7.1. Introduction

The bycatch includes the discarded catch and the incidental catch. The discarded catch is defined as the portion of the animal in the catch that is thrown away or discarded into the sea for various reasons (Huang and Liu, 2010). Discarded catch represent a significant quantity of global marine catch and is considered to hinder the measures for the sustainable exploitation of global marine resources (Alverson et al., 1994). Tuna longlines, apart from the targeted species, has been reported to catch many other species such as marine turtles, seabirds and cetaceans which pose a threat to the global efforts for conservation of already depleted marine biodiversity (Pierpoint, 2000; Majkowski, 2007; Huang and Liu, 2010). The yearly average discarded quantities of bycatch were estimated to be around 7.3 million tonnes (Kelleher, 2005).

Marine turtle bycatch issues in the pelagic longline fishing operation is widely studied (Polovina et al., 2003; Kiyota et al., 2004; Ovetz, 2005; Brazner and McMillan, 2008; Jribi et al., 2008; Donoso and Dutton, 2010;
Varghese et al., 2010). Many factors are reported to be influencing the incidental hooking of the marine turtles. They are attracted by the baits and eventually hooked when trying to swallow the bait and die due to drowning or due to injuries caused by the hook. A majority of these bycatch species can be significantly reduced by deep deployment of the hooks (Shiga et al., 2000; Beverly et al., 2009). Rate of bycatch can considerably reduced with change in hook design and bait type (Poulsen et al., 2004; Joung et al., 2005; Watson et al., 2005; Gilman et al., 2006a & 2006b; Kerstetter and Graves, 2006; Jribi et al., 2008; Ward et al., 2009; Yokota et al., 2009; Piovano et al., 2010).

Seabirds are another group of animals which are accidently caught during the longline operation and it is considered as a serious issue in the longline fishery (Belda and Sanchez, 2001). The interaction with seabirds has been reported to be deter the efficiency of the longline operation (Milessi and Defeo, 2002). There are many effective mitigation measures for reducing the seabird bycatch, viz., changing longline setting time, underwater setting funnel, side setting of hooks, dyed baits, tori lines and forecasting of homogenized offal during line setting which deter the birds from taking the baits (Cherel et al., 1996; Belda and Sanchez, 2001; Lokkeborg, 2001; Ryan et al., 2002; Gilman, 2004; Gilman et al., 2007b; Cocking et al., 2008; Gilman et al., 2008c).

Marine mega faunal bycatch is another serious concern in longline fisheries which needs serious attention (Lewison et al., 2004; Diaz, 2005; Ovetz, 2005; Garrison, 2007). Major group of animals contributing to the marine mega faunal bycatch are sharks and cetaceans (Stevens, 1992; Hall,
Studies on Bycatch and Depredation

1998; Domingo et al., 2005; Matsunaga et al., 2005; Gilman et al., 2008b & 2008c; Mandelman et al., 2008; Milian et al., 2008; Mangel, 2010).

These bycatch have been effectively reduced by certain adjustments and modifications in the fishing gear and fishing operations. Mitigation measures include deep setting of the hooks, magnetic repellents and avoidance of peak areas and periods of bycatch abundance (Francis et al., 2001; Gilman et al., 2008b & 2008c).

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

Sharks and cetaceans cause significant damage in pelagic longline fisheries operations worldwide. The damages are in the form of bite-offs, loss of gear, catch displacement, reduced gear efficiency and depredation of the catch (Sivasubramaniam, 1965; Yano and Dahlheim, 1994; Sechi and Vaske, 1998; Kock et al., 2006; Garrison, 2007; Gilman, 2007b). Depredation, the partial or complete removal of hooked fish and baits from the fishing gear, is caused primarily by cetaceans and sharks results in substantial ecological and economic losses in the longline fishing sector (Lawson, 2001; Gilman et al., 2006b). Killer whale depredation is a serious setback in the Brazil longline fisheries (Secchi and Vaske, 1998). The main issue with the shark interactions is the considerable loss of the fish caught and time required to repair damaged and lost gear by shark hooking. Understanding the fishing methods and the factors that drive interactions
between mammals and longline fishing gears is very essential for reducing both incidental mortality and depredation in longline fishing operations. The depredation takes place in almost half of all longline sets and if the loss is 20% or more, economic losses can amount to thousands of dollars in lost revenue from a single set (Gilman et al., 2008a). The warmer and deeper waters favoured by target billfish and tunas are areas likely to encounter high levels of depredation (MacNeil et al., 2009). One possible way to reduce the depredation level is by avoiding the gear operating from the foraging range of species responsible for depredation. Modifications in gear structure can be an effective measure to reduce the depredation rate (Branstetter and Musick, 1993; Williams, 1997; Gilman et al., 2006b; Garrison, 2007). The economic costs associated with longline depredation can be substantial and is an inevitable part of conducting longline operations in the open ocean (Lawson, 2001).

