



Bycatch and discards by Taiwanese large-scale tuna longline fleets in the Indian Ocean

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ARTICLE INFO

Article history:

Received 3 June 2010

Received in revised form 11 August 2010

Accepted 12 August 2010

Keywords:

Bycatch

Discards

Indian Ocean

Seabirds

Sea turtles

Tuna catches

Tuna longline fisheries

ABSTRACT

Conservation of ecologically related species and understanding the discard composition of fisheries are major concerns for marine ecosystem conservation. However, high sea longline fisheries data are insufficient because of difficulties in deploying observers for data collection. Observer data collected from 77 trips on Taiwanese large-scale longline fishing vessels in the Indian Ocean from June 2004 to March 2008 were used to estimate the scale of the bycatch. At least 40 species were recorded. Albacore, bigeye, yellowfin, and southern bluefin tuna were the major species recorded and comprised over 73.30% of the total retained catch. Major bycatch species were swordfish, blue shark, sailfish, pomfret, and escolar. The average discard rate was 14.09%, ranging from 3.20% for the yellowfin tuna fleet to 18.09% for the bigeye tuna fleet. In total, 0.80% of the catch of the albacore, 4.74% of the bigeye, and 2.32% of the yellowfin tuna were discarded. There were significant differences among seasons and areas for the discard rates of the bigeye and yellowfin tuna. The discard rates of the bigeye and southern bluefin tuna were positively correlated to the catch per unit effort. The depredation percentage of tuna by cetaceans was from 0.7% to 12.3% of total discards for the different fleets. The high discard and cetacean depredation rates showed that major possible reasons for discards are depredation by cetaceans, economic factors, and quota limitations. Regarding other species, 61 seabirds and 84 sea turtles were a part of the bycatch. The major species were Indian Yellow-nosed Albatross in the southern Indian Ocean and Olive Ridley turtles in tropical areas. The estimated annual incidental catch numbers were 715 to 311 seabirds and 1856 to 1127 sea turtles from 2004 to 2007. For conservation, this discard information could be used to assess tuna stocks. Mitigation measures, including the live release of small-sized fish, and the use of bird-scaring lines and circle hooks, are required to minimize the bycatch.

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1. Introduction

The bycatch includes the discarded catch plus the incidental catch. The discard is defined as the portion of the total animals in the catch that is thrown away or dumped at sea for whatever reason. Discards represent a significant proportion of global marine catches and are generally considered to constitute waste, or suboptimal use of fishery resources (Alverson et al., 1994). The yearly average discard amounts were estimated to be 7.3 million tons from 1992 to 2001 (Kelleher, 2005). There are several studies on discard practices and their relation to the survival of discarded fish (Kaimmer and Trumble, 1998; Revill et al., 2005). However, most research on discards has focused on trawl fisheries, as trawling has high discard and mortality rates (Allen et al., 2001; Chen and Gordon, 1997; Machias et al., 2001; Tamsett et al., 1999; Walmsley et al., 2007). There are relatively few reports on discard rates or the fates of dis-

carded fish from commercial longline fisheries (Rudershausen et al., 2007; Trumble et al., 2000; Welch et al., 2008; Willis and Millar, 2001).

The term incidental catch is used in the context of rare incidents or events such as catches of marine mammals, turtles, and seabirds (Kelleher, 2005). There is increasing global awareness of the need to protect incidentally caught species. Fisheries bycatch has been implicated in population declines of several species of sea turtles and seabirds (Baker and Wise, 2005; Brothers, 1991; Lewison et al., 2004a; Rogan and Mackey, 2007; Tuck et al., 2001). To conserve these ecosystem-related species and minimize the impacts from longline fisheries, the Food and Agriculture Organization (FAO) has developed an International Plan of Action to avoid seabird bycatch by longline fisheries (FAO, 1999) and published guidelines for sea turtle conservation (FAO, 2005).

Indian Ocean tuna fisheries have developed since the late 1970s (Majkowski, 2007). Longline fisheries catch yellowfin (*Thunnus albacares*), bigeye (*T. obesus*), albacore (*T. alalunga*), and southern bluefin tuna (*T. maccoyii*). Tuna species account for the largest proportion of total tuna-fishing catches (IOTC, 2006). The initial

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development of the tuna longline fisheries occurred as the Japanese fleet expanded its operation in the 1960s, followed by the Taiwanese fleet in the 1970s and the Korean fleet in the 1980s. Many countries have recently also started fisheries, including China, the Philippines, and the Seychelles. Longline catches averaged around 280,000 tons/year over the last 2 decades and peaked in 1998 (319,000 tons) but were lower than average in 2002 and 2003 (IOTC, 2006). The number of Taiwanese large-scale tuna longline fishing vessels (LTLVs) operating in the Indian Ocean was 322 in 2004. Because of bigeye tuna quota restrictions by the Indian Ocean Tuna Commission (IOTC) in 2005 (IOTC, 2005a), the Taiwanese government carried out a fleet buyback program (Huang and Chuang, 2010), and the number of LTLVs decreased by 37% to 203 vessels in 2007. The total catch decreased from 142,000 tons in 2004 to 94,000 tons in 2007 (IOTC, 2006; OFDC, 2008), with a decrease of fishing effort from 275 million to 180 million hooks. The Taiwanese fleet is currently the largest distant-water longline fleet fishing in the Indian Ocean (IOTC, 2006).

The levels of discards and incidental catch are difficult to estimate because captains rarely report discard data in their logbooks (IOTC, 2006). However, depredation is a particular manifestation of the interaction between fisheries and non-target species such as marine mammals, elasmobranch and teleost fish, birds, mollusks, and crustaceans; depredation is also an issue for longline fisheries (Gilman et al., 2008b; IOTC, 2009).

