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Original research article

Study on the catch, bycatch and discard of Chinese pelagic longline fisheries in the Atlantic Ocean

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ABSTRACT

Catch, bycatch and discard information is important for the assessment and management of fisheries. Using Chinese pelagic tuna longline observer data from 2010 to 2018, we studied the catch composition in the Chinese pelagic tuna longline fisheries in Atlantic targeting bigeye tuna (*Thunnus obesus*) and bluefin tuna (*Thunnus thynnus*), and analyzed the survival status and discard rates of common bycatch species. A total of 55 species, including tunas, billfishes, sharks, sea turtles, cetaceans, seabirds, and other pelagic species, were observed. The results indicated that the catch composition of the Chinese pelagic tuna longline fishery targeting bigeye tuna was significantly different from that targeting bluefin tuna. The annual discard rates of common species decreased over this period. Discard rate by length and discard mortality for common species were varied among species. This is the first study to estimate catch, bycatch, and discard using Chinese pelagic tuna longline observer data in the Atlantic Ocean, which is important for the management of Chinese tuna longline fisheries in Atlantic Ocean.

1. Introduction

The bycatch in commercial fisheries has become a worldwide concern with the increased acknowledgement of the importance of marine animal protection (Anderson et al., 2011; Gilman, 2011; Huang, 2011). Tuna fisheries have a large number of bycatch species, such as tuna-like species and sharks (ICCAT, 2011). The bycatch process is often accompanied by discarding, which Huang and Liu (2010) define as part of the total catch thrown away at sea for whatever reason.

The pelagic tuna longline fishery is the major commercial tuna fishery in the Atlantic Ocean (Allen, 2010). The tuna longline fishery in the tropical Atlantic Ocean mainly targets bigeye tuna (*Thunnus obesus*), with bycatch including yellowfin tuna (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), tuna-like species, sharks, and sea turtles (Gilman, 2011; Jiménez et al., 2020). In the northern temperate Atlantic Ocean, tuna longline fishery targets bluefin tuna (*Thunnus thynnus*) and generally catches fewer bycatch species than in tropical waters.

The tuna longline bycatch information is obtained from logbooks, observer reports, and port sampling data. However, bycatch and discards of low commercial value species are rarely recorded in detail in logbooks and are usually only summarized in the "other fishes" category (Clarke et al., 2014; Jordaan et al., 2020). Port sampling data often cannot record the precise capture time and location of these species. The longline observer program in the Atlantic Ocean is the primary means of obtaining detailed information on specific bycatch species and is an important source of data for studying the population dynamics and conservation of tunas and tuna-like species. According to ICCAT recommendation 16-14, the Atlantic longline fishery must keep a minimum of 5% observer coverage (ICCAT, 2017a). Furthermore, observer data over a long time period can provide essential information in estimating fishing mortality of bycatch species.

The pelagic tuna longline fishery, China's only tuna fishery in the Atlantic Ocean, began in 1993 (Zhang et al., 2009) and includes fleets in tropical waters targeting bigeye tuna and fleets in northern temperate waters targeting bluefin tuna in recent years.

This study focuses on the estimation of catch rate, discard rate, and survival status for common bycatch species caught in the Chinese tuna longline using observer trips from 2010 to 2018. The difference in species composition, catch rate, and discard rate between the tropical and temperate areas is compared. The main objective of this study is to estimate the discard and survival status of different species caught by Chinese tuna longline fleets in the Atlantic Ocean. The results will

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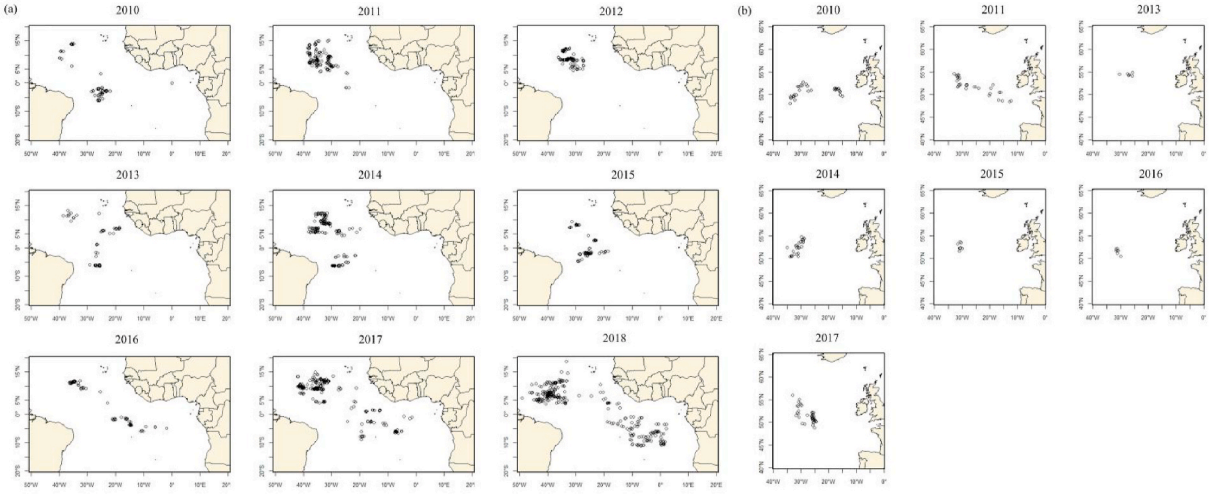

Fig. 1. Locations of observed fishing sets from 2010 to 2018 in the Atlantic Ocean. (a) bigeye tuna trips and (b) bluefin tuna trips.

provide scientific information for improving catch, bycatch, and discard estimates in the Chinese Atlantic longline fisheries and facilitate Atlantic tuna longline management.