The objectives of the present study has been to find out

- hooking rate and composition of bycatch;
- monthly variation in the bycatch rates;
- the effect of depth on the bycatch rates;
- variation in the bycatch rates with respect to time of operation;
- the effect of soaking time on bycatch rates; and
- depredation rates in longline operations in Lakshadweep Sea.

7.2. Materials and methods

The experimental studies have been carried out in converted Pablo boats viz., Noorjahan (L_{OA} 7.6 m, Kirloskar 16.5 hp), Jeelani (L_{OA} 7.6 m,
Rustom 23.5 hp) and Pondichery (LOA 8.5 m, Rustom 16.5 hp) equipped for experimental tuna longlining operation in Lakshadweep Sea. Fishing operations were conducted in the Lakshadweep Sea around Agatti Island (10°38’ - 11°07’ N and 70°08’ - 72°08’ E). The depth of longline operation ranged from 35 to 100 m. Different species were used as baits for this study viz., Amblygaster clupeoides, Rastrelliger kanagurta, Sardinella longiceps, carangid spp. and tuna head. Three types of baits, viz., Sardinella longiceps, Amblygaster clupeoides and Rastrelliger kanagurta were considered for the statistical analysis since the data from other baits species were not sufficient for the analysis. The analysis has been carried out based on a total of 22,333 hooks operated during the fishing operations. Shooting of the lines was carried out just before dusk or dawn by four to five crew members. The hauling operations after 15:00 h were catogorised as evening fishing. The soaking time varied from 1 to 7 h depending on the weather condition. Maximum number of branchlines shot was 100. Each basket contained five hooks. The fishermen recorded the basic information on the fishing activities such as number of hooks and time of setting and hauling, catch information in the logbook kept onboard. Length and weight of the fish were recorded onboard. CPUE was calculated for each operation as catch per 1000 hooks.

Bycatch rate is the proportion of non-targeted species in the total catch that is caught (Alverson et al., 1994; Huang and Liu, 2010). Since the fishery is free from common bycatch species such as marine turtles, seabirds and cetaceans, there were no discards after operation. The incidental bycatch rate was calculated based on the number of species
caught per 1000 hooks (Brothers, 1991). The bycatch rate might be affected by both spatial and temporal factors. The effect of spatial factor on the bycatch rate was not studied since fishing operation was limited to a small geographical area.

The data collected were compiled and analysed using $\chi^2$ for test of goodness of fit and two factor ANOVA.

7.3. Results

7.3.1. Status of bycatch in longline fishing operation

The data set had observations from total of 22,333 hooks. The catch per unit effort was calculated as hooking rate (no/1000 hooks). A total of 221 fishes were caught during the experimental fishing operations. The fishes are grouped in to four categories viz., tunas, sharks, sailfish and miscellaneous fishes. Fish species except tuna were considered as bycatch and used for the analysis. The details of species, morphometric details and their IUCN conservation status are shown in the Table 7.1 and Fig. 7.1 & 7.2. Eleven different species of fishes are encountered during the study as the bycatch which includes six species of sharks, one species of sailfish and four species of lagoon fishes.
### Table 7.1 Detailed list of fish species included in bycatch category

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

*Source: IUCN (2012)*
Fig. 7.1 Shark species encountered as bycatch (A: Carcharhinus falciformis, B: Sphyrna lewini, C: Alopias pelagicus, D: Carcharhinus amblyrhynchos, E: Galeocerdo cuvier, F: Negaprion acutidens)
The comparative analysis has been shown that sharks are the main group of fishes which dominated in the bycatch (74.1%), followed by sailfish (15.7%) and miscellaneous fishes (10.2%) (Fig. 7.3). The percentage composition of different species of sharks contributing to the bycatch rate is given in the Fig. 7.4. The hooking rate reported for the target catch (tunas) was 4.6/1000 hooks and bycatch was 21.6/1000 hooks (Fig. 7.5). The percentage composition of the targeted and bycatch species was recorded as 17.6 and 82.4%, respectively (Fig. 7.6). There was significant difference in hooking rate of different fishes (P<0.01). Hooking rate of shark is significantly higher than other type of fishes.
Fig. 7.3 The percentage composition of bycatch species

