Investigations on Longline Fishing in Lakshadweep Sea with special reference to Bycatch Issues, Bait and Hook Selectivity

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by

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This is to certify that this thesis titled ***'Investigations on Longline Fishing in Lakshadweep Sea with special reference to Bycatch Issues, Bait and Hook Selectivity'*** is an authentic record of the research work carried out by Mr. Aneesh Kumar, K.V., M.Sc., under my guidance and supervision in the Fishing Technology Division of Central Institute of Fisheries Technology, Cochin, in partial fulfillment of the requirements for the degree of Doctor of Philosophy and that no part thereof has previously formed the basis for award of any degree, diploma, associateship, fellowship or any other similar titles of this or any other University or Institution.

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Declaration

I, Aneesh Kumar, K.V., hereby declare that the thesis entitled ***'Investigations on Longline Fishing in Lakshadweep Sea with special reference to Bycatch Issues, Bait and Hook Selectivity'***, is an authentic record of the research work carried out by me under the supervision and guidance Dr. B. Meenakumari, Deputy Director General (Fisheries), Indian Council of Agricultural Research, New Delhi and joint supervision of Dr. M.P. Remesan, Principal Scientist, Fishing Technology Division, Central Institute of Fisheries Technology, Cochin, in partial fulfillment of the requirements for the Ph.D. degree under the Faculty of Environmental Studies and that no part thereof has previously formed the basis for award of any degree, diploma, associateship, fellowship or any other similar titles of this or any other University or Institution.

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Dedicated to

my beloved Amma

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Aneesh Kumar, K.V.

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Chapter 1

INTRODUCTION

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1.1. Marine fisheries of India

India is bestowed with a coastline of over 8,128 km, vast Exclusive Economic Zone (EEZ) spanning 2.02 milliion sq km and a continental shelf area of 0.5 million sq. km (Ayyappan and Diwan, 2007). India has a significant marine fisheries sector which is considered as an important source of occupation and livelihood for at least 3 million people in the coastal communities of India in over 3,600 fishing villages along the Indian coastline. Small scale and artisanal fish workers belonging to the sector obtain their livelihood from fishing, artisanal processing and small scale trading activities. Total fishermen population in India is about 3.57 million of which 0.81 million are active fishermen (Anon, 2006). Total fish production in India increased from 0.73 million tonnes in 1950 to 7.85 million tonnes in 2009-2010 (Anon, 2011a). Capture fisheries is a valuable source of food, income and cheap source of protein especially for the protein deficient coastal fisherfolk. The fisheries sector contributed 1.07% to the Gross Domestic Product (GDP) and 5.30% to the agricultural component during 2009 (Anon, 2009). Export of marine products during

2010-2011 has reached US$ 2.84 billion by achieving a growth of 18.96% in quantity, 27.64% in rupee value and 33.17% in US$ (Anon, 2011b). European Union (EU) has continued to the largest market with a share of 26.66%, followed by USA and Southeast countries.

Substantial development has been witnessed in fisheries sector due to the innovative and efficient fishing practices, government policies, developments in the harvest and post-harvest infrastructure and technologies, and the increased demand for fish products in the domestic as well as international markets. Increased demand of the seafood has lead to the modernisation of the craft and gears, intensification of fishing efforts, capacity of the vessels, shift towards multiday fishing operation and motorisation of the traditional fishing vessels to increase the efficiency. India is blessed with rich fishery resources comprising of nearly 2,163 species of finfishes and 1,000 species of shellfishes. Around 200 species of commercially important finfishes and shellfishes contribute to the marine fishery of the country. Major groups belonging to the pelagic realm are sardines, mackerel, anchovies, carangids, Bombay duck, ribbonfishes, seerfishes, tunas and the demersal realm is enriched with sharks, rays, sciaenids, perches, silverbellies, lizardfishes, catfishes and crustaceans such as penaeid and non-penaeid shrimps, crabs and lobsters and cephalopods. Distribution and abundance of these species vary from region to region. Large pelagic species like tunas and other tuna-like species are more abundant in the Island territories and the small pelagic species like sardines and mackerel contribute substantially to the landings along the southwest and southeast coasts especially in the Gulf of Mannar, Palk Bay and Wadge Bank.

Marine landings of India in 2010 have been estimated as 3.07 million tonnes showing a decrease of about 1.31 lakh tonnes against the estimate of the previous year (Anon, 2011c). Pelagic species contributed 55%, demersal 26%, crustaceans 14% and molluscs 5% of the total catch landed. West coast ranks first (55%) for the total quantity of the fish landed over east coast (45%). Mechanised sector ranks first by contributing 73% of the catch and motorised and artisanal sector contributed 25% and 2%, respectively. Most of the marine fish landings are from the fishing operations in the coastal shelf area, especially from the shallower region ranging from 5 to 100 m depth (Rao, 2010). Oil sardine (*Sardinella longiceps*) alone contributed 13.1% of the total catch (4,03,932 tonnes), followed by Indian mackerel (*Rastrelliger kanagurta*) which accounted for 7.9% of the total landings (2,43,154 tonnes) (Anon, 2011c). High valued crustacean resources show a declining trend (Radhakrishnan *et al*., 2007). Wide fluctuations are evident in the production of oil sardine and mackerel due to various biological and environmental factors (Pillai and Ganga, 2010). Heavy demand for seafood in domestic and international markets underlines the need for increasing the marine fish production. Catch trends indicated that the production from the coastal fisheries is almost stagnant and point towards the need for harvesting unexploited or under exploited oceanic fish resources. Present fleet size of the distant water fishing vessels is very less in spite of India's vast EEZ of 2.02 million sq km and two Islands groups, *viz*., Andaman & Nicobar and Lakshadweep. The species diversity of the offshore and deep sea fishing comprised of a few highly valued species of oceanic tunas and pelagic sharks as well as several non-conventional species. The estimated potential yield of oceanic tuna resources is 2.78 lakh tonnes (Pillai and Jyothi, 2007). Estimated potential of total tuna resources in Lakshadweep Islands is about 50,000 tonnes (Pillai *et al*., 2006). Total tuna landings in India in 2010 was 60,512 tonnes along the mainland and 7,883 tonnes in Lakshadweep. They accounted for

1.97% of the total marine production of the mainland and 81.3% of the fish production of Lakshadweep Islands. A wide range of gears are used for the exploitation of these resources *viz.*, longlines, purse seines, gill nets, pole and line and troll lines.

Government of India has taken many initiatives to increase the tuna production like providing subsidies and financial assistance for the conversion of shrimp trawlers to tuna longliners. Sharks (*Centrophorus* spp.), chimaeras (*Neoharriota pinnata*) and thresher sharks (*Alopias* spp.) are caught by longliners and trawlers as bycatch which fetch high prices (Rs 300 per kg) (Akhilesh *et al.*, 2009). Deep sea shrimp are also landed in the west coast in large quantity and *Plesionika spinipes* is the dominant species followed by *Heterocarpus woodmasoni* (Anon, 2009a).

Marine fisheries sector in India is facing many problems like over capitalization, over capacity, increased operational expenses and reduced catch rates. Proper policy interventions which address the concerns for ecological integrity and biodiversity are needed for the optimum utilisation of the fishery resources in a sustainable manner. A shift from the intensively fished coastal fishery resources to other potential resources like oceanic tuna is very much needed.

1.2. Fisheries in Lakshadweep

The Lakshadweep Islands lying off the west coast of India approximately between 8° to 13° N Lat. and 71° to 74° E Long. are comprised of coral atolls, reefs and submerged banks, which surround 36 low lying coralline islands (eleven inhabited and 25 uninhabited Islands) scattered in the Arabian Sea at about 200-400 km from the Malabar Coast. These Islands are located on the Chagos Ridge covering an area of 32 sq. km.

Being oceanic Islands, they have very limited continental shelf about 4,336 sq km. There is a vast lagoon area of about 4,200 sq km. The Islands bear 20,000 sq km of territorial waters and about 4,00,000 sq km of Exclusive Economic Zone. Lakshadweep is considered as one of the largest oceanic territories of our nation (Anon, 2012a).

Livelihood opportunities for the Lakshadweep Islanders are limited. Natural resources form the basis for the traditional economy of the people. In the past, this was principally associated with coconut cultivation. However, this has now been replaced by the pole and line tuna fishery, which is considered as the mainstay of the Island economy. The introduction of mechanization of the fishing boats in the early sixties and the extension of small scale pole and line fishing played significant development in the skipjack tuna fishery in the Lakshadweep Islands (James *et al.,* 1987). It includes chumming with bait fishes to attract and hooking by pole and line. Total population from the inhabited Islands is 40,322. About 5,381 households belong to fisherfolk. 20% of the fisherfolk population is involved in fishing activities and 9% is engaged in fishing associated activities. Out of 8,040 fishermen involved in fishing, 33% are fulltime fishing, 30% are doing part time fishing and the rest 37% undertake occasional fishing.

The main fishing associated activities in the Islands are curing (54%), marketing (7%), curing/peeling (4%), other activities (20%) and labour (15%). The total number of fishing vessels in Lakshadweep is 2,275. Out of these, 586 (26%) are mechanised, 371 (16%) are motorized and 1,318 (58%) are non-motorized (Anon, 2005). Among mechanised boats, pole and line boat forms 67%, followed by liners (19%), gillnetters (12%) and the others (2%). Wooden crafts contributed nearly 80% of the motorised craft. The most popular gears in Lakshadweep include pole and line, gillnets, hook and line, troll line, shore seines and traps and the most popular fishing method is pole and line fishing (Anon, 2005). Wounding gears like *Chilla*, *Kooduli* and *Chatuli* are very popular in most of the Islands (Anand, 1990). Trolling is considered as a very effective fishing method in the Islands. This method was introduced by the Department of Fisheries, Lakshadweep and it has been very well accepted by the fishermen of the Islands. Shark fishing by hand is a popular fishing method but is not a well organized fishery. The sharks are attracted by the freshly cut tuna pieces and lured close to the side of the boat. When the shark come to the side of the boat, it is lifted either by its dorsal fin by hand or by a hangman's noose put to the head or the tail (Anand, 1990).

Lakshadweep Sea is rich in fishery resources such as tunas, billfishes, pelagic sharks, other food fishes, live baits and ornamental fishes. Jones and Kumaran (1980) recorded 603 fish species from the Lakshadweep Archipelago. Estimated marine fishery resources potential in the Lakshadweep waters is about 63,000 to 1,40,000 tonnes of various groups of fishes (Pillai *et al*., 2006). *Katsuwonus pelamis* (skipjack tuna), *Thunnus albacares* (yellowfin tuna), *Auxis thazard* (frigate tuna) and *Euthynnus affinis* (little tunny) are the species commonly seen in Lakshadweep waters. The principal fishing method for catching tuna is pole and line fishing. Lakshadweep Islands are the only place in India where pole and line fishing is practiced for catching tuna. Fish Aggregating Devices (FADs) were introduced in Lakshadweep waters in 2002 and the pole and line fishing near FADs have proved to be very effective for catching tuna. The estimated total fish catch from Lakshadweep in 2009 was 10,189 t, of which tunas constituted 81.1% (8,264 t) and other fishes formed 18.9% (1,925 t).

The resource potential of tunas in the Lakshadweep Sea has been estimated at 50,000 tonnes indicating further scope for development of the tuna fishery in the Islands (Pillai *et al.*, 2006). Pole and line is the most important gear for tuna fishery with a contribution of 94.8% followed by troll line, drift gillnet and handline, contributing 3.3%, 1.66% and 0.28%, respectively. Among tunas, *Katsuwonus pelamis* (80%) was the most important species landed (Anon, 2010a). The tuna contribution has shown an increase of 4.5% compared to 2008. This was mainly due to the increase of 13.8% in pole and line catches at Minicoy and increase in drift gillnet catches by 98.3% at Androth. However, the pole and line catches at Agatti showed a decline of 21.6%.

The lack of adequate supply of live bait is a major bottleneck for the development of pole and line fisheries in Lakshadweep. Main live bait resources of Lakshadweep Islands are reef associated fishes with localised distribution comprising sprats, pomacentrids, apogonids, atherinids and juvaniles of caesionids. *Spratelloides delicatulus* is the only live bait species exploited for tuna pole and line fisheries in Lakshadweep Islands except Minicoy (Gopakumar, 1991). Indian top minnow or the Killi fish, *Panchax panchax*, locally called *incha-mas* which are seen in the ponds in the Islands, are collected with the help of wide meshed cloth and used when sufficient bait fish are not available (Jones, 1958). In addition to the tunas, flying fishes, barracuda, seerfish, sailfish, dolphin fish, rainbow runner, gar fishes, half beaks, snappers, perches and other reef fishes, shark, rays, trigger fishes, octopus, etc are also contributing to the fisheries of Lakshadweep Islands. The major fishing season in Lakshadweep is the period between September and May (Nair, 1986). Government has intervened through modern scientific and technological inputs to tap the vast marine wealth of the Lakshadweep Islands for uplifting the socio-economic status of the Lakshadweep people (James, 1989).

1.3. Fishing boats and gears of Lakshadweep

The main fishing method practiced in Lakshadweep Islands is pole and line for tuna by using live baits. The advantages of this type of fishing are relatively small capital investment, ability to catch small shoals of fishes, ability to operate from small ports with minimum technical support and to utilize unskilled labour. The operation is carried out from specially designed mechanised boats of 7.6 m to 10.3 m length overall (L_{OA}) (James *et al.,* 1987). As per the reports of National Fisheries Census (2005) (Anon, 2006) there are 2,384 fishing boats in Lakshadweep. Non mechanised boats formed 56.25% of the fleet, followed by mechanised boats (27.99%) and motorized boats (15.76%). Out of 2,275 boats owned by the fishermen, 586 (26%) were mechanised, 371 (16%) were motorized and 1,318 (58%) were non-motorized. Pole and line boats contributed 67% of the mechanised fleet, followed by liners (19%), gillnetters (12%) and others (2%).

Wood was the most popular boat building material and 80% of the mechanised fishing boats were plank built. Agatti Island has the maximum number of mechanised fishing boats and contributed 27.82% of the total mechanized fleet in Lakshadweep Islands (Anon, 2005). Around 350-400 boats were actively engaged in fishing (Anon, 2001; Pillai *et al.,* 2006). The traditional fishing boats were constructed out of wood and were carvel-built. The wooden planks were fastened together and fixed to ribs with coir yarn. Prior to 1960s, only non-mechanised boats were used for tuna fishing.

Mechanised boats of two types *viz.,* 7.9 m and 9.1 m L_{OA} are used for pole and line tuna fishing. The boats were fitted with engines of 10 to 40 hp in the middle of the boat and the engine room is safely sheltered with wooden planks. Bait tanks are placed in the front of the engine room for keeping the live baits used for pole and line fishing (Mohan *et al.,* 1985). Hornell (1910) has given an account of the pole and line fishing method of Lakshadweep. Pole and line fishing is done by all the Islands except Androth (Pillai *et al.,* 2006). *Mas odi* or *Mas dhoni* are the country crafts used for the collection of bait fishes for pole and line fishing (Jones, 1958). Mechanisation of the fishing boats in the early sixties and the extension of small-scale pole and line fishing which was traditionally operated only in Minicoy Island to other Islands have been significant developments in the fisheries sector of Lakshadweep Islands. Demand for mechanised boats increased after the successful introduction of mechanisation in the pole and line fishery. To meet the demand, two boat building yards, one each at Kavaratti and Chetlat were setup for the construction of mechanised fishing boats. About 510 mechanised boats were supplied to the fishermen of various Islands under hire purchase scheme. These initiatives have helped to increase the annual fish production from 500 t in 1960s to 10,000 t in 2006 (Pillai *et al.,* 2006). James *et al.* (1987) described the economical aspects of pole and line fishing operation in Lakshadweep Islands.

The major fishing gears in the Lakshadweep Islands include pole and line, troll lines, hook and line, gillnets and longlines. Gillnets comprise 30% of the gear owned by the fishermen of Lakshadweep Islands followed by hook and line (22.37%), troll lines (12.82%), seine nets (12.28%) and pole and line (10.08%) (Anon, 2005). Pole and line fishing is the most popular fishing method in the Islands and the fishery is mainly concentrated at Agatti, Bengaram, Perumal Par Reef, Minicoy, Suheli Par and Bitra Islands (James *et al.*, 1987a). Shark longlining in mechanised boats is a popular fishing practice in the Islands (Pillai *et al.*, 2006).

The pre-requisite for the pole and line fishing is the availability of sufficient quantity of bait fishes. Two types of nets are used by the fishermen to catch the bait fishes *viz.*, encircling nets and lift nets. Encircling net is made of nylon mosquito netting and measures about 80 m long and 3 m deep with lead sinkers and floats to maintain the vertical orientation of the net. Lift net is made of nylon netting of less than 6 mm mesh size (Sivadas and Nasser, 2000). Once enough quantity of live baits has been caught, the boat set out for tuna fishing. Barbless hooks are used as the terminal gear for catching tuna. The barbless hook helps for easy detachment of the fish from the hook. Bamboo poles of 3 to 4 m in length and 35 to 40 mm dia which are straight, strong and flexible are used as poles (Mohan *et al.*, 1985). More than 90% of the tuna catch landed in the Islands are contributed by pole and line fishing (Sivadas, 2000). Scarcity of the live baits are considered as the main limiting factor in the pole and line fishing operation in the Lakshadweep Islands (James *et al.*, 1989; Gopakumar, 1991).

Handlines are used for fishing in areas near to the Islands. The gear consists of a few meters of cotton line with a hook attached to the end. Nowadays, the cotton line has been replaced by polyamide (PA) monofilament. Pelagic longline gears are gaining popularity in Lakshadweep especially in the Agatti Island. Horizontal longline fishing method was introduced in Lakshadweep under the NAIP project entitled ‘A Value Chain in Oceanic Tuna Fisheries in Lakshadweep Sea’. Another popular form of fishing technique is trolling. During monsoon season *i.e.*, from June to August, the pole and line fishing is fully suspended and the boats will be beached for maintenance. During this period, troll lines are operated from small wooden boats of 5 m L_{OA} fitted with outboard engines of 9.9 hp (Sivadas, 2000). Bare hooks and hooks covered with feathers are used. Trolling is conducted in deeper waters for catching fast moving pelagic carnivorous fishes like tunas, billfishes, seerfishes and barracudas. PA monofilament is used as line (Mohan *et al.*, 1985).

Two indigenous drive-in fishing techniques based on tide, habit of fish, type of fish and season exist in Minicoy. They are called as *Chaal* and *Padhi*. It is the method of constructing pathways for fish on the reef margin by piling up dead coral boulders pointing to an open or closed end (Anand, 1990). Cast net (*Veeshu vala*) is an age old practice in the Islands. It is coming under the category of falling gears. It is a conical shaped net with a rope on the top and sinkers with sufficient weight attached around the perimeter. This gear is used to catch fish along the shore, in the lagoon or near the reef flat to catch fishes like perches, half beaks, parrot fish and wrasses. Several types of cast nets based on the mesh size of the nets are popular in the Agatti Island. The nets are named based on the fish caught e.g. *Mannakatha bala* (goat fish net), *Furachi bala* (Majjara net) (Hoon, 2002). *Idumanakam* is a fishing method in Kalpeni to catch goat fishes with a number of fishermen standing in a row by using cast nets.

Kallumoodal fishing is a fishing method used to catch the fish which are hiding under large boulders on the coral flat. A conical net which looks like a cast net is used for fishing (Anand, 1990). *Koodu* fishing is a fishing method with trap practiced in Kalpeni. Two types of traps *viz.*, *Koodu* and *Moorotha Koodu* are seen. The former one is used to catch fishes like lutjanids, goatfishes and rock cods and the latter is very effective in catching sharks and rays (Anon, 1986; Anand, 1990).

Set and drift gillnets are commonly used in the Island fishermen to catch shark, perches, and carangids. The nets vary greatly in size ranging from 10 to 90 m in length and 2-4 m in depth (Anand, 1990). *Chilla* is a wounding gear used to catch flying fishes and halfbeaks. This gear is very effectively used to catch octopuses. The harpooning of octopuses is known as '*Appal kuthal'*. *Enghili kavaru* (single pronged), *Thinghili kavaru* (three pronged) and *Fassili kavaru* (five pronged) are names of the harpoons used in Minicoy Island (Anon, 1986). *Kandali valei* fishing is a method which uses scare lines made of dried coconuts leaflets. Light fishing to catch flying fish is very popular in Kalpeni Islands. It is a harpoon fishing method done in the night. The lights made by burning dried coconut leaves are used to lure the fish. Various types of seine nets are used in the Lakshadweep Islands to catch carangids and scarids, from the lagoon waters. Shark fishing by hand is a common fishing method in the Lakshadweep Islands. Use of poison to catch the lagoon fish is quite common in Kalpeni. Most of the fishing methods are limited to the subsistence level.

1.4. Line fishing

The principle of the line fishing is attracting or luring the fishes with partly fixed baits on the hooks which make it unable to be released once it enters in to the mouth so that it can be lifted from the water with the bait (Gabriel *et al.*, 2005). The success of the operation is closely related with feeding and hunting behaviour of targeted fish (Hameed and Boopendranath, 2000). The popular line fishing techniques are pole and line, handlines, troll lines, jigging lines and longlines. The line fishing is considered as eco-friendly and fuel efficient fishing method to catch scattered and sparsely distributed fishes. This fishing technique makes it possible to fish in the rocky and uneven bottom, where other fishing methods are inefficient. The catches obtained by the line fishing are found to be of superior quality.

Hook and line fishing is considered as a size selective fishing gear and ensure the quality of the fish caught. The hooks are considered as the heart of the line fishing and other accessories are just a means of offering the hook in front of the fish and attract the fish in to it. Hook shapes vary greatly in terms of size, shape and materials used. Most popular design of hooks in the line fishing is 'J' hook, Japanese tuna hooks and circle hooks. Previously, iron was the principal metal used for making hooks which have a tendency to break or bent under stress condition and were susceptible to corrosion. Material and tensile strength of the line vary according to the type of fishing and targeted fishes. The material and tensile strength of line have profound effect on the success of the line fishing operations. Polyamide (PA), polyvinyl alcohol (PVAA), polyvinyl chloride (PVC), polyester (PES) and their combinations and steel wires are used as material for making lines (Hameed and Boopendranath, 2000).

The hook design has undergone significant changes. According to the fishing purpose, they can be mainly classified into hooks for commercial and sport fishing. Another important factor with hooks is the fact that they can be either offset or non-offset. Non-offset hooks are the hooks in which the point lies in the same plane as the shank of the hook. With offset hooks, the point is bent away from the plane of the shank by anywhere between 5 and 25°. If the point is offset to the left, that hook is said to be 'kirbed' and if the point is offset to the right, the hook is 'reversed'. Japanese tuna hooks, typically have a 10-20° (kirbed) offset (Beverly, 2006). Circle hooks and 'J' hooks are either offset or non-offset. The Japanese tuna hooks and circle hooks are used widely in the longline fishing operation. 'J' hooks are mostly accepted in the troll line fishing operations because of its better penetration and fish holding properties. The type and size of the hook is very important to determine the success of fishing operation. New gear materials have improved the efficiency of the longlining. In the past, lines were made from the materials of the plants and animal origin like cotton, jute, linen and silk (Gabriel *et al*., 2005). These materials were replaced by synthetic polymers such as monofilaments of polyamide (PA) and polyester (PE).

Handlines

Handlines are considered as the simplest form of hook and line fishing method consisting of a hand held single line with one or more hooks spaced along the other end of the line (Mathai, 2009). This fishing method is extensively used in the small scale sector. Usually, handlines have only one hook at the terminal end, while multiple hook handline has several hooks connected to the mainline through short branchlines (Hameed and Boopendranath, 2000; Gabriel *et al.*, 2005). Sinkers with suitable weight and a snood wire are also used. The operation is very simple by holding one end of the line in hand and feeling with finger for the bite of the fish. These gears are widely used to catch benthic species like snappers, groupers and large predatory fishes such as tunas and can be operated in the rough grounds where the operations of longlines are difficult.

Pole and line

Pole and line fishing is another popular form of fishing method extensively used in Lakshadweep Islands, Japan, Maldives, Sri Lanka, California and Hawaii for catching shoaling fishes like skipjack tuna and other scombroid fishes like mackerel and bonitos (Mathai, 2009; Hameed and Boopendranath, 2000). Line is not held in the hand of the fishermen but may be attached to a wooden or bamboo pole or metallic rod. Bamboo poles of 2.4-2.7 m are commonly used and the line is fastened to the pole. Bifurcated poles with two lines are also operated by commercial fishermen (Gabriel *et al.,* 2005). The hooks and lures used are different in different areas. Main similarity is the use of barbless hooks as the terminal gear. Usually, fishermen fishes individually with his own pole and line. Sometimes single leader is attached to the lines from two poles to facilitate catching of large fishes. This fishing method is very popular in sport fisheries. The shoals are attracted by throwing live baits, which are stored in the bait tanks placed onboard, on sighting the fishing shoal.