2. Materials and methods

2.1. Data source

The data was collected by the Chinese national scientific observer program from 2010 to 2018 and observers were trained in accordance with the requirements of the ICCAT data collection framework. Observer records include operation information (set position, set speed, set number, type of hooks, weather condition, bait condition, etc.), individual catch information (species name, size, weight, sex, maturity, retain status, survival status, etc.), fishing effort, and observation coverage per set. Retain status indicates whether an individual was retained on board or discarded. Survival status recorded the state of an individual when it was landed onboard, including alive and healthy (refer to A1), dying (refer to A2), dead (refer to D), and unknown (refer to U) status. All trips targeting bluefin used 4.2 inch Japanese tuna hooks and trips targeting bigeye tuna used 4.0 inch Japanese tuna hooks.

A total of 1361 longline sets from 12 observer trips targeting bigeye tuna in the tropical Atlantic and 171 longline sets from 10 observer trips targeting bluefin tuna in the northern temperate Atlantic were collected. The bigeye tuna trips operating throughout all-seasons covered the area of 50° W - 25° E and 25° N - 15° S (Fig. 1a). The bluefin tuna trips operating from September to January of the following year covered the area of 35°W - 10°W and 45°N - 50°N (Fig. 1b). Bigeye tuna trips used sardines as bait and bluefin tuna trips used squids and sardines as bait in the majority of operations. The observer could not record all the retrieved hooks due to the long time necessary to retrieve a single set, but 73.14% of the hooks per set were observed. Two observers in 2010 did not record discard data. Therefore, the discard analysis only covered from 2011 to 2018.

Table 1
The catch composition (nominal values and percent of the total) of bigeye tuna trips and bluefin tuna trips.

Common name	Bigeye tuna trips (%)	Bluefin tuna trips (%)	Common name	Bigeye tuna trips (%)	Bluefin tuna trips (%)
Tunas	24,739 (56.79)	1175 (33.99)	Sickle pomfret	749 (1.72)	2 (0.06)
Bigeye tuna	22,653 (52.00)	0 (0.00)	Dagger pomfret	997 (2.29)	0 (0.00)
Bluefin tuna	0 (0.00)	1140 (32.98)	Common dolphinfish	316 (0.72)	0 (0.00)
Yellowfin tuna	1049 (2.41)	0 (0.00)	Wahoo	287 (0.66)	0 (0.00)
Albacore	1026 (2.35)	35 (1.01)	Escolar	544 (1.25)	2 (0.06)
Skipjack	11 (0.03)	0 (0.00)	Opah	157 (0.36)	0 (0.00)
			Spinetail mobula	19 (0.04)	3 (0.09)
Billfishes	2141 (4.89)	3 (0.09)	Sharptail sunfish	12 (0.03)	10 (0.29)
Blue marlin	257 (0.59)	0 (0.00)	Ocean sunfish	106 (0.24)	0 (0.00)
Swordfish	1701 (3.90)	3 (0.09)	Pelagic stingray	98 (0.22)	0 (0.00)
Longbill spearfish	87 (0.20)	0 (0.00)	Oilfish	8 (0.02)	0 (0.00)
Sailfish	46 (0.11)	0 (0.00)	Greater amberjack	25 (0.06)	0 (0.00)
			Almaco	7 (0.02)	0 (0.00)
Sharks	9740 (22.26)	2226 (64.45)	Bigeye trevally	10 (0.02)	0 (0.00)
Oceanic whitetip shark	35 (0.08)	0 (0.00)			
Silky shark	9 (0.02)	0 (0.00)	Sea turtles	82 (0.19)	0 (0.00)
Blue shark	6757 (15.5)	2040 (59.01)	Olive ridley turtle	38 (0.09)	0 (0.00)
Shortfin mako	155 (0.36)	185 (5.35)	Leatherback turtle	43 (0.10)	0 (0.00)
Longfin mako	142 (0.33)	4 (0.12)	Loggerhead turtle	1 (<0.01)	0 (0.00)
Bigeye thresher	522 (1.20)	0 (0.00)			
Crocodile shark	1665 (3.83)	1 (0.03)	Cetaceans		
Velvet dogfish	416 (0.95)	0 (0.00)	Atlantic white-sided dolphin	2 (<0.01)	0 (0.00)
Smooth hammerhead	31 (0.07)	0 (0.00)			
			Seabirds		
Other fishes	7052 (16.12)	51 (1.48)	Great shearwater	2 (<0.01)	0 (0.00)
Longnose lancetfish	3501 (8.03)	34 (0.98)			

Note: The scientific names of all species and fish species with catches less than or equal to 1% are listed in Appendix.

