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Tori line experiments on Taiwanese tuna longline fishing vessels in the North Pacific Ocean

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Abstract

Many seabird species are facing a significant threat from the bycatch associated with longline fisheries. To mitigate this issue, bird-scaring lines, also known as tori lines, are commonly employed on tuna longline vessels to minimize seabird bycatch. While numerous tuna regional fisheries management organizations (RFMOs) have imposed regulations requiring the use of tori lines that adhere to specific specifications, no research has been conducted to assess the suitability of such regulations for Taiwanese tuna longline vessels. In order to address this knowledge gap, our study aimed to conduct experiments on three large vessels in the North Pacific Ocean to evaluate the effectiveness of internationally standardized tori lines in comparison to the lines made by the captains on these vessels. The results indicated that the seabird bycatch per unit effort ranged from 0.07 to 0.63 birds per 1000 hooks per vessel. Using zero-inflated generalized linear mixed models, we identified that the probability of seabird bycatch increased in higher latitudes, while the bycatch rate was higher when using tori lines with the international standard than in the tori line made by the captains. This discrepancy may be attributed to the standard tori lines broke more frequently during the experiment. Based on the findings, we recommend the adoption of "O-Kuan" as the material for the main rope of the tori line, which is the same material used for the main fishing rope on Taiwanese vessels. Additionally, we suggest retaining the dragging part of the line while reducing the total length of the tori line. Furthermore, we conducted measurements on the sinking rates of the hooks for the three experimental vessels, which ranged from 0.19 to 0.43 m/s. Conducting further research to explore the sinking rate, while utilizing toriline to prevent seabird bycatch, would be valuable in establishing effective seabird mitigation practices for Taiwanese longline vessels.

1. Introduction

Among the 378 species of seabirds (waterbirds) recorded as bycatch in fisheries, 228 species (60%) interact with at least one type of fishing gear (Pott and Wiedenfeld 2017). An estimate has suggested that about 160,000 seabirds die each year due to bycatch in longline fishing (Anderson et al. 2011). Albatrosses are one of the most threatened groups of birds affected by longline bycatch, with 15 of 22 species threatened with extinction. The bycatch rate of seabirds is influenced by various factors, including location, species biology, season, and mitigation measures. In particular, tori line (bird-scaring lines), night setting, and weighted branch line are considered the most effective and commonly-used seabird mitigation measures for tuna longline fisheries.

As one of the major fleets in the high seas, Taiwan's longline fishery overlaps with the distribution of many albatross and petrel species. Previous research has indicated the seabird bycatch rate of Taiwanese vessels ranged from 0.01-0.048 birds/1000 hooks in 2004-2008, when mitigation measures were not mandated to be used. Considering the wide-range impacts of the fishery to seabird populations, it is essential to understand bycatch rates and factors to improve bycatch mitigation measures in this fleet for tackling seabird bycatch globally.

The Fisheries Agency of Taiwan has been actively promoting seabird mitigation measures to the tuna longline fleet, but many fishers have raised concerns about the current tori lines' weight, entanglement risk, and difficulty in deployment during rough conditions. Following a decision made in the first 'Mitigation of Seabird Bycatch Workshop' in Kaohsiung, Taiwan, Port Based Outreaches (PBO) were conducted in Mauritius in 2016 and 2018. The PBO provided Taiwanese longline skippers with information on seabird bycatch mitigation measures. During the PBOs, skippers provided valuable feedback about different mitigation methods, particularly for tori lines. This feedback subsequently led to an international tori line workshop, held in Kaohsiung in April 2019. The workshop focused on improving streamer materials, tori pole height, and overall tori line usage to align with ACAP's best practices. Fishers presented their hand-made tori lines and discussed the effectiveness of available options. One question raised from the workshop: what is the best design of tori line for Taiwanese tuna longline vessels?

