

Shark bycatch in the experimental tuna longline fishery in Lakshadweep Sea, India

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Summary

Bycatch from the experimental longline operations in the Lakshadweep Sea were studied. The experiments were conducted on converted Pablo boats, originally used for pole and line fishing operations, to capture skipjack tuna in the Lakshadweep Islands. The overall bycatch rate was very high, with a mean hooking rate of 8.05/1000 hooks compared to the targeted tuna catch (1.75/1000 hooks). Bycatch contributed 82.4% of the catch in comparison to the tuna (17.6%) *Thunnus albacares*, in the longline operations. Silky shark (*Carcharhinus falciformes*) with 89.9% was the dominant shark species followed by *C. amblyrhynchos*, *Galeocerdo cuvier*, *Alopias pelagicus*, *Negaprion acutedens* and *Sphyrna lewini* with 4.7, 2.7, 1.4, 0.7 and 0.7%, respectively. Sharks contributed to 74.1% of the catch, followed by 15.7% sailfishes and 10.2% miscellaneous fishes. Higher bycatch rates were evident during evening hours compared to mornings, but the results were not significant statistically. Studies on the effects of depth on the overall fishing performance and species selectivity failed to establish any significant relationship at a depth range of 35–100 m. Soaking time had a significant effect on bycatch rates. The hooking rate of sharks declined with an increase in soaking time. Considering the high shark bycatch in the fishery, an accurate monitoring of the longline fish catches in the Lakshadweep waters is an important step towards ensuring the sustainability of other populations, especially sharks.

Introduction

High seas tuna fishery in the Indian Ocean is supported mainly by four species: yellowfin tuna (*Thunnus albacares*), bluefin tuna (*T. thynnus*), albacore tuna (*T. alalunga*) and bigeye tuna (*T. obesus*) (Joseph, 1972). India does not have an organized longline fishery for the capture of yellowfin tuna. Converted trawler longliners are operating in many coastal states in India for the catch of large pelagic fishes such as yellowfin tuna and sharks; however, the targeted and bycatch rates from these boats are the least-monitored and -reported. In 2010, total tuna landings in India were 60 512 tonnes (t) along the mainland and 7883 t in Lakshadweep

waters. The resource potential of tunas in the Lakshadweep Sea has been estimated at 50 000 t, indicating further scope for development of the tuna fishery in the Lakshadweep Islands (Pillai et al., 2006). Among tunas, *Katsuwonus pelamis* (80%) was the most important species landed in the Lakshadweep waters (Anon, 2010). Pole and line is the principal fishing gear for the capture of skipjack tuna, with a contribution of 94.8% followed by troll line, drift gillnet and handlines, contributing 3.3, 1.66 and 0.28%, respectively. Information on oceanic tunas in Indian EEZ indicate that tuna longlining can be carried out throughout the year, with better hooking rates during the pre-monsoon and monsoon seasons in the Arabian Sea and during the monsoon and post-monsoon season in Andaman and Nicobar waters (Somvanshi and Varghese, 2007).

Small-scale longline fisheries are considered to be the least monitored and documented fisheries sector and the bycatch poorly understood. Thorough research is needed to quantify the bycatch from the small-scale fisheries sector, as it is suspected of producing large bycatch quantities (Peckham et al., 2007; Mangel et al., 2010).

Considerable work has been carried out worldwide on bycatch issues regarding longline fishing operations (Alverson et al., 1994; Kelleher, 2005; Gillett, 2011). Previous studies have shown that the longline bycatch or discard rate ranges from 20 to 40% (Kelleher, 2005; Huang and Liu, 2010). Tuna longlines have been reported to catch many other non-targeted species such as seabirds, marine turtles, sharks and cetaceans, posing a threat to the global efforts for conservation of marine biodiversity (Belda and Sanchez, 2001; Gilman et al., 2006; Garrison, 2007; Donoso and Dutton, 2010; Varghese et al., 2010). The incidence of bycatch has been reduced effectively by certain adjustments and modifications in the fishing gear and fishing operations. Mitigation measures include deep setting of the hooks, magnetic repellents, avoidance of peak areas and periods of bycatch abundance, in addition to other approaches (Francis et al., 2001; Lokkeborg, 2001; Kerstetter and Graves, 2006; Cocking et al., 2008; Gilman et al., 2008a,b; Beverly et al., 2009; Piovano et al., 2010).

