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Pelagic megafauna bycatch in the tuna longline fisheries off India

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ABSTRACT

To assess the diversity and abundance of pelagic megafauna caught in the tuna longline survey in the seas around India, data was collected and analysed from survey voyages of four research longliners of the Fishery Survey of India (FSI) during 2004-2010. Study was conducted by operating 11.99 million hooks in three regions of seas around India, i.e., eastern Arabian Sea, western Bay of Bengal and Andaman and Nicobar waters. Significant variations in the diversity and abundance of large pelagics were observed among the three regions of the study area. Besides the target species (yellowfin tuna, *Thunnus albacares*), 60 species of large pelagics and sea turtles were incidentally caught. Indo-Pacific sailfish, *Istiophorus platypterus*, was the main bycatch species. In the order of abundance, pelagic stingray (*Pteroplatytrygon violacea*), common dolphinfish (*Coryphaena hippurus*), pelagic thresher (*Alopias pelagicus*), skipjack tuna (*Katsuwonus pelamis*), and long snouted lancetfish (*Alepisaurus ferox*), were the other important species recorded. Of the three species of sea turtles caught, olive ridley, *Lepidochelys olivacea* was prominent. Sea birds and cetaceans were not represented in the longline bycatch of seas around India. Length-weight relationship of 34 species and spatial distribution of seven species are presented and discussed. This study provides information on the relative abundance, size structure and sex ratio of the pelagic megafauna of the seas around India which should be useful for identifying management measures for these ecologically and economically important resources.

Key words: bycatch, longline, sea turtle, shark, tunas, billfish, lancetfish, pelagic stingray

INTRODUCTION

Pelagic longline fishery targeting tunas and swordfish catches a number of other species as bycatch. The ecological, social and economic implications of bycatch in the marine fisheries are becoming an increasingly prominent international concern (Gilman *et al.* 2008) and the importance of documentation and quantification of bycacth in different fishing methods is being recognized world over. The composition of the bycatch in the tuna longline fishery in the seas around India shows many interesting species which are hitherto not reported or poorly documented. Fishery Survey of India (FSI) is making all efforts to record the abundance and distribution pattern of major bycatch species of the longline fishery in the seas around India. Bhargava *et al*. (2002), Somvanshi *et al*. (2005), Varghese *et al*. (2007, 2010[a]) and Kar *et al*. (2011) has described the bycatch of tuna longline survey in the Indian seas. The present paper is an update on the diversity, abundance and length-weight structure of large pelagic species bycaught during the tuna longline survey in the seas around India.

MATERIALS AND METHODS

Data collected onboard four tuna longline survey vessels of FSI during January 2004 to December 2010 were anlaysed for studying the distribution, abundance and biology of these species. The vessels, *Matsya Vrushti* (OAL 37.5 m, GRT 465 t, Mumbai Base), and *Yellow Fin* (OAL 36.0 m, GRT 290 t, Goa Base) operated from Mumbai and Goa surveyed the west coast of India (eastern Arabian Sea), while the other two vessels, *Matsya Drushti* (OAL 37.5 m, GRT 465 t) and *Blue Marlin* (OAL 36.0 m, GRT 290 t) belonging to Chennai and Port Blair Base surveyed the east coast (Bay of Bengal and Andaman and Nicobar waters). Conventional Japanese multifilament longline with 5 hooks per basket was operated from the vessels *Yellow Fin* and *Blue Marlin*, whereas, the other two vessels operated monofilament longline gear with 7 hooks per basket. Every month, these vessels were deployed for voyages of 20 days duration, and about 15 longline operations (sets) were conducted in each voyage, operating an average of 9000 hooks. Shooting of the line commences before sunrise and is completed in about 2-2.5 hours. On an average 550 hooks are operated in a

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set. Immersion time of 5 hours is allowed and hauling is done in the afternoon starting from the initially shot end.

The fish caught during the survey, after the identification, were subjected to morphometric measurements using a measuring tape to the nearest cm and then weighed using digital weighing balance having a precision of 1.0 kg. The fish were dissected out to study their sex, maturity stages, stomach condition etc. For data analysis, seas around India was divided in to three regions *viz*., eastern Arabian Sea, western Bay of Bengal and Andaman and Nicobar waters. Hooking Rate (HR), the number of fish caught in 100 hooks and Catch Rate (CR), weight of fish caught in kg per 1000 hooks operated was expressed as relative abundance index.

To study the structure and ecological dynamics of megafauna community, the following indices of richness, diversity and evenness were calculated.

(a) Species richness (*s*) was estimated as the total number of species sampled in each area.
(b) Diversity indices: Simpson, Shannon, Brillouin, Margalef, and Fisher's alpha.
(c) To estimate the degree of equitability of the distribution, the Pielou's evenness, *E* was calculated.

The length (total length, TL, cm)-weight (total weight, W, g) relationship was estimated by linear regression on the transformed equation given by LeCren (1951). Fulton's Condition Factor (K) and relative condition factor (Kn) also were determined using length and weight data following LeCren (1951).

The software package PAST v. 2.00 (Hammer *et al*., 2001) was used for the statistical analyses.