The Indian Ocean is an important habitat for six species of marine turtles, and most populations of these turtles have declined in recent years (Shanker and Pilcher, 2003). Human activities that directly or indirectly threaten marine turtles include the exploitation of eggs and turtles, fishery-related mortality, inappropriate management practices, the modification and destruction of habitats, pollution, mariculture, and tourism (Shanker and Pilcher, 2003). Four species of albatross and four species of petrel in the southern Indian Ocean have overlapping distributions with longline fisheries and are vulnerable, near threatened, critically endangered, or endangered (IOTC, 2009). Understanding the scale of the bycatch across large ocean regions and its impacts on the ecosystem could aid in assessing the stock status and manage the bycatch (Alverson et al., 1994; Lewison et al., 2005; Pauly et al., 2002). However, bycatch information is very limited due to the lack of observer programs. This is the first study using observer data to analyze the discard and incidental catch rates of the Taiwanese tuna longline fishery in the Indian Ocean. Furthermore, the incidental catch rates are raised to give estimates of the incidental catch level with the tuna longline fisheries in the Indian Ocean and provide conservation implementation.

2. Materials and methods

2.1. Data

Catch and bycatch data were collected by onboard observers. To implement the scientific missions, two-week training courses were designed for the observers. The specific aims of the training were to understand the relevant fisheries management policy and regulations, to understand fishing vessel facilities, to develop proficiency in the identification of marine species and recording of catch/bycatch information, to practice biological sampling techniques, and to understand onboard health and safety regulations.

For each fishing trip, observers recorded basic information on the vessels, daily fishing activities (including fishing position (latitude and longitude), the number of hooks and time of set and hauling, the use of bird-scaring equipment (or not), the bait types used), the catch information (the number of retained, discarded, and live-released fish, depredation by sharks, cetaceans,

and unknown animals, and the weight of the retained catch), and ecologically related species information (the species and numbers sighted during fishing operations and the number, species, and living status (live/dead) of the incidental catch). Finally, biological samples were taken for some species. The sightings of ecologically related species were made in daylight. Observations were conducted at the stern of the vessel to estimate the number of birds flying or cetaceans/sea turtles swimming around the vessel. From the top of a deck that provided 10–170 degree vision and censuses were drawn. Digital photographs were taken for those individuals that could not be immediately identified.

Data on the total fishing effort were collected from logbooks submitted by the captains. The logbooks recorded the position of fishing sets (latitude and longitude), the number of hooks, the number and weight of the catch and bycatch by species, and the length of all of the first 30 fish caught. In addition, the vessels are required to set up a vessel monitoring system to automatically report their position, and this was used to verify the fishing position. A few captains did not submit their logbooks on time because the vessels were operating on the high seas and did not frequently return to port. The data collected were extrapolated to the entire Taiwanese fleet based on the recovery rates of the logbooks.

2.2. Analysis of discards

The discard rate is the proportion (percentage) of the total catch that is discarded (Alverson et al., 1994). The total discard includes dead discard, live release, and depredation by cetaceans, sharks, and unknown species. The species-specific discard rates were estimated by calculating the percentage of the discard to the total catch by number. The depredation rate was calculated as the percentage of depredation by cetaceans, sharks, and unknown species to the total catch by number.

2.2.1. Spatial and temporal analysis

The discard rate might be affected by spatial and temporal factors. We used the following stratification to test for homogeneity. For temporal factors, we separated the data into 4 periods: the 1st season (January to March), 2nd season (April to June), 3rd season (July to September), and 4th season (October to December). For spatial stratification, we stratified the area into 4 areas as shown in Fig. 1, among which NIND (north of 10°N) is the major fishing ground for the yellowfin tuna fleet; TropIND (between

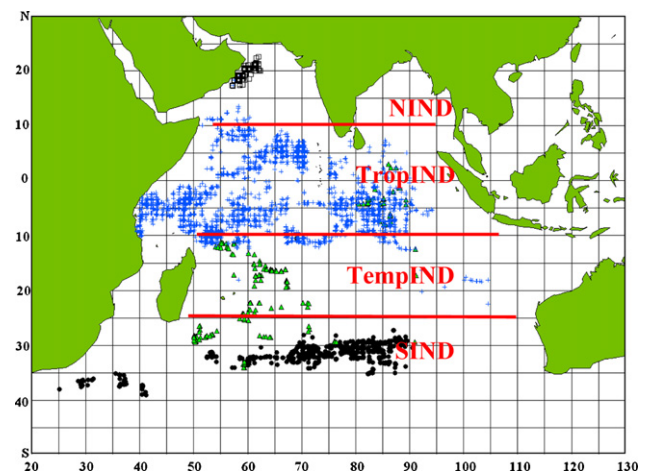


Fig. 1. Areas and observed effort distributions in the Indian Ocean. Black squares, yellowfin tuna fleet; blue crosses, bigeye fleet; green triangles, albacore fleet; black circles, bluefin tuna fleet. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1

Summary of the Taiwanese observer program in the Indian Ocean during 2004–2008.

Year	Trips					Sets	Thousand hooks
	BET fleet	ALB fleet	YFT fleet	SBT fleet	Sum		
2004	2	2	0	4	8	349	1219
2005	3	1	0	3	7	465	1559
2006	5	0	0	1	6	508	1700
2007	29	3	3	5	40	2352	7433
2008	13	1	1	1	16	735	2210
Sum	52	7	4	14	77	4409	14,121

Note: BET, bigeye tuna; ALB, albacore; YFT, yellowfin tuna; SBT, southern bluefin tuna.

10°N and 10°S) is the major ground for the bigeye tuna fleet; and TempIND (between 10°S and 25°S) and SIND (south of 25°S) are the major grounds for the albacore and southern bluefin tuna fleets respectively. To determine potentially significant differences among seasons and areas, nonparametric analysis of variance (the Kruskal–Wallis test) was applied to target-species discard rates because they were not normally distributed (Sidney and Castellan, 1988).

2.3. Analysis of the incidental catch

2.3.1. Incidental catch rate

The incidental catch rate was computed based on the numbers of species caught per 1000 hooks (Brothers, 1991; Gales et al., 1998; Minami et al., 2007). The distribution of bycatch rates of ecologically related species was assumed to follow binomial models (Brothers et al., 1999; Gales et al., 1998; Gilman et al., 2008a), classical Poisson models (Gilman et al., 2008a), and classical negative binomial models (Hamel et al., 2009). The binomial estimator with Clopper–Pearson confidence intervals was used to calculate the incidental catch rates using the R program (Agresti, 2002; Gilman et al., 2008a).