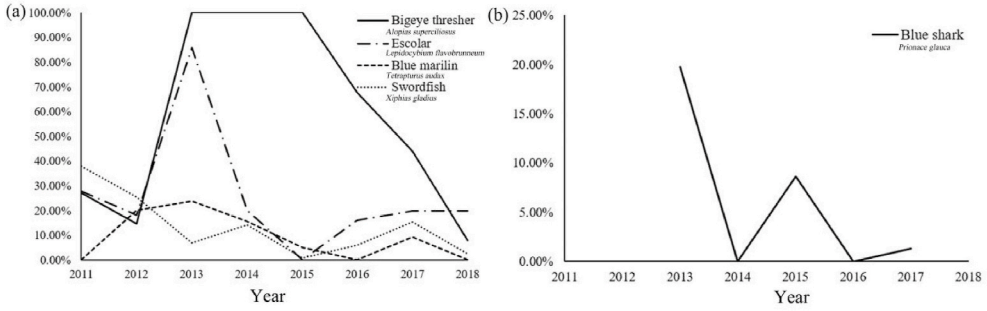

Fig. 2. Annual discard rate variations of common species caught by (a) bigeye tuna trips and (b) bluefin tuna trips.

2.2. Data analysis

Catch in number by species ("catch" means the retained species plus the discarded or released species in this study) was recorded and catch composition (percentage of catch by species to the total catch) was calculated of different fleets. All catches other than the target species were considered as bycatch. Discard rates by species were also calculated and compared between fleets. The discard rate refers to the percentage of discarded catch to the total catch of the species (Hall et al., 2000). The annual discard rates of common species caught by both fleets were calculated. Given limited sample size, this study calculated bigeye thresher (*Alopias superciliosus*), escolar (*Lepidocybium flavobrunneum*), blue marlin (*Makaira nigricans*), and swordfish (*Xiphias gladius*) in the bigeye tuna trips, and blue shark (*Prionace glauca*) in the bluefin tuna trips. Furthermore, this study calculated the proportion of discarded species in different survival status (alive and healthy, dying, dead, or unknown) of each fleet.

Five common bycatch species in bigeye tuna trips and three common bycatch species in bluefin tuna trips were studied for their discard rate with different size groups. Bigeye tuna trips include blue marlin, blue shark, longfin mako (*Isurus paucus*), shortfin mako (*Isurus oxyrinchus*), and swordfish. Bluefin tuna trips include albacore (*Thunnus alalunga*), blue shark, and shortfin mako. The shortfin mako caught by bigeye tuna trips was divided into 30 cm fork length bins; the blue marlin and swordfish caught by bigeye and bluefin tuna trips was divided into 30 cm low jaw fork length bins; the albacore caught by bluefin tuna trips was divided into 10 cm fork length bins; and other species were divided into 20 cm fork length bins. The discard rates of different size groups were calculated separately.

Differences in the discard rates of catches between bigeye tuna trips and bluefin tuna trips were determined by applying the Kruskal-Wallis test ($\alpha = 0.05$) because the data were not normally distributed (Huang, 2015). Differences in the catch composition between bigeye tuna trips and bluefin tuna trips were determined by applying the Fisher's Exact Test ($\alpha = 0.05$).

3. Results

3.1. Catch composition

A total of 54 species were caught in the observed trips targeting bigeye tuna (bigeye tuna trips), including 4 tunas, 7 billfishes, 15 sharks,

Table 2
The discard rate (discarding individuals' percent of the total) of bigeye and bluefin tuna trips.

Common name	Discard rate		Common name	Discard rate	
	Bigeye tuna trips(%)	Bluefin tuna trips (%)		Bigeye tuna trips (%)	Bluefin tuna trips (%)
Tunas	3.11	1.48	Galapagos shark	100.00	No catch
Bigeye tuna	1.69	No catch	Sandbar shark	0.00	No catch
Bluefin tuna	No catch	0.00	Blacktip shark	100.00	No catch
Yellowfin tuna	0.73	No catch			
Albacore	34.16	68.00	Other fishes	79.94	97.78
Skipjack	50.00	No catch	Longnose lancetfish	98.53	100.00
			Sickle pomfret	75.07	No catch
Billfishes	15.39	0.00	Dagger pomfret	66.98	No catch
Blue marlin	8.81	No catch	Common dolphinfish	84.56	No catch
Striped Marlin	Discard status unknown	No catch	Wahoo	36.63	No catch
Swordfish	11.32	0.00	Escolar	20.43	50.00
Shortbill spearfish	Discard status unknown	No catch	Snake mackerel	97.73	No catch
Longbill spearfish	64.21	No catch	Opah	29.51	No catch
Sailfish	21.57	No catch	Spinetail mobula	100.00	No catch
Atlantic white marlin	72.92	No catch	Sharptail sunfish	100.00	No catch
			Ocean sunfish	73.08	Discard status unknown
Sharks	36.36	6.57	Pelagic stingray	98.82	No catch
Oceanic whitetip shark	96.55	No catch	Oilfish	100.00	No catch
Silky shark	66.67	No catch	Tapertail ribbonfish	100.00	100.00
Blue shark	11.50	6.19	Greater amberjack	100.00	No catch
Shortfin mako	45.04	9.29	Rainbow runner	100.00	No catch
Longfin mako	39.44	25.00	Polka-dot ribbonfish	100.00	No catch
Bigeye thresher	45.00	No catch	Almaco	28.57	No catch
Crocodile shark	99.14	0.00	Pompano dolphinfish	100.00	No catch
Velvet dogfish	99.78	No catch	White snake mackerel	100.00	No catch
Smooth hammerhead	63.33	No catch	Bigeye trevally	100.00	No catch
Tiger shark	100.00	No catch	Atlantic tripletail	100.00	No catch
Bigeye sand tiger	100.00	No catch	Rough triggerfish	100.00	No catch
Thresher shark	100.00	No catch			

Table 3
The percentages of different survival statuses at discard in bigeye and bluefin tuna trips. A1: alive and healthy, A2: dying, D: dead, and U: unknown status.