Troll lines

Troll lines are considered as an effective gear for the capture of fast swimming pelagic fishes like seerfishes, skipjack, yellowfin, bonitos and other large predatory fishes (Gabriel *et al.*, 2005). The shape and jerking of the jigs in the water, lures the fishes such as tunas and seerfishes (Hameed and Boopendranath, 2000). This gear can be operated from small mechanised boats as well as from small sailing boats with very minor modification in the deck arrangements (Mathai, 2009). The main attraction is the limited crew that is required for the fishing operation. The lines are fastened to the out rigger booms fixed in the boat. 6-10 lines can be operated from one boat. Polyamide lines of 3 mm dia are commonly used as the mainline. The length of the line varies from 40 to 50 m. The size of the hook depends upon the species and size of the targeted fish. Cotton rags, coir fibres, sisal fibres and synthetic materials, metal spoons, feather jigs are used as artificial bait for troll lines. Special types of lures which are usually bright in colour are used to attract the fish and induce them to bite the hook.

Jigging

Artificial jigs or lures are used to catch squid and a wide variety of jigs are available for the purpose. The jig consists of a stem made of flexible plastic with 1 to 2 rings of sharp, barbless hooks at the lower end (Mathai, 2009). One jigging line carries a large number of such jigs which may be of different colour and shape. Lines are made up of polyamide lines. The jigs are usually operated in the boundary between illuminated and shadow zones where maximum aggregation of fish are noticed (Hameed and Boopendranath, 2000). The visibility of the line affects the fishing operation adversely. Two types of squid jigging are in practice *viz.*, hand jigging or automated jigging operations. Considerable saving in the crew and labour is possible by using automated jigging machines.

Longlines

Longlines are passive fishing gears designed to catch sparsely distributed carnivorous fishes like tunas, billfishes and sharks. The principle behind the capture is based on the foraging behaviour of the target species. This fishing method is considered as highly energy efficient, eco-friendly and species and size selective compared to other fishing practices like trawling and purse seining (Mathai, 2009). The fishes are attracted by the bait, hooked and eventually caught by the mouth until they are brought aboard the vessel (Sainsbury, 1971). Based on the structure and mode of operation, longlines are classified into 4 categories, *viz.,* drift longline, bottom set longlines, vertical longline and bottom vertical longlines (Hameed and Boopendranath, 2000).

Horizontal longline fishing uses a long stretch of mainline made of either synthetic rope or nylon monofilament to which hundreds or thousands of branchlines with single baited hooks at the terminal end are attached (Beverly *et al.,* 2003). Drift longlines are operated close to the surface or middle layers mainly targeting large pelagic fishes like tunas and billfishes. Bottom set longlines are mainly used to catch demersal fishes like shark and other bottom living species. In vertical longlines, mainlines set vertically from the buoy on the surface and weights are attached at the other end to maintain a vertical orientation of the line. The vertical longlines are effective to catch the fishes which have a pronounced vertical range of distribution (Hameed and Boopendranath, 2000). Vertical longline operations near the floating objects or floatsams and Fish Aggregating Devices (FADs) are found to be very effective. The types of materials used for making FADs range from floating rafts made of bamboo to glass, aluminum and fiberglass FADs equipped with radar reflectors and solar powered lights (Preston *et al.*, 1998). Bottom vertical longlines combine the properties of bottom set longlines and vertical longlines (Hameed and Boopendranath, 2000). This gear has been found to be suitable for operating in rough grounds to catch high value perches. The unit of a tuna longline is called a basket and it mainly consists of mainline, branchlines, floats and float line, sinkers, flag pole with flag, light buoys and radio buoys with line (Gopalakrishnan, 1998). The longlines are set, either by hand or mechanically.

1.5. Horizontal longline fishing - World scenario

Tuna and tuna like fishes include approximately 40 species occurring in the Atlantic, Indian and Pacific Oceans and in the Mediterranean Sea. The global tuna production has increased from 0.6 million tonnes in 1950s to over 6 million tonnes recently (Anon, 2008a). Today, tuna and tuna like fishes are mainly caught with purse seining, longlining and pole and line fishing. Longline vessels accounts for approximately 14% of the world production of tuna (FAO, 2003). Chinese Taipei ranks first on the maximum number of distant water tuna longliners (600) followed by Japan (532) and Republic of Korea (198) (FAO, 2003). Most of the large longliners of European and western hemisphere countries are targeting swordfishes, though some tunas are taken as bycatch. Majority of the catch in terms of weight is taken by purse seiners (FAO, 2007a). Skipjack remains the major species landed in the world oceans in terms of quantity and most of the catch is utilised for canning (FAO, 2003).

Industrial tuna fisheries *viz.*, purse seine, longline and pole and line produced about ten times the amount of fish produced by other fisheries from the Pacific Ocean (FAO, 2007b). The main tuna species targeted in the Pacific Ocean waters are skipjack (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*) and south Pacific albacore tuna (*Thunnus alalunga*) (Anon, 2010b). Korea has a dominant position in the tuna longlining operations in the Pacific waters and the main targeted species are skipjack, yellowfin and bigeye tuna (Moon *et al.*, 2005). The Philippines have a well developed longline fishery in the Pacific waters to catch oceanic tuna mainly bigeye (Lewis, 2004). Since 1990, bigeye tuna has accounted for around 44% of the total tuna longline catch by weight in the Pacific Ocean (Lawson, 2007). In Pacific Ocean, about

70% of the tuna caught is contributed by purse seines, 10% by pole and lines and 8% by longlines (FAO, 2007a).

In the Indian Ocean waters, the contribution by purse seine, pole and line and longlines are 45, 15 and 20%, respectively (FAO, 2007a). Industrial and artisanal fisheries have exploited Indian Ocean yellowfin tuna since the 1950s (Lee, 1998). Longline fishing has been the only fishing method practiced by the mainland China fishing fleets for tuna and tuna-like species in the Indian Ocean since the development of tuna fishing in 1995 (Liuxiong *et al.*, 2010). Most purse seine and pole and line catches are sold for canning and the longline catches mainly go to the *sashimi* market which is a traditional delicacy in Japan. Two species, skipjack and yellowfin tuna, contributed nearly 80% of the total catch from the Indian Ocean (FAO, 2003). Small scale longline fishing for high quality fish in Indian Ocean for the *sashimi* market is well developed in the Asian countries like China and Taiwan (FAO, 2007a). Albacore, bigeye and yellowfin are the main tuna species targeted by the tuna longline operations by Taiwanese vessels (Lee *et al.*, 2005; Huang *et al.*, 2008a). Taiwanese longliners operating in the Indian Ocean are equipped with super-cooled storage facilities and target bigeye tuna using deep longline (Lee *et al.*, 2005). The tuna catches of Japan and Taiwan province of China are the largest (0.5 million tonnes), followed by Indonesia (0.3 million tonnes) and the Philippines (0.2 million tonnes) (FAO, 2007a). Korea and China together contributed more than 83% of the total production from longline fisheries (IOTC, 2008). Thailand is a leading producer of canned tuna (Nootmorn *et al.*, 2010). Catches from tuna longline fishing contributed 16% to the total tuna production in the Indian Ocean (1.67 million tonnes) in 2006 (Nootmorn *et al.*, 2010). A significant growth in the fishery of small tunas like skipjack and yellowfin tuna is evident in the artisanal longline sector of both Indian Ocean and Pacific Ocean coastal countries (FAO, 2007a). Japanese industrial longliners have exploited yellowfin tuna since 1952, Taiwanese longliners since 1954, and Korean longliners since 1966 and the new entrants since the 1980s include Indian, Indonesian and Sri Lankan industrial longliners (Lee, 1998). There is no organised fishery in India for tunas except the organized pole and line fishery in the Lakshadweep Islands for skipjack (Hameed, 1998). Yellowfin and skipjack tuna are the two major species of tuna fisheries in the Indian EEZ (Somvanshi and Varghese, 2007).

Longlines ranked second by value in Atlantic Ocean and contributed 20% of the catch (FAO, 2007a). In terms of weight of fish caught, skipjack is the most important tuna species in the Atlantic Ocean. Nearly 85% of the catch is taken in the eastern Atlantic and the rest are caught off Brazil (FAO, 2003). Atlantic Ocean contributed nearly 14% of the world production of tuna (FAO, 2003). Principal tuna species landed, in terms of quantity, are skipjack and yellowfin with nearly 80% of the landing coming from the eastern Atlantic (FAO, 2003). Taiwan started the tuna fishing operations in the Atlantic Ocean since 1960s. Initially they have targeted on albacore and yellowfin tuna and shifted to bigeye tuna after the development of deep longline operations since 1980s (Huang *et al.*, 2008b). The blackfin tuna (*Thunnus atlanticus)* is one of the most common tuna species caught in longline fishing operation in the west central Atlantic Ocean (Taquet *et al.*, 2000). The bigeye tuna catch rates in Atlantic Ocean showed a declining trend from the late 1960s to early 2000s due to overfishing (Anon, 2009b).

World tuna fisheries face a number of problems that threaten the sustainable utilisation of the fishery resources. The problems such as alarming decrease of the tuna stock, poor conservation and management strategies, high levels of illegal, unreported and unregulated (IUU) fishing and significant bycatch of marine turtles, seabirds, sharks and cetacean resources are encountered in longline fisheries (WWF, 2007). In pelagic tuna longline fishing, the reduction of incidental catch of marine turtles, sharks and seabirds has become a focus of fisheries research (SCTB, 2003).

1.6. Longline fishing - Indian scenario

The marine fishing industry in India has made significant contribution towards the increased fish production over the past several years. The coastal fishery resources of India are under immense fishing pressure and as most of the fishery stocks are fully exploited and there is not much scope for further development. Traditional and mechanised fishing sectors in India is mostly depending upon the coastal fishery resources and comparatively less efforts have been made towards the exploitation of the offshore and deep sea resources. Commercial deep sea fishing in India has been restricted to shrimp trawling. Increased pressure on these resources led to the depletion of the resources and catch rates have drastically come down. Great scope exists for tuna fishery through longlining as an industrial type of fishing (Menon, 1970). Tuna and billfish resources of the country remain under exploited to the commercial level.

Tuna fishing is a highly sophisticated technique which requires large infrastructure and logistical requirements like well equipped vessels, onboard freezing facilities, infrastructure onshore for handling and marketing the catch and experienced crew. Tuna resources of our EEZ had been exploited by the neighbouring coastal countries like Taiwan, Japan and Republic of Korea (Menon, 1970). Longlining is considered as one of the most effective type of fishing method for the exploitation of sparsely distributed large tunas especially in the high seas (Joseph, 1972). Longline is a passive gear which can be operated as horizontal longlines and vertical longlines. This method is found to be eco-friendly, fuel efficient and size and species selective. The Government of India, with the assistance of an FAO expert, started a tuna longline fishing operation from Cochin in 1964. The studies were carried out in a trawler converted vessel of 25 m L_{OA}. Exploratory tuna longline operations were carried out off the south west coast of India using Pratap, Kalyani IV and Kalyani V during 1965-66 (Viswanathan, 1999). Species such as bigeye tuna each weighing 150-200 kg were caught from Indian waters (Joseph, 1972).

Central Institute of Fisheries and Nautical Engineering Technology (CIFNET) and Fishery Survey of India (FSI) through a joint programme in October 1983 made an attempt to establish tuna fishing technology in Indian waters. This project started in full swing in 1990s after the Government of India permitted the foreign chartered tuna longliners to fish in the Indian EEZ under Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Rules 1982 and its amendments in 1984 and 1991 (Panote, 1994). CIFNET has made considerable progress in the tuna longlining technique which was quite unfamiliar to the Indian fishing industry, with the acquisition of the tuna longliner namely M. V. Prashikshani from Japan in 1980. M. V. Prashikshani of CIFNET and FSI vessels conducted extensive experimental longline fishing operations off west coast and in Bay of Bengal and results indicated high potential tuna resources around the equatorial waters (Sulochanan *et al*. 1986; Pillai *et al.*, 1993).

Chartering of foreign fishing vessels by Indian enterprises was considered as a failure since no adequate data was made available from the chartered vessels as envisaged (Gokhale, 1991). Studies conducted by FSI demonstrated that the tuna fisheries in the Indian EEZ showed higher hooking rates during the pre-monsoon and monsoon seasons in the Arabian Sea and the Andaman and Nicobar waters and results indicated the scope of commercial tuna longlining operations. The commercialization of the tuna longlining did not get momentum even after the demonstration of the potential of the tuna resources and it was mostly confined to exploratory surveys and research cruises. The lack of suitable vessels and technical expertise in longline operation and technology, lack of capacity in handling larger vessels and readiness of the crew to remain in the sea for longer period were the major hurdles in the development of tuna longline fishery in the country (Viswanathan, 1999).

Swaminath and Nair (1983) reviewed the development of tuna longlining in India since 1960s. Tuna longline operations in the west coast of India have been reported by many authors (Eapen, 1964; Pillai and Sarma, 1985; Silas *et al.*, 1985; Raje, 1987). The tuna resources in the Indian EEZ and the harvest and post harvest technologies for the sustainable utilisation and management of the resources has been reviewed by various workers (James *et al.*, 1987, James and Pillai, 1987a; James and Jayaprakash, 1988; James *et al.*, 1989; James and Pillai, 1994; Sudarsan and John, 1994). Silas *et al.* (1985), Swaminath *et al.* (1986), and John and Sudarsan (1994) reported differential abundance indices and distribution pattern of yellowfin tuna and higher hooking rate in the longline catches from Bay of Bengal waters. They have indicated a positive relationship between thermal boundaries and CPUE of yellowfin tuna. Srinivasarengan *et al.* (1994) analysed the tuna resources of the Madras coast indicated the present status of the coastal tuna resources of the region and emphasis towards the need of exploiting the oceanic tuna resources. The longliners presently operating in India are all converted shrimp trawlers (Premchand and Pandian, 2004). Longline operations with converted trawlers targeting tuna were reported off north Andhra Pradesh (Sujatha *et al.,* 2006). The longline fishing was found to be very effective to catch large tunas which usually inhabit in the deeper waters (Pravin *et al.,* 2008). During 2006 mechanised sector entered into the oceanic tuna fisheries with converted trawlers for the longline fishing in the Visakhapatanam region (Rohit and Rammohan, 2009).

Fisheries experts have opined that fuel efficient, multipurpose fishing vessels capable of fishing about 100 km off shore with an endurance of about 10 to 12 days are more suitable for tuna longlining in the Indian waters (Lewis, 1991). Longlines are considered as most effective gear to catch sharks which form around 80% of the total catch (Devadoss, 1996). Significant increase of tuna catch was reported from the southwest coast of India and Lakshadweep Islands after the motorisation of country crafts and the targeted operation of the mechanised vessels (James *et al.*, 1992). Beenakumari *et al.* (1993) reveal the relationship between tuna shoals and sea surface temperatures (SST) with help of satellite imageries.

Targeted shark fishery by longlining was reported from off Maharashtra and Gujarat coast and the vessels are equipped for multi-day fishing (Rekha and Venugopal, 2003). Thoothoor fishermen from Tamil Nadu are considered as skilled in the longline fishing technique in Indian waters. The fishing method is locally called as '*mattu*' and they are using large sized hooks. They have used strong steel wires to rig the hooks for preventing the sharks from biting the line (Joel and Ebenezer, 1993). This mode of fishing method is a popular fishing technique and found to be very profitable off Mangalore. They are operating all along the west coast of India. Balasubramaniam (2000) documented the modification of the country boats in diversified tuna fishery carried out at Tharuvaikulam, Gulf of Mannar, India. Marine Products Export Development Authority (MPEDA) has initiated the conversion of large and medium trawlers to tuna longliners under different schemes. MPEDA has given assistance of rupees 0.75 million to the mechanised fishing vessels and rupees 1.5 million to deep sea fishing for the conversion of existing vessels in to tuna longliners and they have taken initiatives for the conversion of country boats for tuna longlining (Thomas, 2008). These ventures attracted many new entrepreneurs into the tuna longline fishing on a commercial scale. National Agricultural Innovation Project (NAIP) has a started project to exploit the untapped oceanic tuna resources in the Lakshadweep Sea under the funding of World Bank in 2008.

1.7. Rationale and objectives of the study

Longline is a passive fishing gear which is considered as a species and size selective fishing gear to catch sparsely distributed large pelagic fishes like tuna and tuna-like fishes. This method is also considered as an environment friendly and fuel efficient fishing method. Longline fishing in India commenced on exploratory scale in early 1970s. Harvesting of oceanic tuna resources was confined to large commercial longline vessels operating in the Indian EEZ under joint-venture schemes for a short period and the exploratory survey has been carried out by Govt. of India vessels.

The charter scheme was gradually phased out between 1992 and 1995. The Maximum Sustainable Yield (MSY) of tuna and allied species from Indian EEZ is nearly 2 lakh tonnes but the production in 2010 was only 60,512 tonnes (Pillai *et al.,* 2006). Estimated potential of total tuna resources in Lakshadweep Islands is 50,000 tonnes (Pillai *et al.,* 2006). The present annual production from Lakshadweep waters, which is only about 20% of the estimated potential of the area, can be enhanced by adoption of innovative fishing techniques like tuna longlining. Under an NAIP project component, initiated in Central Institute of Fisheries Technology, Cochin, selected Pablo boats from Agatti were modified for the experimental longline operations. The present study has used the fishing data from the experimental fishing operations carried out from the three modified Pablo boats in the Agatti Island. The estimation and standardization of Catch per Unit effort (CPUE) is very important to understand the efficiency and profitability of the longline fishing. The factors such as shape and size of the hook, type of bait, depth of operation, time of operation and season have significant effects on the catchability. The process of minimizing the effect of these factors on the CPUE is called as standardization of CPUE. Apart from the targeted species, many bycatch species such as marine turtles, sharks and seabirds are also encountered during the fishing operation. Most of these untargeted species doesn't have any commercial value and many of them are protected species. Commercial tuna longlining in India is in its nascent stage. There is a dearth of scientific information on the longline fishing in Indian waters and its impact on the marine ecosystem.

The main objectives of the present study have been:

- studies on the operational performance of tuna longline in Lakshadweep Sea
- studies on the efficiency of hooks in the longline operation
- studies on the efficiency of baits in the longline operation
- studies on bycatch in longline operation
- studies on predation on the longline catch and the hook loss encountered during the fishing operation

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Chapter 2

REVIEW OF LITERATURE

Contents

2.1. Historical evolution of tuna longlining

The longline gear appears to have been originally developed by the Japanese. Nakamura (1951) reported that according to the local tradition in the Izu region of Japan, the gear was invented by an individual named Fujii in the Kaei Era (1848-1853). Shapiro (1950) opined that the gear was imported from the Wakayama Prefecture almost 100 years earlier and developed further by the fishermen of Mera, a fishing village near the entrance of Tokyo Bay. The longline fishing techniques spread outside the Japan after the Second World War (Shapiro, 1948). Due to increase in demand for canned tuna, most of the coastal countries started commercial fishing operations for tuna during 1940s and 1950s. In the middle of 1960s, Republic of Korea and Taiwan started longline fishing operations for tuna in Indian Ocean. Maldives started longline fishing operations for large pelagic fishes in 1990 (Anderson and Waheed, 1990). During late 1950s, Sri Lanka ventured into the longline fishing operation. Today, Sri Lanka has a well developed tuna longline fishery which uses modified small boats. India started commercial tuna fishing operations since 1985 under the charter scheme. The adoption of longline operation elevated India to the position of second largest producer of yellowfin tuna in the Indian Ocean in 1990 (Somvanshi and John, 1995). Taiwanese longline fleets in Indian Ocean began catching bigeye tuna during 1986 (Lee *et al*., 2005). In recent years, this fishing method is very popular in the Indian Ocean coastal countries like Korea and Taiwan with specialised fleets undertaking multi-day fishing operations. English fishermen have developed an early form of the longline gear on Stellwagen Bank in the mid 1940s to target bluefin tuna *Thunnus thynnus* (Wilson, 1960). Many coastal countries near the oceans started new tuna fishing operations by chartering boats with flags of convenience. 1950s and 1960s witnessed a global expansion of the tuna longline fisheries throughout the Mediterranean and Atlantic waters initially dominated by the Japanese fleet. Tuna longline contributed around 16% to the total tuna production in the Indian Ocean (1.67 million tonnes) in 2006 and the leading contributors were Taiwan, Japan, Indonesia, Korea and Japan (IOTC, 2008). In the world tuna catch rates, Pacific Ocean predominated throughout. The rate of increase of the tuna catch from the Atlantic Ocean was slower than the other world oceans. Indian Ocean catch rates surpassed Atlantic Ocean since 1998. The contribution of tuna from the world oceans are about 15, 20 and 65 percent for Atlantic, Indian and Pacific Oceans, respectively. Longlines mainly targets yellowfin tuna and most of the large scale longliners now targeting bluefin tunas (FAO, 2004). China started commercial longline operations in Indian Ocean since 1995. The targeted tuna species were bigeye tuna, yellowfin tuna and swordfishes (IOTC, 1999). 150 fishing boats were recorded at the peak time in 1998 consisting of small boats and converted trawlers and gillnetters (IOTC, 2010a). Around 500 surface tuna longline boats have been reported in

Thailand for targeting large pelagic fishes like yellowfin tuna, bigeye tuna, marlins and swordfishes (Nootmorn *et al.,* 2002). Norway has developed a form of longline gear which used heavy braided synthetic line floated just under the surface of the water in the late 1960s to target Porbeagle shark, *Lamna nasus* (Gibson, 1998). The development of single strand monofilament and combination of baited hooks with chemical light sticks led to the greater acceptance of longlining for commercially harvesting large pelagic species. Pacific Ocean was the leader in the race followed by Atlantic and Indian Ocean (Lewison *et al*., 2004). Japan, Korea, and the Republic of China (Taiwan) are the primary industrial fleets in the Pacific Ocean. Mediterranean Sea fishery was dominated by European and North African nations. Spain is the dominant member in the Atlantic Ocean followed by Japan, United States, Portugal and Canada (Lewison *et al.,* 2004).

2.2. Longline fishing

Longline fishing is considered as an effective and traditional gear used to catch large predatory fishes like tunas. Longlines are passive fishing gears which are highly fuel efficient, eco-friendly and size and species selective (Hameed and Boopendranath, 2000). This method was developed and perfected by the Japanese in 1930s (Sakagawa *et al*., 1987).

The basic structure of the gear includes a mainline suspended from floats to which branchlines with hooks are attached (Shingu *et al*. 1980). Mainline and branchlines are made of materials of high specific gravity such as hard twisted polyamide, polyvinyl chloride or polyvinyl alcohol (Hameed and Boopendranath, 2000). The floatlines are attached to regulate the depth of the fishing operation (Gabriel *et al*., 2005). Hard plastic and fibreglass floats are generally used for regulating the depth of the fishing operation. In the industrial longliners, each operation involves the setting of 150-350 baskets of mainline, extending over a distance of 25-75 km, with about 2,000 baited hooks and each basket carries 4-6 branchlines (Sakagawa *et al*., 1987). Bamboo pole or aluminium poles with bright coloured flags, usually red or yellow are attached to the longline to locate the gear during day time. Flags are replaced by light buoys, radio buoys and radar reflectors to track the location and position of the line during night (Hameed and Boopendranath, 2000). Japanese tuna longlines set early in the morning from the stern of the vessels and hauled from the bow with the help of line hauling machine (Gabriel *et al.,* 2005). Previously, ‘J’ hooks were the preferred hook type for the longline fishing which has been replaced by Japanese tuna hooks of 3.6 sun (Beverly, 2006).

Modifications such as type of hook and bait, time of operation and depth of operation are made on the gear to improve the catching efficiency with respect to the targeted fish (Pajot *et al*., 1980; Peeling, 1985; Carr *et al.,* 1986; Huse and Ferno, 1990; Rey *et al*., 1991; Lokkeborg and Bjordal, 1992; Erzini *et al.,* 1996; Montrey, 1999; Keith *et al.,* 2003; Ward *et al*., 2004; Kerstetter and Graves, 2006; Yokawa *et al.*, 2007; Shiga *et al*., 2008; Beverly *et al*., 2009). Longlines other than drift longlines are not so popular for tuna fishing (Gabriel *et al.*, 2005).