2.4. Incidental catch estimation

The total number of bycatch was estimated using extrapolations obtained by multiplying the bycatch rate and total effort. Because these ecologically related species were not evenly distributed (Tuck et al., 2003), we stratified the data into four seasons and four areas as previously defined for a total of 16 strata. Annual numbers of the incidental catch were obtained using the following formula:

$$C_t = \sum_{i=1}^n c_i e_{i,t};$$

where C_t is the estimated mortality for year t , c_i is the estimated bycatch per unit effort (BPUE) in strata i , and $e_{i,t}$ is the number of hooks deployed by the fleet (in thousands) in strata i for year t .

To understand the impact on the populations of specific species, we used the bycatch species composition of the observed data for each stratum to estimate the annual bycatch mortality by species.

3. Results

3.1. Fishing operation patterns and catch composition by fleet

There were 4 types of fleets studied here based on the target species: albacore, bigeye, yellowfin, and southern bluefin tuna fleets. In total, seventy-seven observer trips were deployed with 4409 sets and 14 million hooks from June 2004 to March 2008. Of these trips, fifty-two were for the bigeye tuna fleet, seven for the albacore fleet, four for the yellowfin tuna fleet, and fourteen for the south bluefin tuna fleet. The overall coverage rate increased from

2.2% in 2004 to 20.8% in 2007. The number of observation days per trip ranged from 21 to 216 days. Details of the deployment are shown in Table 1. The four types of fleets had different operating patterns, such as the number of hooks per set, types of bait used, and fishing season. Their fishing grounds are shown in Fig. 1. The yellowfin fleet operated in coastal areas, with 4032 ± 484 hooks per set, using sardines and scad as bait. The bigeye fleet used 3037 ± 307 hooks per set, with squid, mackerel, and milkfish as bait. The albacore fleet deployed 3475 ± 332 hooks per set and used sardines and squid as bait. The southern bluefin tuna fleet used 3759 ± 435 hooks per set, with sardines and saury as bait. Effort in the north and tropical areas (NIND and TropIND) were around 70.6–79.5% of the total effort. There was higher effort in the NIND in season 1 by the yellowfin fleet, higher effort in the TempIND in season 3 by the seasonal southern bluefin tuna fleet, and higher effort in SIND in season 4 by the albacore fleet.

At least forty species and a total of 176,153 animals were recorded, including six species of tuna, seven billfish species, ten shark species, seven species of other fishes, six species of seabirds and four species of sea turtles. Catch compositions are summarized by fleet in Table 2. Among them, four target tuna species, including bigeye (34.7%), albacore (21.7%), yellowfin (10.3%), and southern bluefin tuna (6.3%) comprised >73.0% of the total catch. Swordfish (3.0%), blue shark (2.0%), sailfish (1.6%), pomfret (1.4%), escolar (1.3%), and common dolphinfish (1.1%) were the major species in the bycatch. All billfish species comprised 5.6%. All shark species comprised 4.4%. Other fishes combined were around 16.6%, and other ecologically related species comprised 0.1%. The species compositions of the southern bluefin and yellowfin tuna fleets were limited to a few species. In contrast, the species composition of the bigeye tuna fleets was diverse; in particular, some billfishes and sharks were only caught by bigeye fleets in small numbers.

3.2. Discards

Among the observed sets, 39.5% had zero discard. The average discard rate was 14.9%. The discard rates and composition by fleets are shown in Table 3. The bigeye fleet had the highest discard rate of 18.09%, whereas that of the southern bluefin tuna fleet was 9.23%, that of the albacore fleet was 7.74%, and that of the yellowfin tuna fleet was 3.20%. Among the species recorded, the highest discard rates were for species other than fishes, with 93.80% of spotted opah and 84.51% of pomfret being discarded. The average discard rate for sharks was 54.20%. Compared to these species, the discard rates of tuna species (3.10%) and billfish species (6.35%) were low. A nonparametric analysis showed significant differences in the discard rates of bigeye tuna (Kruskal–Wallis test for bigeye, season: $\chi^2 = 69.093$, $df = 3$, $p = 0.000$, area: $\chi^2 = 149.514$, $df = 3$, $p = 0.000$) and yellowfin tuna (Kruskal–Wallis test, season: $\chi^2 = 27.394$, $df = 3$, $p = 0.000$, area: $\chi^2 = 36.747$, $df = 3$, $p = 0.000$) for both seasons and areas. On the other hand, only area was significant for albacore (Kruskal–Wallis test, area: $\chi^2 = 11.162$, $df = 3$,

Table 2
Percentage and numbers of species caught by fleet.