RESULTS

a). Abundance and diversity

During the period 2004-2010, the longline survey vessels operated 11,99,177 longline hooks in the seas around India (Figure 1). The survey yielded a total catch of 7699 specimens (2875 specimens from eastern Arabian Sea, 2388 from western Bay of Bengal and 2486 from A&N waters) at a HR of 0.64 (table 1). Catch consisted of 61 species, including two pomfrets; three carangids; 22 sharks; two dolphinfishes; three rays; five billfishes; three oceanic tunas; three neritic tunas; two barracudas; three sea turtles and twelve other species. The targeted species, yellowfin tuna constituted 34.5% of the total catch. Major bycatch species caught were Indo-Pacific sailfish, *Istiophorus platypterus* (9.47%); pelagic stingray, *Pteroplatytrygon violacea* (9.11%); common dolphinfish, *Coryphaena hippurus* (7.55%); pelagic thresher, *Alopias pelagicus* (6.12%); skipjack tuna, *Katsuwonus pelamis* (5.86%) and long snouted lancetfish, *Alepisaurus ferox* (4.07%). Maximum value for Species richness, s was recorded in the Andaman and Nicobar waters (45), while in the Bay of Bengal, this index was 31 and the *s* calculated for Arabian Sea was 43 (table 2). Diversity indices and Pielou's evenness index also were higher for the Andaman and Nicobar waters.

In the eastern Arabian Sea, *I. platypterus* remained the dominant bycatch species, contributing 16% of the total catch by number. *C. hippurus* (13.81%), *K. pelamis* (10.54%), *P. violacea* (5.43%) and *A. ferox* (4.45%) were the other dominant bycatch species recorded. Bycatch of sharks were not significant in this area. Twenty-seven numbers of sea turtles were incidentally caught from eastern Arabian Sea during the study period. *P. violacea* was the dominant bycatch species from the western Bay of Bengal. *C. hippurus* (6.63%), *I. platypterus* (6.63%), *K. pelamis* (4.88%) and *Carcharhinus melanopterus* (3.55%) were the other dominant bycatch species from this area. Incidental catch of sea turtles was highest in this area, in comparison with other two areas surveyed. In the Andaman and Nicobar waters, pelagic sharks were the most important bycatch group. Pelagic thresher, *A. pelagicus* (16.71%), *P. violacea* (12.36%), *Alopias superciliosus* (5.96%), *A. ferox* (4.99%), *Alopias vulpinus* (4.47%) were the major bycatch species recorded from this region. In comparison with other areas, sea turtle interaction was lowest in the Andaman and Nicobar waters.

b. Distribution pattern of major species

Figure 2 describe the distribution patterns of major bycatch species/groups in the study area. Bycatch of *I. platypterus* was prominent in the Lat. 15-18° N of the eastern Arabian Sea. Maximum hooking rate for sharks were recorded from the Lat. 9° N of Andaman and Nicobar waters. *P. violacea* bycatch was significant in the area between Lat. 6-9° N of western Bay of Bengal. *C. hippurus* was caught in appreciable quantities from the Arabian Sea in the latitudes 10°-14° N and 20-22° N. In the eastern Arabian Sea, *A. ferox* was recorded from the southern latitudes only (Lat. 7 to 16° N). Incidental catch of sea turtles were maximum in the area between lat. 15-18° N of western Bay of Bengal. Two species of sea turtles (olive ridley, *Lepidochelys olivacea* and green, *Chelonia mydas*) were identified in the longline bycatch from the western Bay of Bengal, one species (olive ridley) from the Andaman and Nicobar waters, whereas three species (olive ridley, green and hawksbill, *Eretmochelys imbricata*) were recorded in the longline bycatch from the eastern Arabian Sea.

c. Size structure, length-weight relationship and sex ratio of major species

Table 3 presents the length and weight and length-weight relationship identified for large pelagic predatory fishes of the seas around India. The 'a' (constant) values in the length-weight relationships were in the range from 0.00009 (*C. Albimarginatus*) to 345.2 (*Mola mola*), whereas, the exponent (b) calculated ranged between 3.86 for *C. albimarginatus* and 1.14 for *M. mola*. Linear regression performed on the 'log a' and 'b' values of all species indicated a negative correlation (figure 3) and the formula is given by y = -0.415x + 2.058; R^2 = 0.928. The mean value for b was 2.94 (SE=0.090), and the median value of b was 3.02, indicating a general isometry in the length-weight relationships (Table 4). The R^2 values in the length weight relationships were in the range of 0.62 (for *A. solandri*) to 0.98 (for *S. zygaena*), indicating good fit of the values. The mean values for Fulton's Condition Factor was in the range of 0.16 (A. ferox) to 4.29 (*M. mola*) and Relative Condition Factor was in the range of 0.89 (*C. obscurus*) to 1.70 (*E. bipinnulata*). Sex ratio (F:M) of major bycacth species of seas around India were in the range of 1:0.125 (*C. longimanus*) to 1:13 (*C. dussumieri*) (Table 5).

DISCUSSION

Fisheries bycatch, the incidental take of undesirable size or age classes of target fish species, or to the incidental take of other non-target species, can have direct effects on a single species that is incidentally caught, but can also lead to changes at the community or ecosystem level (Lewison, *et al*., 2004). Identifying and quantifying is the first step in management of the bycatch. Pelagic megafauna bycatch in the tuna longline fisheries off India is consisting of 60 species of large pelagics and sea turtles. Indo-Pacific sailfish, *I. platypterus*, was the main bycatch species. In the order of abundance, pelagic stingray (*P. violacea*), common dolphinfish (*C. hippurus*), pelagic thresher (*A. pelagicus*), skipjack tuna (*K. pelamis*) and long snouted lancetfish (*A. ferox*) were the other dominant species recorded. However, sharks formed the largest group representing the bycatch megafauna in the Indian longline fishery. Incidentally caught sea turtles were represented by three species, olive ridley, green and hawksbill. Sea birds and cetaceans, reported to form a part of longline catch in the Indian Ocean (Huang and Liu, 2010) is never reported in the longline catch of the seas around India. Our study has documented many coastal species in the bycatch of tuna longline survey. This can be attributed to the presence of two archipelagos, *viz.*, Lakshadweep and Andaman & Nicobar in the study area. The coastal species were mainly caught in the longline stations near the islands.