2.3. Classification of longline gear

Longline is a passive gear and can be operated as horizontal longlines and vertical longlines. The horizontal longlines are used to catch sparsely distributed pelagic fishes like tunas and billfishes. Longlines are operated to catch both pelagic and demersal fishes. The operation of longlines ranges from small artisanal longliners to large industrial longliners. Based on the structure and mode of operation, longlines are grouped in to four categories *viz.*, horizontal pelagic longlines, bottom set longlines, vertical longline and bottom vertical longlines (Nedlec, 1982; Hameed and Boopendranath, 2000; Gabriel *et al*., 2005).

Horizontal pelagic longlines

These gears are otherwise known as drift longlines operated close to surface or middle layers for catching sparsely distributed pelagic fishes such as tunas, billfishes, marlins and pelagic sharks (Hameed and Boopendranath, 2000). Pelagic longlines composed of a long length of mainline deployed across the ocean and numerous baited branchlines attached to it (Sainsbury, 1971) (Fig. 2.1). The branchlines are suspended in the water column between regularly spaced floats. Branchlines connects the mainline to the baited hooks.

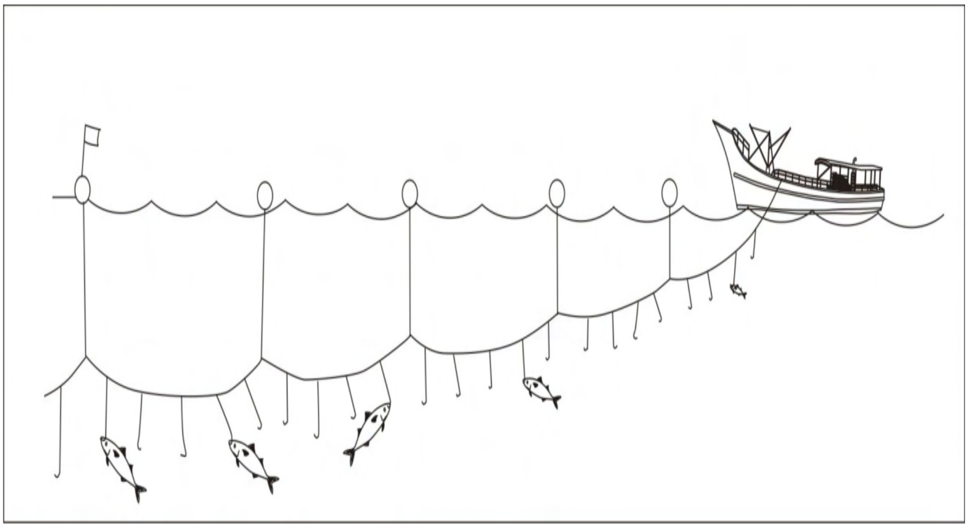

Fig. 2.1 Horizontal Pelagic Longlines

The number of hooks between the two floats varies from 4-30. The use of polyamide monofilament branchlines and use of light sticks are the recent developments in the tuna longlining (Pravin *et al.*, 2008). The major components of the longline system are mainline, branchlines, snood wire (leader wire), hook, floats and floatlines, flag poles, various buoys (light buoys and radio buoys) and radar reflectors. In traditional longline operations, the mainline associated with the branchlines are coiled and stored in units known as baskets whereas in modern systems, mainline is continuous and stored on powered reels (Hameed and Boopendrranath, 2000). The longlines are set, either by hand or mechanically, while the boat steams away from the line and are hauled mechanically while the boat steams towards the line (Beverly *et al.,* 2003)

Bottom set longlines

The longline, along with the baited hooks, lies on or near the bottom and its position is maintained by anchors at each end (Sainsbury, 1971) (Fig. 2.2). This fishing method is operated to catch the predatory demersal fishes such as sharks, sea breams, sea bass and groupers, snappers (Hameed and Boopendranath, 2000). Due to the closeness to the sea bottom the gear is vulnerable to tear off in rough bottom conditions.

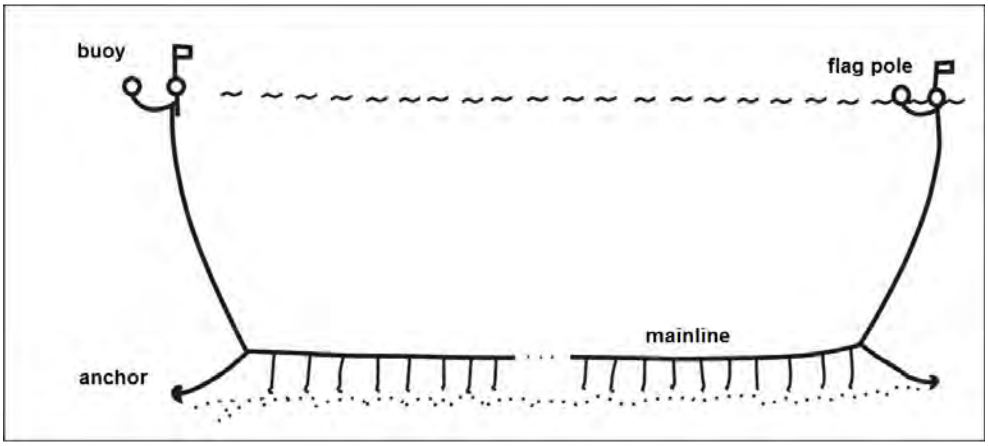

Fig. 2.2 Bottom set longlines

Vertical longlines

In the vertical longlines, the mainline is set vertically from the buoy on the surface and sufficient weight is attached at the other end to maintain the vertical orientation (Fig. 2.3). This fishing gear exploiting the vertical range of distribution of the target species and is very effective to catch the fish species showing distinct vertical range of distribution. Vertical longlines are very useful in operating where the bottom conditions are rough. FAD associated vertical longlining is found to be very effective to catch the fish species which shows the tendency to aggregate near floating objects. This technique enables the fishermen to simultaneously fish a range of depths while also concentrating many hooks close to FAD (Preston *et al.*, 1998)

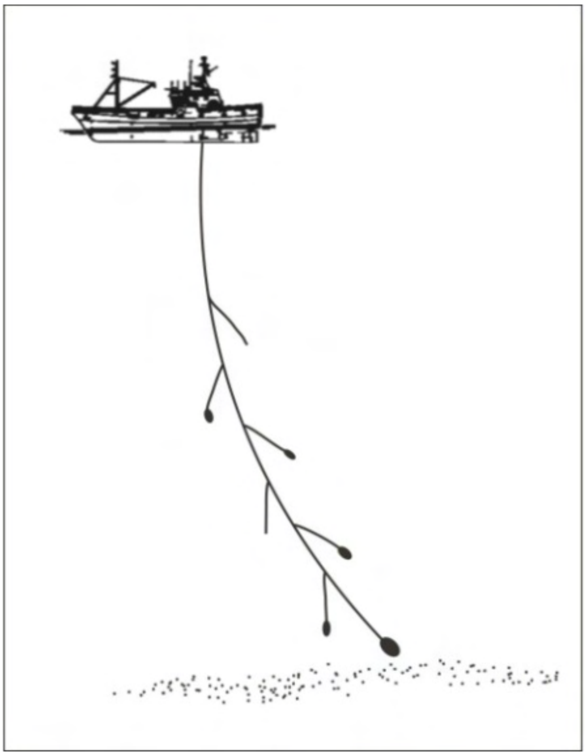

Fig. 2.3 Vertical longlines

Bottom vertical longlines

This gear is a combination of the properties of bottom set longline and vertical longline (Hameed and Boopendranath, 2000) (Fig. 2.4). A number of hooks are attached at equal intervals to the branchlines. The length of the line attached to the branchline is not less than 2 m made of PA monofilament. For maintaining the vertical stature of the branchlines, floats and sinkers are attached at the distal ends. This system of operation is intended to catch high value perches inhabiting in the rough grounds.

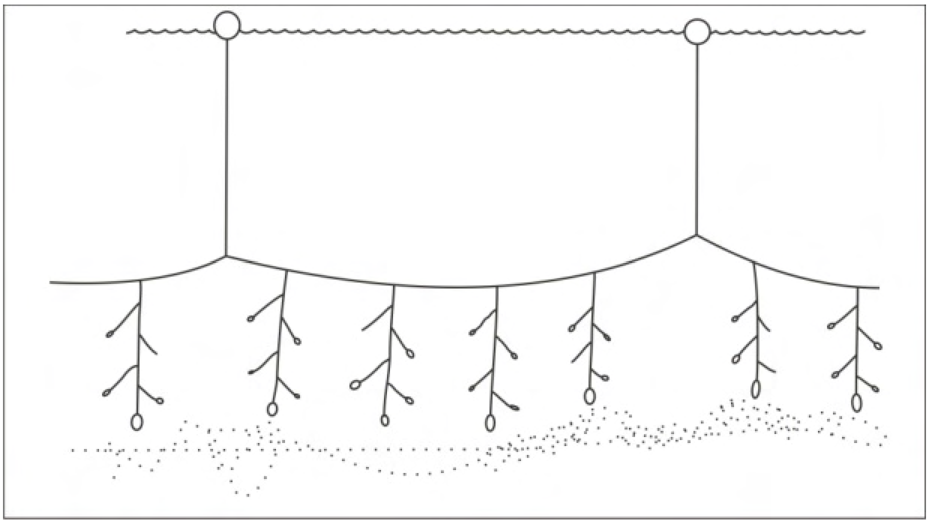

Fig. 2.4 Bottom vertical longlines

2.4. Tuna longline performance

The fishing efficiency of the longline gears is influenced by small changes in the gear configuration (Broadhurst and Hazin, 2000). The monofilament longlines has been reported to be catching more yellowfin and bluefin tunas than multifilament longlines (Hazin *et al.*, 2002). The shift from multifilament to monofilament longline gear is a major development in the longline fishing operations.

Catch per day and catch per 100 hooks are considered as good indicators of apparent abundance than catch per trip (Yoshida, 1975). Fishing efficiency of longlines is generally expressed as hooking rate *i.e.* the number or average weight of fish caught per 100 or 1000 hooks (Joseph, 1972; Sun and Yeh, 2000; An *et al.*, 2008). Species-wise hooking rate for the longlines reported from different geographical locations is given in Table 2.1.

2.4.1. Tuna longline hooking rate in Indian Ocean region

High tuna hooking rate of 0.7 to 1.3 fish per 100 hooks has been reported from Indian Ocean during 2000 to 2006 period (Nootmorn *et al*., 2010). The major species caught were yellowfin tuna, bigeye tuna, albacore tuna, swordfish and other large pelagic species comprising 36.64, 35.77, 20.08 and 7.31%, respectively. Yellowfin tuna is the main targeted species by the longliners in Indian Ocean region. The yellowfin tuna hooking rate in Indian Ocean waters ranged from 0.05 to 2 fish/100 hooks (BOBP, 1988; Lee *et al.*, 2005). Seas off Somalia and Seychelles are considered as productive fishing grounds for yellowfin tuna (Nootmorn *et al*., 2010). High yellowfin tuna hooking rate has been reported in Sri Lanka and Maldivian waters (2 fish/100 hooks) (BOBP, 1988). Reported data showed that bluefin tuna is not significant in the landings of pelagic longline fisheries in Indian Ocean. However, an experimental tuna longlining operation has given bluefin tuna landing with a hooking rate of 1.1 fish per 100 hooks in Indian EEZ (BOBP, 1983).

Existing information on oceanic tunas in Indian EEZ indicate that tuna longlining can be carried out round the year with better hooking rate during pre-monsoon and monsoon seasons in the Arabian Sea and during monsoon and post monsoon season in the Andaman and Nicobar waters (Somvanshi and Varghese, 2007). The main targeted species of Chinese longline fleet in Indian Ocean waters are bigeye tuna, yellowfin tuna and swordfish (IOTC, 1999). The strong market for southern bluefin tuna has led to increased fishing effort resulting in declining catch began in the early 1960s (Sakagawa, 1987). Total nominal catch of tuna and tuna like fishes in the IOTC waters in 2008 is 7,097.4 metric tonnes and showed a 34.8% reduction compared with that in 2007 (Liuxiong *et al.* 2010). An increase in the tuna landings mainly yellowfin has been reported from Thailand during 1994-2001 (Nootmorn *et al.,* 2002). October to May has been considered as the peak season for the tuna fishing in Thailand (Nootmorn *et al*., 2002). Two types of longline systems have been used in Taiwan *viz.*, regular and deep longline systems based on the number of hooks per basket. In regular longlines, albacore tuna was the major catch and in deep longlines, the major catch was bigeye tuna (Lee *et al*., 2005). The high seas tuna fishery of the Indian Ocean is supported mainly by four species *viz.*, yellowfin tuna, southern bluefin tuna, albacore tuna and bigeye tuna (Joseph, 1972). Tuna hooking rate reported in the world oceans is shown in the Table 2.1.

Table 2.1 The tuna hooking rates in the world oceans.

Geographical areas	Hooking rate (no of fish/100 hooks)					Authors
	YF	BF	BE	ALB	Total hooking rate	
Indian Ocean						
Indian Ocean	0.16-0.28	-	0-0.2	-	0.2-0.5	Joseph, 1972
Indian EEZ	1.4	1.1	-	-	1.1-1.4	BOBP, 1983
	1.8	-	-	-	1.8	Sudarsan and Sivaprakasam, 1993
	0.5-1.8	-	-	-	0.5-1.8	FSI, 2006
Sri Lankan EEZ	2.0	-	-	-	2.0	BOBP, 1988
Indian Ocean	0.05-0.4	-	0.01-0.8	1.0-3.0	1.06-4.2	Lee *et al*., 2005
Northeastern Arabian Sea	0.2-0.6	-	-	-	0.2-0.6	Somvanshi and Varghese, 2007
Andaman and Nicobar waters	0.08-0.34	-	-	-	0.08-0.34	Somvanshi and Varghese, 2007
Indian Ocean		-	-	0.09-1.4	0.09-1.4	Lirdwitayaprasit *et al*., 2011
Southwestern Indian Ocean	Trace	-	0.05	-	0.05	Zhu *et al*., 2011
Pacific Ocean						
Pacific Ocean	-	-	-	1-7	1-7	Yoshida, 1975
Tropical Pacific	1.1-1.9	-	0.3-0.5	-	1.4-2.4	Polacheck, 1991
Central and Western Pacific	-	-	0.06-0.4	-	0.06-0.4	Sun and Yeh, 2000
Atlantic Ocean						
Northeast Atlantic	-	0.2-6.6	-	-	0.2-16.6	Boyd, 2008
Northeast Atlantic	-	1	-	-	1	Boyd, 2008
Western Atlantic	-	0.1-0.8	-	-	0.1-0.8	Oshima and Miyabe, 2010
Central Atlantic	-	0.1-0.2	-	-	0.1-0.2	Oshima and Miyabe, 2010
Eastern Atlantic	-	0.1-0.4	-	-	0.1-0.4	Oshima and Miyabe, 2010
Atlantic Ocean (Gulf of Mexico)	0.5-1.3	0.04	-	-	0.5-1.34	Teo and Block, 2010

YF-Yellowfin; **BF**- Bluefin; **BE**-Bigeye; **ALB**-Albacore

2.4.2. Tuna longline hooking rate in Pacific Ocean region

Taiwanese fishing vessels start fishing in the Pacific Ocean since 1963 (Sun and Yeh, 2000). The main targeted species in these regions are albacore, yellowfin and bluefin tuna. Longline operations near the seamounts have been found to be very effective in central and west Pacific waters (Morato *et al.,* 2010). Korean tuna longliners operating in Pacific Ocean reported a downward trend of the oceanic tunas from 2000 to 2004 (Moon *et al.,* 2005). A positive trend has been evident in the catch rates of yellowfin and bigeye tuna with negative trend in albacore tuna and swordfish catches from the Japanese longline fisheries (Uosaki *et al.,* 2005). The yellowfin tuna hooking has been reported to be 1.1-1.9 fish/100 hooks). The bigeye catch rate ranged from 0.06 to 0.5 per 100 hooks (Polacheck, 1991; Sun and Yeh, 2000). Not much information is available on the hooking rate of the albacore tuna from the Pacific Oceans. Yoshida (1975) has reported high albacore tuna hooking rate from the Pacific waters (1 to 7 fish/ 100 hooks).

2.4.3. Tuna longline hooking rate in Atlantic Ocean region

Taiwanese has started longline fishing operation in Atlantic Ocean in 1960s (Liu, 2011). Initially they have targeted solely albacore tuna and later shifted to bigeye and yellowfin tunas. The recorded yellowfin tuna hooking rate in Atlantic Ocean ranged from 0.5 to 1.3 fish/100 hooks (Teo and Block, 2010). Bluefin tunas are other major group of tunas targeted in the Atlantic Ocean. The bluefin tuna hooking rate ranged from 0.04 to 16.6 per 100 hooks (Boyd, 2008; Oshima and Miyabe, 2010; Teo and Block, 2010). Landing of oceanic tunas from these waters showed a declining trend from 2000 to 2007 (Liu, 2011). Japanese tuna longliners reported high bluefin tuna catch rates from the Atlantic Ocean during 1997 (16.6 fish/100 hooks) (Boyd, 2008).

FAD assisted tuna longline operations were found to be more effective to catch tunas (Naeem and Latheefa, 1994). Nishida *et al.* (2001) reported that steep bathymetric areas have positively affect the yellowfin tuna catch rates while which has no effect on bigeye tuna catch rates. Studies have shown that surface longline set at night are more productive for capturing large pelagic fishes like swordfishes (Kume and Joseph, 1969). The bigeye tuna catch was found to be high during days characterised by weak lunar illumination mainly during low tide (Poisson *et al.,* 2010). Tunas are very mobile and unequally distributed species throughout the year and they are reported to aggregate in some regions favourable for their feeding (Viswanathan, 1999). Albacore tuna CPUE reached maximum during the full moon period (Poisson *et al.,* 2010). Bluefin tuna was found to be abundant in the areas with negative sea surface height anomalies (SSH) and cooler sea surface temperature (SST) and it has showed high level of spatio-temporal variability (Teo and Block, 2010).

2.5. Hooks and hook loss in tuna longlining

History of hook

Gorge is believed to be the primitive form of a hook which is used by ancient people. It has two points made from bone and was about four inches long, often with a hafling grove in the center (Anon, 2012b & 2012c). The primitive type of hook is possibly developed using bones, upper bills of eagles, shells and thorns of plant. The oldest known hooks were excavated from Czechoslovakia and belonged to late Paleolithic era. The oldest hook that was found in Palestine is believed to be 9000 years old (Anon, 2004). Britain has started hook making as part of the industrial revolution. The first form of hook were “blind” (*i.e.* they lacked an eye) and first illustration of an eyed hook was in 1660, in Les Ruses Innocentes, by Fortin (Anon, 2008).

The hook making has become completely automated, utilizing sophisticated machines. The high carbon content steel was the main raw material for producing hooks. Occasionally steel alloys were also used. The physical strength of the hook is determined by many factors starting from the selection of material to depth and angle of cutting of steel wire for making hook barb (Baranov, 1977). Most of the works on hooks are limited to the catching efficiency or size selectivity aspects (Takeuchi and Koike, 1969; Despande *et al.,* 1970; Kartha, 1973; Lokkeborg and Bjordal, 1992). Thomas *et al.* (2007) made an attempt to consolidate and review the information on various aspects of tuna hooks.

Structure of hooks

The hook mainly consists of an eye, shank, bent, point, gape and throat. The most important measurement of a hook is its gape, which contributes the distance between point and shank and the depth of the throat (Fig. 2.5). They varied considerably in shape, size and materials used. Predominantly three kinds of hooks are using in the longline fisheries *i.e.* 'J' hooks, Japanese tuna hooks and circle hooks. Earlier iron was the principal metal used for making hooks which have disadvantages of breaking or bending under stress and susceptibility to corrosion. Hooks used in 1950s were straight-shanked J-shaped hooks made of either tin plated iron, galvanized steel and later stainless steel (Ward and Hindmarsh, 2007). Shapiro (1950), Otsu (1954) and Joy *et al*. (1985) documented the use of square type galvanized iron hooks in the Indian Ocean longline fisheries during 1980s (Yamoguchi, 1989). More durable, non-corrosive stainless steel hooks have been common in most longline fisheries since the mid 1990s. In order to protect iron hook from corrosion, they are coated with metals such as tin, nickel, cadmium or a combination of these metals, or other anti corrosives. To meet the requirements of strength and elasticity in the working progress, a hardening process is used to make the hooks neither too soft nor too brittle. The hook design also has undergone tremendous changes. According to the fishing purpose they can be mainly classified into hooks for commercial and sport fishing.

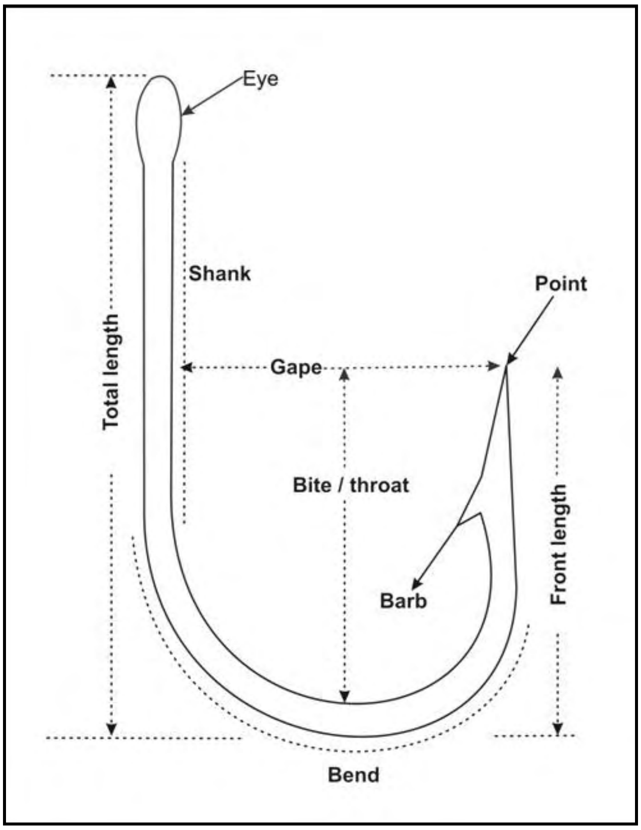

Fig. 2.5 Anatomy of hooks (Anon, 2004)

Another important factor with hooks is the fact that they can be either offset or non-offset (Fig. 2.6). Non-offset hooks are the hooks with their points lying in the same plane as the shank of the hook. With offset hooks, the point is bent away from the plane of the shank by 5-25° angle. When the point is offset to the left, the hook is said to be 'kirbed'. If the point is offset to the right, the hook is said to be reversed. Japanese tuna hooks, for example, typically have a 10-20° offset to the left (kirbed). Circle hooks and 'J' hooks can be either offset or non-offset. The type and size of the hook is very important to determine the success of fishing operation. New gear materials have improved the efficiency of the longliners like the quality of the hook, monofilament, and other accessories.

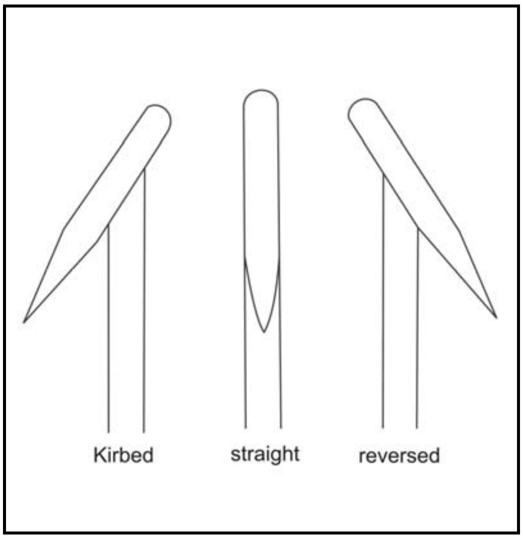

Fig. 2.6 Offset of hooks

Hook numbering system

There are no internationally recognized standard for hooks and numbering systems varies among manufacturers (Anon, 2012d). The hook numbering system is categorised in to two numbering sets or series. The first series denotes the smaller hooks and uses numbering system generally ranging from 32 to 1. In this series, the larger the number the smaller is the hook. The other series applied for the big hooks. Fishing hooks larger than the number 1, a transition in to the "aught" series begins which is a number followed by backslash and zero. Here the larger the number *viz.,* 1/0, 2/0, 3/0 the larger is the hook. The hook size varies from very small size represented by No. 32 to very large represented by No. 20/0 (Anon, 2012e & 2012f). The numbers represents relative sizes, normally related with gap (Anon, 2012d). Almost all hook manufactures are following this basic system to indicate the size of hook in individual pattern.