Fig. 7.4 Percentage composition of different shark species contributing to the bycatch
Fig. 7.5 The hooking rate reported for targeted catch and bycatch

Fig. 7.6 The percentage composition of targeted catch and bycatch
Chapter 7

7.3.2. Effect of time of operation on bycatch rates

The comparative studies carried out to understand the variation of bycatch rate with respect to time of fishing (Fig. 7.7). Shark catch reported in morning and evening was 6.3 and 9.7/1000 hooks, respectively. The hooking rate for sailfish in morning and evening was found to be 0.4 and 3/1000 hooks. The hooking rate of the fishes which included in the miscellaneous category was found to be 0.7 and 1.5/1000 hooks for morning and evening, respectively. There was no significant difference in the species wise hooking rate between morning and evening hours (P>0.05).

![Fig. 7.7 Species-wise hooking rate in morning and evening contributed to bycatch](image)

Fig. 7.7 Species-wise hooking rate in morning and evening contributed to bycatch
7.3.3. Effect of hook depth in bycatch rates

The study compared the effect of hook depth on the bycatch rate and the composition of bycatch. The fishing depth was categorised into three depth groups viz., 35 m, 60 m, and 100 m. The overall bycatch rate reported at 35, 60, and 100 m depth were 7.8, 9.9, and 5/1000 hooks, respectively (Fig. 7.8). There was no significant association between the overall bycatch rate and depth.

![Chart showing bycatch rates at different depths](image)

**Fig. 7.8 The overall bycatch rate at three different depths**

The hooking rates reported for different species in 35 m depth were sharks 5.6, sailfish 0.9 and miscellaneous fish 1.3/1000 hooks, respectively (Fig. 7.9). The hooking rate obtained at 60 m depth was sharks 9/1000 hooks, followed by sailfish and miscellaneous fishes (0.5 and 0.4/1000 hooks, respectively). The hooking rate realised at 100 m was 4.3/1000 hooks.
hooks for sharks, followed by sailfish and miscellaneous fishes (0.2 and 0.5/1000 hooks, respectively). Shark formed the major catch at all three depths. Shark catch was significantly high at all three depths compared to other species caught.

![Fig. 7.9 Species wise hooking rate in three different depths](image)

**7.3.4. Seasonal variation in the bycatch rates**

Fishing operations were carried out to understand the monthly variation in the overall bycatch rate and species composition of the bycatch. Highest overall bycatch rate was reported during October 2010 (20/1000 hooks) and minimum during December 2009 (1.14/1000 hooks) (Fig. 7.10). During May to September 2009, being off-season due to southwest monsoon, fishing operations were not possible. Study compared the monthly variation in the species contributing to the bycatch (Fig. 7.11). Comparative analysis has shown that season and month of operation has no
effect on the species contributing to the bycatch rate except sailfish. There was significant difference in the hooking rate of sailfish between seasons (P<0.01) and between months (P<0.01) (Table 7.2). Hooking rate of sailfish in post-monsoon is significantly higher than that of pre-monsoon. Among months, January registered significantly higher hooking rate of sailfish compared to other months.

Table 7.2 ANOVA of seasonal and monthly variation in hooking rate of sailfish

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>ms</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>17.4436</td>
<td>11</td>
<td>1.5881</td>
<td>74.42</td>
<td>P&lt; 0.01</td>
</tr>
<tr>
<td>Seasons</td>
<td>8.5881</td>
<td>1</td>
<td>8.5881</td>
<td>74.42</td>
<td>P&lt; 0.01</td>
</tr>
<tr>
<td>Months</td>
<td>8.2786</td>
<td>5</td>
<td>1.6557</td>
<td>14.35</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>0.5769</td>
<td>5</td>
<td>0.1154</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7.10 Month-wise overall bycatch rate
7.3.5. Effect of soaking time on bycatch rates