Huang and Liu (2010) had documented 40 bycatch species in the large scale tuna longline fishery by Taiwanese vessels in the Indian Ocean. In the seas around India, Somvanshi *et al*. (2005) documented 25 bycatch species in the tuna longline survey, whereas Kar *et al*. (2011) has documented 30 bycatch species in the tuna longline survey conducted in the Indian EEZ around Andaman and Nicobar waters. Both these earlier studies in seas around India reported sharks as the dominant bycatch group. Kar *et al*. (2011) reported that pelagic shark bycatch constituted 37.8% of the longline catch recorded from the Andaman and Nicobar waters during 2003-2010. Average HR for sharks for sharks in their study was 0.23 no/100 hooks, whereas the average HR of sharks from the Andaman and Nicobar waters in our study was 0.22.

Our study reveals that, Indo-Pacific sailfish, *I. platypterus* was the dominant bycatch species in the tuna longline survey of the seas around India. Varghese *et al*. (2004) reported that *I. platypterus* was caught from the northwestern Indian EEZ at a HR of 0.16 numbers in 100 during the period 1989-2000. The forklength of specimens caught in their study were in the range of 100-260 cm, and the length weight relationship established was $W = 0.0069L^{1.5596}$. Ganga *et al*. (2012) reported that the length range of sailfish landed by commercial longliners and gillnetters at Cochin Fisheries harbour during 2005-2008 was 80-230 cm and the length-weight relationship was estimated as $0.024L^{2.65}$. Sailfish specimens caught in our study was in the total length range of 84-303 cm, whereas the length-weight relationship identified was given by $W = 0.0650L^{2.3810}$. Indo-Pacific sailfish formed 1.6% of the total catch of Taiwanese large scale tuna longline fishery in the Indian Ocean (Huang and Liu, 2010).

Pelagic stingray, *P. violacea* was the second most prevalent bycatch species in the longline fishery off India. Somvanshi *et al*. (2009) reported hooking of pelagic stingray at a HR of 0.06 per 100 hooks in the tuna longline survey conducted in the seas around India during the period 2005-2007. The disc width (DW) of the specimens caught was in the range of 40-62 cm, weighing 2.0-5.6 kg. Jellyfish, oceanic squids, argonauts, swimming crabs, pelagic shrimps, euphausiids and finfish were the main components of diet of this species in their study. Egg bearing females of this species were reported during December-March. Pregnant females were caught during May and parturition was observed during June-September in the Arabian Sea (Somvanshi *et al*., 2009). In our study, maximum HR for this species were recorded from the Andaman and Nicobar waters (0.077), followed by Bay of Bengal region (0.064) while the least was from the Arabian Sea (0.036) and the collected specimens were in the DW range of 39-59 cm, weighing 2-6 kg.

Common dolphinfish, *C. hippurus* was caught from the Indian seas at a HR of 0.048 in 100 hooks. Landing of common dolphinfish in appreciable quantities by Indian tuna longliners have previously been reported by Benjamin and Kurup (2012) and Varghese *et al*. (2013). In the Taiwanese large scale tuna longline fishery in the Indian Ocean, dolphinfish contributed 1.1% to the total catch (Huang and Liu, 2010).

As reported in the earlier investigations on the bycatch in the tuna longline survey in the seas around India (Varghese *et al*., 2007, Kar *et al*., 2011), pelagic thresher, *A. pelagicus* was the next major species in our study, contributing 6.12% of the longline catch. Kar *et al*. (2011) reported that the pre-caudal length (PCL) of pelagic thresher caught from Andaman and Nicobar waters were in the range of 50-135, weighing 2-70 kg and the length-weight relationship established was $w = 0.00002PCL^{3.01}$, whereas the samples caught in our study was in the total length range of 75-323 cm, weighing 1-75 kg and the length-weight relationship established was $w = 0.0380TL^{2.4850}$.

Somvanshi *et al*. (2008) reported that, during the period 2005-07, skipjack tuna (*Katsuwonus pelamis*) were caught at a HR of 0.05 and 0.02 numbers in 100 hooks by monofilament and multifilament longlining respectively in the Indian EEZ, whereas in our study, HR recorded for this species was 0.04.

Distribution pattern of *A. ferox* in the Indian EEZ was studied by Varghese *et al*. (2010[b]), reporting that the existence of perennial Oxygen Minimum Zone (OMZ) in the northern Arabian Sea restricted the distribution of this species in the Arabian Sea. Northern limit of this species in the Arabian Sea part of Indian EEZ is reported to be Latitude 17°N, which was further confirmed by the present study also. Length-weight relationship of the species established in our study ($W = 0.0010TL^{3.0130}$) deviates slightly from the relationship established by Varghese *et al*., 2010[b] ($W = 0.0071FL^{2.7106}$).

Length-weight relationship of large pelagic predators established in our study agrees in general with the values in Fishbase (Froese and Pauly, 2009). The 'a' (constant) values in the length-weight relationships in our study were in the range from 0.00009 (*C. Albimarginatus*) to 345.2 (*M. mola*), whereas, the maximum value for the exponent (b) calculated was for *C. albimarginatus* (3.86) while minimum (1.14) was calculated for *M. mola*. Unusual values for 'a' and 'b' in the length-weight relationship established for *M. mola* can be attributed to the peculiar body shape and growth pattern of this very interesting species. Linear regression performed on the 'log a' and 'b' of the length-weight relationship established in our study indicated a strong negative correlation ($Y= -0.415x+2.058$; $R^2 = 0.928$). Similar observations were made by Artigues *et al*. (2003) while analysing the length weight relationships of Antarctic fishes collected from Weddell Sea and Antarctic Peninsula.