'J' Hooks

'J' hooks are very similar to big game trolling hooks and are used to catch tunas, marlins and other game fish species (Fig. 2.7). 'J' hooks size ranges from 1/0 to 22/0. The most common size of 'J' hooks used is 8/0 and 9/0. The hooking rate is reported to be very high in 'J' hooks (Kerstetter and Graves, 2006). The unique feature of 'J' hook that makes it different from Japanese hook or circle hook is the barbed point which is almost parallel to the shank of the hook. In Japanese tuna hooks the shank is bent towards the tip of the hook and in circle hooks the point is bent at the shank at a 90° angle. Of the three hook designs, the 'J' hook has the largest gape. This is one of the main reasons for higher marine turtle bycatch rates in the 'J' hook than other hook deigns (Beverly, 2006). 'J' hooks are not advisable because of the injury caused on the fish and the reduction in the survival rate of the untargeted animals like dolphin, marine turtles after the release (Huse and Ferno, 1990). The Erzini *et al.* (1996) reported increasing catchability and selectivity with decreased hook size. Smaller hooks may however increase the risk of hooks tearing out of larger fish.

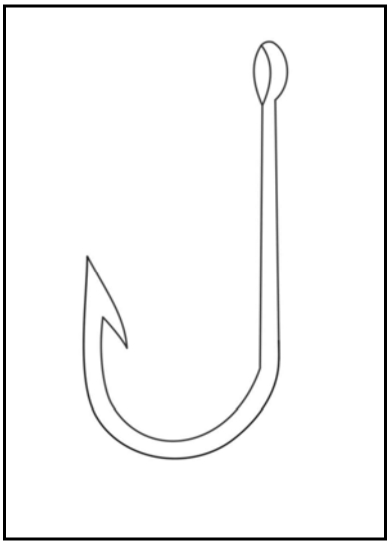

Fig. 2.7 'J' Hook (Not drawn to scale)

Fish caught by longlines are generally hooked in the mouth, particularly in the jaw, or in the alimentary tract if the fish has swallowed the hook. Hook design is also a parameter that affects species selectivity of longlining (Huse and Ferno, 1990). The E-Z baiter hook which is an intermediate form between circle and 'J' hook has been found to be having superior catching efficiency (Skeide *et al.*, 1986; Gill and Palmason, 2005). A study on comparative performance of two types of tuna hooks *viz.*, imported Taiwanese hooks and Indian tuna hooks in an experimental tuna longline operation in India concluded that the locally made Indian tuna hooks registered better hooking rates than the Taiwanese hooks (Premchand and Pandian, 2004). 'J' hooks is still being used in troll fisheries for large tuna and other game fish such as marlin. The 'J' hooks were largely replaced by Japanese tuna hooks in recent years.

Japanese tuna hooks

Japanese tuna hooks have been the most popular for years, especially with tuna longliners (Fig. 2.8). They come in a variety of sizes and the unit of measurement called ‘sun’, which is about 3.3 cm and is used to measure the length of the hook. A 3.4 sun hook for example, is 3.4 sun X 3.3 cm long representing the entire length of the wire used to make the hook from the eye to the tip of the point. These measurements have no relation with the shape of the hook or the size of the other measurements of the hook such as bite, throat, and gape. Popular sizes of Japanese tuna hooks for longline operation are 3.4, 3.6 and 3.8 sun. Japanese tuna hooks are either ringed or non-ringed in the eye. 3.6 sun stainless steel Japanese tuna hook with ring is the most accepted hook for tune longline operations (Beverly, 2006). The Japanese tuna hook which is an intermediate style between ‘J’ hook and circle hook has been in wide spread usage since the early 1980s (Whitelaw and Baron, 1995). The post release mortality due to deep hooking is reported to be very high in this type of hooks. Studies conducted by various workers confirms its superiority to catch fish (Ward *et al.*, 2009).

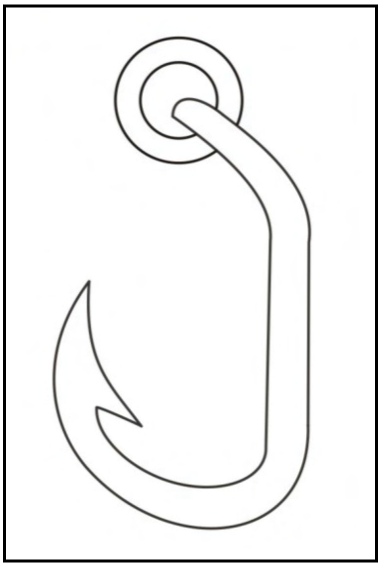

Fig. 2.8 Japanese Tuna Hook (Not drawn to scale)

Circle hooks

A circle hook is a non-offset hook with the point turned perpendicularly back to the shank (Anon, 2003) (Fig. 2.9). Circle hooks are also called ‘G’ hooks. Japanese made circle hooks used in longline fishing generally come in size ranging from 4.2 sun to 5.5 sun. Most of the western made circle hooks are following this numbering system with units of measurements in centimeters. Tankichie and Maruto brand hooks are following a different numbering system in which they are numbered from 28 to 44. Circle hooks are popular as they are proved to be very effective in mitigating marine turtle and seabird bycatch (Watson *et al.*, 2005; Kerstetter and Graves, 2006; Ward *et al.*, 2009).

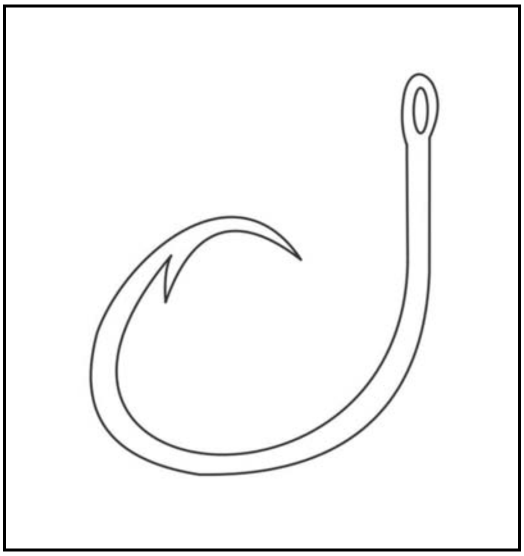

Fig. 2.9 Circle Hook (Not drawn to scale)

The most accepted size of circle hooks for longline fishing range from 14/0 to 18/0. Circle hooks do not usually come with rings (Beverly, 2006). The auto-baited type of hook is used in auto line systems. This kind of hook is a compromise between circle hook and the straight shank hook required by the automatic baiter of some systems (Gill and Palmason, 2005). The circle hooks have a unique curve which makes it more effective at avoiding deep hooking than traditional 'J' shaped hooks. In contrast to 'J' hooks, circle hooks have a tendency to slide over soft tissues and rotator resulting hook catching in the jaw (Cooke and Suski, 2004). Watson *et al.* (2005) opined that circle hook can considerably reduce the shark catch. Many countries have already banned fish imports from countries where longlines do not use acceptable mitigation measures. The design of hook strongly influences hooking location in the fish as well as the degree of hook damage (Skomal *et al.,* 2002; *Ward et al.,* 2009). Deep hooking of the hook can be significantly reduced by using circle hooks. The release mortality can be considerably minimized by using circle hooks without compromising on the overall catching rate (Yokota *et al.*, 2006; Curran and Bigelow, 2011). Circle hook cause less physical damage than straight hooks and can be a valuable conservation tool in the fisheries (Prince *et al.*, 2002; Watson *et al.*, 2004; Kim *et al.,* 2006; Pacheco *et al.*, 2011). The foul hooking is reported to be very less in circle hooks (Gilman *et al.,* 2007a, 2007b & 2007c). Circle hook has been reported to be more effective in catching tuna than other form of hooks (Kerstetter and Graves, 2006; Yokota *et al.*, 2006; Kerstetter *et al*., 2007; Ward *et al.*, 2009). Circle hooks have been proposed as a means of reducing bycatch in pelagic longline fisheries. Several studies indicate that circle hook can produce higher catch rates than traditional hooks (Peeling and Rodgers, 1985; Montrey, 1999; Falterman and Graves, 2002; Poulsen *et al.,* 2004; Kerstetter *et al.,* 2007; Ward *et al.,* 2009; Swimmer *et al.,* 2011). Yokota *et al*. (2006) and Pacheco *et al.* (2011) has opined that the change in hook pattern have little effect on the catch composition. Ward *et al*. (2009) concluded that there was no difference between the mean size of the species caught on the circle and

Japanese tuna hooks except for striped marlin (*Tetrapturus audax*). Catch could be improved by placing the majority of the hooks at the depth range preferred by the target species (Lokkeborg and Bjordal, 1992; Liuxiong and Guoping, 2006; Beverly *et al.,* 2009). A method for calculating the required buoyancy of mid water floats to put the hooks in the desired depth has been reported by Shiga *et al*. (2008).

Hook size is an important factor determining the efficiency of the longline fishing. Deep hooking can be significantly reduced by increasing the hook size (Grixtii *et al.,* 2007). Large hook size proved to be very effective in minimizing the bycatch without compromising on the catching ability for targeted fish (Shapiro, 1950; Piovano *et al*., 2010; Curran and Bigelow, 2011). Larger hooks are superior to small hooks for capturing large fish and have an optimum catching efficiency for certain fish lengths (Cortez-Zaragoza *et al.,* 1989; Lokkeborg and Bjordal, 1992). Large hook is less readily broken or straightened and its wider gap may allow the hook point to enter more deeply in the mouth cavity thus ensuring secure holding of the fish caught (Lokkeborg and Bjordal, 1992). The Erzini *et al.* (1996) reported increasing catchability and selectivity with decreased hook size. Ralston (1982) and Bertrand (1988) opined that hook size has no effect on size selectivity in line fishing.

Depredation and hook loss

Sharks and cetaceans cause significant damage in pelagic longline fishing operations worldwide. The damages are in the form of bite-offs, loss of gear, catch displacement, reduced gear efficiency and depredation of the catch (Gilman, 2007b & 2007c). Depredation which includes the partial or complete removal of hooked fish and baits from the fishing gear, is caused primarily by cetaceans and sharks in pelagic longline fisheries. Depredation cause considerable damage and loss to the fishery. Shark and marine mammal interactions cause substantial ecological, economic and social problems in the longline fishing sector (Lawson, 2001). Depredation raises many ecological concerns like the shift in foraging behaviour and distribution of sharks and cetaceans, increasing fishing effort, errors in fish stock assessment and deliberate injury and mortality of cetaceans and sharks by fishers to discourage depredation and avoid future interactions (Gilman *et al.*, 2006b). The presence of cetacean is mainly related to the catch rates of particular species (Milian *et al.,* 2008). The main problem with the shark interactions is the considerable loss of the fish caught, time required to repair damaged gear and loss of gear. Sharks which are caught as bycatch are also responsible for removing baits and gear (bite-offs) and inflicting damage upon other catch already hooked and thus less able to avoid predation (Gilman *et al.,* 2006b, 2007a, 2007b, 2008a). The occurrence of depredation in commercial longline gear is a very serious global issue (Garrison, 2007). The depredation by marine mammal has been reported in both pelagic and bottom longlines (Secchi and Vaske, 1998; Kock *et al.*, 2006). Yano and Dahlheim (1994) have reported the killer whale (*Orcinus orca*) depredation on the longline fishery targeting bottomfish. Depredation has direct economic impact on the fishermen in terms of loss of commercially valuable catch. Understanding the factors contributing to interactions between mammals and longline fishing gears is very important in reducing both incidental mortality and depredation in longline fishing operations. Killer whale depredation is a serious problem in the Brazil longline fisheries (Secchi and Vaske, 1998). Killer whales and sharks cause significant damage and loss to the tuna longline operations in Indian Ocean (Sivasubramanium, 1965). The predation 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 targeted billfish and tunas are areas likely to encounter high levels of depredation (MacNeil *et al.*, 2009). The possible way to reduce the depredation level is by keeping the gear away from their foraging range. Reducing the length of the mainline can be an effective measure to reduce the depredation rate (Garrison, 2007). The type of hook and nature of bait used have significant effect on the depredation rate (Williams, 1997; Gilman *et al.*, 2006b). Avoiding the use of certain gear materials could also reduce depredation levels (Branstetter and Musick, 1993). There have been numerous measures designed, tested and implemented to repel sharks (Sisneros and Nelson, 2001). The main objective of these measures is to deter the shark from taking the bait. The shark repellent chemicals are found to be very effective in preventing the shark from taking the bait (Sisneros and Nelson, 2001). Deep setting of the hooks, magnetic repellents, avoidance of peak areas and periods of shark abundance and hot spot avoidance through fleet communication are considered as the most efficient means for reducing the shark and cetacean bycatch (Francis *et al.*, 2001; Gilman *et al.*, 2008b & 2008c). The economic costs associated with longline depredation can be substantial and depredation is an inevitable part of conducing longline operations in the open ocean (Lawson, 2001). The future studies on depredation may benefit from a closer examination of the site-specific environmental characteristics and their influences.

2.6. Baits and bait loss in tuna longlining

Line fishing is a technique that lures fish to bite the bait. Catch rates depends to a large extend on bait type, quality and size (Bach *et al.*, 2000).

Fishermen use different types of bait based on their experience over the years. Bait type is the most significant gear parameter affecting the species selectivity of longlines (Pajot *et al.*, 1980; Carr *et al*., 1986; Lokkeborg and Bjordal, 1992). Bait must also be suitable to the target species. The preferences for bait vary seasonally and that may be affected by previous diet experiences, indicating that bait which is effective in one season/area may not be effective in other seasons or areas (Sutterlin *et al*., 1982). Odour from the bait is the factor which attracts the fish to the hook. Usually frozen whole fish such as milkfish, mackerels, scad, Japanese threadfin bream and flying fishes are used as baits for tuna longlining (Pravin, 2008). The quality of bait is also understood as how well it remains on the hook during the period of fishing operation. Physical strength and ability of the bait to remain on the hook throughout the soaking time determine the effectiveness of the bait. Studies by Januma (1999 & 2003) have shown that natural bait is superior to artificial bait. Squid bait was found to be superior to fish bait in the hook holding properties (Shomura, 1955; Pingguo, 1996; Ward and Myers, 2007). The fresh bait has been found to be superior to frozen bait. A 50% reduction in the catch rate was evident with the fishing operations conducted with pre-soaked mackerel bait than fresh bait (Lokkeborg, 1994).

Visibility of baits in the water column is a significant parameter affecting the fishing efficiency (Lokkeborg, 1994). Bait size is regarded as the most important factor that affects the size of fish caught by longlines (Lokkeborg and Bjordal, 1992; Lokkeborg, 1994). The effect of bait size is stronger in pelagic longlines than bottom longlines (Lokkeborg, 1994). The effect of bait size on size selectivity may reflect an optimal relationship between predator size and the size of prey (Lokkeborg, 1990). Increasing the bait size has been found to be effective in improving the size selectivity in pelagic longline for haddock when fishing under controlled conditions (Lokkeborg and Bjordal, 1995). Bait tenacity is one of the major factors affecting the catch rate and more tenacious baits were found to provide a longer effective fishing time (Pingguo, 1996). Brothers *et al.* (1995) studied the influence of bait quality in sinking rate of bait and the effect of adding lead sinkers to the baited hooks. The factors like weather, propeller turbulence, bait shape and thaw conditions have significant effect on the catch rate (Brothers, 1995; Keith, 2003). The response of fishes to baited hooks has been reported to be retarded when currents are strong (Lokkeborg, 1994).

Bait loss can significantly affect the longline catch rate and the main factors affecting the bait loss are hook depth, time of operation and bait species (Pingguo, 1996; Ward and Myers, 2007). Seabirds are considered as a potential cause for the bait loss and it depends mainly on seasons and fishing grounds (Pingguo, 1996). Sinking rate of baited hooks is an important factor that affects the seabird bycatch (Anderson and Mcardle, 2002). Partially thawed bait has been reported to sink faster than completely thawed bait (Brothers, 1991). Loss rate is the number of lost baits divided by the number deployed. Loss rate was reported to be minimum in squid than fish bait due to the firm nature of the flesh (Shomura, 1955; Ward and Myers, 2007). Removal by scavengers or target species, disintegration, and stresses from wave action and longline deployment and retrieval are the common causes of bait loss (Shomura, 1955). Bait loss vary among bait species and are increase with water depth (Sullivan and Rebert, 1998). Ward and Myers (2007) reported that bait loss rate decreases with hook depth and possible reason might be due to the lower influence of mechanical effect of surface waves. They have reported that loss rates are maximum during rough weather. The bait loss has been reported to be high at night and in rough weather (Ward *et al*., 2004; Ward and Myers, 2007).

Baits that are used by fisherman in India are either live or dead edible small fishes such as clupeids, small perches, mackerel, mullets, ribbonfishes, pomfret, silverbar, Bombay duck, eels, prawns and cephalopods (Balasubramanyan, 1964). Tuna showed quick response to live baits. Balasubramanyan (1964) reported that the Indian fisherman use neither salted nor frozen fishes as bait. But now a days, frozen sardine and mackerel are commonly used as baits for tuna longlining in India. The baiting may be done manually or by using baiting machines. In the manual baiting operation, the crew members attach the bait to the hooks by piercing the bait by the hook at the time of casting the branchlines. The baiting machine is usually located in the deck of the vessel. The baits are fed into the machine through a spiked conveyor belt. In the automated baiting, the bait should be very firm as it helps for good hooking rate. Before the line is set, the bait should be thawed partially before use. Baiting machine can bait around 10,000-20,000 hooks per day. Baiting machines are not in use in the longline fisheries of India.

2.7. Bycatch issues and mitigation measures

Tuna longline not only catch the targeted species but also many other species that are not targeted. These non targeted species are called bycatch. Marine turtles, dolphins, seabirds, and sharks are the main species which are discarded as bycatch in longline fishing operations (Pierpoint, 2000; Majkowski, 2007; Huang and Liu, 2010). Hook type in longline fisheries have received wide international attention recently because of the problem of bycatch. It has been confirmed that terminal gear like circle hooks can considerably reduce bycatch while maintaining the catch of targeted species. The overall width of the hook is the main factor that determines whether or not a turtle can swallow the baited hook (Watson *et al.,* 2004).

Incidence of marine turtle bycatch in the tuna longline fisheries and mitigation have been studied by many researchers (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). There are several factors influencing the incidental hooking of marine turtles in the longline gears. They are attracted by the baits and are eventually hooked and die due to drowning or sometimes due to injuries caused by the hook. The catch of economically important deep water species like bigeye tuna and bluefin tuna can be maximized by eliminating the shallow hooks which usually catch the marine turtles, sharks and porpoises (Beverly *et al*., 2009). Hook design and bait type can considerably reduce the bycatch (Poulsen *et al*., 2004; Joung *et al*., 2005; Watson *et al*., 2005; Gilman *et al*., 2006a; Kerstetter and Graves, 2006; Jribi *et al*., 2008; Ward *et al*., 2009; Yokota *et al*., 2009; Piovano *et al*., 2010). Deep setting of longlines with mid water float system having long floatlines have been found to be effective to avoid the marine turtle bycatch considerably (Shiga *et al*., 2000). It is a simple method of keeping the all hooks in the same depth range. The use of enough floats to maintain the desired depth that is deeper than the usual foraging ground of marine turtles, reduced the turtle bycatch significantly.

Seabirds are considered as one of the main victims which are accidently caught during the longline operation. Incidental seabird bycatch is a serious issue in commercial longline fishery (Belda and Sanchez, 2001). The interaction between seabirds and hooks considerably reduced efficiency of the fishing gear. Milessi and Defeo (2002) discussed the long-term impact of incidental catches by tuna longlines with special emphasis on the Black Escolar (*Lepidocybium flavobrunneum*). The main mitigation measures adopted for the seabird bycatch reduction includes changing longline setting time, underwater setting funnel, side setting of hooks, dyed baits, tori lines and forecasting of homogenized offal during line setting which ultimately 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). Seabird bycatch mainly depends upon fishing area, time, bait, fishing gears and seabird behaviours (Huang *et al.*, 2008a). Sinking rate of baited hooks is an important factor that affects the seabird bycatch (Anderson and Mcardle, 2002). Partially thawed bait has been reported to sink faster than completely thawed bait (Brothers, 1991). Keith (2000) studied the seabird interaction on small domestic longliners with video monitoring technique. The effect of tori lines and its optimisation has been widely studied by many authors as a means to mitigate the seabird bycatch (Duckworth, 1998; Nelson, 1998; Cooper *et al.*, 2001; Mancini *et al.*, 2008; Melvin *et al.*, 2008).

Several studies have been conducted to evaluate the impact of fishing on the marine mega fauna (Lewison *et al.*, 2004; Diaz, 2005; Ovetz, 2005; Garrison, 2007). Animals which are caught as bycatch will have detrimental effects on the natural population leading to their decline. Identification of the fishing methods and environmental parameters and process that control and regulate the interactions between marine mammals and longline fishing gears is very imperative to assess and control the bycatch issues. Pelagic shark bycatch is considered as a serious issue in commercial tuna longlining and their impact on shark stock is potentially very high. Their specific reproductive and growth characteristics lead to over exploitation. Extensive works have been done to study the interaction of marine mammals and elasmobranches in longline fishing (Stevens, 1992; Domingo *et al.*, 2005; Matsunaga and Nakano, 2005; Gilman *et al.*, 2008b & 2008c; Mandelman *et al.*, 2008; Milian *et al.*, 2008; Mangel, 2010). Deep setting of the hooks, magnetic repellents, avoidance of peak areas and periods of shark abundance and hot spot avoidance through fleet communication are considered as the most efficient way to reduce these bycatches (Francis *et al.*, 2001; Gilman *et al.*, 2008b & 2008c). Longlines caught less number of marine mammals like dolphins when compared with other fishing practices like purse seining (Hall, 1998). Surface longline gears can operate at a range of depths, and hooks placed at different depths can have different fishing efficiencies, depending on the target species and its behaviour. With better knowledge of the relationship between hook depth and catch rates, catch rates could be improved by placing the majority of hooks at the depth range favored by the target species. A successful fishing and catch rates greatly depends on the soaking time. The effect of soaking time and timing vary considerably between species to species. Soak time during dusk showed higher catch rates and it will affect the bycatch also (Ward *et al.*, 2004).

Ghost fishing is a serious concern in the longline fishing. The discarded monofilament lines are also detrimental to the marine biodiversity. These lost or discarded gears continue to fish and this process is known as ghost fishing. Seabirds, cetaceans, marine turtles are the main groups of animals usually caught. The ghost fishing by abandoned or discarded gear is considered as a major issue in the marine biodiversity conservation programmes (Reeves, 2003; Manville, 2005).

Research is needed to quantify bycatch from the small scale fisheries sector since it is reported to be producing huge quantity of bycatch every year (Peckham *et al*., 2007; Mangel *et al*., 2010). A concerted effort is needed from the governmental and non-governmental organisations and industry for educating fishers on bycatch mitigation measures (Francis *et al*., 2004). The issue of the bycatch should be addressed in pro-active and precautionary manner (Chapman, 2001). Bycatch reduction is possible without compromising the profit from the fleets by relocating fishing effort and by adopting proper management measures (Pradhan *et al*., 2006). Any attempt towards the bycatch mitigation in small scale sector has to be very simple to implement, be inexpensive and contribute to lower bycatch rates while maintaining the target species catch rates and be sustainable.

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Chapter 3

MATERIALS AND METHODS

Contents

3.1. Fishing area

Fishing experiments were conducted onboard the 3 Pablo boats modified for longlining in the Lakshadweep Sea around Agatti Island (10°38 - 11°07 N and 70°08 - 73°18 E) from November 2009 to April 2011. The Agatti Islands is a part of Lakshadweep group of Islands located between 8° - 12° N and 71° - 74° E in the Arabian Sea about 225 to 450 km from the Kerala coast of India (Fig. 3.1). They consist of 12 atolls, 3 reefs, 5 submerged banks, including 36 Islands, with a total land area of 32 km^2, and usable land area of 26 km^2. Lakshadweep is the smallest Union Territory of India with a population of 60,595 persons in 2001. Eleven out of the thirty-six Islands are inhabited. These are Agatti, Andrott, Amini, Bangaram, Bitra, Chetlat, Kadmat, Kavaratti, Kalpeni, Kiltan and Minicoy. The Lakshadweep Islands have 20,000 km^2 as their territorial waters and 4,00,000 km^2 of Exclusive Economic Zone. Fishing in the territorial waters is restricted to the Island fishermen only. The Lakshadweep Sea is blessed with rich marine resources. Several species of tuna, sharks and other large pelagic species have been reported from Lakshadweep Sea.