Species	Scientific name	YFT fleet		BET fleet		ALB fleet		SBT fleet		Sum	
Tuna											
Albacore	<i>Thunnus alalunga</i>			1162	(1.1%)	3774	(60.3%)	33,253	(55.5%)	38,189	(21.7%)
Bigeye	<i>Thunnus obesus</i>			56,209	(54.7%)	180	(2.9%)	4698	(7.8%)	61,087	(34.7%)
Yellowfin tuna	<i>Thunnus albacares</i>	5731	(78.2%)	11,617	(11.3%)	305	(4.9%)	566	(0.9%)	18,219	(10.3%)
Southern bluefin tuna	<i>Thunnus maccoyii</i>							11,147	(18.6%)	11,147	(6.3%)
Bluefin tuna	<i>Thunnus thynnus</i>			4	(0.0%)			7	(0.0%)	11	(0.0%)
Skipjack	<i>Katsuwonus pelamis</i>			92	(0.1%)	261	(4.2%)	39	(0.1%)	392	(0.2%)
Other tuna				9	(0.0%)					9	(0.0%)
Billfish											
Swordfish	<i>Xiphias gladius</i>	50	(0.7%)	4857	(4.7%)	74	(1.2%)	313	(0.5%)	5294	(3.0%)
Sailfish	<i>Istiophorus platypterus</i>	175	(2.4%)	2598	(2.5%)	36	(0.6%)	1	(0.0%)	2810	(1.6%)
Blue marlin	<i>Makaira mazara</i>	21	(0.3%)	1003	(1.0%)	17	(0.3%)			1041	(0.6%)
Black marlin	<i>Makaira indica</i>	2	(0.0%)	129	(0.1%)					131	(0.1%)
White marlin	<i>Tetrapturus albidus</i>	31	(0.4%)	320	(0.3%)	18	(0.3%)	7	(0.0%)	376	(0.2%)
Shortbill spearfish	<i>Tetrapturus angustirostris</i>			90	(0.1%)	23	(0.4%)	26	(0.0%)	139	(0.1%)
Longbill spearfish	<i>Tetrapturus pfluegeri</i>			6	(0.0%)					6	(0.0%)
Other billfish				7	(0.0%)	48	(0.8%)	5	(0.0%)	60	(0.0%)
Sharks											
Blue shark	<i>Prionace glauca</i>			2067	(2.0%)	147	(2.3%)	1322	(2.2%)	3536	(2.0%)
Silky shark	<i>Carcharhinus falciformis</i>	551	(7.5%)	621	(0.6%)	1	(0.0%)	11	(0.0%)	1184	(0.7%)
Shortfin mako	<i>Isurus oxyrinchus</i>	129	(1.8%)	219	(0.2%)	18	(0.3%)	242	(0.4%)	608	(0.3%)
Bigeye thresher	<i>Alopias superciliosus</i>	2	(0.0%)	439	(0.4%)	1	(0.0%)	3	(0.0%)	445	(0.3%)
Oceanic whitetip shark	<i>Carcharhinus longimanus</i>	1	(0.0%)	73	(0.1%)	3	(0.0%)			77	(0.0%)
Thresher	<i>Alopias vulpinus</i>	12	(0.2%)	55	(0.1%)					67	(0.0%)
Great white shark	<i>Carcharodon carcharias</i>			27	(0.0%)			37	(0.1%)	64	(0.0%)
Scalloped hammerhead	<i>Sphyrna lewini</i>			6	(0.0%)					6	(0.0%)
Smooth hammerhead	<i>Sphyrna zygaena</i>			5	(0.0%)					5	(0.0%)
Tiger shark	<i>Galeocerdo cuvier</i>	1	(0.0%)	4	(0.0%)	2	(0.0%)			7	(0.0%)
Other shark		56	(0.8%)	475	(0.5%)	116	(1.9%)	1157	(1.9%)	1804	(1.0%)
Other fish											
Pomfret	<i>Brama brama</i>	8	(0.1%)	2332	(2.3%)	28	(0.4%)	59	(0.1%)	2427	(1.4%)
Dolphinfish	<i>Coryphaena hippurus</i>	511	(7.0%)	1062	(1.0%)	307	(4.9%)	83	(0.1%)	1963	(1.1%)
Escolar	<i>Lepidocybium flavobrunneum</i>			1435	(1.4%)	170	(2.7%)	748	(1.2%)	2353	(1.3%)
Spotted Opah	<i>Lampris gattatus</i>			72	(0.1%)	150	(2.4%)	1358	(2.3%)	1580	(0.9%)
Ocean sunfish	<i>Mola mola</i>	29	(0.4%)	354	(0.3%)	8	(0.1%)	21	(0.0%)	412	(0.2%)
Oilfish	<i>Ruvettus pretiosus</i>			576	(0.6%)	23	(0.4%)	554	(0.9%)	1153	(0.7%)
King mackerel	<i>Scomberomorus cavalla</i>			731	(0.7%)	280	(4.5%)	15	(0.0%)	1026	(0.6%)
Others		3	(0.0%)	13,955	(13.6%)	266	(4.3%)	4156	(6.9%)	18,380	(10.4%)
Other species											
Olive Ridley turtle	<i>Lepidochelys olivacea</i>	10	(0.1%)	46	(0.0%)						
Leatherback turtle	<i>Dermochelys coriacea</i>			9	(0.0%)						
Loggerhead turtle	<i>Caretta caretta</i>	1	(0.0%)	4	(0.0%)	1	(0.0%)				
Green turtle	<i>Chelonia mydas</i>			3	(0.0%)						
Unknown turtle				10	(0.0%)						
Yellow-nosed Albatross	<i>Thalassarche carteri</i>							18	(0.0%)		
Wandering Albatross	<i>Diomedea exulans</i>							5	(0.0%)		
Sooty Albatross	<i>Phoebastria fusca</i>							5	(0.0%)		
Salvin's Albatross	<i>Thalassarche salvini</i>							1	(0.0%)		
Other albatross								25	(0.0%)		
White-chinned Petrel	<i>Procellaria aequinoctialis</i>							2	(0.0%)		
Short-tailed Shearwater	<i>Puffinus tenuirostris</i>							1	(0.0%)		
Other seabirds		2	(0.0%)	1	(0.0%)			1	(0.0%)		
Tuna		5731	(78.2%)	69,093	(67.3%)	4520	(72.2%)	49,710	(83.0%)	129,054	(73.3%)
Billfishes		279	(3.8%)	9010	(8.8%)	216	(3.5%)	352	(0.6%)	9857	(5.6%)
Sharks		752	(10.3%)	3991	(3.9%)	288	(4.6%)	2772	(4.6%)	7803	(4.4%)
Other fishes		551	(7.5%)	20,517	(20.0%)	1232	(19.7%)	6994	(11.7%)	29,294	(16.6%)
Other species		13	(0.2%)	73	(0.1%)	1	(0.0%)	58	(0.1%)	145	(0.1%)
Total		7326	(100.0%)	102,684	(100.0%)	6257	(100.0%)	59,886	(100.0%)	176,153	(100.0%)

$p = 0.011$, season: $\chi^2 = 4.659$, $df = 3$, $p = 0.199$). Southern bluefin tuna were only caught in the SIND and also had no seasonal significance (Kruskal–Wallis test, season: $\chi^2 = 1.617$, $df = 3$, $p = 0.656$). In addition, significant correlations were found between the monthly discard rate and catch per unit effort (CPUE) for bigeye ($r = 0.72$) and southern bluefin ($r = 0.91$) tuna (Fig. 2).