Sharks and cetaceans cause significant damage worldwide in pelagic longline fishery operations. Damages are in the form of bite-offs, loss of gear, catch displacement, reduced gear efficiency, and depredation of the catch (Yano and Dahlheim, 1994; Secchi and Vaske, 1998; Garrison, 2007).

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The experimental longlines operated in Indian waters showed a very high shark catch (John and Neelakandan, 2004). Experimental fishing operations were initiated in Lakshadweep waters where there is a scope for the exploitation of unexploited oceanic tuna resources. The aim of this study was therefore to estimate the quantity and species contribution of the bycatch, particularly pelagic sharks, as well as the various factors influencing the bycatch rates in longline fishing operations in the region. We envisage that this study will be useful for managing the longline fishing in the region and ensure the sustainability of the fishing operations.

Materials and methods

Experiments were conducted from 2009 to 2011 using three Pablo boats (7.6–8.5 m LOA) modified for longline fishing in the Lakshadweep Sea around Agatti Island (10°38′–11°07′N; 70°08′–72°08′E) (Fig. 1). These mechanized wooden Lakshadweep Islands fishing boats ranged from 7.62 to 8.5 m LOA with an engine capacity of 10–23.5 hp. Modifications were a stainless steel (grade IS 304) hand-operated winch for hauling the line, a stainless steel (grade IS 304) guide pulley on the forward port side of the boat to guide the mainline towards the drum, and a PUF (polyurethane foam) insulated FRP (fibre-glass reinforced plastic) box to store the fish catch and the bait fish. An FRP bin was also provided, with stainless steel rings to facilitate the storing of branch lines and avoid line entanglements. Total length of the mainline was 5 km. Mainline and branch lines of the experimental gear were made of 3 mm and 1.8 mm polyamide monofilament, respectively, and float lines were made of 4 mm Ø polyester. Branch lines were 22.5 m long, and hooks were deployed in depth ranges of 35–100 m by adjusting the length of the floatlines. Fishes were grouped into four categories: tuna, sharks, sailfish, and miscellaneous fishes. Miscellaneous fishes were mainly lagoon fishes, including *Lutjanus gibbus*, *Aprion virescens*, and *Epi-*

nepelus polylepis. Seasonal variations in the longline catches were also studied whereby seasons were grouped into pre-monsoon and post-monsoon for the analyses. Fishing was carried out for 7 months a year from October to April, for two consecutive years (2009–2010 and 2010–2011; February to April = pre-monsoon; October to January + post-monsoon season). During the monsoon season, bad weather precludes longline fishing. Fishing depths were at 35, 60 and 100 m depth levels. Japanese tuna hooks of 3.4 sun with 10° offset were used. Shooting of the lines was done before dusk or dawn by four or five crew members. Maximum number of branchlines shot was 100, depending on the bait. Overall depth of the fishing grounds ranged from ~500 to ~2000 m. Hauling operations after 15:00 h were categorized as evening fishing. Soaking time was categorized into three groups for the analysis: Group A (1–3 h), Group B (3.1–5 h) and Group C (5.1–7 h). Bait species used were Indian mackerel (*Rastrelliger kanagurta*), Indian oil sardine (*Sardinella longiceps*), smoothbelly sardinella (*Amblygaster clupeioides*), and tuna heads. The hooking rate was calculated based on the number of fish caught per 1000 hooks; captured species were measured for length and weight. The fishery was free from common bycatch species such as marine turtles, seabirds and cetaceans. The incidental bycatch rate was calculated based on the number of species caught per 1000 hooks (Brothers, 1991).

Data collected from 22 333 hooks were compiled and analyzed using the χ^2 to test for goodness of fit, and ANOVA was tested using SPSS (IBM SPSS Statistics, Version 20).

Results

Bycatch details

A total of 221 fishes using 22 333 hooks were caught during the experiment, with yellowfin tuna the target species; fish species other than tuna were categorized as bycatch. Morphometric details of the bycatch species and their IUCN