Huang and Liu (2010) reported that 14.09% of the total landings by Taiwanese longline fishery in the Indian Ocean are discarded. However, monitoring of landings by Indian small scale commercial longliners at the Cochin fisheries harbour (by the lead author) revealed that almost all the species recorded in our study, except lancetfish, sea turtles, pomfrets and suckerfish are landed by the Indian small scale longline fishery. Even the pelagic stingray (*P. violacea*), discarded by the longline fishery in other parts of world oceans, were landed and auctioned at the landing centre which are used for local consumption. Further, shark finning is not practiced by the Indian small-scale longline fishery and all the sharks were landed with fins on. Therefore, the level of discards by Indian small scale tuna longline fishery will be much lower than the discards by Taiwanese fishery. However, by analysing the trends in the relative abundance indices, John and Varghese (2009), Romanov *et al*. (2010) and Varghese *et al*. (2011) have documented drastic decline in the abundance of pelagic megafauna including sharks, billfishes and tunas in the Indian Ocean. The situation warrants need for immediate management measures for maintaining healthy stocks of these resources in the Indian Ocean.

CONCLUSION

This study provides information on the relative abundance, size structure and sex ratio of the pelagic megafauna of the seas around India. Further, our study provides distribution pattern of these resources and length-weight relationship of major species in the study area which may be useful to fishermen and to fishery managers for identifying measures for managing these ecologically and economically important resources. However, it should be admitted that the sample sizes of many species, used for length weight relationship and sex ratio analyses were not adequate for reaching to acceptable conclusions. Further studies, for quantifying the impact of fisheries on the oceanic megafauna and for developing effective bycatch mitigation measures for longline fisheries are to be undertaken.

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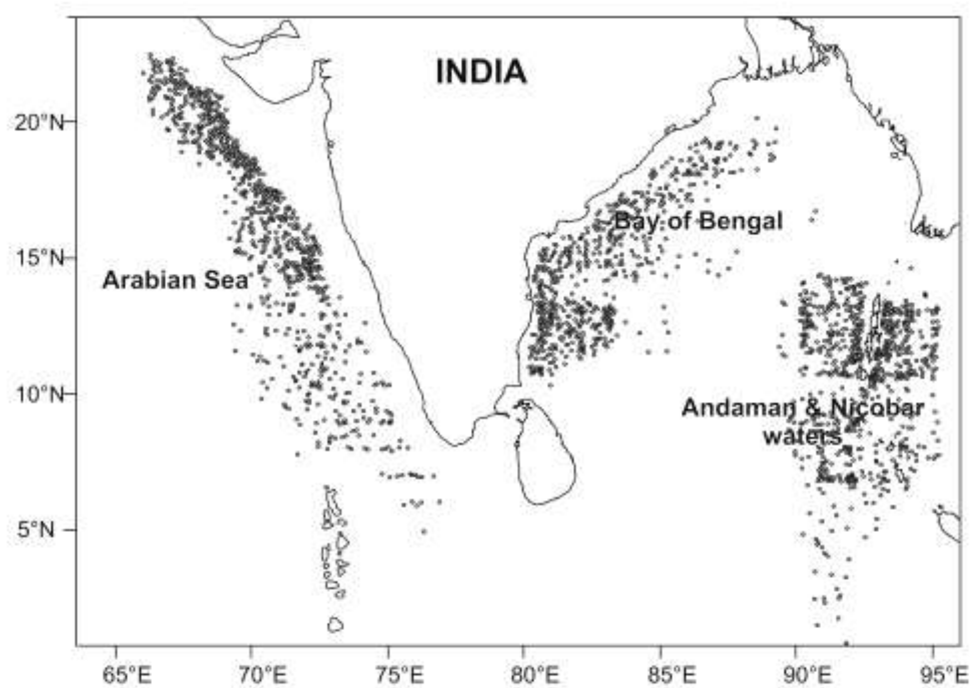
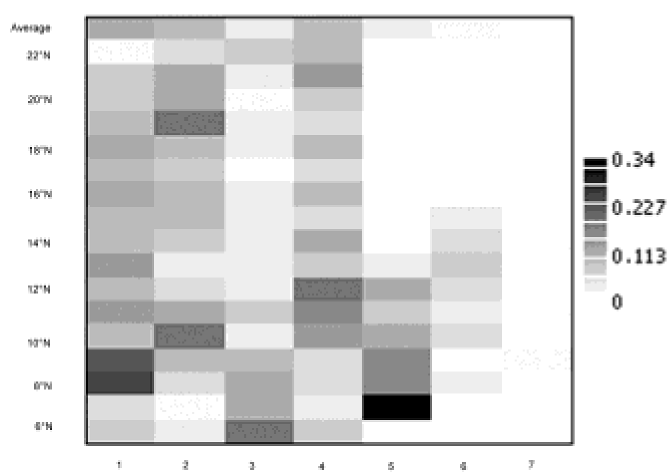
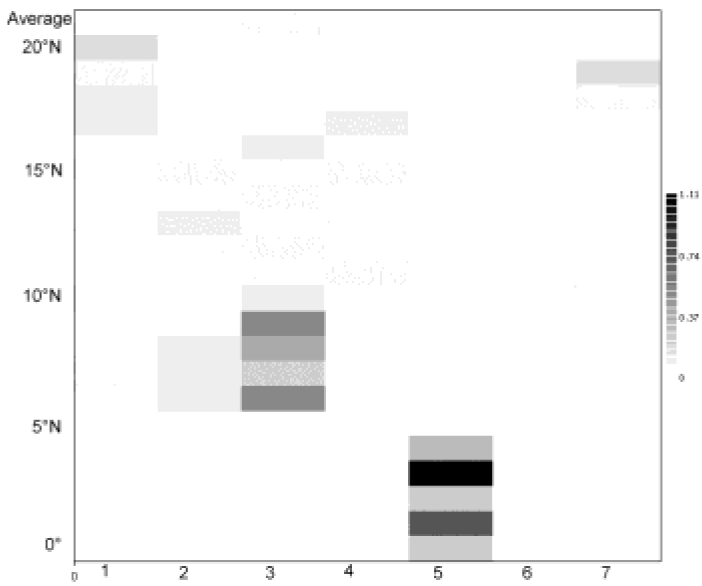