Studies were carried out to understand the effect of soaking time on the fish species contributing to the bycatch (Fig. 7.12). The soaking rate ranged from 1 to 7 hours. The soaking time has been categorised in to three groups for the comparative analysis i.e., Group A: 1 to 3 h, Group B: 3.1 to 5 h and Group C: 5.1 to 7 hours. Shark catch reported in group A was 8.9/1000 hooks, followed by group B and C (6.5 and 4.9/1000 hooks, respectively). Sailfish hooking rate observed in group A and B was 0.4 and 1.1/1000 hooks and no sailfish catch was observed in group C. Hooking rates for the fishes included in the miscellaneous category were 1.1 and 0.9/1000 hooks for group A and B and no catch was observed in the group C. Sharks contributed majority of the catch. There was a decreasing trend...
of shark hooking rate with increase in soaking time. The effect of soaking
time on sailfishes and miscellaneous fishes was not carried out since the
catch of these species found to be very low.

![Graph showing the effect of soaking time on bycatch rates](image)

Fig. 7.12 The effect of soaking time on bycatch rates

### 7.3.6. Depredation

An attempt has been made to understand the rate of depredation and
hook loss in the pelagic longline operations in Lakshadweep Sea.
Depredation in the fishing operations significantly affects the profits of the
fishermen. No quantitative analysis was possible due to the lack of
sufficient data sets. Only six incidents of depredation presumably by
sharks, has been reported during the entire span of fishing operations using
22,333 hooks. The depredation was seen mainly on the tuna. The instances
of depredation on the catch is shown in the Fig. 7.13. Sharks are considered
as the species responsible for the depredation of the longline catches as per the opinion of the fishermen. It was not possible to identify the exact species responsible for this. Hook loss is the main problem concerned with the depredation other than loss of the fishes hooked. A total of 108 hooks were lost during the fishing operations (0.5% of the total hooks deployed).

Fig. 7.13 The depredation of sharks on tuna caught in the longline

7.4. Discussion

Tuna longline fishing has been considered an eco-friendly and size and species selective fishing compared to other fishing operations such as trawling. Apart from the targeted species many other species are reported as bycatch during the fishing operations. The present study has been carried out to understand the level of bycatch in the longline fishing operations in...
Studies on Bycatch and Depredation

the Lakshadweep Sea. Considerable number of work has been carried out on the bycatch issues in the longline fishing operations worldwide. Shark bycatch was found to be high during the experimental fishing operations. Previous studies showed that the bycatch or discard rate in longline fishing range from 20 to 40% (Huang and Liu, 2010). The average discard rate in tuna longline fishing was observed to be approximately 22% (Kelleher, 2005). Pelagic sharks and sailfish are the main bycatch species and to a lesser extent, reefcod, groupers, carangids were also encountered during the longline fishing. During the present study it was observed that a total of 11 fish species were caught during the longline operations as bycatch. Bycatch species encountered during the fishing operations are not generally discarded as the shark and sailfish meat fetch comparatively better price in the local market. The shark meat is mainly used for drying. The fishing operation is totally free from marine turtle, cetacean and seabird bycatch issues. The species contributing to the bycatch were categorised into three groups viz., sharks, sailfish and miscellaneous fishes (reefcods, groupers, carangids and green jobfish). A total of 6 shark species have been encountered during the fishing operations. Three species belonged to ‘Near Threatened’, two species to ‘Vulnerable’ and one species comes under ‘Endangered’ category under the IUCN Red list (IUCN, 2012). The single species of the sailfish (Istiophorus platypterus) comes under the ‘Unknown, and small scaled grouper (Epinephelus polylepis) comes under the ‘Decreasing’ status. No information is available on the green jobfish (Aprion virescens). Among the 6 shark species reported, two species (Alopias pelagicus and Carcharhinus amblyrhynchos) are new reports from the Lakshadweep waters (Kumar et al., 2012a & 2012b). Silky shark (Carcharhinus falciformis) was the dominant shark bycatch species in the fishing operation which contributed nearly 90% of the total shark catch and
grey reef shark (*Carcharhinus amblyrhynchos*) ranked second (4.7%). The other shark species reported are *Galeocerdo cuvier*, *Alopias pelagicus*, *Negaprion acutedens* and *Sphyrna lewinii* contributing 2.7, 1.4, 0.7 and 0.7%, respectively. Most of the species belonged to the family Carcharhinidae, followed by Alopidae, Sphyrnidae. Sharks belonging to the family Carcharhinidae were the major group of sharks contributing to the elasmobranch bycatch of longlines (Gilman *et al.*, 2007b). Around 163 tonnes of *Carcharhinus falciformis* discards has been reported in US pelagic tuna longline operations (Harrington *et al.*, 2005).