Therefore, the aim of this study is to compare the performance of the tori lines made by the skippers on Taiwanese pelagic longline vessels and the tori line design recommended internationally. Additionally, we seek to gain insights into the perspectives of the tori line users and identify opportunities for improving the tori lines currently used. This project is a collaboration between Taiwan's Fishery Agency, Overseas Fisheries Development Council, the Taiwan Wild Bird Federation, the Royal Society for the Protection of Birds in the UK, and National Taiwan Ocean University.

2. Methods

The at sea trials were conducted on three Taiwanese large-scale vessels fishing in the North Pacific Ocean in 2021. We experimentally compared the performance of tori lines made by the vessel captains (termed "control" tori lines) against the international-standard tori line recommended by ACAP and tuna RFMOs (termed “experimental” tori line).

2.1 Fleet description

In 2021, there were about 872 longline vessels operating in the WCPFC Convention Area, including Taiwanese EEZ. The longline vessels are currently categorized by their tonnage as large-scale and small-scale tuna longliner. The large-scale tuna longliner mostly fish in the high seas. Those vessels usually set 3,000-4,000 hooks per set. For the large-scale tuna longliner fish at high latitude of north Pacific, they often target albacore tunas.

2.2 Experimental design

For the large-scale vessels (>35m in length), the experiment was conducted in area between 28°N-36°N and 160°E-178°E, in North Pacific, from December, 2021 to March, 2022 (Figure 1). Three vessels (BI2665, BI2196, and BI3275) conducted the experiment. Vessel BI2665 and BI2196 are both at size class CT7 (500-1000 tonnage), targeting albacore, and belonging to the same fishing company. BI3275 is at size class CT6 (200-500 tonnage), and also targets albacore. BI2665 conducted 25 sets of experiments for both experimental and control tori lines. It deployed only one tori line for each set. BI2196 conducted 30 sets of experiments with experimental line and 31 sets with control line. For the experimental sets, BI2196 deployed one experimental line and one control line. It deployed two control lines for the control sets. BI3275 conducted 6 sets of experiments with experimental lines and 25 sets with control lines. It only deployed one line for the experimental sets, but deployed two lines for the control sets. The control lines used on all three vessels were hand-made by the captains, all with bright wrapping paper streamers and the main rope made of O-kuan. Of BI2665 and BI2196, the control lines were at about 80-100m in length. Each streamer was about 1.2-2m, and there was 1m between each streamer. The control lines of BI3275 were 100m in length, with streamers at about 4.5m. The designs of tori lines used in this experiment are described below:

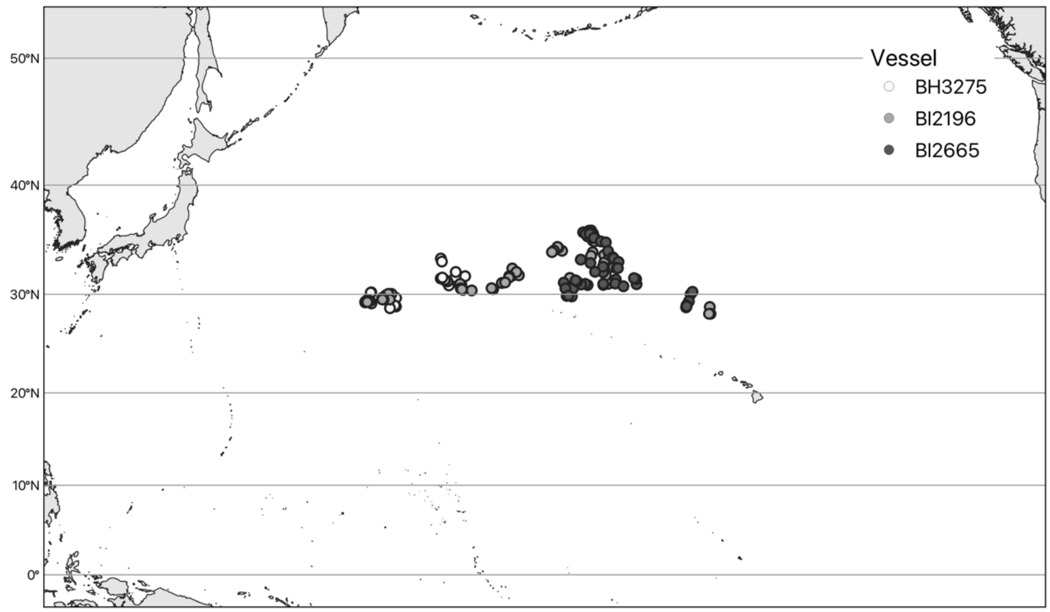

Figure 1. Locations of each vessel conducted the experiment. Each dot represents each set the experiment was carried out.

2.3 Tori Line Design: Experimental lines (International standard)

The design of tori line for large-scale vessels are followed the design in (Melvin et al. 2010, 2014) (Figure 2). The experimental tori line consists of three sections: an aerial section, a connection section and a drag section. These sections were connected with small un-weighted swivels (size 4/0; 2.5 g).

The tori line was 200m in length for large-scale vessels. The first long streamer pair was 10m from the stern of the vessel and long streamers will be placed every 5 meters to the 60m mark. These long streamer pairs will be made of a strong plastic canva and go in descending length (7m, 6.7m, 6.4m, 6.1m, 5.8m, 5.5m, 5.2m, 4.9m, 4.6m, 4.3m, 4.0m). Regardless of length, long streamers should be as close as possible to the water's surface without entering the water. Short streamers consisting of two 1m nylon/plastic ribbons (1.9 g/m) of different colors, were spliced at their midpoint to the backbone every 3 meters (the midpoint) between the long streamers. Then from the 60m mark, they were attached every 2 meters until the 90m mark. There was no streamers for the last 10m before the connection section. A white marker was placed every 25m to denote the length of the tori line and to allow the observer to know that the aerial extent is correct. The connection section (20m length) was made from monofilament (polyamide, 2.0mm) joined to the aerial section and to the drag section with unweighted swivels.

Finally, the drag section consisted of an 80m multifilament (polyethylene 4.0±6.0 mm) line with 0.8m packing straps placed every 0.35m (approx.) and tied at their midpoint to the line. This line was attached to the connection section with two swivels to prevent it from becoming twisted.