Figure 1. Tuna longline survey stations sampled in the present study (not in scale)

a). Arabian Sea



b). Bay of Bengal



c). Andaman & Nicobar waters

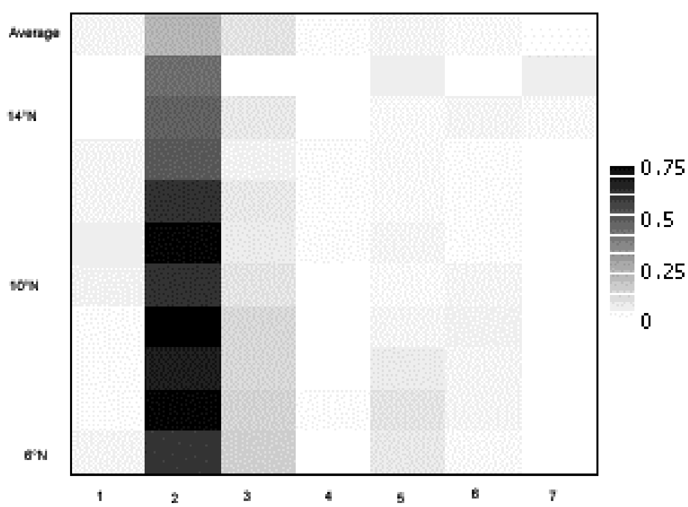


Figure 2. Distribution pattern (HR, number of specimens/100 hooks) of major megafauna bycatch in the tuna longline fisheries off India (1-*I. platypterus*; 2-sharks; 3-*P. violacea*; 4-*C. hippurus*; 5-*A. ferox*; 6-*X. gladius*; 7-sea turtles).

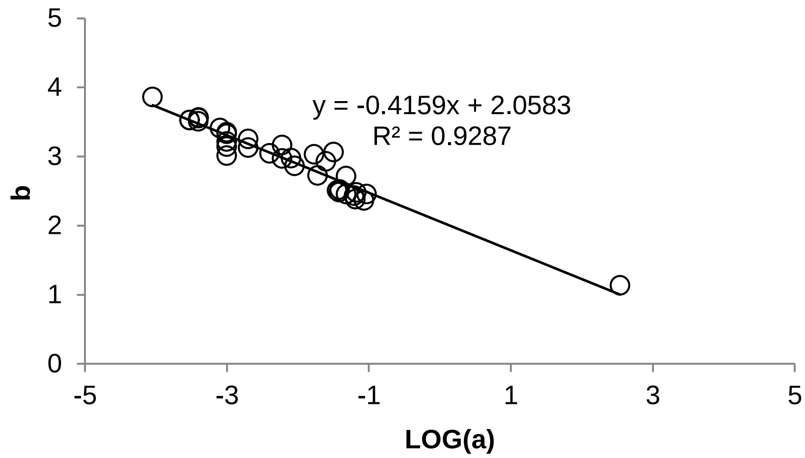


Figure 2. Regression of exponent b and log(Constant a) of the length-weight relationship of bycatch species in the tuna longline survey

Table 1. Hooking rate (HR, number of specimens/100 hooks) and Catch Rate (kg/1000 hooks) of megafauna bycatch in the tuna longline survey off India