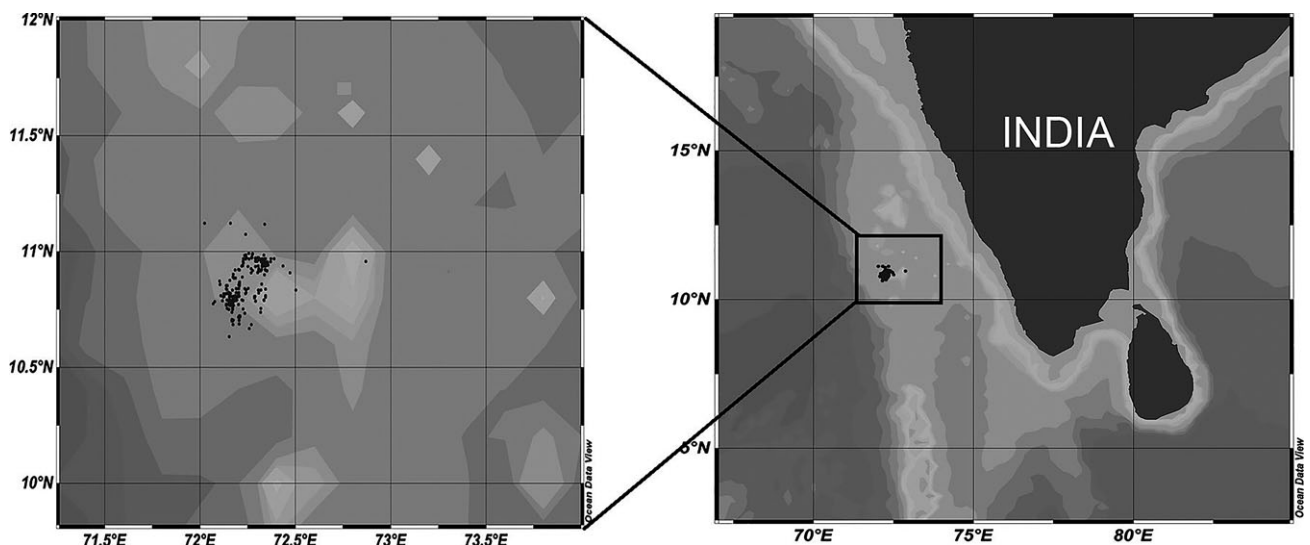


Fig. 1. Map of fishing area, Lakshadweep waters, Arabian Sea, India (10°38′–11°07′N; 72°01′–73°18′E), 16 Nov 2009 to 23 April 2011. Black dots: fishing locations. Fishing grounds depth ranges: ~500 to ~2000 m

Table 1
Bycatch in experimental tuna longline fishing operations, Lakshadweep Sea, India: species composition, numbers and length/weight ranges and conservation status of specimens

Scientific name	Common name	Number of fishes caught	Total length (cm)	Weight (kg)	Conservation status ¹	Population trend ¹
<i>Carcharhinus falciformis</i> (Müller & Henle, 1839)	Silky shark	133	50–243	5–98	Near-threatened	Decreasing
<i>Carcharhinus amblyrhynchos</i> (Bleeker, 1856)	Grey reef shark	7	114–210	16–41	Near-threatened	Unknown
<i>Galeocerdo cuvier</i> (Péron & Lesueur, 1822)	Tiger shark	4	183–213	31–74	Near-threatened	Unknown
<i>Alopias pelagicus</i> (Nakamura, 1935)	Thresher shark	2	240–276	50–55	Vulnerable	Decreasing
<i>Negaprion acutidens</i> (Rüppell, 1837)	Sicklefin lemon shark	1	256	105	Vulnerable	Decreasing
<i>Sphyrna lewini</i> (Griffith & Smith, 1834)	Scalloped hammerhead shark	1	320	130	Endangered	Decreasing
<i>Istiophorus platypterus</i> (Shaw, 1792)	Sailfish	14	50–288	1–44	Least concern	Unknown
<i>Aprion virescens</i> (Valenciennes, 1830)	Green jobfish	5	0.3–95	1–9	Not assessed	Not assessed
<i>Caranx</i> spp.	Carangids	2	29	5	–	–
<i>Epinephelus polylepis</i> (Randall & Heemstra, 1991)	Small scale grouper	1	No data	4	Near-threatened	Decreasing
<i>Lutjanus gibbus</i> (Forsskal, 1775)	Humpback red snapper	8	61–68	2–6		

¹IUCN (2012).

conservation status are given in Table 1. Eleven species of fishes constituted the bycatch, which included six species of shark, one species of sailfish and four species of lagoon fishes. Marine turtles, seabirds and cetaceans were absent in the bycatch during the experimental operations.