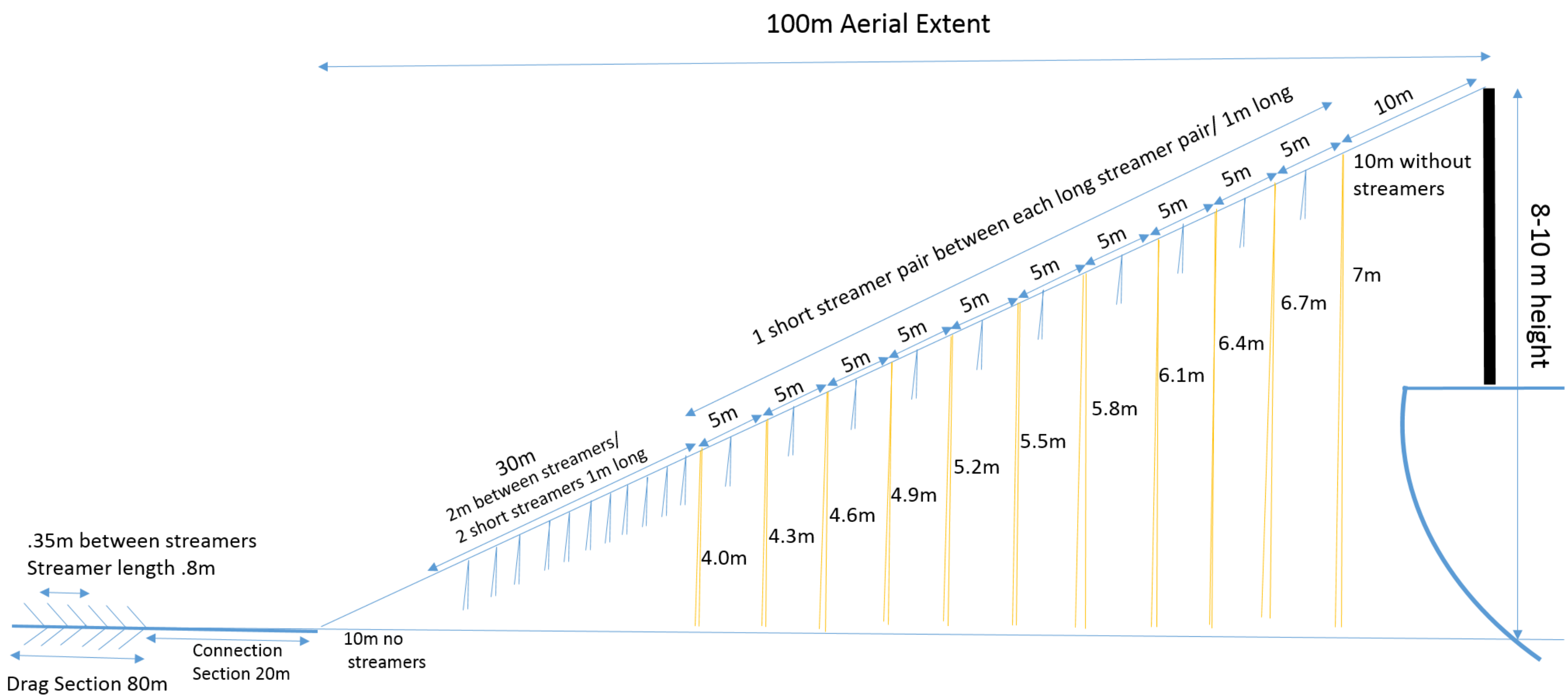

Figure 2. Experimental line design for large-scale vessels.