Abundance rank	Family	Species Name	ARABIAN SEA			BAY OF BENGAL			A&N WATERS			ALL AREAS		
			HR	%by no	CR	HR	%by no	CR	HR	%by no	CR	HR	%by no	CR
1	Scombridae	*Thunnus albacares*	0.172	25.739	48.768	0.323	51.540	83.929	0.180	28.681	58.693	0.222	34.524	62.988
2	Istiophoridae	*Istiophorus platypterus*	0.107	15.965	25.864	0.042	6.630	10.548	0.029	4.626	6.922	0.061	9.469	14.829
3	Dasyatidae	*Pteroplatytrygon violacea*	0.036	5.426	1.276	0.064	10.180	1.663	0.077	12.349	0.559	0.058	9.105	1.159
4	Coryphaenidae	*Coryphaena hippurus*	0.092	13.809	5.268	0.042	6.630	1.637	0.007	1.167	0.327	0.048	7.546	2.503
5	Alopiidae	*Alopias pelagicus*	0.007	0.974	1.864	0.008	1.198	2.910	0.105	16.693	37.874	0.039	6.118	14.114
6	Scombridae	*Katsuwonus pelamis*	0.071	10.539	2.482	0.031	4.876	1.118	0.009	1.368	0.327	0.038	5.858	1.344
7	Alepisauridae	*Alepisaurus ferox*	0.030	4.452	0.700	0.016	2.609	0.343	0.031	4.988	0.144	0.026	4.065	0.405
8	Carcharhinidae	*Carcharhinus limbatus*	0.028	4.243	3.537	0.008	1.240	1.224	0.033	5.310	9.171	0.024	3.676	4.684
9	Xiphiidae	*Xiphias gladius*	0.022	3.339	2.491	0.012	1.925	2.155	0.018	2.896	3.331	0.018	2.767	2.665
10		Sharks n.i.	0.036	5.426	5.096	0.004	0.599	1.035	0.001	0.161		0.015	2.260	2.146
11	Alopiidae	*Alopias superciliosus*	0.001	0.104	0.235	0.001	0.128	0.268	0.037	5.953	17.375	0.013	2.000	5.922
12	Alopiidae	*Alopias vulpinus*	<0.001	0.070	0.079	0.001	0.171	0.421	0.028	4.465	11.072	0.010	1.520	3.826
13	Carcharhinidae	*Carcharhinus melanopterus*	0.007	0.974	0.691	0.022	3.550	3.647	0.001	0.121	0.443	0.010	1.481	1.528
14	Sphyraenidae	*Sphyraena jello*				0.004	0.599	0.148	0.024	3.781	1.249	0.009	1.403	0.459
15		Sea turtle	0.006	0.939	0.000	0.017	2.695		0.004	0.603		0.009	1.364	0.000
16	Istiophoridae	*Makaira nigricans*	0.005	0.765	2.594	0.006	0.941	3.830	0.006	0.925	3.765	0.006	0.870	3.366
17	Sphyraenidae	*Sphyraena barracuda*	0.005	0.696	0.248	0.011	1.754	0.459	0.001	0.080	0.018	0.005	0.818	0.237
18	Istiophoridae	*Istiompax indica*	0.005	0.730	2.528	0.005	0.855	2.017	0.000	0.040	0.093	0.004	0.546	1.563
19	Scombridae	*Thunnus obesus*	0.000	0.035	0.144	0.001	0.214	0.974	0.007	1.126	3.029	0.003	0.442	1.358
20	Carcharhinidae	*Carcharhinus falciformis*	0.007	0.974	1.019				0.001	0.121	0.252	0.003	0.403	0.448
21	Carcharhinidae	*Carcharhinus sorrah*	0.005	0.800	0.967				0.001	0.161	0.259	0.002	0.351	0.432
22	Carcharhinidae	*Galeocerdo cuvier*	0.001	0.139	0.585	0.001	0.086	0.032	0.005	0.805	5.104	0.002	0.338	1.910
23	Coryphaenidae	*Coryphaena equiselis*	0.006	0.835	0.311							0.002	0.312	0.111
24	Scombridae	*Acanthocybium solandri*	0.000	0.035	0.019	0.001	0.214	0.102	0.004	0.684	0.461	0.002	0.299	0.191
25	Bramidae	*Taractichthys longipinnis*							0.005	0.724	0.278	0.002	0.234	0.092
26	Carcharhinidae	*Carcharhinus dussumieri*	0.004	0.557	0.603							0.001	0.208	0.216

27	Lamnidae	*Isurus oxyrinchus*	0.002	0.243	0.331	0.000	0.043	0.067	0.001	0.201	0.483	0.001	0.169	0.299
28	Echeneidae	*Echeneis naucrates*	0.003	0.452	0.042							0.001	0.169	0.015
29	Carcharhinidae	*Carcharhinus* spp.	0.002	0.348	0.280	0.001	0.086	0.072				0.001	0.156	0.123
30	Sphyrnidae	*Sphyrna lewini*	0.000	0.035	0.163	0.003	0.428	1.223	0.000	0.040	0.174	0.001	0.156	0.496
31	Carcharhinidae	*Carcharhinus macloti*	0.002	0.243	0.193				0.001	0.161	0.141	0.001	0.143	0.116
32	Rachycentridae	*Rachycentron canadum*	0.001	0.209	0.051	0.001	0.128	0.020				0.001	0.117	0.025
33	Molidae	*Mola mola*	0.001	0.174	0.890	0.001	0.128	0.000				0.001	0.104	0.319
34	Carcharhinidae	*Carcharhinus albimarginatus*	0.000	0.070	0.030	0.001	0.128	0.241	0.001	0.080	0.108	0.001	0.091	0.122
35	Scombridae	*Euthynnus affinis*				0.002	0.299	0.013				0.001	0.091	0.004
36	Carcharhinidae	*Carcharhinus amblyrhynchos*							0.002	0.241	0.395	0.001	0.078	0.131
37	Carcharhinidae	*Scoliodon laticaudus*							0.002	0.241	0.431	0.001	0.078	0.143
38	Carangidae	*Elagatis bipinnulata*	0.001	0.174	0.024							<0.001	0.065	0.009
39	Carcharhinidae	*Carcharhinus longimanus*	0.000	0.070	0.023	0.000	0.043	0.005	0.001		0.144	<0.001	0.065	0.058
40	Sphyrnidae	*Sphyrna zygaena*	0.001	0.104	0.457	0.000	0.043	0.040	0.000	0.040	0.176	<0.001	0.065	0.234
41	Bramidae	*Taractichthys steindachneri*							0.001	0.161	0.081	<0.001	0.052	0.027
42	Carcharhinidae	*Carcharhinus obscurus*							0.001	0.161	0.617	<0.001	0.052	0.204
43	Myliobatidae	*Manta birostris*							0.001	0.161	0.264	<0.001	0.052	0.088
44	Sphyrnidae	Sphyrnidae n.i.	0.001	0.104	0.326							<0.001	0.039	0.117
45	Balistidae	*Abalistes stellaris*	<0.001	0.035	0.002				<0.001	0.040	0.005	<0.001	0.026	0.003
46	Istiophoridae	*Kajikia audax*	<0.001	0.035	0.142				<0.001	0.040	0.121	<0.001	0.026	0.091
47	Myliobatidae	*Mobula mobular*				0.000	0.043	0.107	<0.001	0.040	0.050	<0.001	0.026	0.050
48	Carcharhinidae	*Rhizoprionodon acutus*							0.001	0.080	0.136	<0.001	0.026	0.045
49	Gempylidae	*Ruvettus pretiosus*							0.001	0.080	0.101	<0.001	0.026	0.033
50	Carangidae	*Caranx* sp.	<0.001	0.035	0.037							<0.001	0.013	0.013
51	Carangidae	*Carangoides fulvoguttatus*							<0.001	0.040	0.001	<0.001	0.013	<0.001
52	Sphyrnidae	*Sphyrna mokarran*	<0.001	0.035	0.349							<0.001	0.013	0.125
53	Lethrinidae	*Gymnocranius grandoculis*							<0.001	0.040	0.004	<0.001	0.013	0.001
54	Lutjanidae	*Lutjanus malabaricus*							<0.001	0.040	0.008	<0.001	0.013	0.003
55	Scombridae	*Auxis thazard*							<0.001	0.040	0.010	<0.001	0.013	0.003
56	Scombridae	*Gymnosarda unicolor*							<0.001	0.040	0.141	<0.001	0.013	0.047
57	Serranidae	*Cephalopholis sonnerati*							<0.001	0.040	0.004	<0.001	0.013	0.001