Common reasons for discarding were damaged condition and low or no commercial value. The percentages of discard type by fleet are shown in Fig. 3. Of the animals, 38.3–63.4% were dead, and 24.7–54.5% were released live. An average of 10.0% had been depredated by cetaceans, and this was highest at 12.3% for the big-

eye fleet. Another 1.3–3.8% had been depredated by sharks, and this was highest at 3.8% for the yellowfin tuna fleet.

3.3. Incidental catch

Thirty-three species of seabirds, five species of sea turtles, and seven species of cetaceans were sighted (Table 4). The distributions of sightings and the incidental catch are shown in Figs. 4 and 5. The bycatch rates by area are shown in Table 5.

Sixty-one seabirds were incidentally caught, mainly within 29° to 32°S by 70° to 90°E. Indian Yellow-nosed Albatross, Sooty

Table 3
Discard rates of species by fleet.

Species	YFT fleet	BET fleet	ALB fleet	SBT fleet	Sum
Albacore		1.20%	1.32%	0.72%	0.80%
Bigeye		4.97%	37.78%	0.79%	4.74%
Bluefin tuna		–		–	–
Skipjack		38.04%	–	28.21%	11.73%
Southern bluefin tuna				2.86%	2.86%
Yellowfin tuna	0.42%	3.43%	–	0.18%	2.32%
Other tunas		88.89%			88.89%
Black marlins	–	3.10%			3.05%
Bluefin marlin	–	2.79%	–		2.69%
Longbill marlin		–			–
Sailfish	–	2.93%	–	–	2.70%
Shortbill marlin		3.33%	–	34.62%	8.63%
Swordfish	12.00%	9.61%	4.05%	4.79%	9.27%
White marlins	–	4.06%	–	–	3.46%
Other billfishes		–	–	40.00%	3.33%
Blue shark		35.22%	21.09%	82.90%	52.46%
Bigeye thresher	–	61.73%	100.00%	33.33%	61.35%
Great white shark		7.41%		100.00%	60.94%
Oceanic whitetip shark	100.00%	19.18%	–		19.48%
Scalloped hammerhead	–			–	
Shortfin mako	1.55%	14.16%	–	28.93%	16.94%
Silky shark	18.33%	24.96%	–	81.82%	22.38%
Smooth hammerhead		40.00%			40.00%
Thresher shark	66.67%	32.73%			38.81%
Tiger shark	–	50.00%	–		28.57%
Other sharks	82.14%	70.74%	98.28%	99.65%	91.41%
Dolphinfish	8.02%	15.16%	0.98%	37.35%	12.02%
Escolar		4.46%	–	–	2.72%
Ocean sunfish	–	18.64%	100.00%	80.95%	22.09%
Oilfish		15.63%	–	–	7.81%
Pacific king-fish		13.95%	0.36%	26.67%	10.43%
Pomfret	62.50%	85.08%	10.71%	100.00%	84.51%
Spotted Opah		61.11%	82.00%	96.83%	93.80%
Other fishes	–	76.33%	29.70%	26.30%	64.33%
Tuna	0.42%	4.70%	2.61%	1.23%	3.10%
Billfish	2.15%	6.56%	1.39%	7.39%	6.35%
Shark	21.01%	39.06%	50.69%	85.35%	54.20%
Other fishes	8.35%	64.16%	17.61%	36.02%	54.43%
Sum	3.20%	18.09%	7.74%	9.23%	14.09%

Note: A blank indicates a zero catch; “–” indicates that the discard rate was < 0.01%.

Albatross, Wandering Albatross, Salvin's Albatross, White-chinned Petrel, and Short-tailed Shearwater were identified (Table 2). Most were incidentally caught by the albacore and southern bluefin tuna fleets. The bycatch of seabirds ranged from 0 to 4 birds per haul. Seventy percent (43/61) were dead, and thirty percent (18/61) were released live. The bycatch rates ranged from 0.0002 (0.0000–0.0009) per 1000 hooks in the TropIND area to 0.0158 (0.0120–0.0205) per 1000 hooks in the SIND.

Eighty-four sea turtles were caught incidentally, including fifty-six Olive Ridley turtles, nine leatherback turtles, six loggerhead turtles, three green turtles, and ten unidentified turtles. Most were incidentally caught by the bigeye tuna fleet (Table 2). The sea turtles were a bycatch in tropical areas, especially within 10°N to 7°S by 48° to 90°E. The bycatch of sea turtles ranged from 0 to 4 turtles per haul. Fifty seven percent (48/64) were dead, and forty three percent (36/84) were released live. The bycatch rate ranged from 0.0000 (0.0000–0.0010) per 1000 hooks in the SIND to 0.0112 (0.0088–0.0141) per 1000 hooks in the TropIND.

It was estimated that 311–715 seabirds and 1127–1856 turtles were incidentally caught annually during 2004 and 2008 (Table 6). This included 69–181 Indian Yellow-nosed Albatross, 19–50 Wandering Albatross, 30–74 Sooty Albatross, and 4–10 Salvin's Albatross. For turtles, the estimates were 782–1245 Olive Ridley turtles, 137–217 leatherback turtles, and 35–71 green turtles. These numbers decreased annually due to decreased fishing effort.

4. Discussion

4.1. Reasons for discards

The reasons for discards or live releases were small sizes, a lack of economic value, and depredation by sharks or cetaceans (IOTC, 2006, 2009). Furthermore, management measures, such as quota limitations and size limits, might have affected the discard rates (Welch et al., 2008). Previous studies showed that the discard rate for longline fisheries was approximately 0–40%, and the average discard rate of tuna longline fisheries was 22% (Kelleher, 2005). The average discard rates of Taiwanese large-scale longline fleets in the Indian Ocean were lower than the average, and a high diversity of discard rates was found among fleets. The yellowfin tuna fleet, which operates in coastal areas and can easily return to fishing ports for landing or transshipment, had the lowest discard rate. There are several possible reasons for the high discard rate for the bigeye and southern bluefin tuna fleets. First, these two fleets spend longer times at sea and only transship through carriers to save fuel costs. Therefore, these fleets attempt to retain high-value fish in the fish hold. Second, 70% of the discards of the bigeye tuna fleet were depredated by cetaceans. High sighting rates of dolphin widely distributed in tropical areas reveal the high possibility of depredation. Third, quota limitations exist for bigeye and southern bluefin tuna. Due to economic factors, bigger fish fetch a higher price in the Japanese sashimi market. When the CPUE is high, fishermen have