Agatti Island is the western most Island in the Union Territory of Lakshadweep located at 10° 48 - 10°53 N and 72^0 09 - 72°13 E. The Island covers a total area of 3.84 km^2 stretching 10 km in length with the width varying from 1,000 m at its widest point in the north to 100 m in the south. A coral reef, which lies along its eastern arc, forms an ellipse, 8 km in length and 5 km in breadth, enclosing Agatti Island with a lagoon on the western side of the Island (Fig. 3.2). Kalpitti is a small uninhabited islet situated at the southern most end of Agatti, separated by a narrow channel. The natural resources like coconut and fishes form the basis of the traditional economy of the people of Agatti Island and surrounding reefs of Bangaram, Thinnakara and Parelli and the sunken reef known as Perumal Par are considered as the potential fishing grounds of Agatti. Fishing operations were carried out in the area beyond the reef.

Fig. 3.1 Map showing the Lakshadweep group of Islands in the Arabian Sea

Fig. 3.2 Agatti Island in Lakshadweep Sea

3.2. Fishing systems

3.2.1. Fishing boat

Under the National Agricultural Innovation Project (NAIP), five Pablo boats have been modified for the tuna longlining operations in the Lakshadweep Sea. Pablo boats selected for the study were mechanised wooden fishing boats of Lakshadweep Islands ranging from 7.62 m to 8.5 m L_{OA} with engine capacity ranging from 10 to 23.5 hp. A typical Pablo boat and the general deck layout of the boat is given in Fig. 3.3 & 3.4. A typical Pablo boat and its deck layout after modification is depicted in Fig. 3.5 & 3.6. Among the five modified boats, the data from three boats were taken for the study. The detailed specifications of the selected boats namely, *Noorjahan, Jeelani* and *Pondicherry* are given in the Table 3.1. The modification were carried out by installing a stainless steel (grade IS 304) hand operated winch (Fig. 3.7 & 3.8) installed for hauling the line, a stainless steel (grade IS 304) guide pulley (Fig. 3.9) in the forward port side of the boat for guiding the mainline towards the drum, a PUF (polyurethene Foam) insulated FRP (Fibreglass Reinforced Plastic) box (Fig. 3.10 & 3.11) was provided for storing the fish catch and a PUF insulated FRP box (Fig. 3.12) for storing the bait fish. An FRP bin was also provided with stainless steel rings for storing the branchlines (Fig. 3.13 & 3.14). This facilitates storing of branchlines and avoiding entanglement of lines.

Table 3.1 Details of the boats selected for the modification of Pablo boat at UT of Lakshadweep.

Name of the boat	Place	L_{OA} (m)	Breadth (m)	Depth (m)	Engine type hp
Noorjahan	Agatti	7.60	2.00	0.80	Kirloskar (16.5)
Jeelani	Agatti	7.60	2.00	0.80	Ruston (23.5)
Pondichery	Agatti	8.50	2.00	0.90	Ruston (23.5)

Fig. 3.3 Conventional Pablo boat in operation, Off Agatti

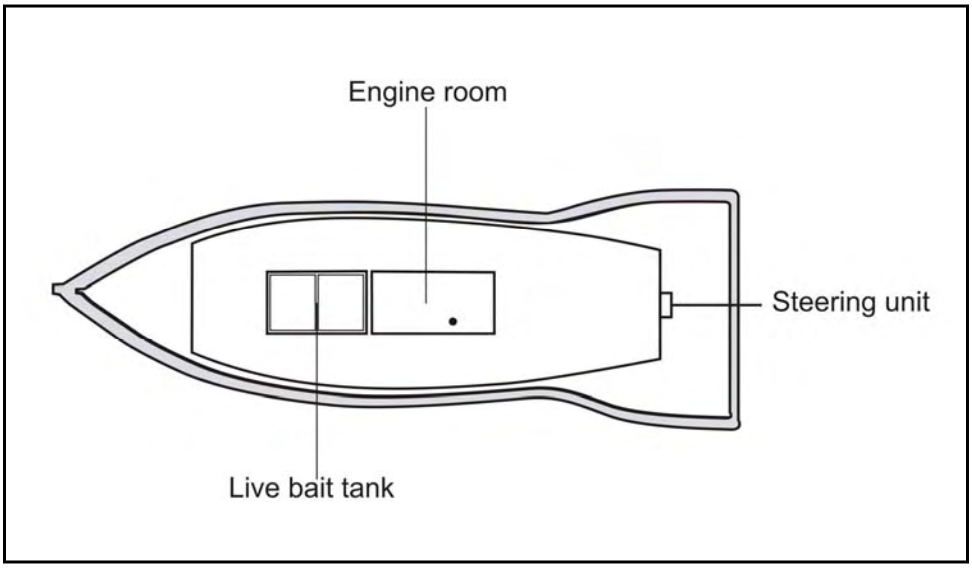

Fig. 3.4 General deck layout of conventional Pablo boat

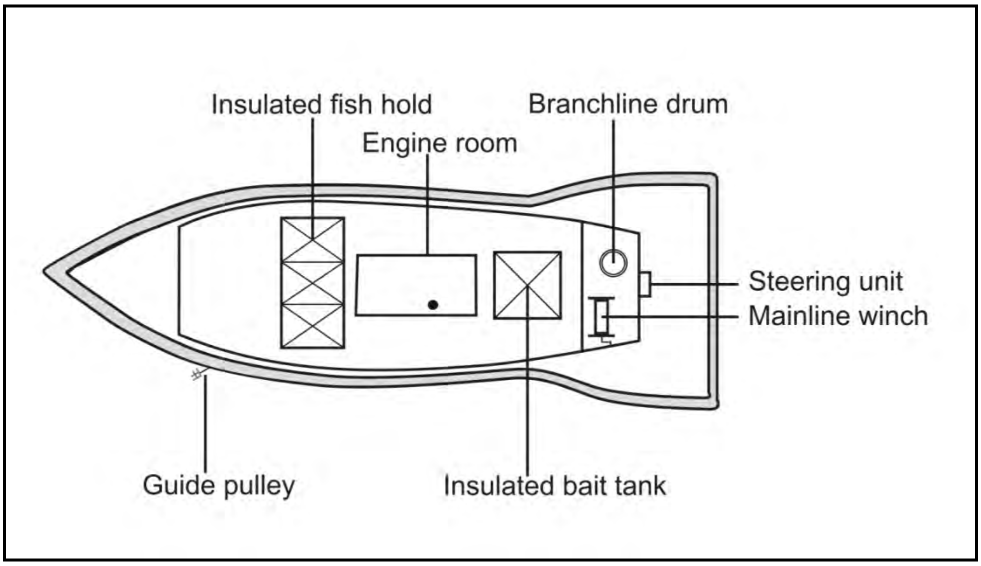

Fig. 3.5 General deck layout of modified Pablo boat

Fig. 3.6 Modified Pablo boat in operation Off Agatti

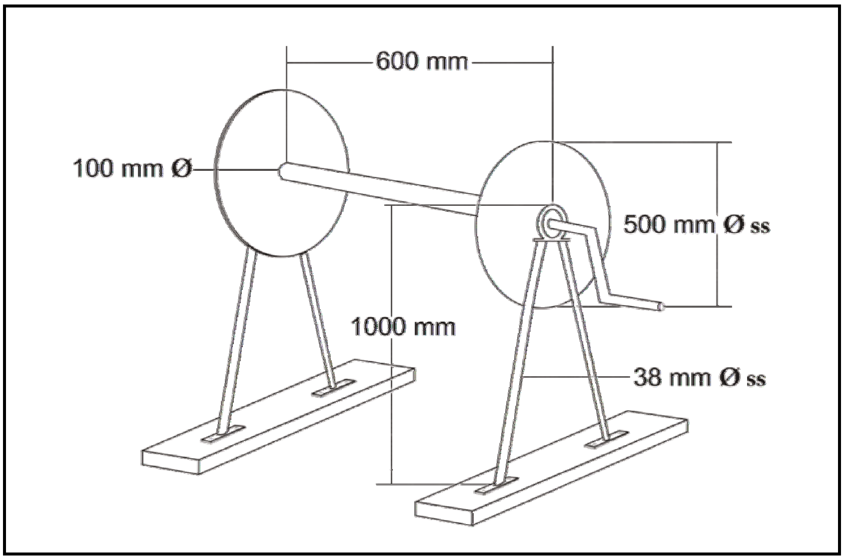

Fig. 3.7 Stainless steel winch

Fig. 3.8 Stainless steel winch

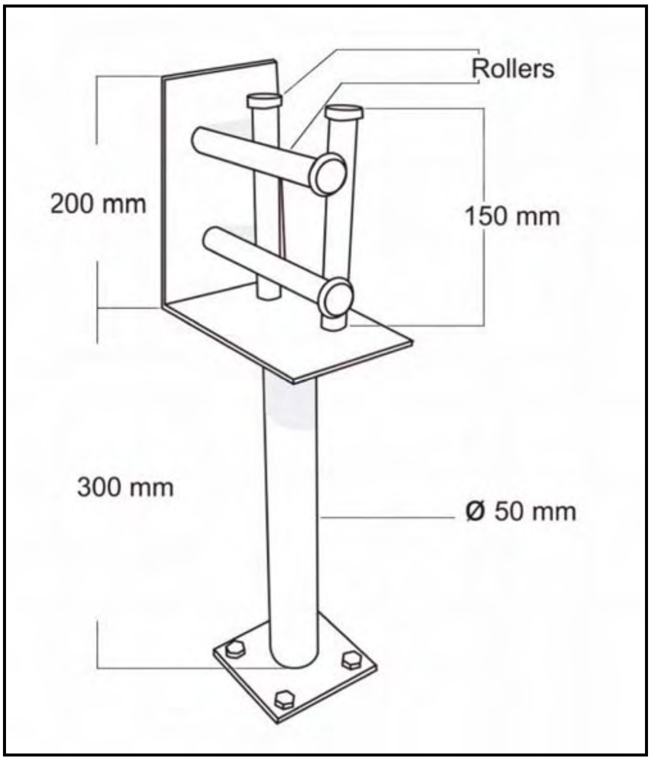

Fig. 3.9 Stainless steel guide pulley

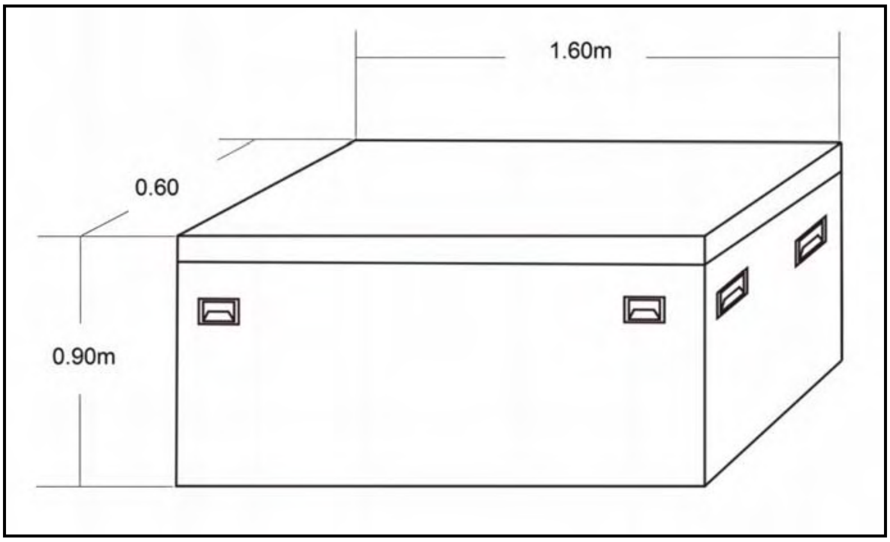

Fig. 3.10 PUF insulated FRP box for fish storage

Fig. 3.11 PUF insulated FRP box for fish storage

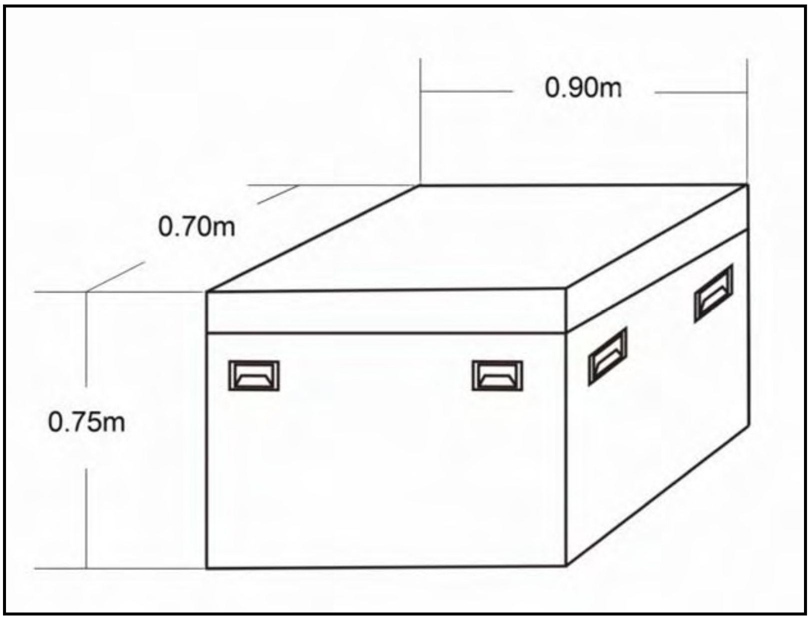

Fig. 3.12 PUF insulated FRP box for storing bait fish

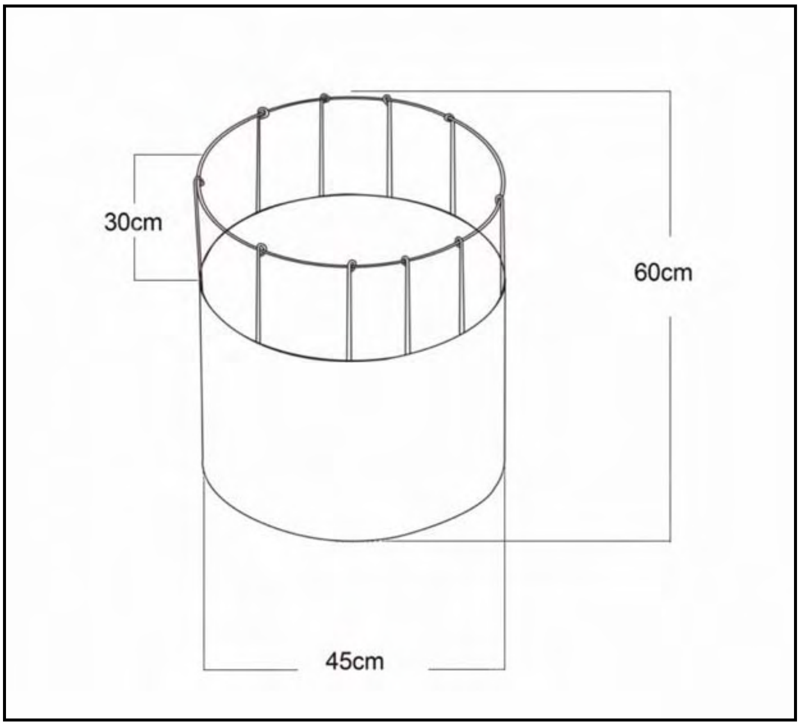

Fig. 3.13 FRP bin for storing branchlines

Fig. 3.14 FRP bin for storing branchlines

Modification work of Pablo boat can be carried out by fishermen themselves. They can switch from pole and line fishing to longline fishing depending on the fishing seasons. The longline equipment fixed onboard can be taken out easily during off season for maintenance and repairs.

3.2.2. Fishing gear

The horizontal longline fishing method was introduced in Lakshadweep under the NAIP project titled “A Value Chain on Oceanic Tuna Fisheries in Lakshadweep Sea”. The structure of the tuna longline system used for the experiment showed in Fig. 3.15. The tuna longline gear introduced at Lakshadweep Islands consist of 3.0 mm diameter PA monofilament mainline, 1.8 mm diameter PA monofilament branchline, stainless steel swivel, plastic floats, stainless steel snap clip, stainless steel hook, luminous heart, aluminum sleeves, copper sleeves, snood wire and tuna hook. The length of the branchline was 22.5 m. The length of the floatline varied between 12.5 to 77.5 m and was made of 4 mm dia polypropylene (PP). The snood wire is provided just before the hook so as to prevent sharks from cutting off the monofilament branchline. Design details of branchline, floats, hook and snap clip is show in Fig. 3.16.

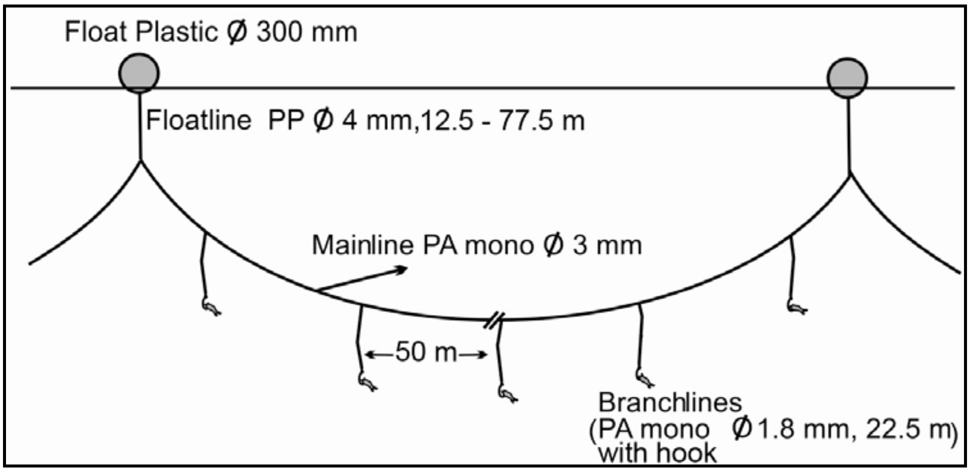

Fig. 3.15 Horizontal longline fishing gear

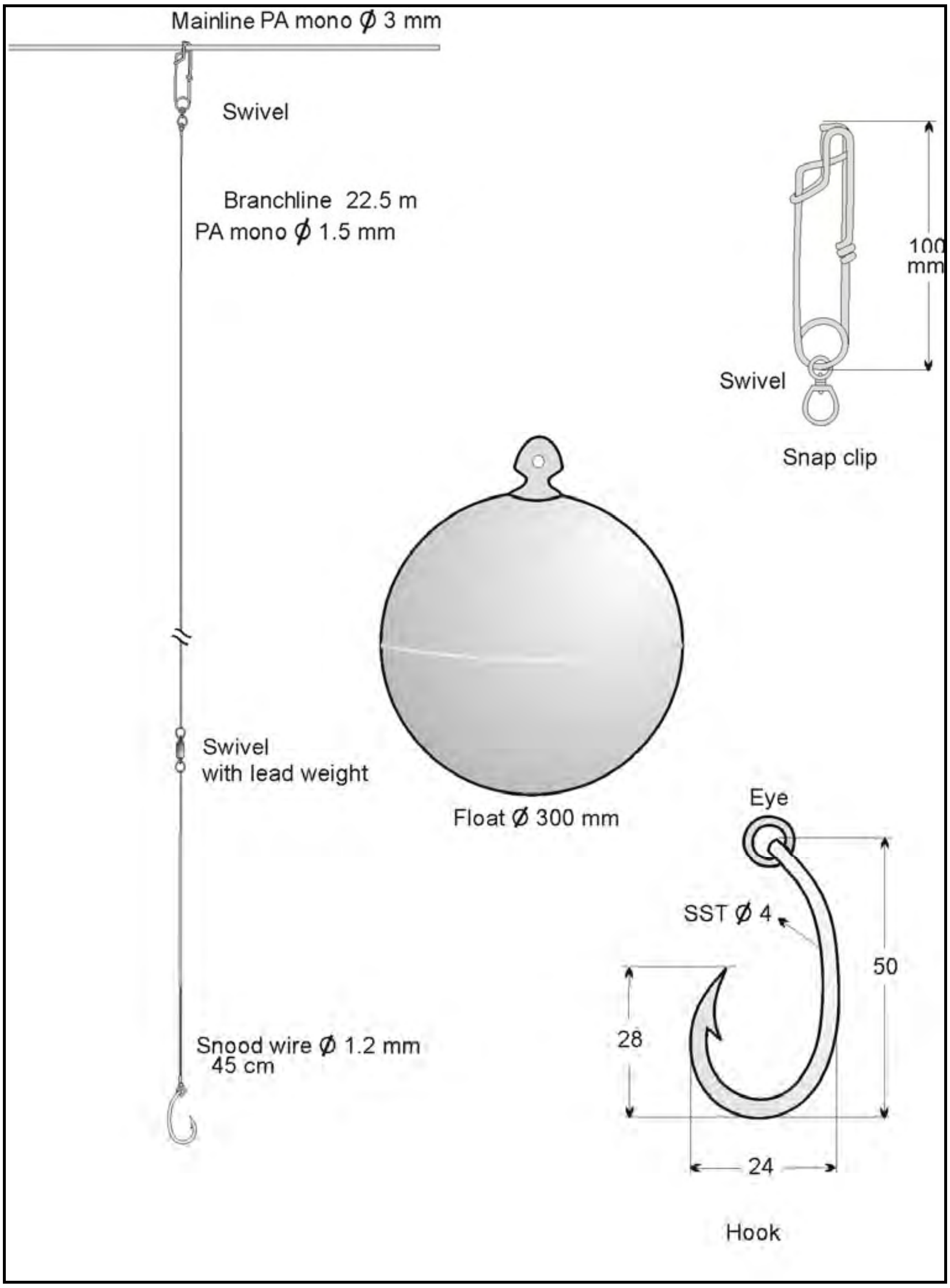

Fig. 3.16 Structure and design details of branchline, floats, hook and snap clip

3.3. Fishing operation

Shooting of the lines was carried out just before dusk or dawn by four crew members. The flag with pole was released first. The hooks were baited either by using flying fish, sardines, half beaks and mackerel. Global Positioning System (GPS) was used by the fishermen to record the position (Latitude and Longitude) of the fishing ground. After shooting the lines, it was allowed to soak for 1 to 7 h and then hauled.

Hauling was carried out after locating the flag pole. During hauling, the mainline was taken back into the drum manually through a guide pulley after removing the branchlines. The branchlines were stored in a branchline bin by clipping it on to the rods in the branchline bin along with the hooks in a way as to avoid entangling. The depth of operation of the mainline varied by changing the distance between the buoys, and also by changing the speed of the vessel while shooting. Light buoys were used for locating the lines during night. The last buoy set was usually the first to be hauled onboard and detached from the mainline. When a fish was caught on a line, the vessel was slowed down and the fish brought alongside the vessel and a gaff hook was used to take the fish onboard the vessel.

3.4. Field trials, data collection and analysis

Experiments were conducted onboard 3 Pablo boats modified for the tuna longline operations in the Lakshadweep Sea (10°38’ - 11°07’ N and 70°08’ - 73°18’ E). The studies on the operational performance of the longlines have been carried out based on the log book data maintained by the fishermen. The data have been collected from 22,298 hooks operated during 370 fishing operations (one operation per day). The detailed specification of the gear used is discussed in the Chapter 3. *Rastrelliger* *kanagurta*, *Sardinella longiceps* and *Amblygaster clupeoides* were the main bait species used for the study. The detailed description of the experimental fishing operations is discussed in the Chapter 3. CPUE was expressed as catch per 1000 hooks.

The data collected were compiled and analysed using χ^2 for the goodness of fit and ANOVA using SPSS (IBM SPSS Statistics, Version 20) (Prince *et al.,* 2002; Pacheco *et al.,* 2011). The detailed methodology, data collection procedure and analysis methods are discussed in the respective chapters.

The effect of bait type on the overall catching and species selective efficiency, bait loss during the fishing operation were evaluated using comparative fishing experiments. Data have been collected from 19,038 hooks operated during 361 fishing operations for this study. Efficiency of the three bait species *viz*., *Rastrelliger kanagurta*, *Sardinella longiceps* and *Amblygaster clupeoides* was tested. Frozen baits were used for the fishing operations. The data collected were compiled and analysed using χ^2 for the goodness of fit and ANOVA using SPSS (IBM SPSS Statistics, Version 20). Detailed methodology is discussed in Chapter 5.