Common name	Bigeye tuna trips				Bluefin tuna trips			
	A1 (%)	A2 (%)	D (%)	U (%)	A1 (%)	A2 (%)	D (%)	U (%)
Tunas	41.24	8.90	47.74	4.87	58.83	5.88	35.29	0.00
Bigeye tuna	15.64	0.00	84.08	0.28	No catches			
Bluefin tuna	No catches				No discarded catches			
Yellowfin tuna	0.00	0.00	100.00	0.00	No catches			
Albacore	0.00	0.00	100.00	0.00	58.83	5.88	35.29	0.00
Skipjack	80.00	0.00	20.00	0.00	No catch			
Billfishes	12.12	1.35	85.52	1.01	No discarded catches			
Blue marlin	5.00	0.00	95.00	0.00	No catches			
Swordfish	14.62	0.00	83.63	1.75	No discarded catches			
Longbill spearfish	9.84	2.34	90.16	0.00	No catches			
Sailfish	9.09	0.00	90.91	0.00	No catches			
Atlantic white marlin	20.00	0.00	80.00	0.00	No catches			
Sharks	61.08	7.73	23.24	7.94	78.46	6.15	1.54	13.85
Oceanic whitetip shark	10.71	0.00	89.29	0.00	No catches			
Silky shark	33.33	0.00	66.67	0.00	No catches			
Blue shark	61.90	6.86	35.01	1.82	75.45	6.36	1.82	16.36
Shortfin mako	54.24	8.47	42.37	3.39	94.12	5.88	0.00	0.00
Longfin mako	46.43	19.64	50.00	3.57	100.00	0.00	0.00	0.00
Bigeye thresher	66.16	6.06	31.31	2.53	No catches			
Crocodile shark	79.73	5.62	8.32	11.62	No discarded catches			
Velvet dogfish	46.09	17.67	46.76	7.16	No catches			
Smooth hammerhead	0.00	0.00	100.00	0.00	No catches			
Other fishes	27.09	5.02	60.01	7.87	20.45	11.36	65.91	2.27
Longnose lancetfish	9.04	6.72	80.94	9.94	20.59	2.94	76.47	0.00
Sickle pomfret	55.29	2.74	37.04	7.48	No catches			
Dagger pomfret	59.84	4.19	33.64	6.20	No catches			
Common dolphinfish	27.39	3.32	61.83	10.37	No catches			
Wahoo	59.55	1.12	32.58	7.87	No catches			
Escolar	25.00	3.85	67.31	4.81	Survive status unknown			
Snake mackerel	16.28	4.65	83.72	0.00	No catches			
Opah	66.67	7.41	33.33	0.00	No catches			
Spinetail mobula	100.00	0.00	0.00	0.00	No catches			
Sharptail sunfish	70.00	10.00	0.00	30.00	No catches			
Ocean sunfish	89.47	8.77	3.51	5.26	Discard status unknown			
Pelagic stingray	92.86	1.19	6.55	0.60	No catches			
Oilfish	42.86	0.00	57.14	0.00	No catches			
Greater amberjack	92.59	0.00	3.70	3.70	No catches			
Almaco	100.00	0.00	0.00	0.00	No catches			
Bigeye trevally	100.00	0.00	0.00	0.00	No catches			
Tapertail ribbonfish	44.44	11.11	44.44	0.00	20.00	40.00	30.00	10.00

Note: The species with catches less than or equal to 1% (AppendixI) are listed in AppendixII.

23 other fishes, 3 sea turtles, 1 cetacean, and 1 seabird. Tunas had the largest proportion of catch in number (56.79%): bigeye tuna (52.00%), yellowfin tuna (2.41%), albacore (2.35%), and skipjack (0.03%). The blue shark had the largest proportion in bycatch species, accounting for 15.50% of the total catch (Table 1). A total of 12 species were caught in the observer trips targeting bluefin tuna (bluefin tuna trips), including 2 species of tunas, 1 billfish, 4 species of sharks, 5 species of other fishes, and no incidental catch of sea turtles, seabirds, or cetaceans. Sharks had the largest proportion of catch in number (64.45%): blue shark (59.01%), and shortfin mako (5.35%), longfin mako (0.12%). The blue shark had the largest proportion in bycatch species, accounting for 59.01% of the total catch (Table 1).

The species composition differed between bigeye tuna trips and bluefin tuna trips (Fisher's Exact Test P = 0.0004998) and when considering only the same species captured by both trips, the same result was also evident (Fisher's Exact Test P = 0.0004998).