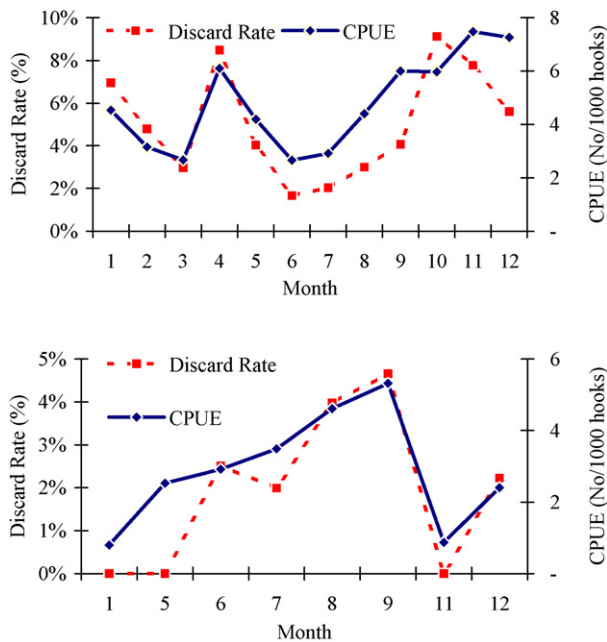


Fig. 2. Discard rate and catch per unit effort (CPUE) of bigeye tuna (top) and southern bluefin tuna (bottom) by month.

a better chance of catching more fish, and they might discard or release smaller fish to maximize their profits due to quota limitations. These results are similar to those for small-scale fisheries in the Mediterranean (Tzanatos et al., 2007), which underscores the economic impacts of catch limits (Welch et al., 2008).

Sharks are a significant component of the bycatch of Taiwanese longline fleets (3.9–10.3%), with blue shark being the dominant species. The IOTC has requested member countries to report shark catch information by species since 2005 because shark-specific species data are limited (IOTC, 2005b). Ten species of shark were recorded in this study. Those species of low value for both meat and fins are released live or discarded. Some shark meat is of high value in Taiwan; fishermen will transship such shark meat to Taiwan for domestic consumption. The discard rates of shark by the Taiwanese fleets were low compared with some other longline (Beerkircher et al., 2002) and gillnet fisheries (Rogan and Mackey,

2007). The survival rates of live-release sharks are high in longline fisheries (Campana et al., 2005; Campana et al., 2009). There are many ways for fishermen to reduce the shark bycatch, including selection of appropriate line material and the use of larger hooks (Piovano et al., 2010), and they are encouraged to release sharks alive for conservation purposes. In addition, some mitigating measures have been suggested or are under development (Swimmer et al., 2008; Ward et al., 2008; Yokota et al., 2006). Those experiments are expected to contribute to a reduction in the bycatch of shark species.

The rate of the seabird bycatch varied by season (Gales et al., 1998; Stehn et al., 2001; Tuck et al., 2003). Most species sighted in tropical areas are species of least conservation concern. Due to the different foraging behaviors of tropical seabirds, many boobies and terns do not follow ships or feed on discarded material (Blaber et al., 1995, 1998), resulting in low bycatch rates and mortality compared to albatrosses in temperate areas. However, bycatch rates for albatross were high in winter in the southern Indian Ocean. The estimated bycatch of Indian Yellow-nosed Albatross was approximately 113–250 individuals. Seventy Wandering Albatross died. Compared to albatrosses, the bycatch of the White-chinned Petrel was around 20, suggesting that bycatch of this species is of lesser concern. Although bycatch estimation was not high, due to the uncertainty of mortality estimates, regular monitoring is likely to be a more reliable method to monitor the sustainability of seabird populations. Considering the endangered status of some species of albatross (Tuck et al., 2001), mitigation measures should be required to reduce the incidental catch of seabirds (Gilman, 2001; IOTC, 2010; Melvin, 2001).

4.2. Sea turtle conservation

In accordance with available references, the Olive Ridley is the most abundant sea turtle in the Indian Ocean with around 120,000 turtles nesting. Hawksbills have the fewest nesting pairs at approximately 4600 (Shanker and Pilcher, 2003). One of the most dramatic impacts of fisheries is the incidental mortality caused by trawl nets, with more than 100,000 turtles having been caught by accident in the last decade (Shanker et al., 2004). A previous study showed that the longline bycatch numbers of loggerhead and leatherback turtles were 6000 and 4000, respectively (Lewison et al., 2004b). In this study, the estimated annual incidental catch numbers were around 1180–1800, most of which were Olive Ridley turtles. The

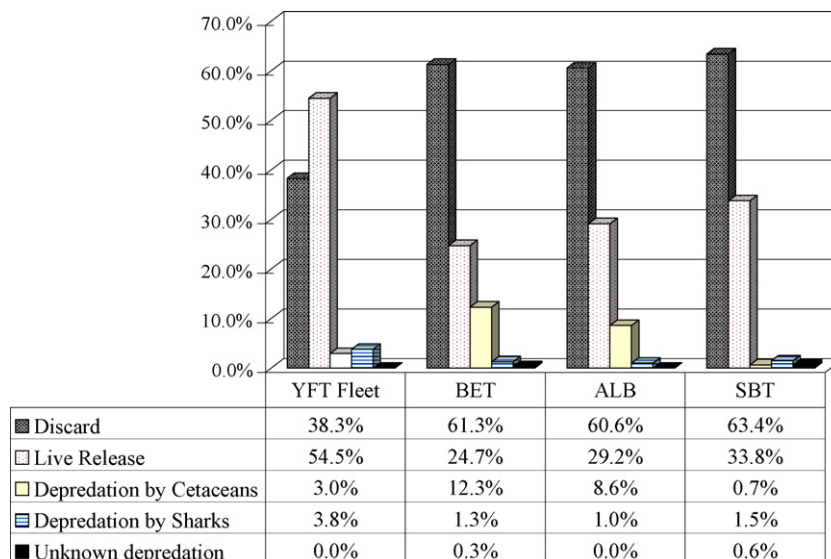


Fig. 3. Reasons for discards by fleet.