Specially designed comparative fishing experiments were carried out to study the effect of hook type on the catch rate and selectivity in the longline fishing operations (Kerstetter and Graves, 2006, Pacheco *et al.*, 2011). Three sets of experiments has been carried out to understand the effect of hook type on the catch rates. Two types of hooks were used for the study *viz.,* 14/0 non-offset circle hooks and 3.5 sun Japanese tuna hooks. The data collected were compiled and analysed using χ^2 for the goodness of fit and ANOVA using SPSS (IBM SPSS Statistics, Version

20). Detailed methodology and data analysis procedures adopted are discussed in Chapter 6.

Studies have been carried out to understand the bycatch issues in the longline fishing in Lakshadweep Sea. The analysis has been carried out based on the catch of a total of 22,333 hooks operated. Bycatch is the proportion of non-targeted species in the total catch (Alverson *et al.*, 1994; Huang *et al.,* 2010). The bycatch rate was calculated as the number of non-targeted species caught per 1000 hooks (Brothers, 1991). Monthly and seasonal variations in the bycatch have been studied. The spatial variation in the bycatch rates has not been studied since the fishing operation was limited to a small geographical area. The effect of various fishery variables such as depth of operation, time of operation and soaking time has been analysed. The data collected were compiled and analysed using χ^2 for test of goodness of fit and two factor ANOVA (IBM SPSS Statistics, Version 20). The detailed description of the methodology is given in Chapter 7.

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Chapter 4

STUDIES ON OPERATIONAL PERFORMANCE OF TUNA LONGLINES

Contents

4.1. Introduction

Pelagic longlines are considered as an effective fishing method to catch sparsely distributed large pelagic fishes. This method was perfected by Japanese fishermen in 1930 (Shapiro, 1948). The basic design of the gear is generally simple and uniform as a mainline suspended from floats to which branchlines with hooks are attached. The preferred fishing time for tuna longlining begin early in the morning and the hauling beginning in the noon and ending after midnight (Ueyanagi, 1974). The length of the mainline extending over a distance of 25-75 km with 2000 baited hooks (Sakagawa *et al.*, 1987). Pelagic longlines usually fishes at a depth of around 170 m with 4-6 branchlines per basket and deep longlines fishes at around 300 m with an average of 13 branchline per basket of mainline (Sakagawa *et al.*, 1987). Pelagic longlines usually targets yellowfin tuna, swordfishes and deep longlines targets bluefin tuna and bigeye tuna.

Catch per day and catch per 100 or 1000 hooks are considered as good indicators of apparent abundance (Yoshida, 1975). CPUE in longlines is generally expressed as hooking rate *i.e.*, the number or average weight of fish caught per 100 or 1000 hooks (Joseph, 1972; Sun and Yeh, 2000; An *et al.,* 2008). Great variability in the tuna hooking rates is observed in the region. The hooking rate of yellowfin tuna is ranged from 0.05 to 2 tuna/100 hooks (BOBP, 1988; Lee *et al.*, 2005). The oceanic tuna fishery of the Indian Ocean is contributed mainly by four species *viz.,* yellowfin tuna, southern bluefin tuna, albacore tuna and bigeye tuna (Joseph, 1972). Albacore, bluefin and yellowfin tuna are the main targeted tuna species in Pacific Ocean. Fishing near seamounts is found to be very productive to catch tunas (Morato *et al.,* 2010). Bluefin tuna is the major targeted fish in Atlantic Ocean and hooking rate is found to be very fluctuating (0.04-17/1000 hooks) (Boyd, 2008; Oshima and Miyabe, 2010; Teo and Block, 2010).

Fishing efficiency of the longline gears are influenced by minor changes in the gear configuration such as type of terminal gear and depth of hooking operations (Broadhurst and Hazin, 2000). A change in the hook design from Japanese tuna hooks to circle hooks is considered as an effective mitigative measure to reduce the bycatch (Gilman *et al.,* 2006a; Kerstetter and Graves, 2006). Deep setting of the longline gear found to be very effective to reduce the bycatch rate (Shiga *et al.,* 2000). The depth at which longline fishes is mainly influenced by the configuration primarily by the length of mainline between floats (baskets), sagging rate and parameters such as wind and currents (Suzuki *et al.*,1977; Boggs, 1992). Tuna shows an aggregation nature near the floating objects which can be effectively utilised by vertical longline operations in the floatsams or FADs (Naeem and Latheefa, 1994). Various environmental and spatio-temporal factors influences the tuna catch rates. Tuna aggregations are based on the factors such as sea temperature, currents, moon phases and temperature gradients and they show preference to inhabit the areas such as continental slope, sea mounts, sea basins and sea canyons (Nishida, 2001; Morato *et al.*, 2010). Bluefin tunas exhibit higher spatio-temporal variability compared to yellowfin tuna and preferred to stay in the areas with negative sea surface height anomalies and cooler seawater temperatures (Teo and Block, 2010). Pelagic longlines operated at night are found to be more productive to catch large pelagic predatory fishes like swordfishes and tunas (Kume and Joseph, 1969). Bluefin tuna hooking rate was reported to be high during the days with weak lunar illumination mainly during low tide (Poisson *et al.*, 2010). Studies reported that, in Indian Ocean, tuna longlining operations can be operated round the year with better hooking rates. Tuna longlining operations in Arabian Sea give better hooking rate during pre-monsoon and monsoon and during monsoon and post-monsoon season in the Bay of Bengal waters (Somvanshi and Varghese, 2007).

The objectives of the study has been

- to study the catch composition and CPUE in the longline operation
- to study the relationship between depth of operation and catch rates
- to evaluate the effect of time of fishing on the catch rates
- to understand the monthly and seasonal variation in longline catch rates and;
- to study the effect of soaking time on catch rates

4.2. Materials and methods

Experiments were conducted on the 3 Pablo boats modified for longlining in the Lakshadweep Sea around Agatti Island (10°38’ - 11°07’ N and 72°01' - 73°18' E) from 16 Nov 2009 to 23 April 2011 (Fig. 4.1, 4.2). The L_{OA} of the boat ranged from 7.6 to 8.5 m. Mainline and branchlines were made of polyamide monofilament of 3 mm and 1.8 mm dia, respectively. The floatlines were made up of polypropylene of 4 mm dia. The Length of the branchline was 22.5 m long. 3.4 sun Japanese tuna hooks with 10° offset were used for the study. The depth of the gear is regulated by adjusting the length of the floatline. A stainless steel snood wire has been provided to avoid the bite-off of the gear due to shark attack. The maximum number of branchlines shot at a time was limited to 100 numbers. The number of branchlines operated depended mainly on the availability of the bait. The data has been collected from 22,298 hooks operated during 370 fishing operations. The average number of hooks per set was 60. The fishing operations were mostly carried out during the dawn and dusk. Fishermen use their traditional knowledge and experience to choose the fishing ground. The detailed description of the fishing boats, gear and their operation are given in Chapter 3. The duration of the soaking time ranged from 1 to 7 h, depending mainly on weather conditions. The shooting and hauling of the lines took approximately 1.30 and 2 h, respectively. The duration of the hauling mainly depended upon the catch rate. The number of hooks in each basket was 5. Fishing operation was carried out at a depth range of 35-100 m.

Rastrelliger kanagurta (Indian mackerel), *Sardinella longiceps* (Indian oil sardine) and *Amblygaster clupeoides* (Smoothbelly sardinella) were the main bait species used for the study. The size of the bait ranged from 10 to 25 mm total length.

The longline catches were grouped in to 4 categories *viz.*, tunas, sharks, sailfishes and miscellaneous fishes. The seasonal variations in the longline catches were also studied. The seasons are grouped in to two categories *viz.*, pre-monsoon and post-monsoon. Fishing was carried out for seven months in a year from October to April for the two consecutive years (2009-2010 and 2010-2011). February to April has been considered as pre-monsoon and October to January as post-monsoon season. May to September was considered as monsoon season and longline fishing was not possible during this period due to of bad weather. The study evaluated the effect of time of fishing on the longline catches. The fishing time was grouped in to two categories *viz.*, dawn and dusk. The study compared the effect of hook depth in the overall catching performance of the longliners. The depth of operation was grouped into three categories *viz.*, 35, 60, and 100 m. The starting and finishing times of both shooting and hauling were recorded to calculate the soaking time of each operation. Soaking time is the duration between completion of setting and the initiation of hauling of the longline. During hauling, the parameters such as type of species, size, number, condition (live or dead) were recorded.

The statistical tests were performed using SPSS (IBM SPSS Statistics, Version 20). The data collected were compiled and analysed using χ^2 for test of goodness of fit and two factor ANOVA.

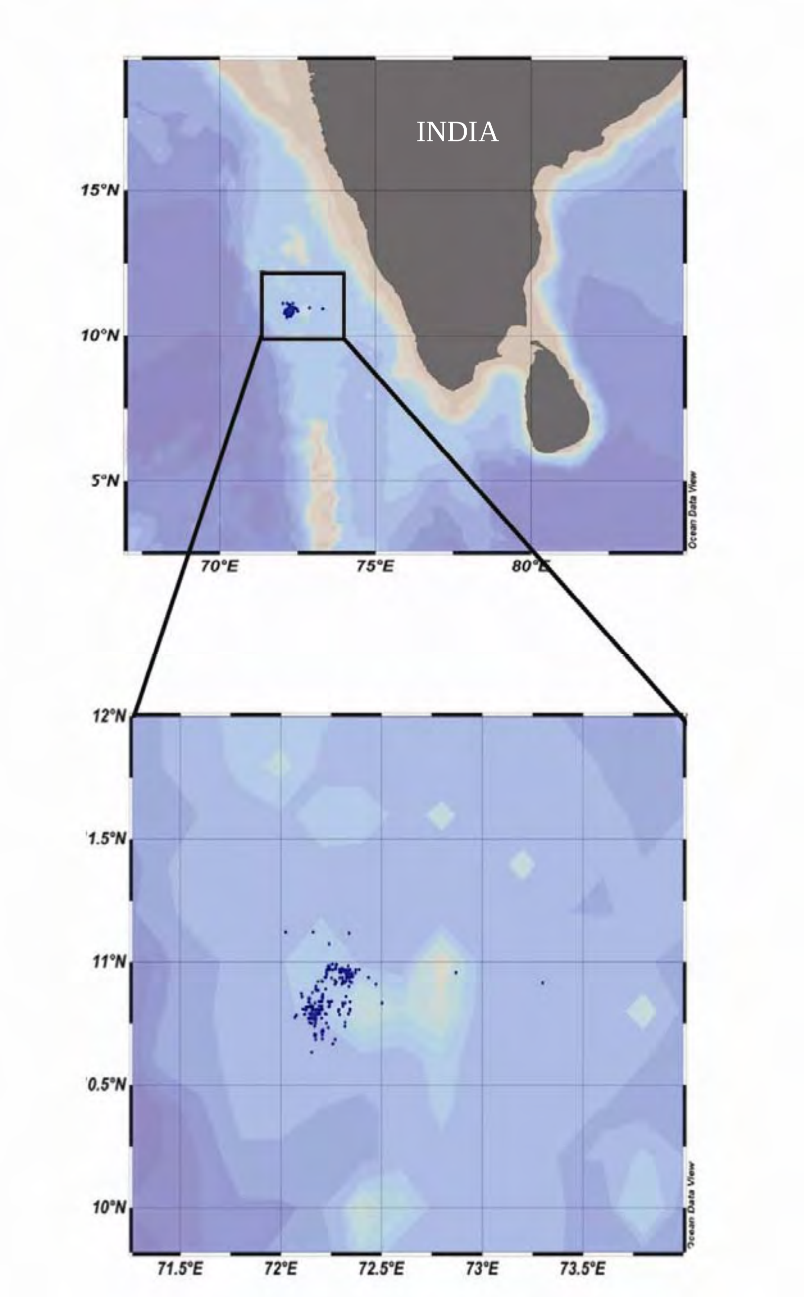

Fig. 4.1 Locations of the longline fishing operations carried out in Lakshadweep Sea during 2009-2011

Fig. 4.2 Longline fishing operations carried out from the modified Pablo boats. (**A**: Gill netting for catching bait fishes, **B**: *Amblygaster clupeoides* caught in gill netting, **C**: Shooting of the longline gear, **D**: Hauling the lines)

4.3. Results

4.3.1. Catch composition, size frequency and CPUE

Catch composition

The species composition was estimated as occurrence percentage (in terms of numbers) for each species. The catch was categorised in to four groups *viz.*, tuna, sharks, sailfish and miscellaneous fishes. The details of the fishes caught in the longline gear are given in the Table 4.1. The photographs of the fishes caught in the experimental fishing operations are shown in the Fig. 4.3. Views of the landings of catch and related activities at Agatti Island are shown in the Fig. 4.4. Two tuna species were recorded during the fishing operation *viz., Thunnus albacares* and *Gymnosarda unicolor.* The sharks comprised of 6 species *viz., Carcharhinus falciformis, Carcharhinus amblyrhynchos, Galeocerdo cuvier, Alopias pelagicus, Negaprion acutidens* and *Sphyrna lewinii.* One species of sailfish recorded was *Istiophorus platypterus*. Miscellaneous species of fishes encountered were *Aprion virescens, Caranx* spp, *Epinephelus polylepis* and *Lutjanus gibbus*.

The percentage composition of the species caught is shown in the Fig. 4.5. The sharks represented the highest percentage of all species caught (61.1%), followed by tunas (17.6%), sailfishes (13%) and miscellaneous (8.4%). *Carcharhinus falciformis* represented the highest percentage of all shark species caught (89.9%), followed by *Carcharhinus amblyrhynchos* (4.7%), *Galeocerdo cuvier* (2.7%), *Alopias pelagicus* (1.4%) and *Negaprion acutidens* and *Sphyrna lewinii* (0.7%) (Fig. 4.6). Among the 6 shark species caught, two shark species *i.e., Alopias pelagicus* and *Carcharhinus amblyrhynchos* were newly reported species from the Lakshadweep waters (Kumar *et al.*, 2012a & 2012b). The fishes included in the miscellaneous category caught during fishing was *Lutjanus gibbus* (44.4%), *Aprion virescens* (27.8%), *Epinephelus polylepis* (16.7%) and *Caranx* spp (11%) (Fig. 4.7).

Table 4.1 Species composition of experimental tuna longline catches in Lakshadweep Sea

Scientific name	Common name	Number of fishes caught	Total length (cm)	Weight (kg)	Conservation status*	Population trend*
Tunas *Thunnus albacares* (Bonnaterre, 1788)	Yellowfin tuna	40	15-147	3-40	Near threatened	Decreasing
Gymnosarda unicolor (Ruppell, 1836)	Dogtooth tuna	1	140	27.5	Near threatened	Decreasing
Sharks *Carcharhinus falciformis* (Muller & Henle, 1839)	Silky shark	133	50-243	5-98	Near threatened	Decreasing
Carcharhinus amblyrhynchos (Bleeker, 1856)	Grey reef shark	7	114-210	16-41	Near threatened	unknown
Galeocerdo cuvier (Peron & Lesueur, 1822)	Tiger shark	4	183-213	31-74	Near threatened	unknown
Alopias pelagicus Nakamura, 1935	Thresher shark	2	240-276	50-55	Vulnerable	Decreasing
Negaprion acutidens (Ruppell, 1837)	Sicklefin lemon shark	1	256	105	Vulnerable	Decreasing
Sphyrna lewini (Griffith & Smith, 1834)	Scalloped Hammer head shark	1	320	130	Endangered	Decreasing
Sailfish *Istiophorus platypterus* (Shaw, 1792)	Sailfish	14	50-288	1-44	Least concern	Unknown
Miscellaneous fishes *Aprion virescens* Valenciennes, 1830	Green jobfish	5	0.3-95	1-9	Not assessed	Not assessed
Caranx spp.	Carangids	2	29	5		
Epinephelus polylepis Randall & Heemstra,1991	Small scaled grouper	1	No data	4-8	Near threatened	Decreasing
Lutjanus gibbus (Forsskål, 1775)	Humpback red snapper	8	61-68	2-6		

*IUCN (2012)

Fig. 4.3 Fish species caught in longline fishing operations

(**A**: *Thunnus albacares,* **B**: *Gymnosarda unicolor,* **C**: *Carcharhinus falciformis,* **D**: *Alopias pelagicus,* **E**: *Galeocerdo cuvier,* **F**: *Carcharhinus amblyrhynchos,* **G**: *Negaprion acutidens,* **H**: *Sphyrna lewinii,* **I**: *Istiophorus platypterus,* **J**: *Lutjanus gibbus,* **K**: *Aprion virescens,* **L**: *Epinephelus polylepis*)

Fishermen with yellowfin tuna and sailfish caught in the longline

The silky shark caught in the longline and fishermen cutting the shark for salt curing

Fishermen cutting the yellowfin tuna and ready for sale tuna chunks

Fig. 4.4 Scenes of longline catches and allied activities in the Agatti Island

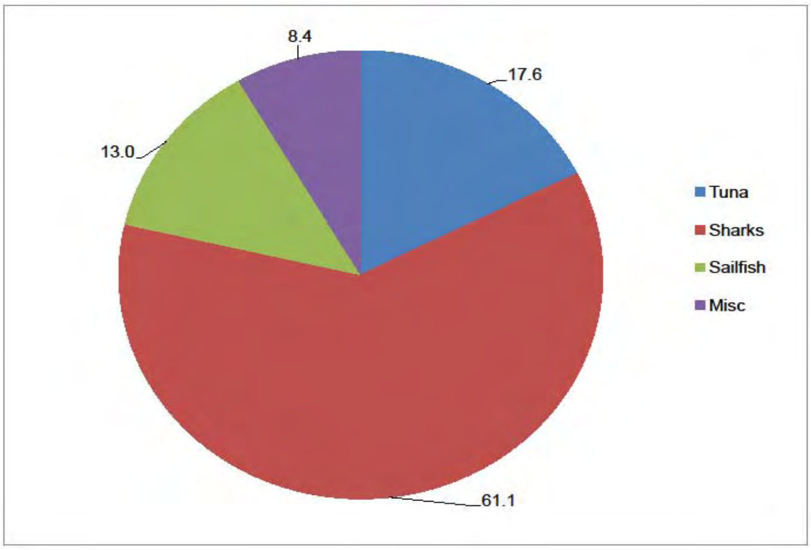

Fig. 4.5 Percentage composition of fish caught during longlining

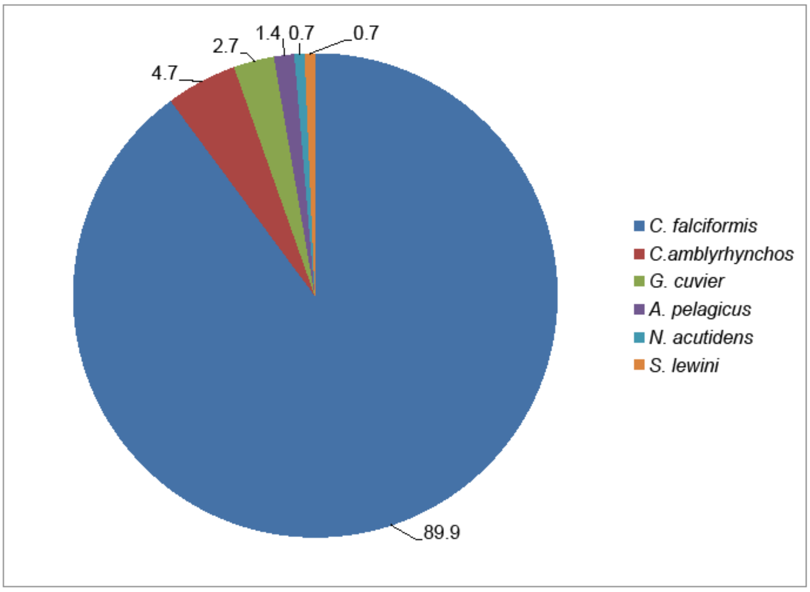

Fig. 4.6 Percentage composition of different species of sharks caught during longlining

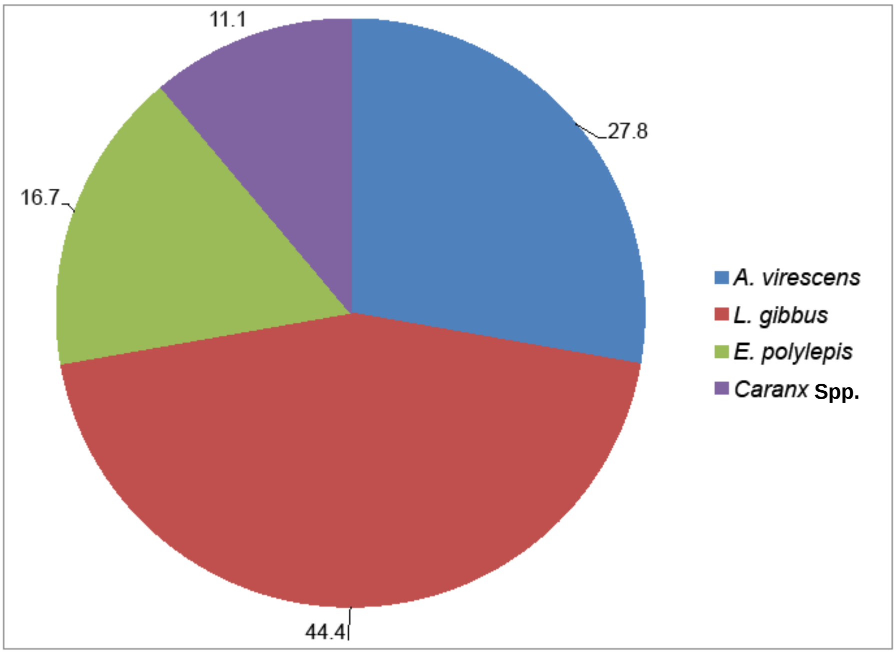

Fig. 4.7 Percentage composition of the miscellaneous fish caught during longlining

Catch per unit effort (CPUE)

Catch per unit effort obtained in tuna longline fishing in the Lakshadweep Sea was analysed. Catch per 1000 hooks was used as the unit for expressing the CPUE. The hooking rate reported for shark was 16/1000 hooks, followed by tuna (4.6/1000 hooks), sailfish (3.4/1000 hooks) and miscellaneous fishes (2.2/1000 hooks), respectively (Fig. 4.8). A total of 41 tuna (40 yellowfin tuna and 1 dogtooth tuna), 148 sharks, 14 sailfish and 16 miscellaneous species of fishes including snappers, groupers and carangids were encountered during the fishing operations. Total weight of the fish caught was 6,324 kg, of which shark contributed the major share of 5,221 kg, followed by tunas (607.5 kg), sailfish (423 kg) and miscellaneous fishes (72.3 kg). Hooking rate reported for various species of fish registered a significant difference ($\chi^2 = 9.867$, $P < 0.05$, df = 3). Overall hooking rate of sharks was significantly higher than tuna, sailfish and miscellaneous fishes.

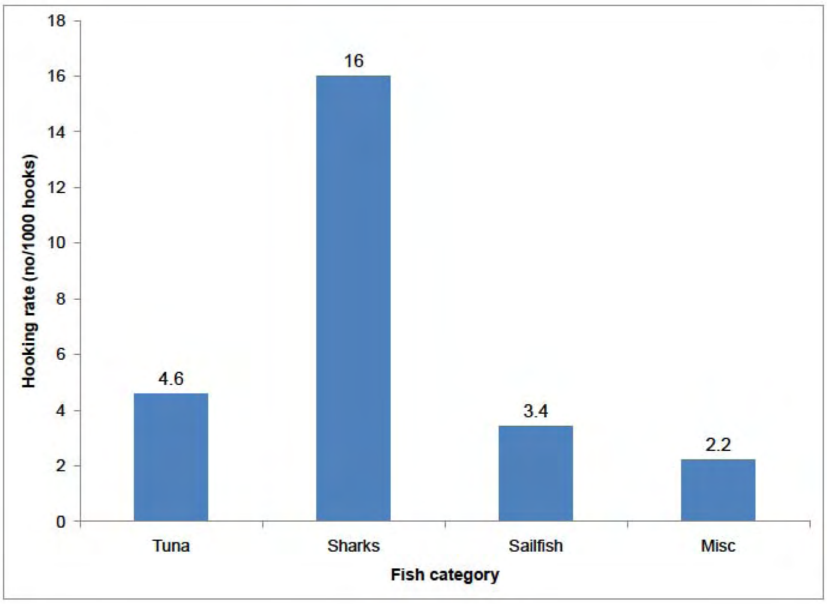

Fig. 4.8 Hooking rate reported for different group of fishes (values expressed as number/1000 hooks)

Size frequency

The size frequency analysis of the silky shark, *Carcharhinus falciformis* showed that the total length ranged from 50 to 275 cm (Fig. 4.9). The average total length was estimated at 164.66±34.34 cm. About 40% of sharks caught were in the length class of 150 to 175 cm, followed by the length class 175 to 200 cm (26.6%). The total weight of the sharks ranged from 5 to 100 kg with an average of 33.56±16.23 kg. The size frequency of other shark species were not analysed due to small sample size.