3.2. Discard rate

3.2.1. Bigeye tuna trips discard

A total of 40,510 individuals were caught and observed during the bigeye tuna trips from 2011 to 2018, among which 9321 individuals were discarded, indicating an overall discard rate of 23.01%. The discard rate of common bycatch species in bigeye tuna trips fluctuated from 2011 to 2018, and showed a decreasing trend (Fig. 2a). Although there was a slight increase in the discard rate of escolar from 2015 to 2018, the average discard rate from 2015 to 2018 (20.36%) was lower than that from 2011 to 2014 (23.43%).

3.2.2. Bluefin tuna trips discard

A total of 3174 caught individuals were observed during bluefin tuna trips from 2011 to 2018, among which 191 individuals were discarded, indicating an overall discard rate of 6.02%. Sharks accounted for the largest percentage of bycatch; there were 2226 sharks out of 3455 caught individuals from all the trips for 2010–2018 (64.45%); however, discard rate of sharks was very low (6.57%). Among them, the discard rate of the common species (e.g., blue shark) showed a downward trend (Fig. 2b).

3.3. Survival status at discard

3.3.1. Survival status at discard from bigeye tuna trips

Sharks had the lowest mortality when they were discarded (referred to as "discard mortality") in the bigeye tuna trips. 61.08% of sharks were

Table 4
The survival status sea turtles, cetaceans, and seabirds observed as bycatch during the bigeye tuna trips. All live individuals were released and dead individuals were directly discarded. A1: alive and healthy, A2: dying, D: dead, and U: unknown status.

	A1	A2	D	U
Sea turtles				
Olive ridley turtle	14	6	15	3
Leatherback turtle	32	4	7	0
Loggerhead turtle	0	1	0	0
Cetaceans				
Atlantic white-sided dolphin	2	0	0	0
Unknown species	4	1	1	2
Seabirds				
Great shearwater	0	0	2	0

in A1 status when discarding, 7.73% of sharks were in A2 status when discarding, and 23.24% of sharks were in D status when discarding (Table 3). For the tuna, billfish, and other pelagic species, the discard mortality was higher than the other statuses. The survival status at discard showed large differences between tunas, billfishes, sharks, and other species (Table 3).

3.3.2. *Survival status at discard from bluefin tuna trips*

The survival status at discard showed large differences between species (Table 3). The proportion of individuals in A1 status at discard was higher than in bigeye tuna trips (e.g., albacore, blue shark, and shortfin mako). The overall proportion of A1 status for sharks was 78.46%, higher than in the bigeye tuna trips (Table 3).

3.4. *The bycatch of sea turtles, seabirds, and cetaceans*

During the bigeye tuna trips, 82 sea turtles, 10 cetaceans, and 2 seabirds were incidentally caught. The reasons of these interactions