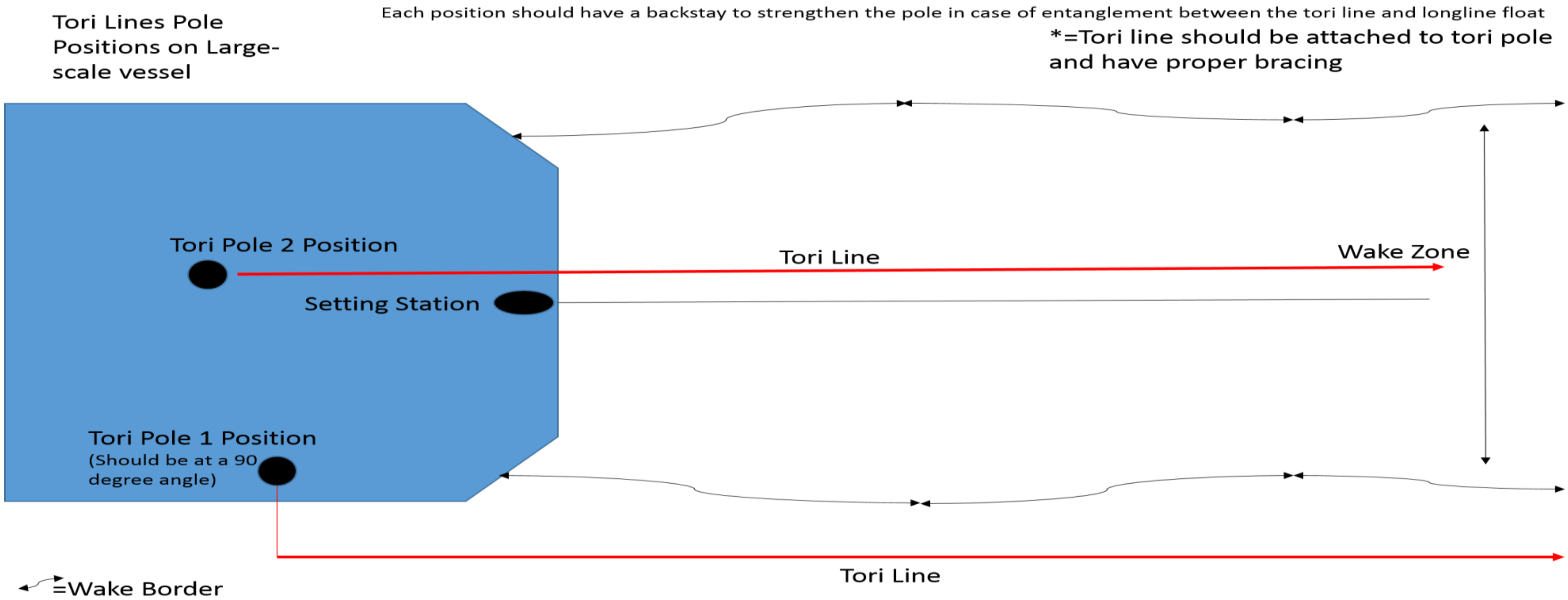

Figure 3. How tori line(s) should be placed in relation to tori poles for the vessels.

2.4 Tori Line Design: Control lines

We compared the international-standard tori lines to the lines made by the captain of each vessel. Prior to performing the experiment, the exact specifications of the on-board tori line was recorded.

2.5 Data collection

Data of this experiment were collected by on-board observers. For each set, the observers had to record the following information: vessel's name, vessel speed during setting, setting/hauling location and time, total number of hooks set, hooks observed, wind speed and direction, sea surface temperature, mitigation measures used, tori line aerial extent, distance of the first streamer from the stern, sighted seabird abundance (in 10 minutes), target fish catch, species and number of seabird bycatch.

Counts of seabirds were made over a 10-minute period during both the set and haul in a 250 m hemisphere centered on the stern of the vessel. During these abundance count, birds were recorded in number by species or the best taxonomy level the observer could identify.

2.5 Time-depth recorder (TDR) deployment

To determine if the aerial extent of the tori line is sufficient to protect baited hooks from seabird attack within the time needed for the hooks to reach 10m, we evaluated the sink rate of the hooks using time depth recorders (TDRs). We deployed TDRs on all of the three vessels. The TDRs were fixed to the branch line with tape 70 cm above the eye of the hook – approximately one turn of a branch line coil. The water entry time should be recorded for each TDR to the nearest second. Seconds to 2 m, 5 m, and 10 m depths were extracted from each data record and corrected to compensate for the weight of the TDR using the results of static sink rate tests. TDRs were then stored in a basket as they come onboard to be downloaded later.

However, one of the large-scale vessels conducting TDR deployment did not record the water entry time. For this vessel, we determined the water entry time assuming that the hooks started to sink at when the pressure started continuously increasing.

We identified that time point by looking for the longest positive first-difference values. We then fitted the recorded time (by second) and pressure (dbar, which is approximately 1m depth in the ocean) with local polynomial regression (LOWESS). Consequently, we predicted the seconds taken to reach 2m, 5m, and 10m with the fitted curve for each TDR.

2.6 Data Analysis

To test whether there is a significant effect of the tori line configuration on seabird bycatch, we fit a zero-inflated generalized linear mixed model (GLMM) with a two-level factorial variable for tori line configuration ('*TORI*') and assumed that there was a statistically significant difference between tori line configurations if the parameter estimate for this effect is different from zero. The model included the vessel as a random intercept to account for inherent differences among vessels. We tested several models in this study, with consideration of various covariates and zero-inflation models. Here we listed the three models that converged in the following code:

Model 1: glmmTMB(Nbirds~offset(Obs.Hooks) + Set_Str_Lat + TORI + (1|Vessel), ziformula = ~., family = nbinom2)