The hooking rate (mean hooking rate) for yellowfin tuna was 4.6/1000 hooks, and of bycatch 21.6/1000 hooks. Tuna and bycatch species contributions by percentage were 17.6 and 82.4%, respectively. Analyses showed that sharks dominated the bycatch significantly (74.1%), followed by sailfish (15.7%), and miscellaneous fishes (10.2%) (Fig. 2). There were significant differences in the hooking rates ($P < 0.01$). Silky shark (*Carcharhinus falciformis*) contributed the bulk of shark catches (89.9%), followed by grey reef shark (*Carcharhinus amblyrhynchos*) (4.7%), tiger shark (*Galeocerdo cuvier*) (2.7%), thresher shark (*Alopias pelagicus*) (1.7%), sicklefin lemon shark (*Negaprion acutidens*) (0.7%), and scalloped hammerhead shark (*Sphyrna lewini*) (0.7%) (Fig. 3).

Variation with respect to hook depth and time of operations

Hooking rates for bycatch species at 35, 60 and 100 m depth were 7.8, 9.9 and 5/1000 hooks, respectively. There was no significant association between the overall bycatch rate and depth ($P > 0.05$). Hooking rates observed at 35 m depth were 5.6/1000 hooks for sharks, 0.9/1000 for sailfish and 1.3/1000 for miscellaneous fishes (Fig. 4). The hooking rate at 60 m depth was 9.0/1000 hooks for sharks, followed by sailfish (0.5/1000 hooks) and miscellaneous fishes (0.4/1000 hooks). Hooking rate at 100 m was 4.3/1000 hooks for sharks, followed by sailfish (0.2/1000 hooks) and miscellaneous fishes (0.5/1000

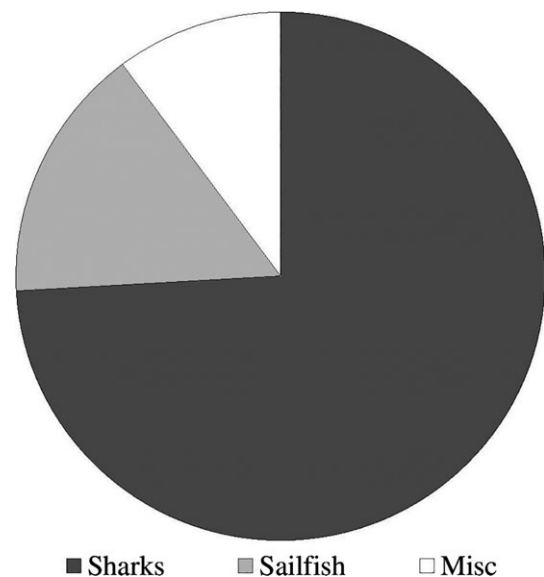


Fig. 2. Percentage of different species groups contributing to bycatch in longline fishing operations, Lakshadweep waters (10°38'–11°07'N; 72°01'–73°18'E), 16 Nov 2009 to 23 April 2011. Total number of fishing operations: 370 (22 333 hooks); total number of bycatch = 178; sharks: *C. falciformis*, *C. amblyrhynchos*, *G. cuvier*, *A. pelagicus*, *N. acutidens*, *S. lewini*; sailfish: *I. platypterus*; misc.: *A. virescens*, *E. polylepis*, *L. gibbus*, *Caranx* spp

hooks). Shark catches were significantly higher at all three depths compared to other bycatch species ($P < 0.01$).

There were no significant differences in the hooking rate per group between morning and evening hours ($P > 0.05$).

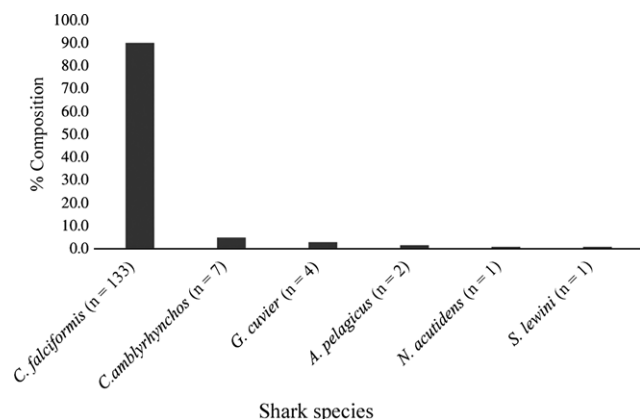


Fig. 3. Composition percentage of shark species contributing to bycatch in longline fishing operations, Lakshadweep waters, 16 Nov 2009 to 23 April 2011