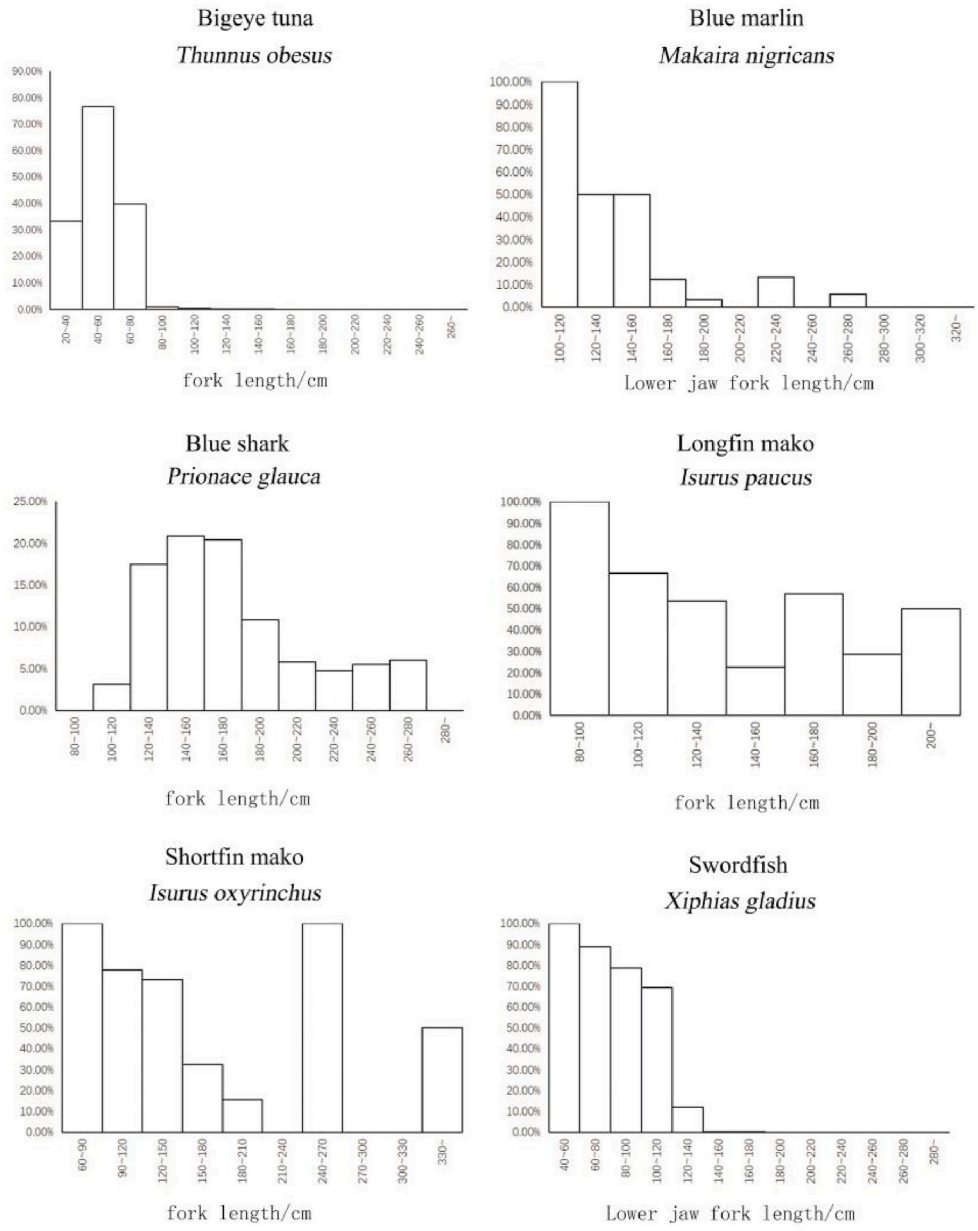

Fig. 3. Discard rates of some species caught by bigeye tuna trips with different size groups.

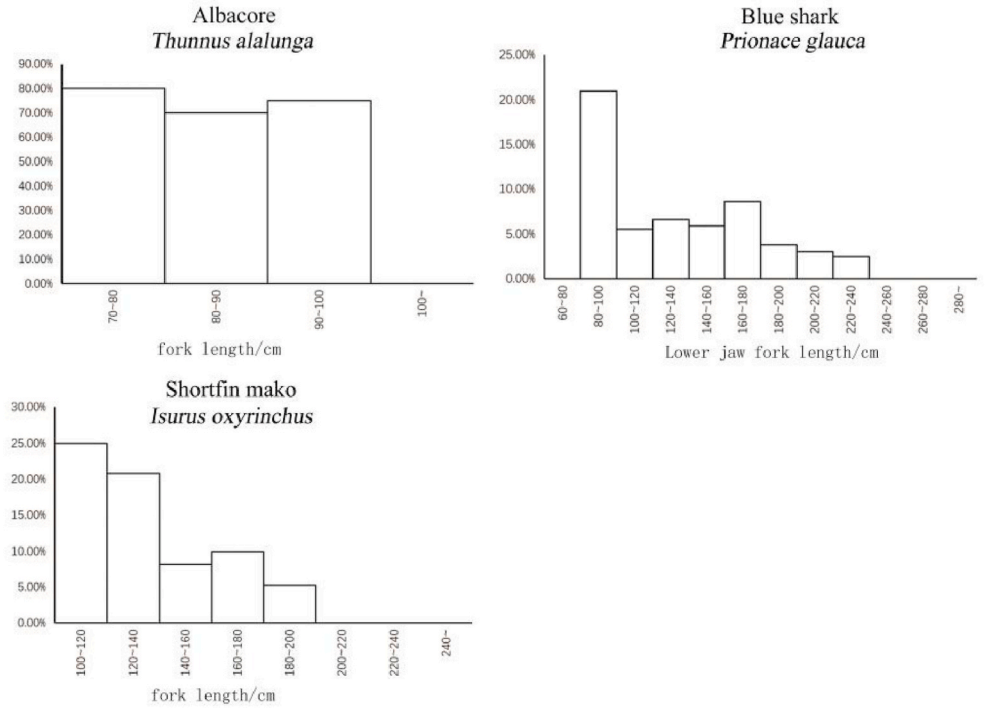

Fig. 4. Discard rates of some species caught by bluefin tuna trips with different size groups.

included eating bait by mistake, entangled by the branchline and float line, and pierced by the hook. All live individuals were released and dead individuals were discarded (Table 4). The incidental capture of sea turtles included 38 olive ridley turtles (*Lepidochelys olivacea*), 43 leatherback turtles (*Dermochelys coriacea*), and 1 loggerhead turtle (*Caretta caretta*) (Tables 1 and 4). Most leatherback turtles were caught at 5°N to 15°N. The incidental catch of the olive ridley turtle was not concentrated within certain latitudes, but was evenly distributed in the tropical Atlantic Ocean. Two cetaceans identified as Atlantic white-sided dolphin (*Lagenorhynchus acutus*), were captured respectively at 10.11°N, 32.35°W and 10.12°N, 32.53°W; the rest of cetaceans were not identified to species level. Only 2 seabirds, great shearwater (*Ardenna gravis*), were caught in a single set (Tables 1 and 4) on September 16, 2015 at the location of 3°24′S, 26°25′W. No sea turtles, cetaceans, or seabirds were incidentally caught during the bluefin tuna trips.

3.5. Discard rates of main species with different size groups

The observation records showed a trend that the discard rates reduced with the increase of the size, especially in the bluefin tuna trips (Figs. 3 and 4). However, blue shark with fork length from 100 to 120 cm had a lower discard rate (3.17%) and the 140–160 cm group had the highest discard rate (20.87%) in bigeye tuna trips. The shortfin mako from bigeye tuna trips has a high discard rate for those measuring 240–270 cm (Fig. 3). These shortfin makos were caught on the same trip and all were discarded. Two of them were caught in December 2017, the center of operation located in the northern hemisphere, Western and Central Atlantic and the other one was caught on July 8, 2018, the center of operation located in the Central Atlantic Ocean.