Model 2: glmmTMB(Nbirds~offset(Obs.Hooks) + Set_Str_Lat + NS + TORI + (1|Vessel), ziformula = ~. ,family = nbinom2)

Model 3: glmmTMB(Nbirds~offset(Obs.Hooks) + Sighting_Num + (1|Vessel), ziformula = ~0, family = nbinom2)

Whereas *Obs.Hooks* represent number of hooks observed, *Set_Str_Lat* is the latitude where setting started, *NS* is a dummy variable indicates night setting or not, *Sighting_Num* is the total number of seabird sightings of that set, *Vessel* represents different vessel. The GLMM was fitted in R (Version 4.0.5) using the 'glmmTMB' package.

In addition, we applied a generalized additive model to test if the number of seabird sightings correlated with the bycatch rate, assuming the bycatch data were from a negative binomial distribution. The model considered the number of sightings as fixed effect, and vessel as random effect. Number of hooks was offset in the model.

3. Results

3.1 Seabird sightings

For all three vessels, the most commonly seen species was Laysan Albatross (*Phoebastria immutabilis*, DIZ), followed by Black-footed Albatross (*Phoebastria nigripes*, DKN) (Table 1).

Table 1. Seabird sightings for the three large-scale vessels during experiments.

	Vessel	Laysan Albatross (**DIZ**)	Black-footed Albatross (**DKN**)	Other Petrels (**PRX**)	Other Procellariidae (**PTZ**)	Christmas Frigatebird (**FRC**)
Setting	BH3275	3040	935			
	BI2196	5264	1264	212	26	
	BI2665	5223	1094	71		4
	Total	13527	3293	283	26	4
		Laysan Albatross (**DIZ**)	Black-footed Albatross (**DKN**)	Other Petrels (**PRX**)	Other Procellariidae (**PTZ**)	Sulids (**SVZ**)
Hauling	BH3275	3,453	1,855			90
	BI2196	6,492	2,114	856	106	
	BI2665	7,867	2,045	366		
	Total	17,812	6,014	1,222	106	90

3.2 Seabird bycatch

Laysan Albatross was bycaught the most, followed by Black-footed Albatross. In general, there was more seabird bycatch with increasing latitude. The bycatch rate of each vessel was between 0.07-0.63 birds/1000 hooks (Table 2, Figure 4).

For the zero-inflated binominal model, the best model (with the smallest AIC = 823.7) considers latitude and tori line (experimental/control) as fixed effects and vessel as a random effect. Number of hooks was offset in the model. The model results indicate that the chance of catching seabirds significantly increased with latitude (Table 3). In addition, there was a significantly higher number of seabird bycatch, if the bycatch event happened, while using experimental tori line (Table 3). We also tested another model considering latitude, tori line, and night setting (1=night setting; 0=without night setting) as fixed effects and vessel as a random effect. The model produced a slightly larger AIC (826.2) than the best model. This model also showed that the probability of bycatching seabirds increased with latitude (Table 4). For the sets bycatching seabirds, sets with experimental tori line and night settings had a higher number of seabird bycatch (Table 4).

Table 2. Seabird bycatch of the three large-scale vessels during the experiment when using the control and experimental line, respectively. DIZ: Laysan Albatross; DKN: Black-footed Albatross. Bycatch per unit effort (BPUE) are calculated as the number of observed seabird bycatch per 1000 observed hooks.