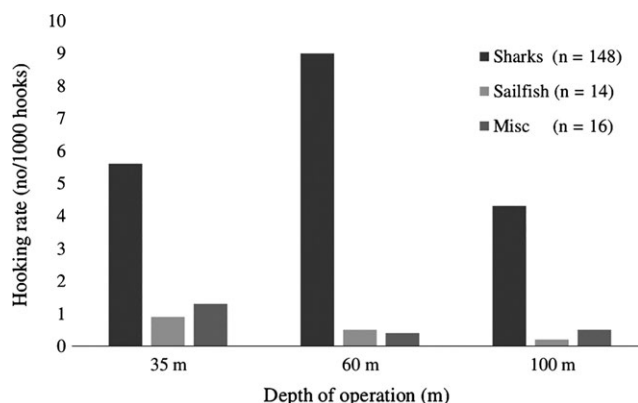


Fig. 4. Hooking rate at three different depth levels during longline fishing operations, Lakshadweep waters, 16 Nov 2009 to 23 April 2011

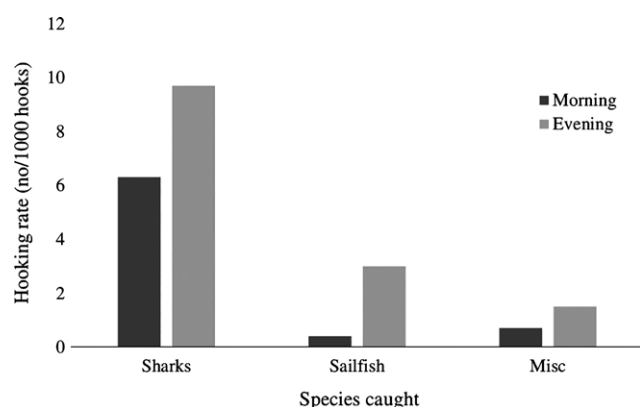


Fig. 5. Hooking rates by group: morning and evening hours during longline fishing operations, Lakshadweep waters, 16 Nov 2009 to 23 April 2011

Hooking rates for sharks in morning and evening operations were 6.3 and 9.7/1000 hooks, respectively (Fig. 5). Corresponding hooking rates for sailfish were 0.4 and 3/1000 hooks, respectively. Hooking rates of fishes in the miscella-

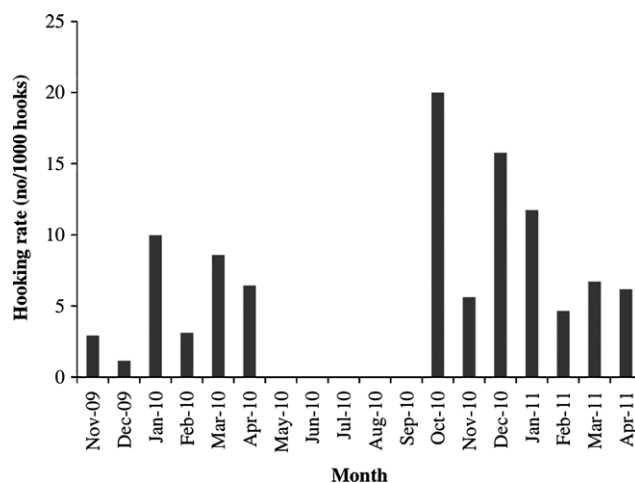


Fig. 6. Monthly overall bycatch rate observed during longline fishing operations, Lakshadweep waters, 16 Nov 2009 to 23 April 2011

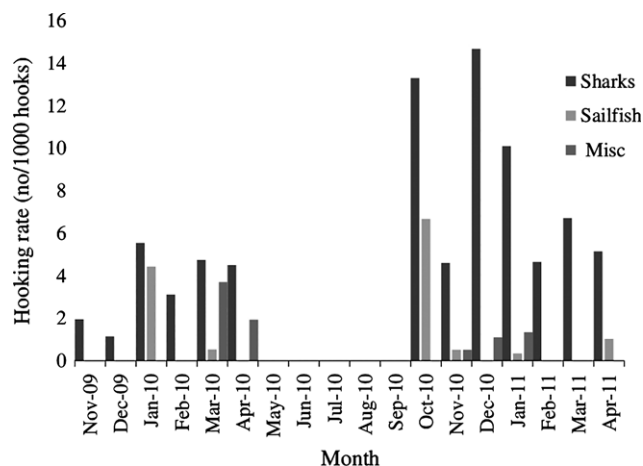


Fig. 7. Monthly hooking rate of different bycatch species groups recorded during longline fishing operations, Lakshadweep waters, 16 Nov 2009 to 23 April 2011

neous category were 0.7 and 1.5/1000 hooks in the morning and evening, respectively.