Table 4
Sighted ecologically related species.

Taxa	Species	Scientific name	IUCN status*
Seabirds	Grey-headed Albatross	<i>Alassarche chrysostoma</i>	Vulnerable
	Wandering Albatross	<i>Diomedea exulans</i>	Vulnerable
	Sooty Albatross	<i>Phoebetria fusca</i>	Endangered
	Light-mantled Albatross	<i>Phoebetria palpebrata</i>	Near threatened
	Indian Yellow-nosed Albatross	<i>Thalassarche carteri</i>	Endangered
	Shy Albatross	<i>Thalassarche cauta</i>	Near threatened
	Black-browed Albatross	<i>Thalassarche melanophrys</i>	Endangered
	Salvin's Albatross	<i>Thalassarche salvini</i>	Vulnerable
	Southern Giant Petrel	<i>Macronectes giganteus</i>	Least concern
	Northern Giant Petrel	<i>Macronectes halli</i>	Least concern
	Black Noddy	<i>Anous minutus</i>	Least concern
	Cattle Egret	<i>Bubulcus ibis</i>	Least concern
	South Polar Skua	<i>Catharacta maccormicki</i>	Least concern
	Cape Petrel	<i>Daption capense</i>	Least concern
	Asian Koel	<i>Eudynamys scolopaceus</i>	Least concern
	White-bellied Storm-Petrel	<i>Fregetta grallaria</i>	Least concern
	Barn Swallow	<i>Hirundo rustica</i>	Least concern
	Sooty Gull	<i>Larus hemprichii</i>	Least concern
	Cape Gannet	<i>Morus capensis</i>	Vulnerable
	Wilson's Storm-Petrel	<i>Oceanites oceanicus</i>	Least concern
	White-chinned Petrel	<i>Procellaria aequinoctialis</i>	Vulnerable
	Grey Petrel	<i>Procellaria cinerea</i>	Near threatened
	Grey Shearwater	<i>Procellaria cinerea</i>	Near threatened
	Spectacled Petrel	<i>Procellaria conspicillata</i>	Vulnerable
	Flesh-footed Shearwater	<i>Puffinus carneipes</i>	Least concern
	Short-tailed Shearwater	<i>Puffinus tenuirostris</i>	Least concern
	Bridled Tern	<i>Sterna anaethetus</i>	Least concern
	Lesser Crested Tern	<i>Sterna bengalensis</i>	Least concern
	Black-naped Tern	<i>Sterna sumatrana</i>	Least concern
	Rosy Starling	<i>Sturnus roseus</i>	Least concern
	Masked Booby	<i>Sula dactylatra</i>	Least concern
	Brown Booby	<i>Sula leucogaster</i>	Least concern
	Red-footed Booby	<i>Sula sula</i>	Least concern
Cetaceans	Blackfish	Family Delphinidae	
	Risso's dolphin	<i>Grampus griseus</i>	Least concern
	Melon-headed whale	<i>Peponocephala electra</i>	Least concern
	False killer whale	<i>Pseudorca crassidens</i>	Data deficient
	Pantropical spotted dolphin	<i>Stenella attenuata</i>	Least concern
	Spinner dolphins	<i>Stenella longirostris</i>	Data deficient
	Common Bottlenose dolphin	<i>Tursiops truncatus</i>	Least concern
Turtles	Loggerhead turtle	<i>Caretta caretta</i>	Endangered
	Green turtle	<i>Chelonia mydas</i>	Endangered
	Leatherback turtle	<i>Dermochelys coriacea</i>	Critically Endangered
	Hawksbill turtle	<i>Eretmochelys imbricata</i>	Critically Endangered
	Olive Ridley turtle	<i>Lepidochelys olivacea</i>	Vulnerable

Note: The International Union for the Conservation of Nature (IUCN) status was downloaded from www.iucnredlist.org.tw on May 23, 2010.

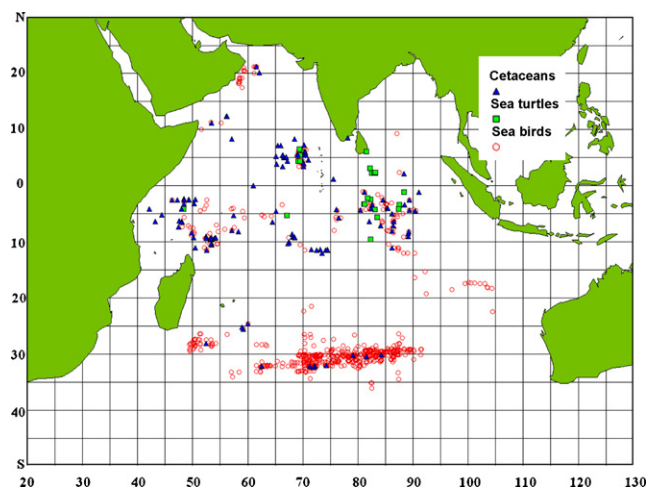


Fig. 4. Distribution of sightings of ecologically related species.

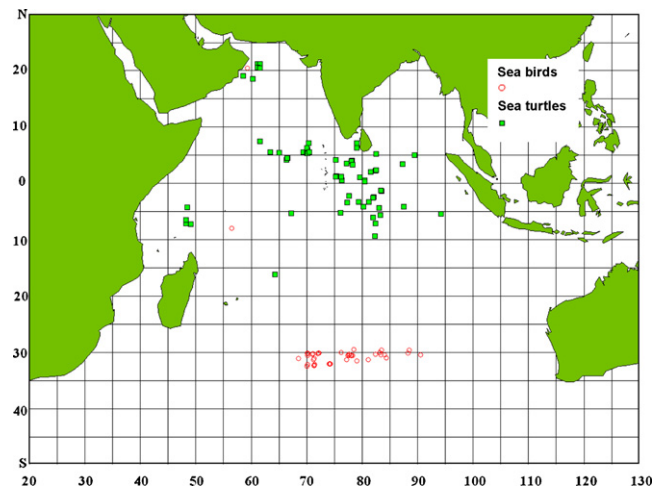


Fig. 5. Distribution of the incidental catch of seabirds and sea turtles.