		BH3275		BI2196		BI2665	
		Control	**Exp.**	**Control**	**Exp.**	**Control**	**Exp.**
(1)	**DIZ**	4	1	34	20	6	13
	DKN	0	0	5	2	0	1
	Total	4	1	39	22	6	14
(2)	**Obs. hooks**	61,072	14,718	62,352	63,986	56,004	55,680
	DIZ BPUE	0.07	0.07	0.55	0.31	0.11	0.23
	DKN BPUE	0.00	0.00	0.08	0.03	0.00	0.02
	Total BPUE	0.07	0.07	0.63	0.34	0.11	0.25

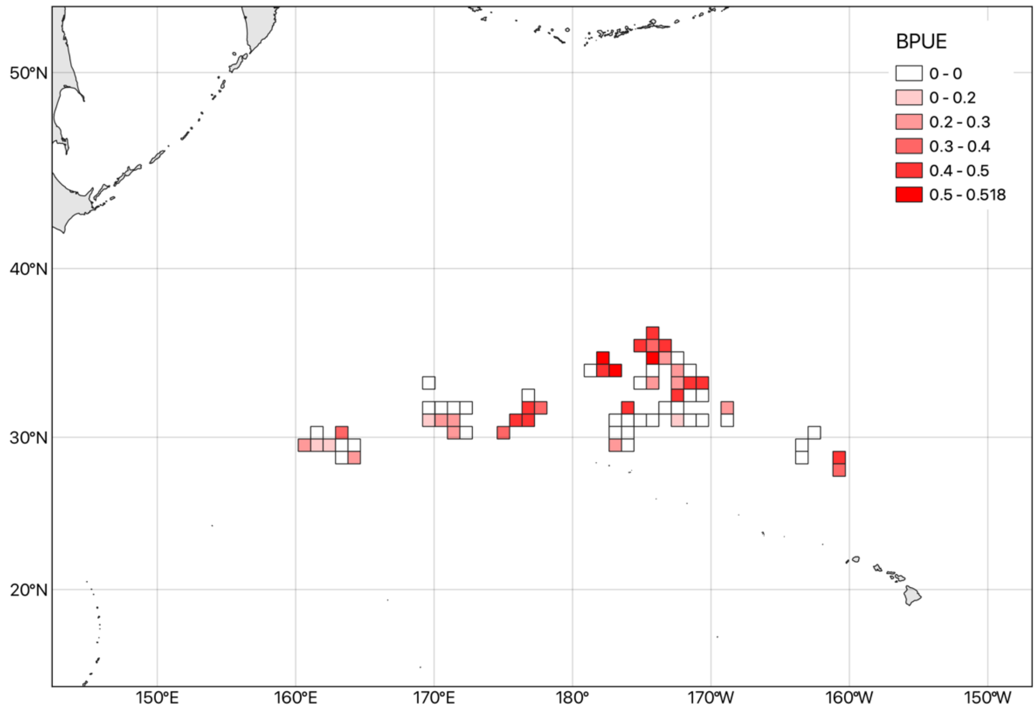

Figure 4. BPUE of seabirds for each 1° by 1° grid.

Table 3. The result of zero-inflated binomial model, with latitude and tori line type as fixed effects. AIC = 823.7

Conditional model: (number of bycatch)				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1952.84	60.68	-32.18	<0.01***
Latitude	0.56	1.86	0.30	0.76
Toriline (Exp)	11.55	4.28	2.70	<0.01*
Zero-inflation model: (prob. of zero bycatch)				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	18.87	7.23	2.61	<0.01**
Latitude	-0.61	0.23	-2.72	<0.01**
Toriline (Exp)	-1.18	0.82	-1.43	0.16

Table 4. The result of zero-inflated binomial model, with latitude, night setting and toriline type as fixed effects. AIC = 826.2

Conditional model: (number of bycatch)				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2040.93	64.76	-31.52	<0.01***
Latitude	3.05	1.92	1.59	0.11

Night setting	10.65	5.17	2.06	0.04*
Toriline (Exp)	9.73	4.47	2.18	0.03*
Zero-inflation model: (prob. of zero bycatch)				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	18.77	7.25	2.59	<0.01**
Latitude	-0.61	0.23	-2.69	<0.01**
Night setting	-0.41	0.77	-0.53	0.60
Toriline (Exp)	-1.16	0.82	-1.41	0.16

The result of generalized additive model shows that the seabird bycatch rate significantly increased with seabird sightings (Table 5).