During the present study, nearly 74.1% of the catch was contributed by sharks, followed by 15.7% by sailfish and 10.2% by the fishes included in the miscellaneous category. The hooking rate reported was about 4.6/1000 hooks for the targeted species and 21.6/1000 hooks for the bycatch species. 82% of the total catch was contributed by bycatch species viz., sharks, sailfish and miscellaneous fishes. Shark bycatch has been considered as a serious issue in the pelagic longline fisheries (Joung *et al.*, 2005; Gilman *et al.*, 2007b). Sharks were reported to be the major component of the bycatch of Taiwanese longline fleets (Huang and Liu, 2010). 15 species of sharks has been reported from tuna longlining operations in south Atlantic Ocean by Taiwan (Joung *et al.*, 2005). The shark bycatch is a serious issue in the longline fishing operation targeting swordfishes and tunas in the US Atlantic pelagic longline fishing operation (Gilman *et al.*, 2007b). Nearly 29,000 individuals of blue shark (*Prionace glauca*) have been discarded as bycatch in 1993 (NMFS, 2006). There was 60-80% decline of several species of sharks in the US Atlantic Ocean waters due to longline fishing operations (Morgan and Carlson, 2010). High shark bycatch of nearly 58% was reported in Indian waters by John
and Neelakandan (2004). The fishing operations were carried out not very far away from the coral ridge. It has been observed that shark catch was maximum in the shallow hooks i.e. first branchlines in the longline basket (mainline catenaries). The sharks have a tendency to aggregate near the coral ridge (Wetherbee et al., 1997; Economakis and Lobel, 1998) and this could be the reason behind the high shark bycatch in the fishing operations.

The results from the previous works have suggested a high level of fluctuation in the shark bycatch worldwide in longlines (Beerkircher et al., 2002). The previous studies have indicated the high shark bycatch in the longline fishing operations (Stevens, 1992; Hall, 1998; Domingo et al., 2005; Matsunaga et al., 2005; Gilman et al., 2008b & 2008c; Mandelman et al., 2008; Milian et al., 2008; Vega and Licandeo, 2009; Huang and Liu, 2010; Mangel, 2010) which agrees with the findings in the present study.

The study analysed the variation in bycatch rate with respect to time of fishing operation. The fishing sessions were categorised into morning and evening. Even though the bycatch rate was higher in the evening, the results were found to be statistically not significant. Bigelow et al. (1999) reported the diurnal vertical movement of the sharks to the surface waters during the night for feeding. The longlines targeting these species are usually set in the surface waters around the sunset and hauled around the sunrise (Milian et al. 2008). Fishing operation during evening hours showed higher catch rates of both targeted and bycatch species (Ward et al., 2004). Previous studies carried out on the effect of time of fishing operations on the catch rates confirmed the effect of time of operation on the shark bycatch rates due to the diurnal vertical movement of the species (Ward et al., 2004; Milan et al., 2008). Kume and Joseph (1969) opined that longlines operated at night are more effective to catch large predatory
fishes. The spatial difference in the bycatch rate was not studied since the fishing is limited to a small geographic area.

An attempt has been made to understand the effect of fishing depth on the bycatch rates. Studies on the effect of depth of operation on the overall bycatch rates indicated no significant relation. Further studies were carried out to understand the effect of depth of operation on the species composition in the longline fishing operations. All the three depths (35, 60 and 100 m), shark catch was found to be very high compared to other fishes. No specific relation between the depth of operation and species selectivity was observed. Considerable number of studies has been carried on the effect of fishing depth in the catch rates (Broadhurst and Hazin, 2000; Shiga et al., 2000). Shiga et al. (2000) confirmed that deep setting of the longline gear can considerably reduce the shark bycatch. Watson et al. (2005) opined that shark catch was found to decline by 9.7 to 11.4% in response to fishing depth. Simpfendorfer et al. (2002) pointed out that blue shark preferred to stay in the sub surface depths with a cooler temperature range. The positive effect of depth of operation on the longline catch was reported by Milian et al. (2008). The study has not tested the effect of depth on the catch rates beyond 100 m. The change in the fishing efficiency and species composition is more evident in the deeper depths. More studies are needed to understand the effect of hook depth on the overall catch rates and species selectivity in different depth ranges to deeper depths.