Seasonal and monthly variation

Highest overall bycatch rate was observed in October 2010 (20/1000 hooks); lowest was in December 2009 (1.14/1000 hooks) (Fig. 6). Variations according to species are given in Fig. 7. Results show that season and month of operation have no effect on the bycatch rate, except for sailfish where there was significant difference between seasons ($P < 0.01$) and between months ($P < 0.01$). Hooking rates of sailfish post-monsoon were significantly higher than pre-monsoon rates. January registered significantly higher hooking rates for sailfish, compared to other months.

Effect of soaking time

Soaking times ranged from 1 to 7 h. Sharks, sailfish, and miscellaneous catch for group A (1–3 h) were 8.9, 0.4 and

1.1/1000 hooks, respectively. Group B (3.1–5 h) was observed as 6.5, 1.1 and 0.9/1000 hooks for sharks, sailfish, and miscellaneous, respectively. Hooking rate for sharks in group C (5.1–7 h) was 4.9/1000 hooks; catch was not noted for sailfish and miscellaneous category in group C. There was a decreasing trend in hooking rates of sharks with an increase in soaking time.

Discussion

Captured bycatch species are not generally discarded, as sharks and sailfish fetch attractive prices in the local market. Seabirds and cetacean catch reportedly contribute to part of the bycatch in the Indian Ocean, but this is never reported in the longline catches in the seas around Lakshadweep waters. Seabird and cetacean bycatch were also not reported in the longline catches in the seas around India (Varghese et al., 2013). The green turtle, *Chelonia mydas*, was the dominant species seen in the Lakshadweep Islands; the population is distributed mainly inside the lagoon waters, where they forage on seagrass. They are not usually observed in open ocean waters where the fishing operations are carried out.

The Carcharhinidae are the major family group of sharks contributing to the longline elasmobranch bycatch (Gilman et al., 2007). The exploratory surveys conducted around Andaman and Nicobar Islands report high hooking rates of pelagic sharks (Kar et al., 2011; Varghese et al., 2013). John and Neelakandan (2004) reported a high shark bycatch of 58% in Indian waters. Shark bycatch is considered to be a serious issue worldwide in the pelagic longline fisheries (Joung et al., 2005; Gilman et al., 2007). Our results are in conformity with the high shark bycatch in the longline fishing operations in the region and elsewhere in the world (Joung et al., 2005; Gilman et al., 2008b; Mandelman et al., 2008; Huang and Liu, 2010). A 60–80% decline of several shark species in Atlantic Ocean waters of the U.S. is due to longline fishing operations (Morgan and Carlson, 2010). All of these results indicate the unavoidable issue of shark bycatch in the tuna longline operations.

The fishing operations were carried out not very far from a coral ridge, where the grey reef sharks have a tendency to aggregate nearby (Wetherbee et al., 1997; Economakis and Lobel, 1998). Morato et al. (2010) reported the higher probability of capture of some shark, billfish, tuna, and other bycatch species near seamounts. *Carcharhinus falciformis* is most often found at the edge of the continental shelf up to depths of 50 m (Compagno, 1984). The inshore waters of Lakshadweep Islands were observed to have a large population of the silky sharks, where longline operations are responsible for their high hooking rate. These results all suggest that the longline operations should be carried out away from the coral ridge to minimize the shark bycatch.

Although the bycatch rate was higher in the evening hours, the results were not significant statistically. Bigelow et al. (1999) reported the diurnal vertical movement of blue sharks to the surface waters (0–100 m) for feeding during the night. Longlines targeting these species are usually set in surface waters around sunset and hauled in around sunrise (Milian et al., 2008). Evening fishing operations showed higher

catch rates of both targeted and bycatch species (Ward et al., 2004). Kume and Joseph (1969) opined that longlines operated at night are more effective in catching large predatory fishes.