Table 5
Bycatch per unit effort (BPUE) of seabirds and sea turtles by area.

Taxa	Area	BPUE (no. per 1000 hooks)	
		Point estimate	95% CI
Seabirds	NIND	0.0009	0.0001–0.0032
	TropIND	0.0002	0.0000–0.0009
	TempIND	0.0000	0.0000–0.0021
	SIND	0.0158	0.0120–0.0205
Sea turtles	NIND	0.0045	0.0031–0.0082
	TropIND	0.0112	0.0088–0.0141
	TempIND	0.0006	0.0000–0.0032
	SIND	0.0000	0.0000–0.0010

Table 6
Estimated annual numbers of the incidental catch of seabirds and sea turtles.

Species	2004	2005	2006	2007
<i>Seabirds</i>	715	455	400	311
Indian Yellow-nosed Albatross	181	104	95	69
Wandering Albatross	50	29	26	19
Sooty Albatross	74	45	41	30
Salvin's Albatross	10	6	5	4
Other albatrosses	251	144	132	96
White-chinned Petrel	44	27	25	19
Short-tailed Shearwater	10	6	5	4
Other seabirds	95	94	71	70
<i>Sea turtles</i>	1856	1732	1197	1127
Olive Ridley turtle	1245	1206	824	782
Leatherback turtle	217	186	150	137
Loggerhead turtle	119	110	91	88
Green turtle	71	44	36	35
Unknown turtles	204	186	96	85

Unit: number of individuals.

numbers also included 70 loggerhead and 127 leatherback turtles. Estimates from this research showed a decrease in the trend due to a decrease in Taiwanese longline fishing effort. However, it is necessary to be cautious and continue encouraging fishermen to test the efficiency of circle hooks to avoid the bycatch of sea turtles (Brazner and McMillan, 2008; Read, 2007).

4.3. Cetacean interactions

The cetacean bycatch is high for some purse-seine and gillnet fisheries (Hall et al., 2000; Rogan and Mackey, 2007; Romanov, 2001). Most of the cetacean research that has been carried out in the Indian Ocean has focused on coastal waters (Amir et al., 2002; Corbett, 1994; Guissamulo and Cockcroft, 2004), and little has been conducted on the open sea (Ballance and Pitman, 1998). In the Indian Ocean, fishing gear (mainly gillnets) poses threats to cetaceans (Brotons et al., 2008a; Kiszka et al., 2009). The estimated incidental catch of cetaceans by longline fisheries is very small. On the other hand, depredation by cetaceans is a serious problem for longline fisheries (IOTC, 2007). Many bigeye tunas are discarded due to depredation by cetaceans. When depredation rates are high, the only option available to most fishermen is to move to other fishing grounds. Developing mitigation measures is necessary to avoid depredation as well as bycatch (Brotons et al., 2008b).

4.4. Conservation implications

For stock assessment of tuna and other fisheries resources, including discard data in the assessment can improve the ability to detect strong year-classes. In addition, ignoring discard data can lead to the conclusion that no recovery of resources has occurred despite large reductions in the total allowable catch (Punt et al., 2006). These discard analyses could be provided to IOTC and the

Commission for the Conservation of Southern Bluefin Tuna (CCSBT) for further tuna stock assessment.

Incidental catch numbers are decreasing because fishing efforts have decreased in recent years. However, caution should be exercised, as the data are limited. Therefore, this research should be considered to be preliminary, and analyses that are more comprehensive and further data collection are needed. The IOTC has adopted measures to request information and take steps to conserve ecologically related species, and to reduce incidental catch, especially sharks (IOTC, 2009). This information regarding shark species-specific and other bycatch species could be used for ecological risk analysis with limited data.

Due to budget and personal limitations, it is important to set priorities for observer programs. We identify areas of concern for incidentally affected species. Observer coverage rates should be higher in these areas of particular concern. Countries and related Regional Fisheries Management Organizations could set aside specific areas for conservation by designating endangered species of albatross and areas of interest for sea turtles conservation, and by requiring mitigation measures to be taken.

Education and outreach are the first tasks required and should be continued to conserve marine resources. The government of Taiwan has disseminated posters, sheets, and booklets on the use of mitigation measures and the identification of seabird and sea turtle species to fishermen for outreach and education purposes. The Wild Bird Federation of Taiwan (WBFT) has conducted a preliminary educational program for the Taiwanese fishermen in Port Louis, Mauritius in 2005 and published a seabird identification guideline in 2010. These materials could improve the knowledge of fishermen and assist them in taking conservation measures.

The Taiwanese government has established regulations for conserving ecologically related species, some of which are in accordance with recommendations adopted by the IOTC and CCSBT, such as the prohibition of shark finning since 2005 and the mandatory installation of bird-scaring lines south of 30°S since 2004 (adjusted to south of 28°S in 2007 and south of 25°S in 2009), and accompany one more mitigation measures to avoid the bycatch of seabirds. Sea turtles mitigation measures (with de-hookers onboard) and limitations on the number of fishing vessels and areas for specific fleets could also contribute. To ensure compliance, the Taiwanese Government has requested that those vessels operating in southern areas provide evidence of setting tori lines, such as providing receipts for the purchase of tori lines and photos of the tori lines installed on the vessels. These actions should be effective in reducing incidental catches. Continuing to monitor fisheries and collect data through observer programs is necessary to ensure conservation and compliance.

5. Conclusions

This study provides an overview of the discard rates and incidental catches of Taiwanese longline fisheries in the Indian Ocean from temporal and spatial perspectives. Our findings identify hot spots for ecologically related species, so that setting priorities for the observation of such areas can be considered. In addition, outreach and conservation measures are required. For future research and conservation, more international cooperation on research would be helpful to ensure the sustainability of marine ecosystems and fisheries.

Acknowledgements

We would like to thank the observers for their effort on board to collect this valuable information and the Fisheries Agency for providing relevant bycatch information. This project was funded

by the Fisheries Agency of the Council of Agriculture, Taiwan (98AS-10.1.1-FA-F6 (3)). We are grateful to Dr. Edward Melvin for providing valuable comments and to the anonymous reviewers for their constructive suggestions regarding this manuscript.

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