58	Serranidae	*Epinephelus bleekeri*	<0.001	0.035	0.005							<0.001	0.013	0.002
59	Tetraodontidae	*Lagocephalus lagocephalus*	<0.001	0.035	0.002							<0.001	0.013	0.001
60		Teleost n.i.							0.001	0.080	0.023	<0.001	0.026	0.008
		TOTAL	**0.7**	**100**	**110.7**	**0.6**	**100**	**120.3**	**0.6**	**100**	**164.4**	**0.6**	**100**	**131.4**

Table 2. Indices of diversity of pelagic megafauna bycatch in the tuna longline survey off India

Diversity index	Arabian Sea	Bay of Bengal	A&N waters
Species richness	43	31	45
Simpson	0.8541	0.7055	0.8579
Shannon	2.351	1.911	2.419
Brillouin	2.32	1.884	2.385
Margalef	5.311	3.87	5.629
Fisher's alpha	7.252	5.055	7.807
Dominance	0.1459	0.2945	0.1421
Pielou's Evenness	0.6251	0.5566	0.6356

Table 3. Length-weight relationship of dominant bycatch species in the tuna longline fisheries off India

Sl. No.	Species	Total Length (cm)		Weight (kg)		Length-weight relationship			K (Av±SD)	Kn (Av±SD)	n
		Min	Max	Min	Max	Constant (a)	Exponent (b)	r^2			
1	*Acanthocybium solandri*	108	149	4	22	0.0090	2.8630	0.6240	0.51±0.11	1.09±0.23	31
2	*Alepisaurus ferox*	90	199	1	7	0.0010	3.0130	0.7470	0.16±0.03	1.50±0.32	51
3	*Alopias pelagicus*	75	323	1	75	0.0380	2.4850	0.6710	0.24±0.11	1.07±0.37	378
4	*Alopias superciliosus*	135	383	15	120	0.0860	2.3630	0.7390	0.26±0.07	1.04±0.21	168
5	*Alopias vulpinus*	119	292	10	70	0.0360	2.5060	0.7350	0.24±0.05	1.04±0.21	114
6	*Carcharhinus albimarginatus*	50	160	1	23	0.0001	3.8590	0.7540	0.50±0.18	0.99±0.34	90
7	*Carcharhinus amblyrhynchos*	76	202	2	80	0.0010	3.3290	0.7740	0.58±0.23	1.27±0.52	53
8	*Carcharhinus dussumieri*	73	163	3	25	0.0020	3.1280	0.9230	0.55±0.09	1.47±0.23	33

9	*Carcharhinus falciformis*	85	223	3	64	0.0040	3.0430	0.9610	0.58±0.08	1.17±0.15	74
10	*Carcharhinus limbatus*	61	243	1	414	0.0004	3.5100	0.8860	0.50±0.15	1.05±0.32	436
11	*Carcharhinus longimanus*	81	195	2	35	0.0190	2.7250	0.8250	0.58±0.31	1.13±0.56	6
12	*Carcharhinus melanopterus*	74	296	3	110	0.0670	2.4800	0.7730	0.56±0.15	1.04±0.25	131
13	*Carcharhinus obscurus*	80	240	2	95	0.0004	3.5548	0.9960	0.63±0.14	0.89±0.06	5
14	*Carcharhinus sorrah*	69	177	1	30	0.0004	3.5640	0.9610	0.53±0.13	0.92±0.18	26
15	*Coryphaena equiselis*	44	132	1	12	0.0390	2.5230	0.8420	0.48±0.19	1.07±0.38	76
16	*Coryphaena hippurus*	11	161	0	15	0.0480	2.4540	0.8180	0.40±0.14	1.05±0.30	523
17	*Elagatis bipinnulata*	57	77	1	2	0.0010	3.1410	0.9200	0.31±0.04	1.70±0.22	7
18	*Galeocerdo cuvier*	165	340	10	206	0.0003	3.5290	0.8880	0.53±0.13	0.97±0.23	31
19	*Istiompax indica*	102	294	5	128	0.0010	3.2180	0.7630	0.40±0.15	1.26±0.45	68
20	*Istiophorus platypterus*	84	303	3	58	0.0650	2.3810	0.7170	0.25±0.07	1.04±0.25	1053
21	*Isurus oxyrinchus*	109	269	10	140	0.0080	2.9740	0.9680	0.78±0.12	1.11±0.17	28
22	*Katsuwonus pelamis*	38	201	1	42	0.0250	2.9310	0.8760	1.96±0.42	1.04±0.22	505
23	*Makaira nigricans*	106	310	15	180	0.0930	2.4560	0.8010	0.50±0.16	1.03±0.23	71
24	*Mola mola*	115	142	75	95	345.20	1.1370	0.9610	4.24±0.71	1.00±0.02	4
25	*Pteroplatytrygon violacea*	39*	62*	2	6	0.0320	3.0650	0.7990	4.15±0.59	1.01±0.15	27
26	*Rachycentron canadum*	64	98	2	6	0.0020	3.2530	1.0000	0.60±0.05	0.99±0.01	2
27	*Sphyraena barracuda*	73	129	2	11	0.0010	3.3500	0.8150	0.55±0.12	1.09±0.24	64
28	*Sphyraena jello*	72	185	1	12	0.0620	2.4350	0.6830	0.50±0.15	1.05±0.30	76
29	*Sphyrna lewini*	143	245	12	75	0.0003	3.5280	0.9710	0.46±0.07	0.96±0.10	10
30	*Sphyrna zygaena*	94	246	4	80	0.0060	2.9690	0.9830	0.59±0.12	1.14±0.23	9
31	*Taractichthys longipinnis*	68	74	6	9	0.0170	3.0330	0.9370	1.98±0.05	1.01±0.02	8
32	*Thunnus albacares*	30	205	1	9	0.0480	2.7160	0.8590	1.27±0.44	1.04±0.31	2104
33	*Thunnus obesus*	112	186	16	100	0.0060	3.1670	0.8700	1.43±0.21	1.04±0.15	28
34	*Xiphias gladius*	61	319	1	150	0.0008	3.4112	0.8587	0.56±0.22	1.02±0.38	295