4. Discussion

4.1. Discards by species

Fishermen usually retained the individuals with the larger size and higher market value, partially for the economic benefits, and because the minimum size limit and releasing are both important approaches to protect Atlantic pelagic stock status (ICCAT, 2017; ICCAT, 2020a; ICCAT, 2020b). In this study, the discard rates of tunas, billfishes, and sharks were lower than the other species. The bigeye tuna trips released or discarded some small-size individuals of target species (i.e., the bigeye tuna; Fig. 3) and the bluefin tuna trips retained all of the target species (Table 2). In general, the retention for most sharks was high, except for species that conservation and management measures required non-retention.

This study showed that the average discard rate of Chinese Atlantic tuna longline fishery was 21%. Previous research showed that the discard rate of highly migratory species including tuna species caught by longline could be 28.5% (Kelleher, 2005). Wang et al. (2021) studied the Chinese tuna longline fishery in the Pacific Ocean from 2010 to 2018, indicating that the discard rate of bigeye tuna fleet was 24.86%. Huang and Liu (2010) estimated that the average discard rate of tuna longline fishery was 22% globally, although there was large difference in discard rate between bigeye tuna trips and bluefin tuna trips (Kruskal-Wallis test, $\chi^2 = 5119.1$, $df = 1$, $P < 0.0001$). This study showed that the average discard rate of bigeye tuna trips is nearly four times that for the bluefin tuna trips. In addition, according to the observation records in this study, the bigeye tuna depredated by cetaceans accounted for 63% of discarded bigeye tuna. These interactions between cetaceans and tuna longline fisheries are difficult to avoid (Charles et al., 2020).

4.2. The survival rate at discard

This study showed that discard mortality of billfishes was higher than other species, with swordfish discard mortality of 83.63%, for example. However, small-sized individuals accounted for a higher proportion in the discarded catch of swordfish and blue marlin. Musyl et al. (2015) conducted a meta-analysis and founded that the majority of billfishes survived after released from various fishing gear. They concluded that catch-and-release may be a good management option to protect billfish population. However, the data used in Musyl et al. (2015) was from tagging experiments and the capture status and size composition which differed from this study. Other studies showed that dead catches may lead to partial hypoxia, causing a negative impact on

the ecosystem on the seabed (Duffy & Stachowicz, 2006; Gilman, 2011).

The discard mortality was generally lower for sharks compared to other species. Shark bycatch rates in pelagic longline fisheries are high (Oliver et al., 2015). Therefore, in fisheries that are not shark-dominated, ICCAT encourages the discarding of shark bycatch that are not used for food or subsistence (ICCAT, 2005) and release may be an appropriate method to protect the status of Atlantic shark populations. Conservation and management measures for sharks can be referenced from stock assessments. The release of live sharks tends to be an effective way to reduce total mortality and the post-release mortality needs to be assessed at the species level. However, some species, such as the oceanic whitetip shark (*Carcharhinus longimanus*) and smooth hammerhead (*Sphyrna zygaena*), high discard rates and mortality may reflect a high susceptibility to the pelagic longline fishery (Cortés et al., 2010). Future research should explore whether these species are at risk of being over-fished. Given limited sampling size, survival status at discard of some shark species were not considered for analysis in this study, including bigeye sand tiger shark (*Odontaspis noronhai*), silky shark (*Carcharhinus falciformis*), and tiger shark (*Galeocerdo cuvier*).

CRediT authorship contribution statement

Boyi Pan: Formal analysis, Software, Methodology, Writing – original draft. **Jiangfeng Zhu:** Conceptualization, Project administration, Methodology, Writing – review & editing. **Qinqin Lin:** Writing – review & editing. **Zhe Geng:** Writing – review & editing. **Feng Wu:** Resources. **Yuying Zhang:** Writing – review & editing.

Declaration of competing interest

The authors declared that they have no conflicts of interest to this work.

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Appendix A. Supplementary data

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References

Allen, R. (2010). *International management of tuna fisheries: Arrangements, challenges and a way forward. FAO fisheries and aquaculture technical paper. No. 536* (p. 45). Rome: FAO, 2010.

Anderson, O. R., Small, C. J., Croxall, J. P., Dunn, E. K., Sullivan, B. J., Yates, O., & Black, A. (2011). Global seabird bycatch in longline fisheries. *Endangered Species Research, 14*(2), 91–106. https://doi.org/10.3354/esr00347

Charles, W. D., Hazin, H., & Travassos, P. (2020). Interactions between cetaceans and the tuna/swordfish pelagic longline fishery in the tropical western Atlantic Ocean. *Fisheries Research, 226*, 105530. https://doi.org/10.1016/j.fishres.2020.105530

Clarke, S., Sato, M., Small, C., Sullivan, B., Inoue, Y., & Ochi, D. (2014). Bycatch in longline fisheries for tuna and tuna-like species: A global review of status and mitigation measures. In *FAO Fish and Aquaculture Technical Paper 588* (pp. 1–199). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.637.8798&rep=rep1&type=pdf.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M. N., Ribera, M., & Simpfendorfer, C. (2010). Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquatic Living Resources, 23*(1), 25–34. https://doi.org/10.1051/alr/2009044