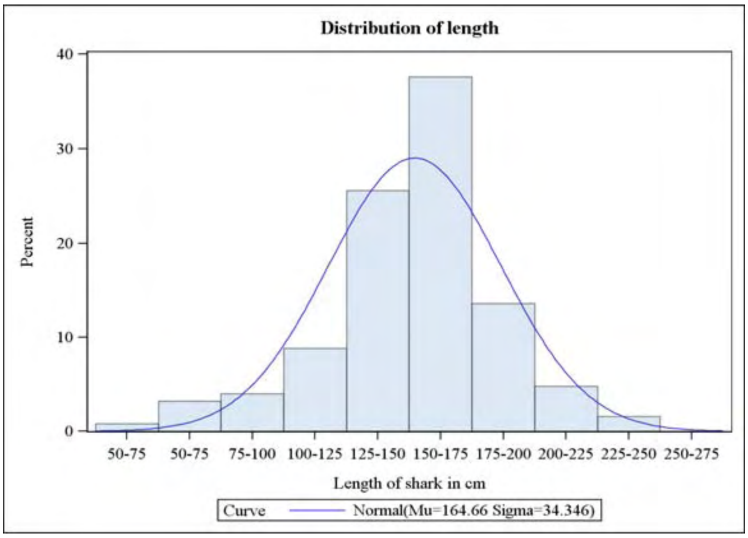

Fig. 4.9 Length frequency distribution of *Carcharhinus falciformis* caught in the longline fishing operations

As shown in the Fig. 4.10, the total length of the yellowfin tuna ranged from 15 to 147 cm. The average total length was estimated at 94±32.58 cm. About 70% of the yellowfin tuna caught were in the length class of 70 to 130 cm. The average weight of the tuna was estimated at 15.44 ±9.25 kg.

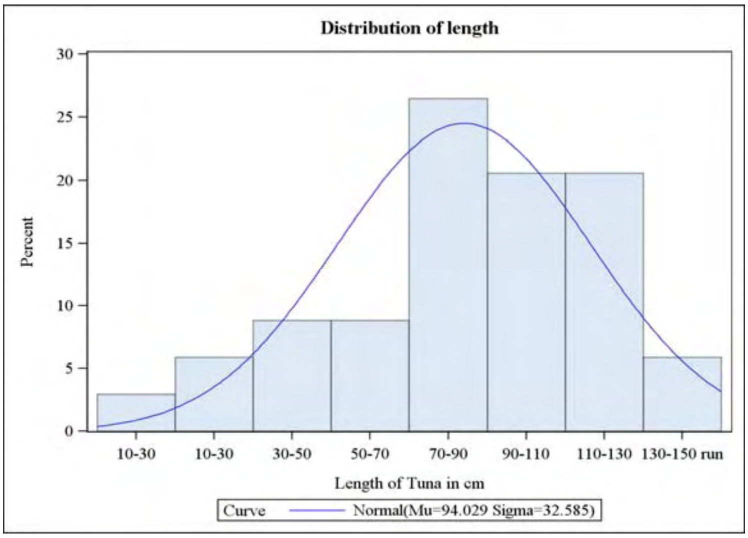

Fig. 4.10 Length frequency distribution of yellowfin tuna caught in the longline fishing operations

The length frequency analysis of the sailfish (*Istiophorus platypterus*) showed that the total length of the fish ranged from 50 to 288 cm. The average total length was estimated at 230±63.55. The weight of the fish was ranged from 1 to 44 kg and the average weight was estimated at 30±11.24 kg. The size frequency of the fishes included in the miscellaneous category was not analysed due to the small sample size.

4.3.2. Effect of time of operation on the catch rates

The comparative studies carried out to understand the effect of time of fishing operation on catch rates have given overall hooking rate in morning as 9/1000 hooks and 17/1000 hooks during the evening hours (Fig. 4.11). High overall hooking rate was observed during the evening hours compared to morning.

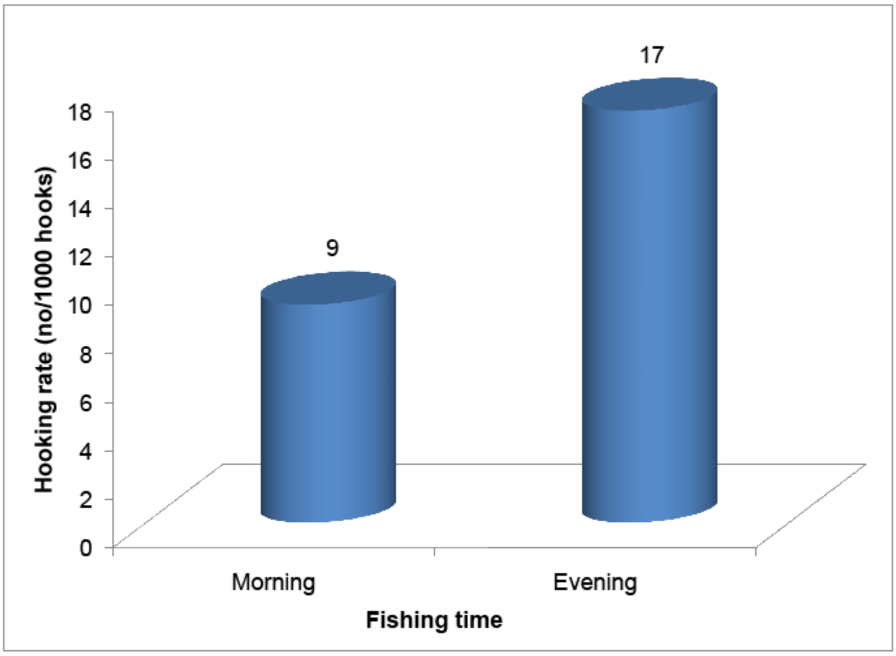

Fig. 4.11 Overall hooking rate in morning and evening

The hooking rate reported for tuna in morning and evening was found to be 1.6 and 3/1000 hooks, respectively (Fig. 4.12). 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 for morning and evening, respectively.

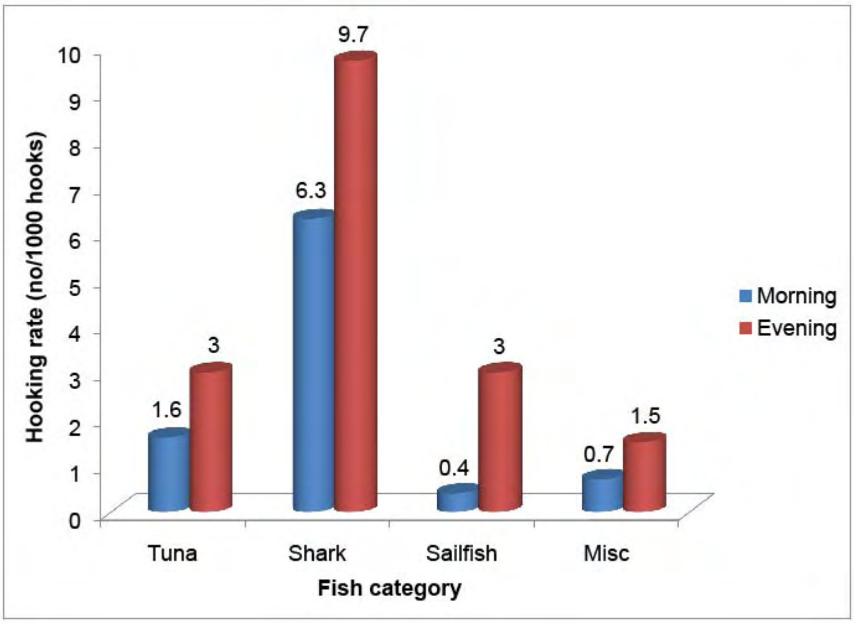

Fig. 4.12 Species wise hooking rate in morning and evening

4.3.3. Monthly and seasonal variation in catch rate

The study compared the month-wise and seasonal variation in the overall hooking rate during longline operations in Lakshadweep Sea. High overall hooking rates was recorded during the month of October 2010 (33.3/1000 hooks) and the lowest hooking rate was recorded during December 2009 (1.1/1000 hooks) (Fig. 4.13). High overall hooking rate was reported during the year 2010-11 (33.3/1000 hooks) compared to 2009-10 (12.2/1000 hooks). May 2009 to September 2010 was monsoon season, which was off-season and fishing operations were not possible. Study compared the seasonal variation (pre-monsoon and post-monsoon) in the overall catch rate. Statistical analysis found that there is no significant difference in the overall catch rate between pre-monsoon and post-monsoons (χ^2 = 1.6, P > 0.05, df = 1). There was significant difference in the overall hooking rate and months (χ^2 = 43.22, P < 0.001, df = 6). Hooking rate was significantly high in the month of October. Significantly lower hooking rate was registered during February, March and April, respectively.

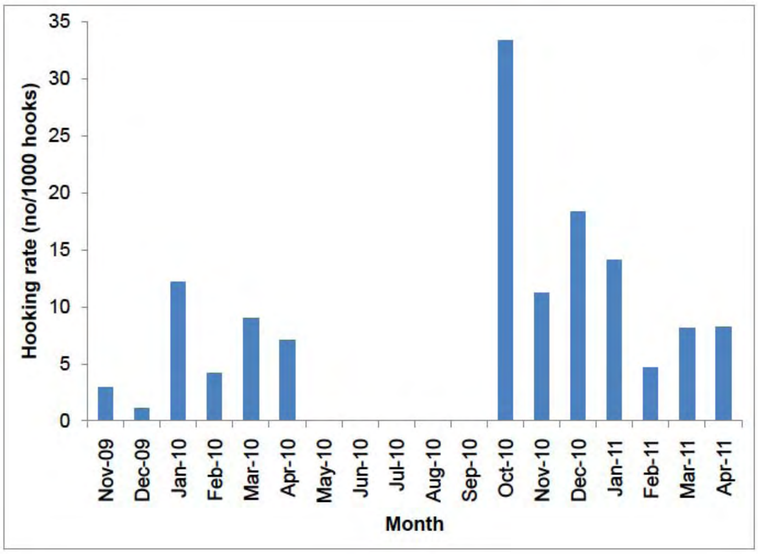

Fig. 4.13 Monthly variations in the overall hooking rate

Hooking rate of tunas ranged from 0 to 13.33/1000 hooks (Fig. 4.14). The highest tuna hooking rate was observed during October 2010

(13.33/1000 hooks). Tuna catches were not recorded during December 2009, March 2010 and February 2011.

The hooking rate of sharks ranged from 1.14 to 14.67/1000 hooks (Fig. 4.15). Highest shark hooking rate was observed during December 2010 and lowest recorded during December 2009.

The hooking rate of sailfish was ranged from 0 to 6.67/1000 hook (Fig. 4.16). Highest hooking rate was observed during October 2010. Sailfish were not recorded in November 2009, December 2009, February 2010, April 2010, December 2010, February 2011 and March 2011.

The hooking rate of the miscellaneous group of fishes ranged from 0 to 3.7/1000 hooks (Fig. 4.17). Highest hooking rate was recorded during March 2010. The miscellaneous group of fishes were recorded only during March, April, November, December 2010 and January 2011.

The monthly variation in the catch composition of the fishes during the period of study is shown in the Fig. 4.18. There was significant difference in the hooking rate between months ($P<0.05$) and between types of fishes ($P<0.01$). Hooking rate of sharks is significantly higher compared to other fishes. October registered significantly higher hooking rate compared to other months. ANOVA of hooking rate of fishes is shown in the Table 4.2

Table 4.2 ANOVA of hooking rate of fishes

Source	SS	df	ms	F	P value
Total	427.1007	27			
Seasons	190.3331	3	63.4444	11.02	P< 0.01
Months	133.0958	6	22.1826	3.85	P< 0.05
Error	103.6718	18	5.7595		
LSD for fishes + 3.128, LSD for months +4.1384					

Statistical analysis was carried out to understand the relationship between pre and post-monsoon on the species composition. There is no significant difference in species composition between pre and post-monsoon seasons (P>0.05).

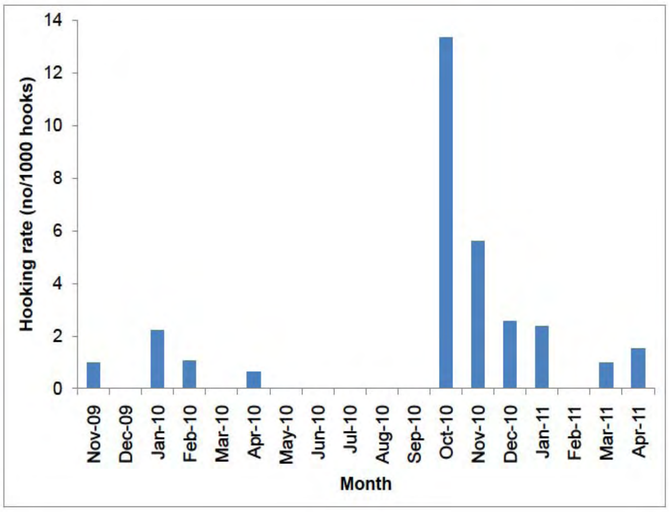

Fig. 4.14 Monthly variation in the tuna hooking rate

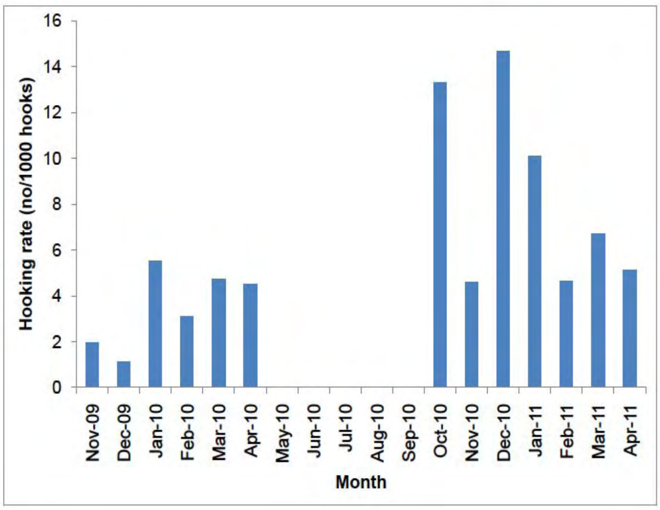

Fig. 4.15 Monthly variation in the shark hooking rate

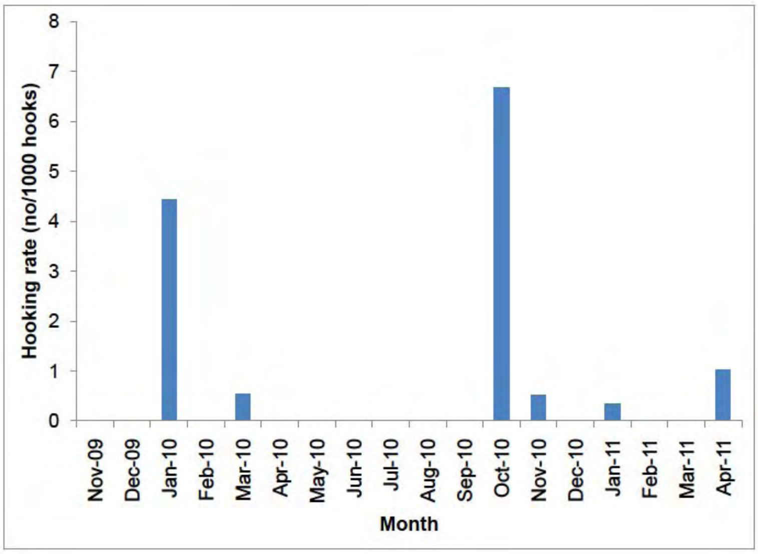

Fig. 4.16 Monthly variation in the sailfish hooking rate

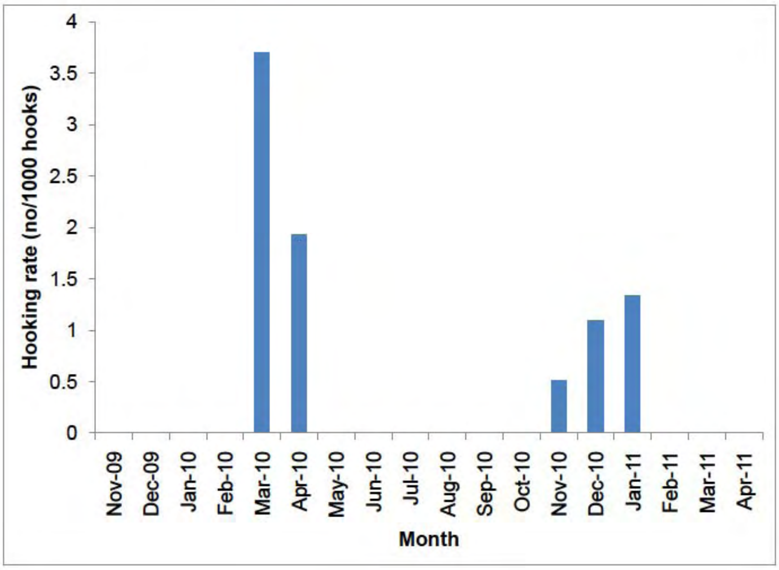

Fig. 4.17 Monthly variation in the miscellaneous fish hooking rate

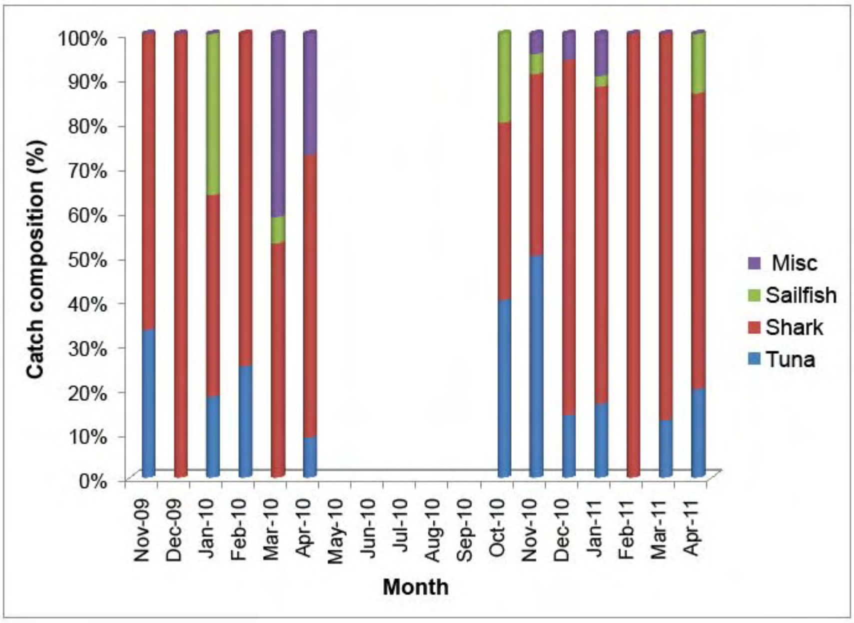

Fig. 4.18 Monthly variation in the catch composition (%) of different groups of fishes reported during October 2009 to April 2011

4.3.4. Effect of hook depth on catch rates

The study compared the effect of hook depth on the overall hooking rate and the species composition. The fishing depth was categorised in to three groups *viz.*, 35 m, 60 m and 100 m. The overall hooking rate observed at 35, 60 and 100 m depth were 8.78, 12.96 and 6.89/1000 hooks, respectively (Fig. 4.19). There was no significant association between the overall hooking rate and depth ($\chi^2 = 2.030$, $P > 0.05$, df = 2).

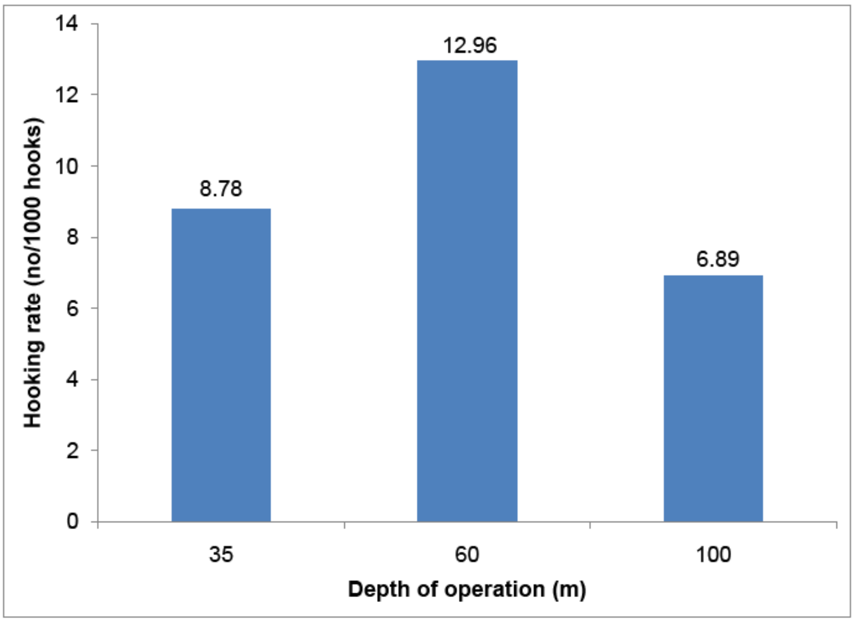

Fig. 4.19 Overall hooking rate reported in three different depths

The study compared the effect of hook depth on the species selectivity in the longline fishing operations (Fig. 4.20). At 35 m depth, shark hooking rate was found to be higher (5.56/1000 hooks) compared to other group of fishes. Hooking rate of other group of fishes observed at 35 m depth are miscellaneous fishes 1.27/1000 hooks followed by tunas and sailfish (0.98 and 0.88/1000 hooks). Shark catch was dominated at 60 m depth by contributing 9.4/1000 hooks followed by tunas, sailfish and miscellaneous fishes (2.67, 0.51 and 0.38/1000 hooks, respectively). Sharks were the dominant group of fishes caught at 100 m depth (4.51/1000 hooks), followed by tunas, miscellaneous fishes and sailfish (1.9, 0.47 and 0.24/1000 hooks, respectively). Sharks dominated at all the three depths. High tuna hooking rate was observed at 60 m depth. Highest hooking rate for sailfish and miscellaneous group of fishes recorded at 35 m depth.

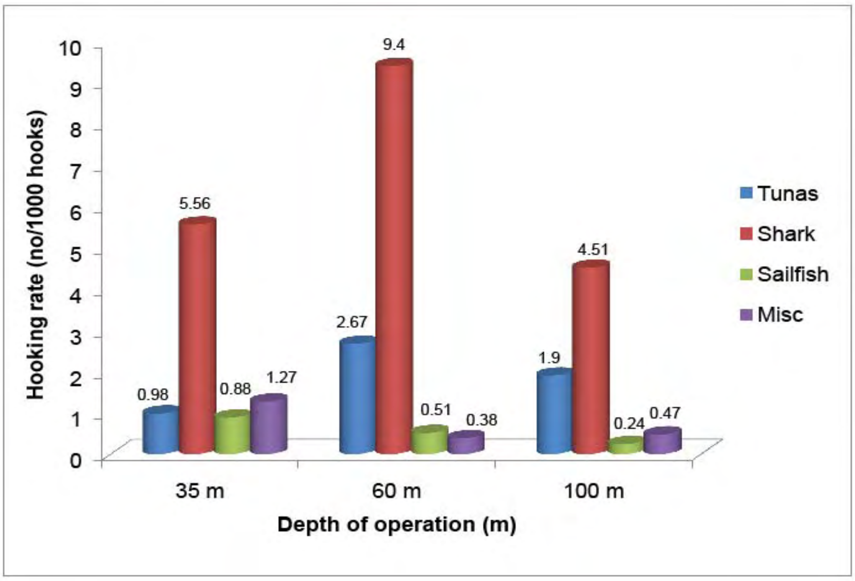

Fig. 4.20 Species wise hooking rate in three different depths

4.3.5. Effect of soaking time on catch rates

The overall hooking rate was found to be high when the soaking time was 1-3 h (13.23/1000 hooks), followed by 3.1-5 and >5.1 h (9.68 and 8.1/1000 hooks, respectively) (Fig. 4.21). Further studies have been carried out to understand the effect of soaking time on the species selectivity. Shark catch was observed to be high (8.86/1000 hooks) when the soaking time was 1-3 h and low (4.86/1000 hooks) when soaking time was >5.1 h (Fig. 4.22). Tuna catch was found to be high (3.24/1000 hooks) when the soaking time was >5.1 h and low (1.17/1000 hooks) when it was 3.1 -5 h (Fig. 4.23). Sailfish hooking rate was found to be high (1.05/1000 hooks) when the soaking time was 3.1-5 h and no sailfish was caught when soaking time was higher than 5.1 h (Fig. 4.24). Miscellaneous group of fishes was found to be high (1.09/1000 hooks) when the soaking time was 1-3 h compared to soaking time of 3.1 and >5.1 h (0.93 and 0/1000 hooks, respectively) (Fig. 4.25). Sailfish hooking and miscellaneous fishes hooking rate was found to be zero when the soaking time was higher than 5.1 h. Soaking time failed to show any significant effect on overall hooking rate (χ^2 = 1.335, P > 0.05, df = 2). Soaking time does not show any significant difference on hooking rate of species (P>0.05).