An attempt has been made to understand the effect of the depth of operation on the bycatch rates. A number of studies confirmed the effect of the fishing depth on bycatch rates (Shiga et al., 2000). Research has indicated that deep setting of longline gear at depths below 100 m can reduce the shark catch considerably (Shiga et al., 2000). Earlier studies reported the effect of the time of fishing operations on the shark bycatch rates due to the diurnal vertical movement (Ward et al., 2004; Milian et al., 2008). Studies on the effect of operational depth on the overall bycatch rates and species composition indicated no significant relation at depth ranges of 35–100 m. At all three depths, compared to other fishes the shark catch was found to be very high. Simpfendorfer et al. (2002) pointed out that blue shark preferred to stay in the sub-surface waters. More studies at deeper depths (>100 m) are needed to understand the effects of the depth of operation on species selectivity.

High shark catch was reported post-monsoon in experimental longline operations in Bay of Bengal waters (John and Neelakandan, 2004). Variations in the hooking rate were observed during different months and seasons, with the overall hooking rate fluctuating between 1 and 20 per 1000 hooks. The results showed that, except for sailfish, the season and months have no statistically significant effect on the hooking rate of fishes. Huang and Liu (2010) reported a significant correlation between the month of operation and the bycatch rate. The hooking rate of sailfish was high during the post-monsoon period. January registered high sailfish hooking rates compared to other months.

Morgan and Carlson (2010) confirmed the correlation of soaking time with the mortality of the sharks caught in bottom longline fishing operations. Vega and Licandeo (2009) opined that the catch rates increase with soaking time. The positive effect of soaking time on the shark catch and mortality has been reported by earlier researchers (Carlson et al., 2004; Ward et al., 2004; Diaz and Serafy, 2005; Morgan and Burgess, 2007). Previous results suggest that the soaking time of longlines has an effect on the mortality of sharks by affecting the flow of oxygenated water through their gills (Carlson et al., 2004; Morgan and Burgess, 2007). During the present experiments, the shark catch was found to decline with increasing soaking time. Separate tests carried out to understand the effect of soaking time on bait loss revealed that bait loss was highest for the soaking time range of 5.1–7 h, presumably due to scavenging of small fishes, firmness of the bait, and the wave action. Hence, it can be concluded that bait loss increases with soaking time, which reduces the opportunity for the fish to catch the bait, eventually deteriorating the fishing efficiency of the longline gear. These results are in agreement with the observations of Shepard et al. (1975), Skud (1978), Shomura (1955) and Pingguo (1996), that the loss rate of bait increased with soaking time.

Separate experiments were carried out to understand the effect of hooks and baits on the catch rate and species selectivity. The results indicate that hook types (Japanese tuna

hooks and circle hooks) have no significant effects on the overall hooking rate but have a significant effect on the species selectivity (Kumar et al., 2013). The tuna-hooking rate was found to be high with circle hooks (32/1000 hooks) compared to Japanese tuna hooks (0/1000 hooks). Shark catch predominates in the Japanese tuna hooks (167/1000 hooks) compared to circle hooks (64/1000 hooks). Studies show that the hook design has a significant influence on the hooking pattern of the fish. The results indicated that circle hooks created minimum injury to the hooked fish. Experimental fishing operations were carried out to assess the effect of bait on the longline catches and species selectivity (in press). The results revealed that a change in bait type had no significant effect on the overall hooking rate or species selectivity.

Further studies at deeper depths (>100 m) and with a better understanding of the thermocline depth are needed to establish the effect of the depth of operation on the catch rates and species selectivity, before popularizing longline fishing in the Island waters. The results indicate that shark catches decline with an increase in soaking time, which needs to be substantiated in further experiments. The overall results show that the experimental pelagic longline operations carried out in Lakshadweep waters were less selective for tuna. Promising results were acquired in a separate set of experiments that indicated the positive effect of circle hooks to minimize shark catches and mortality of hooked fish. The bycatch of sharks in the pelagic longline fishing operations is of serious concern, compromising the conservation strategies for shark populations. With a precautionary approach, the present study indicates the possibilities of a diversification of fishing activities from the conventional pole and line fishing that targets skipjack tuna to longline fishing that targets large, high-value yellowfin tuna. The current fishing vessels used for pole and line fishing can be effectively modified for the operation of longlines, which in turn would reduce the fishing pressure on the skipjack fishery in the Lakshadweep Islands.

Acknowledgements

The authors are grateful for the encouragement given by the Director, Central Institute of Fisheries Technology, Cochin. The authors wish to express their sincere gratitude to Dr. M. R. Boopendranath for the evaluation of the manuscript. Financial assistance received from NAIP, ICAR, Govt. of India is thankfully acknowledged.

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