An attempt was made to understand the monthly and seasonal variation in the bycatch rates. A high level of variability in catch rates was observed during the fishing operations. The overall hooking rate fluctuated from 1/1000 hooks to 20/1000 hooks during the study. The hooking rate was high in 2010-11 compared to 2009-10. The results of the comparative
analysis showed that season (pre-monsoon and post-monsoon) and month has no effect on the hooking rate of fishes except for sailfish. Significant correlation has been reported between month of operation and bycatch rate (Huang and Liu, 2010). High shark catch was reported during post-monsoon in the experimental longline operation in Bay of Bengal waters (John and Neelakandan, 2004). High mustelid shark catch was reported during autumn and summer season in the artisanal elasmobranch fishery of Sonora, Mexico (Bizzarro et al., 2009). No such change with season was observed during the present study, barring the sailfish. The sailfish hooking rate was high during post monsoon period. January registered high sailfish hooking rate compared to other months.

The effect of soaking time on the hooking rate indicated that the shark catches declined with increasing soaking time. Morgan and Carlson (2010) confirm 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. Morgan and Burgess (2007) reported that an increase in soaking time resulted in significant decrease in the shark mortality. Previous results suggest that soaking time can affect the mortality of the longline caught sharks by restricting the oxygenated water over their gills (Carlson et al., 2004; Morgan and Burgess, 2007). The effect of soak time on the catch rates was reported by Ward et al. (2004) who found a positive relation between soak time and shark bycatch. Diaz and Serafy (2005) and Morgan and Burgess (2007) reported the effect of soak time on the shark catch and its mortality rate. The shark mortality rate was found to be increasing with an increase in the soaking time (Carlson et al., 2004). The results of the present study on
the effect of soaking time on hooking rate in Lakshadweep waters is of a preliminary nature and need further research to elucidate the relationship.

The study made an attempt to understand the level of depredation and hook loss in the longline fishing operations. Shark and cetaceans have been reported to cause significant damage to the catch in the pelagic longline fishing operations. The damages are mainly in the form of bite-offs, loss of gear, catch displacement, reduced gear efficiency and depredation of the catch (Sivasubramanium, 1965; Yano and Dahlheim, 1994; Sechi and Vaske, 1998; Kock et al., 2006; Garrison, 2007; Gilman, 2007b). A few incidents of depredation and hook loss were observed during the present study. The sharks which are presumed as responsible for the depredation have taken away the fish hooked and left only the head portion in the hook. It was observed that 90 % of the whole fish was lost due to the depredation of the sharks. No quantitative analysis on the depredation was possible due to the lack of sufficient data sets. Depredation was observed only on tuna catch. Depredation in the tuna longline and its negative impact on the tuna catch were reported by various workers (Secchi and Vaske, 1998; Lawson, 2001; Gilman et al., 2006b). The possible and most effective measure to reduce the rate of depredation by sharks is by keeping away the baited hooks from their foraging range (Branstetter and Musick, 1993; Williams, 1997; Gilman et al., 2006b; Garrison, 2007).

7.5. Conclusion

This is a pioneering work on the status of bycatch in longline fishing operations in the Lakshadweep Sea where much scope is evident on the exploitation of tuna resources. The non-target bycatch of sharks in the pelagic longline fishing operations is a serious concern compromising the
conservation strategies of the shark populations worldwide. Many studies have been carried out on the bycatch issues in the longline fishing operations worldwide. The measures like deep deployment of hooks, change in hook design and bait type have been found to be very effective in reducing the bycatch rate. The effect of hook and bait on the overall catch and bycatch rate has been carried out as a part of the present study and the results are discussed in Chapter 5 and 6. Some preliminary observations have been made on the prevalence of depredation in longline operations and the resultant hook loss. The main bottleneck in the expansion on longline fishing operation is the possible and unavoidable bycatch issue in an area having huge elasmobranches resources and this issue requires further investigations.

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