: 978-1-944827-37-3. Western Pacific Regional Fishery Management Council, Honolulu.

WPRFMC. 2019. *Considerations for Developing Draft Minimum Standards for Tori Lines in the Hawaii Longline Fishery*. Western Pacific Regional Fishery Management Council, Honolulu.

WPRFMC. 2020. *Annual Stock Assessment and Fishery Evaluation Report for U.S. Pacific Island Pelagic Fisheries Ecosystem Plan 2019*. http://www.wpcouncil.org/wp-content/uploads/2020/10/Pelagic-FEP-SAFE-Report-2019-Final-v10.1.pdf. Western Pacific Regional Fishery Management Council, Honolulu.

Wren, J., Shaffer, S., Polovina, J. 2019. Variations in black-footed albatross sightings in a North Pacific transitional area due to changes in fleet dynamics and oceanography 2006–2017. *Deep Sea Research Part II: Topical Studies in Oceanography* 169: 104605.

Yao Y, Vehtari A, Simpson D, Gelman A. 2018. Using stacking to average Bayesian predictive distributions. *Bayesian Analysis* 13: 917–1003

Yokota K, Minami H, Kiyota M. 2011. Effectiveness of tori-lines for further reduction of incidental catch of seabirds in pelagic longline fisheries. *Fisheries Science* 77:479–485.

Zeileis, A., Fisher, J., Hornik, K., Ihaka, R., McWhite, C., Murrell, P., Stauffer, R., Wilke, C. 2020. colorspace: A toolbox for manipulating and assessing colors and palettes. *Journal of Statistical Software* 96: 1-49.