* Disc Width

Table 4. Descriptive statistics of Constant (a) and Exponent (b) values in the length-weight relationship of bycatch species in the tuna longline survey

Parameter	Constant (a)	Exponent (b)
Minimum	9.00E-05	1.137
Maximum	345.2	3.859
Mean	10.1741	2.94394
Geometric mean	0.00742592	2.88712
Median	0.007	3.023
Standard error	10.1523	0.0896622
Standard deviation	59.1976	0.522816
25th percentile	0.001	2.50075
75 percentile	0.04125	3.33425
Skewness	5.83095	-1.10385
Kurtosis	34	2.86714

Table 5. Sex ratio of dominant bycatch species in the tuna longline fisheries off India

			Sex ratio	
Family	Common name	Species Name	F/M	F:M
Alepisauridae	Long snouted lancetfish	*Alepisaurus ferox*	Hermaphrodite?	
Alopiidae	Pelagic thresher	*Alopias pelagicus*	0.581	1:1.72
Alopiidae	Bigeye thresher	*Alopias superciliosus*	0.674	1:1.483
Alopiidae	Thresher	*Alopias vulpinus*	0.31	1:3.227
Bramidae	Big-scale pomfret	*Taractichthys longipinnis*	0.5	1:2
Carangidae	Rainbow runner	*Elagatis bipinnulata*	1	1:1
Carcharhinidae	Silvertip shark	*Carcharhinus albimarginatus*	0.667	1:1.5
Carcharhinidae	Blacktail reef shark	*Carcharhinus amblyrhynchos*	0.31	1:3.22
Carcharhinidae	Whitecheek shark	*Carcharhinus dussumieri*	0.077	1:13
Carcharhinidae	Silky shark	*Carcharhinus falciformis*	1.182	1:0.846
Carcharhinidae	Blacktip shark	*Carcharhinus limbatus*	0.67	1:1.492
Carcharhinidae	Oceanic whitetip shark	*Carcharhinus longimanus*	8	1:0.125
Carcharhinidae	Hardnose shark	*Carcharhinus macloti*	0.293	1:3.417
Carcharhinidae	Blacktip reef shark	*Carcharhinus melanopterus*	0.747	1:1.339
Carcharhinidae	Dusky shark	*Carcharhinus obscurus*	0.25	1:4
Carcharhinidae	Spot-tail shark	*Carcharhinus sorrah*	0.263	1:3.8
Carcharhinidae	Tiger shark	*Galeocerdo cuvier*	0.368	1:2.714
Coryphaenidae	Pompano dolphinfish	*Coryphaena equiselis*	4.429	1:0.226
Coryphaenidae	Common dolphinfish	*Coryphaena hippurus*	0.773	1:1.294
Dasyatidae	Pelagic stingray	*Pteroplatytrygon violacea*	2.5	1:0.4
Echeneidae	Live sharksucker	*Echeneis naucrates*	All females	
Istiophoridae	Black marlin	*Istiompax indica*	0.579	1:1.727
Istiophoridae	Indo-Pacific sailfish	*Istiophorus platypterus*	0.788	1:1.269
Istiophoridae	Indo-Pacific blue marlin	*Makaira nigricans*	0.333	1:3
Lamnidae	Shortfin mako	*Isurus oxyrinchus*	0.667	1:1.5
Molidae	Ocean sunfish	*Mola mola*	0.5	1:2
Myliobatidae	Giant manta	*Manta birostris*	0.5	01:02
Rachycentridae	Cobia	*Rachycentron canadum*	All females	

Scombridae	Wahoo	*Acanthocybium solandri*	2.8	1:0.357
Scombridae	Kawakawa	*Euthynnus affinis*	0.75	1:1.339
Scombridae	Skipjack tuna	*Katsuwonus pelamis*	0.79	1:1.266
Scombridae	Yellowfin tuna	*Thunnus albacares*	0.556	1:1.798
Scombridae	Bigeye tuna	*Thunnus obesus*	0.647	1:1.545
Sphyraenidae	Great barracuda	*Sphyraena barracuda*	0.148	1:6.75
Sphyraenidae	Pickhandle barracuda	*Sphyraena jello*	0.271	1:3.688
Sphyrnidae	Scalloped hammerhead	*Sphyrna lewini*	0.4	1:2.5
Sphyrnidae	Smooth hammerhead	*Sphyrna zygaena*	All males	
Xiphiidae	Swordfish	*Xiphias gladius*	0.388	1:2.579