Table 5. The effects of number of seabird sighted to seabird bycatch, estimated via generalized additive model.

	Estimated Std.	Error	z-value	P-value
Intercept	-0.002	5.26	-369.8	<0.01***
Sighting	0.10	0.04	2.6	0.01**

3.2 Sink rate calculated from the records of TDRs

Two of the three vessels (BH3275 and BI2665) recorded water entry time when using TDRs, while one vessel (BI2196) did not record water entry time. For the two vessels recording water entry time, we calculated the sink rate of TDRs based on the recorded water entry time. The mean sink rate for each of the hooks at different depths was between 0.19-0.30 m/s (Table 6 & 7). For the one vessel without recording water entry time, we determined the TDR entering water at the time that the recorded pressure started to continuously increase. The calculated mean sink rate was between 0.40-1.46 m/s (Table 6). Note that the sink rate calculated based on the pressure curve may be over-estimated (higher than what it really is). Overall, the sink rates of hooks was around the rate recommended by ACAP (0.3 m/s). It will be better to increase the sink rate of hooks by line weighting and other methods.

Table 6. The mean time (seconds) to different depth and the sink rate ± standard error of TDR located at different hooks (B: 1st hook, I: 5th hook, M: 10th hook) for BH3275. Sink rates were calculated for each stratum (0-2m, 2-5m, and 5-10m). Numbers in brackets represent sample size.

		B (30)	I (30)	M (30)
2m	Seconds	13.60±2.03	16.50±3.30	14.00±1.51

	Sink rate 0-2m (m/s)	0.22±0.02	0.20±0.03	0.19±0.02
5m	Seconds	29.60±2.75	36.70±4.52	30.30±2.29
	Sink rate 2-5m (m/s)	0.20±0.01	0.18±0.01	0.20±0.01
10m	Seconds	52.50±3.14	61.20±4.91	52.80±2.73
	Sink rate 5-10m (m/s)	0.22±0.01	0.21±0.01	0.23±0.01

Table 7. The mean time (seconds) to different depths and the sink rate ± standard error of TDR located at different hooks (B: 1st hook, I: 5th hook, M: 10th hook) for BI2665. Sink rates were calculated for each stratum (0-2m, 2-5m, and 5-10m). Numbers in brackets represent sample size.

		B (30)	I (30)	M (29)
2m	Seconds	8.42±1.01	7.14±0.48	7.96±0.57
	Sink rate 0-2m (m/s)	0.28±0.02	0.31±0.02	0.30±0.03
5m	Seconds	23.30±1.50	21.40±1.30	23.20±1.12
	Sink rate 2-5m (m/s)	0.22±0.01	0.23±0.01	0.21±0.01
10m	Seconds	47.0±2.28	44.40±2.33	47.0±1.88
	Sink rate 5-10m (m/s)	0.22±0.01	0.23±0.01	0.22±0.01

Table 8. The mean time (seconds) to different depths and the sink rate ± standard error of TDR located at different hooks (B: 1st hook, I: 3rd or 4th hook, M: 6th hook) for BI2196. Sink rates were calculated for each stratum (0-2m, 2-5m, and 5-10m). Numbers in brackets represent sample size.

		B (28)	I (31)	M (30)
2m	Seconds	5.91±0.52	8.50±2.19	6.20±0.47
	Sink rate 0-2m (m/s)	0.41±0.03	1.46±1.08	0.43±0.01
5m	Seconds	13.70±0.61	16.20±2.26	13.60±0.64
	Sink rate 2-5m (m/s)	0.40±0.01	0.40±0.01	0.43±0.02
10m	Seconds	26.0±0.86	29.70±3.83	25.10±0.98

Sink rate 5-10m (m/s)	0..42±0.01	0.42±0.02	0.45±0.02

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