Duffy, J. E., & Stachowicz, J. J. (2006). Why biodiversity is important to oceanography: Potential roles of genetic, species, and trophic diversity in pelagic ecosystem processes. *Marine Ecology Progress Series, 311*, 179–189. https://doi.org/10.3354/meps311179

Gilman, E. L. (2011). Bycatch governance and best practice mitigation technology in global tuna fisheries. *Marine Policy, 35*(5), 590–609. https://doi.org/10.1016/j.marpol.2011.01.021

Hall, M. A., Alverson, D. L., & Metuzals, K. I. (2000). Bycatch: Problems and solutions. *Marine Pollution Bulletin, 41*(1–6), 204–219. https://doi.org/10.1016/S0025-326X(00)00111-9

Huang, H. W. (2011). Bycatch of high sea longline fisheries and measures taken by Taiwan: Actions and challenges. *Marine Policy, 35*(5), 712–720. https://doi.org/10.1016/j.marpol.2011.02.012

Huang, H. W. (2015). Incidental catch of seabirds and sea turtles by Taiwanese longline fleets in the Pacific Ocean. *Fisheries Research, 170*, 179–189. https://doi.org/10.1016/j.fishres.2015.06.004

Huang, H. W., & Liu, K. M. (2010). Bycatch and discards by Taiwanese large-scale tuna longline fleets in the Indian Ocean. *Fisheries Research, 106*(3), 261–270. https://doi.org/10.1016/j.fishres.2010.08.005

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2005). *[04-10] Recommendation by ICCAT concerning the conservation of sharks caught in association with fisheries managed by ICCAT*. Madrid, Spain: ICCAT. https://www.iccat.int/Documents/Recs/COMPENDIUM_ACTIVE_ENG.pdf.

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2011). Report of the By-catch Coordination Study. Retrieved from https://iccat.int/en/bycatch.html#. (Accessed 14 March 2021).

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2017a). *a. [16-14] Recommendation by ICCAT to establish minimum standards for fishing vessel scientific observer programs. Compendium management recommendations and resolutions adopted by ICCAT for the conservation of Atlantic tunas and tuna-like species* (pp. 275–280). ICCAT. https://www.iccat.int/Documents/Recs/COMPENDIUM_ACTIVE_ENG.pdf.

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2017b). *b. [16-05] Recommendation by ICCAT replacing the Recommendation [13-04] and establishing a multi-annual recovery plan for Mediterranean Swordfish. Compendium management recommendations and resolutions adopted by ICCAT for the conservation of Atlantic tunas and tuna-like species* (pp. 50–58). ICCAT. https://www.iccat.int/Documents/Recs/COMPENDIUM_ACTIVE_ENG.pdf.

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2020a). *[19-05] Recommendation by ICCAT to establish rebuilding programs for Blue Marlin and White Marlin/Roundscale Spearfish. Compendium management recommendations and resolutions adopted by ICCAT for the conservation of Atlantic tunas and tuna-like species* (pp. 160–165). ICCAT. https://www.iccat.int/Documents/Recs/COMPENDIUM_ACTIVE_ENG.pdf.

International Commission for the Conservation of Atlantic Tuna (ICCAT). (2020b). *[19-04] Recommendation by ICCAT amending the recommendation 18-02 establishing amulti-annual management plan for Bluefin tuna in the eastern Atlantic and Mediterranean. Compendium management recommendations and resolutions adopted by ICCAT for the conservation of Atlantic tunas and tuna-like species* (pp. 106–152). ICCAT. https://www.iccat.int/Documents/Recs/COMPENDIUM_ACTIVE_ENG.pdf.

Jiménez, S., Domingo, A., Winker, 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. https://doi.org/10.1016/j.biocon.2020.108642

Jordaan, G. L., Santos, J., & Groeneveld, J. C. (2020). Shark discards in selective and mixed-species pelagic longline fisheries. *PLoS One, 15*(8), Article e0238595. https://doi.org/10.1371/journal.pone.0238595

Kelleher, K. (2005). *Discards in the world's marine fisheries: An update, 470*. Food & Agriculture Org. https://books.google.com.hk/books?id=pSUwN6gVinMC.

Musyl, M. K., Moyes, C. D., Brill, R. W., Mourato, B. L., West, A., McNaughton, L. M., Chiang, W. C., & Sun, C. L. (2015). Postrelease mortality in istiophorid billfish. *Canadian Journal of Fisheries and Aquatic Sciences, 72*(4), 538–556. https://doi.org/10.1139/cjfas-2014-0323

Oliver, S., Braccini, M., Newman, S. J., & Harvey, E. S. (2015). Global patterns in the bycatch of sharks and rays. *Marine Policy, 54*, 86–97. https://doi.org/10.1016/j.marpol.2014.12.017

Wang, J., Gao, C., Wu, F., Gao, X., Chen, J., Dai, X., Tian, S., & Chen, Y. (2021). The discards and bycatch of Chinese tuna longline fleets in the Pacific Ocean from 2010 to 2018. *Biological Conservation, 255*, 109011. https://doi.org/10.1016/j.biocon.2021.109011

Zhang, Q., Wang, X., & Liu, Y. (2009). Status and development trend of tuna fishery in China. *South China Fisheries Science, 5*(1), 68–74. https://doi.org/10.3969/j.issn.1673-2227.2009.01.012