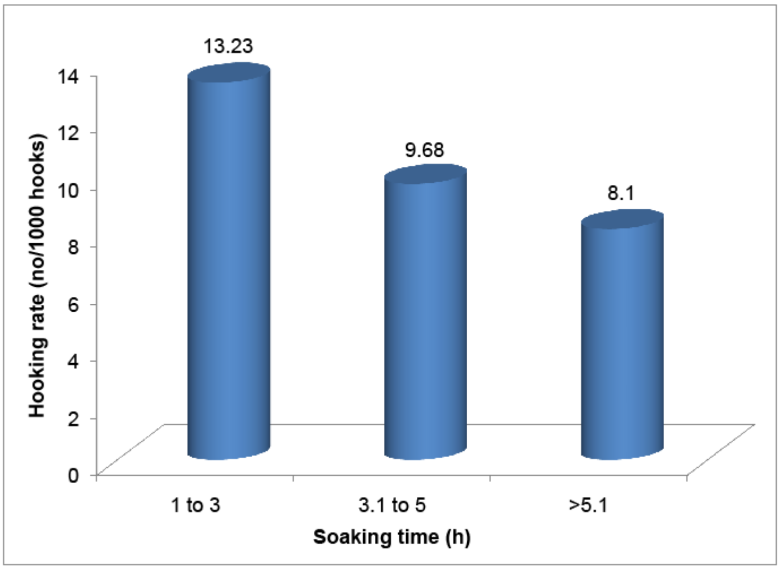

Fig. 4.21 The effect of soaking time on the overall hooking rate

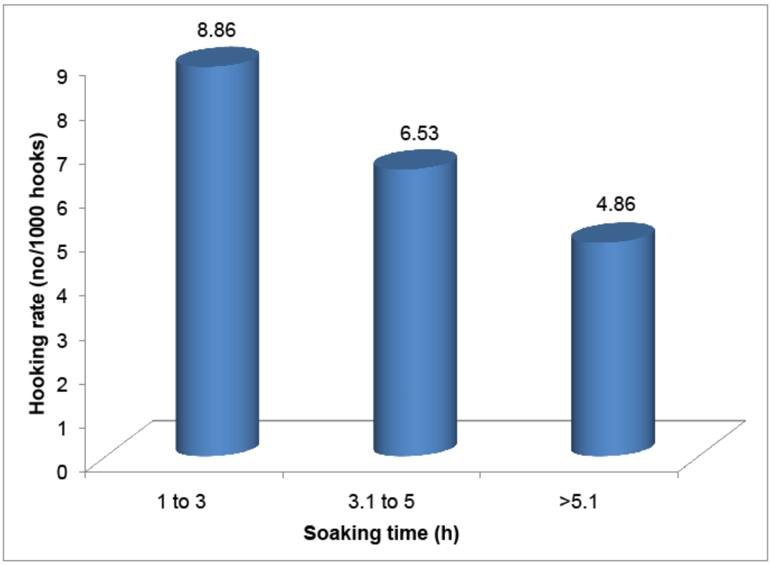

Fig. 4.22 The effect of soaking time on shark hooking rate

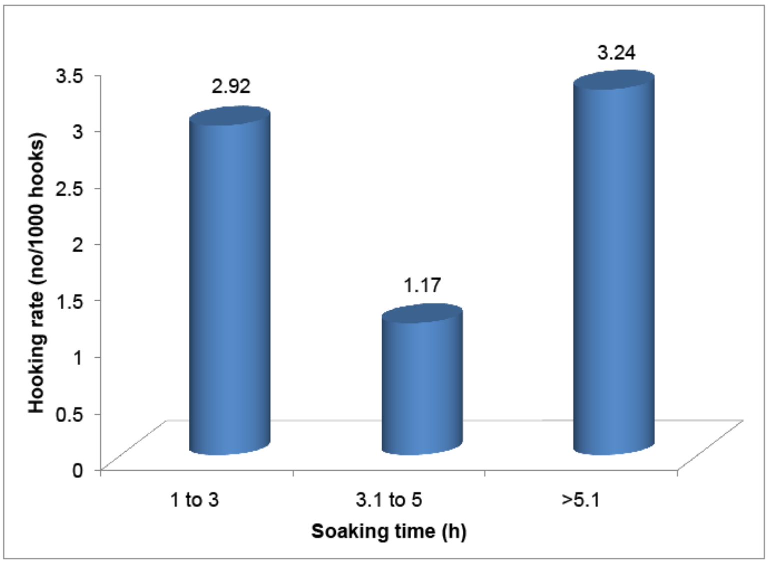

Fig. 4.23 The effect of soaking time on tuna hooking rate

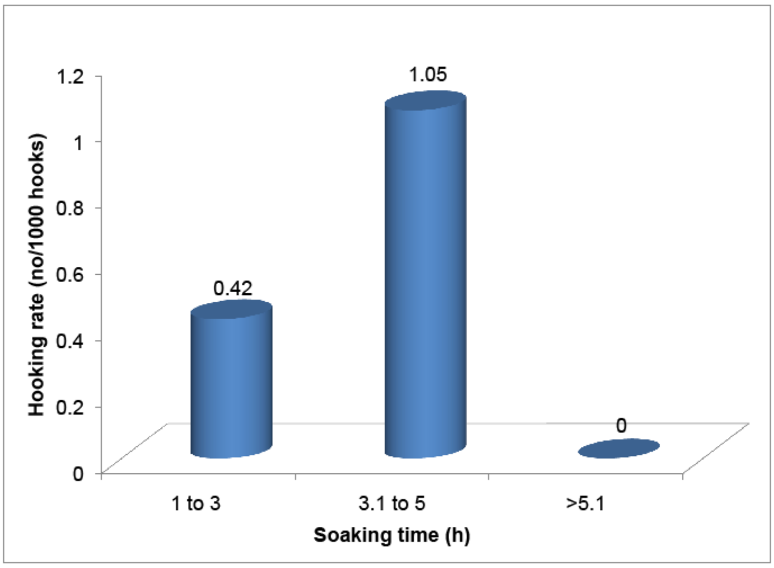

Fig. 4.24 The effect of soaking time on sailfish hooking rate

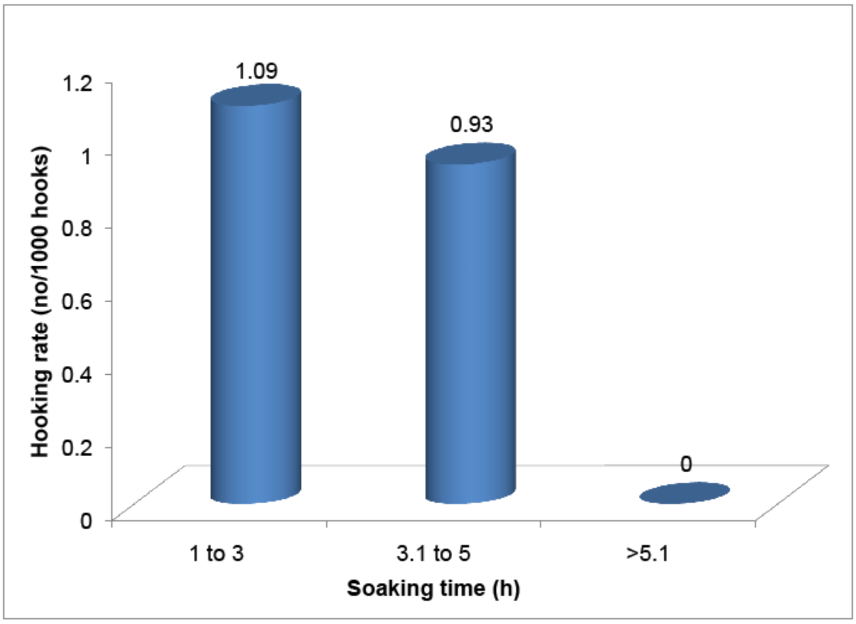

Fig. 4.25 The effect of soaking time on miscellaneous fishes hooking rate

4.4. Discussion

The longline fishing operations in Lakshadweep Sea is a new venture for exploiting the under exploited oceanic tuna resources. The present study was an attempt to investigate the experimental tuna longline fishing operations in the Agatti Island in Lakshadweep Sea. Data collection and sampling were carried out from selected Pablo boats intended for experimental longline fishing operations. The study has analysed the catch composition, size frequency, CPUE, month and seasonal fluctuations in catch, the effect of hook depth, time of fishing operation and soaking time on catch rates in longline fishing operations in Lakshadweep Sea. Longline catches were catogorised into four main groups *viz.*, sharks, tuna, sailfish and miscellaneous fishes. Sharks were the dominant group of fish which contributed nearly 61.1% of the catch, followed by tuna (17.6%), sailfish (13%) and miscellaneous fishes (8.4%). Overall hooking rate of sharks was found to be significantly high (16/1000 hooks), followed by tuna (4.6/1000 hooks), sailfishes (3.4/1000 hooks) and miscellaneous fishes (2.2/1000 hooks). Among the 6 shark species caught, *Carcharhinus falciformis* (silky shark) was the dominant species. *Carcharhinus falciformis* contributed 89.9% followed by *Carcharhinus amblyrhynchos* (4.7%). Other shark species contributed to the catch were *Galeocerdo cuvier, Alopias pelagicus, Negaprion acutedens* and *Sphyrna lewinii* contributing 2.7, 1.4, 0.7 and 0.7%, respectively. High shark hooking rate was observed in most of the longline fleets operated worldwide. High shark catch of 58% was reported in Indian waters targeting tuna (John and Neelakandan, 2004). The Shark catch was considered as a serious issue in the longline fishing operations (Hoey *et al.*, 2002; Joung *et al.*, 2005; Gilman *et al.*, 2007b; Morgan and Carlson, 2010). Huang and Liu (2010) and Kelleher (2005) opined that shark bycatch or discard rate in longline fishing is in the range of 20 to 40%. These shark species inhabit the pelagic waters and, hence, have a good chance to be encountered with the longline gear. The fishing operations during this study were carried out not very far from the coral ridges. The shark catches was found to be maximum at shallow hooks *i.e.*, first branchlines in either side of the longline catenary. Silky shark (*Carcharhinus falciformis)* is considered as one of the major groups of sharks contributing to the elasmobranch bycatch in the longline fishing operations (Gilman *et al.*, 2007b). Silky sharks are the main group of shark species taken as bycatch in the purse seine fisheries in the Indian Ocean (Amande *et al.*, 2008). Amande *et al.* (2008a) observed that purse seine fishing operations near FADs can considerably increase the silky shark bycatch in the French tuna purse seine operated in the Indian Ocean. Very high silky shark hooking rate was observed in the longline catches in United States (Harrington *et al.*, 2005). Among the 6 species of sharks caught during the fishing operations, three species belonged to the 'Near Threatened', two species to 'Vulnerable' and one species to 'Endangered Category' under the IUCN Red List (IUCN, 2012). Two new species of sharks (*Carcharhinus amblyrhynchos* and *Alopias pelagicus*) has been reported from the Lakshadweep waters (Kumar *et al.,* 2012a & 2012b). Sharks which are caught during the fishing operations were not considered as discards by the fishermen of Lakshadweep Islands. Shark meat has good market in the Islands. A detailed discussion on the shark bycatch in the longline operations in Lakshadweep Sea is discussed in Chapter 7.

The high sea tuna fishery of the Indian Ocean waters are supported mainly by four species and these are the southern bluefin tuna, yellowfin tuna, bigeye tuna and albacore tuna. Two species of tunas were caught during fishing experiments *viz.*, *Thunnus albacares* (yellowfin tuna) and *Gymnosarda unicolor* (dogtooth tuna). Tuna ranked second by contributing 17.64% of the total catch. Out of a total of 5,221 kg of fish landed, tuna contributed 607.5 kg and held the second position after sharks which contributed 5,221 kg. Hooking rate of tuna was found to be 4.6/1000 hooks which ranked second after sharks (16/1000 hooks). Tuna hooking rate was found to be very low compared to the shark hooking rate. Longline fishing for yellowfin tuna is mainly concentrated in the Indian Ocean compared to other oceans where bluefin, bigeye and albacore tuna are the preferred tuna species (Yoshida, 1975; Polachek, 1991; Sun and Yeh, 2000; Boyd, 2008; Oshima and Miyabe, 2010; Teo and Block, 2010). High level of fluctuation has been observed in the hooking rate of yellowfin tuna in the world oceans (Lee *et al.*, 2005; Somvanshi and Varghese, 2007; Teo and Block, 2010). Many authors have reported very low yellowfin tuna hooking rate in the Indian

Ocean waters (Joseph, 1972; Lee *et al.*, 2005; FSI, 2006; Somvanshi and Varghese, 2007; Lirdwitayaprasit *et al.*, 2011; Zhu *et al.*, 2011). Gokhale (1991) observed that commercial tuna longlining in Indian EEZ shows a low rate of capture.

One species of sailfish *Istiophorus platypterus* was recorded. The sailfishes along with swordfishes and marlins are reported to be the major group of species encountered in the longline fishing gear worldwide (Hoey *et al.*, 2002; Nootmorn, 2010; Lee *et al.*, 2005; Somvanshi and Varghese, 2007; Zhu *et al.*, 2011). Sailfish do not have much demand in the market in the Lakshadweep Islands.

Lutjanus spp. contributed 44.4% to the miscellaneous group of fishes followed by *Aprion virescens, Epinephelus polylepis and Caranx* spp (27.8, 16.7 and 11%, respectively). The hooking rate observed for the miscellaneous fishes was 2.2/1000 hooks and included reefcods, groupers, carangids and green jobfish. The small scale grouper (*Epinephelus polylepis*) comes under the ‘Decreasing’ status as per the IUCN Red List (IUCN, 2012). These species were mainly caught when the longline was deployed near the coral ridges. The spatial variation of the longline catch composition has not been studied since the fishing area was limited to a small geographic area. The longline fishing operations near the coral ridges are to be strictly monitored since hooking rate of these species are very high in this area.

Sharks represented the bulk of the landed catch of longline, forming 61.1% of the catch compared to tuna which represented 17.6% of the landed catch. These results indicated that the experimental pelagic longline operations carried out in Lakshadweep waters was less selective for tuna.

The low selectivity of this fishing gear was observed by many authors (John and Neelakandan, 2004; Kelleher, 2005; Huang and Liu, 2010). The hooking rate for tuna is comparable with those reported in the longline fishing operations in Indian Ocean waters (Joseph, 1972; Lee *et al.*, 2005; Somvanshi and Varghese, 2007; Zhu *et al.*, 2011). Contrary to this, many longline fishing operations targeting yellowfin tuna in the Indian Ocean waters reported considerably high hooking rate (BOBP, 1983; BOBP, 1988; Sudarsan and Sivaprakasham, 1993; FSI, 2006). Power and May (1991) reported high yellowfin tuna hooking rate of 14/1000 hooks from the Gulf of Mexican waters. Recent reports suggest that there is a drastic decline in the catch of major oceanic tunas from Indian Ocean and other world oceans (IOTC, 2010a & 2010b; IOTC, 2011). Heavy fishing activities in Chagos-Laccadive ridge leads to low CPUE in these waters (Abdussamad *et al.*, 2011). Studies carried out on the effect of hook and baits on the species selective effect in longline fishing operation in Lakshadweep Sea are discussed in Chapters 5 and 6.

Length data for the sharks showed that the total length ranged from 50-275 cm. The average total length was estimated as 164.66±34.34 cm. Sharks belonging to the length class150-175 cm represented 40% of the shark catch. Zhu *et al.* (2011) opined that the majority of blue shark (*Prionace glauca*) caught in the longline fishing in southwestern Indian Ocean was represented by 160-220 cm length class. Silky shark bycatch reported in the longline fishing fleets operated in the Indian Ocean were contributed mainly by 140-200 cm size class (Evgeny and Natalya, 2009).

Length frequency of the tuna showed that total length of the yellowfin tuna ranged from 15 to 147 cm. Fish belonging to length class from 70 to 130 cm represented the bulk of the catch (70%). The average length of the yellowfin tuna was observed to be 94 cm. The size of the exploited yellowfin tuna caught from the Indian Ocean waters ranged from 30 to 180 cm fork length and maximum weight was observed as 200 kg (IOTC, 2011a). The dominant length groups of the yellowfin tuna reported from the Sri Lankan waters is 30-150 cm (Dissanayake *et al.*, 2008). The size range of the yellowfin tunas caught from the Eastern Indian Ocean from the longline catches was observed to be 84-174 cm (Morita, 1973). John and Sudarsan (1994) observed the length frequency of the yellowfin tuna caught in longline gear from the Indian EEZ as 59-155 cm. The tunas caught from the handline fishing operations carried out in Bay of Bengal waters are estimated at 25-190 cm (Rohit and Rammohan, 2009). Almost same length classes of yellowfin tunas have been reported from the longline fleets operated by Maldives in the Indian Ocean waters (Adam and Anderson, 1996). The length frequency distribution of the yellowfin tuna observed during the longline fishing operations during the present study are generally in conformity with the previous reports.

Size frequency of the sailfish catches reported in the longline fishing operations in Lakshadweep Sea are in agreement with the previous studies. Vega *et al.* (2009) observed the average weight of the sailfish catch in the longline catches in Easter Island in the Pacific Ocean as 41.7 kg and average length of the lower jaw fork length as 210±13.1 cm. Sailfishes and marlins are considered as major bycatch species in the Japanese tuna longline fishery in the India Ocean (Uozumi, 1998). Myers and Worm (2003) opined that billfishes are very susceptible to the longline fishing operations and the authors indicated a drastic decline of the sailfish catches due to the fishing pressure. The sailfishes reported to be inhabiting in the shallow waters (0-55 m), are mainly caught in the shallow hooks (Villasenor *et al.*, 2008).

The overall hooking rate was found to be high during evening hours. Ward *et al.* (2004) observed that both targeted catch and bycatch were found to be high during evening. There was no significant relation in the species wise hooking rate between morning and evening operations.

Studies were carried out to understand the monthly and seasonal variation in the catch rate. High level of monthly and seasonal variability in overall catch rates was observed during the fishing operations. The overall hooking rate was found to be high during 2009-2010 compared to 2010-2011. There was no significant difference in the overall hooking rate during pre-monsoon and post-monsoon. There was significant difference in the overall hooking rate between months. October registered high hooking rate. There was significant relation between month of operation and species caught. Shark catch was found to be high during the month of October. Huang and Liu (2010) reported significant relation between the month of operation and shark catch. Somvanshi and Varghese (2007) reported that yellowfin hooking rate have two peaks in the Arabian Sea during March and September. The effect of seasonal variation in the longline catch rates has been discussed by many authors (Shingu *et al.*, 1980; Yang, 1980). Viswanathan (1999) opined that tunas are migrating according to season associated with their feeding and spawning activities which resulted in the localized areas of high density for a short period. Somvanshi and Varghese (2007) indicated that tuna longlining operations can be carried out round the year with better hooking rate during pre-monsoon and monsoon season in the Arabian Sea and monsoon and post-monsoon seasons in the Bay of Bengal waters. John and Neelakandan (2004) observed high shark catch during post-monsoon period in the experimental longline operations in Bay of Bengal waters. Bizzarro *et al.* (2009) indicated high mustelid shark bycatch during autumn and summer seasons in the artisanal shark longline fisheries in Sonora, Mexico.

The spatial distribution of tuna resources are closely related with the abundance of their prey species (Sund *et al.*, 1981; Lezama-Ochoa *et al.*, 2010). The aggregation of tunas is influenced by the oceanographic parameters such as sea surface temperature (SST) and chlorophyll concentration and physical environmental conditions (Lezama-Ochoa *et al.*, 2010). Zagaglia *et al.* (2004) confirmed the SST, chlorophyll-a and sea surface height (SSH) have significant relation with the yellowfin tuna catch rates. Contrary to this results, Power and May (1991) opined that there is no discernable relationship between SST and yellowfin tuna CPUE.

Studies were carried out to understand the effect of fishing depth on the overall catching performance and species selectivity in the longline fishing operations in the Lakshadweep Sea. There was no significant relation between the depth of operation and overall hooking rate. The study analysed the species selectivity at three different depths of operations. The results indicated that the depth of operation has significant effect on the species selectivity. Further studies are needed to understand the effect of depth of operation on the species selectivity beyond 100 m depth. Previous studies indicated that the species selectivity of tuna is more evident at deeper depths (Bigelow *et al.* 2006). Bigeye tuna was the major group of species caught when the fishing carried out beyond 200 m depth compared to spearfish and tripped marlins in the Hawaiian longline fishing (Boggs, 1992). Bigelow *et al.* (2006) confirmed the superiority of deeper hooks to catch tunas. The fishing depth for targeting bigeye and yellowfin tunas usually ranged from 100 to 300 m (An *et al.*, 2008). Honamoto (1976) opined that the CPUE of bigeye tuna can be improved by deep deployment of the hooks. Beverly *et al.* (2009) observed that catch of bluefin and bigeye tuna catch rates can be improved by eliminating the shallow hooks. The deep deployment of the hooks helps to reduce the accidental hooking of the bycatch species such as marine turtles, seabirds, sharks and dolphins (Shiga *et al.*, 2000; Francis *et al.*, 2001; Gilman *et al.*, 2008b & 2008c). High billfish hooking rate was noticed in the shallower hooks in the longline fishing operation targeting large tunas (Bigelow *et al.*, 2006). The yellowfin tunas are found to be occupying the surface mixed layer above the thermocline and are restricted to the water temperature no more than 8° C colder than the surface layers (Dagorn *et al.*, 2006).

Experiments were carried out to assess the effect of soaking time on the catch rates and the results showed no significant relation between soaking time and catch rates. A trend of decreasing the overall catch rate with soaking time was observed but the differences were not found to be statistically significant. Vega and Licandeo (2009) opined that the catch rates increase with soaking time. Results are statistically not significant to establish effect of the soaking time on the species wise hooking rate. Morgan and Carlson (2010) confirm the correlation of soaking time with the mortality of the sharks caught in bottom longline fishing operations. Previous studies indicated that soaking time can enhance the mortality of the sharks caught in the longline gear (Carlson *et al.*, 2004; Morgan and Burgess, 2007). The effect of soaking time on the bycatch rates is discussed in detail in the Chapter 7. Further studies are needed to understand the effect of soaking time on the overall catching performance and catch rates of targeted and bycatch species.

4.5. Conclusion

The present study is a pioneering work on the longline fishing operations in the Lakshadweep Sea and analysed various factors which influenced the fishing performance. Sharks were the dominant group of fishes caught in the longline gear compared to tunas, sailfish and miscellaneous group of fishes. These results indicated the possibility of shark longline fishing in Lakshadweep waters which was reported by various authors. *Carcharhinus falciformis* contributed nearly 90% of the shark catch. However, caution is to be exercised, as this species is included in the ‘Near Threatened’ category as per the IUCN Red List. Longline operations carried out in Lakshadweep waters are found to be less selective for tuna. The results indicated that longline operations can be carried out throughout the day as the time of operation had no significant effect on the hooking rate. Further studies at deeper depths from 100 to 300 m have to be carried out to understand the effect of depth of operations on the species selectivity in longline operations in Lakshadweep Sea. The high shark and low tuna hooking rate are considered as the main bottleneck in the expansion of longline operations in the area. Further studies are needed to understand the effect of various factors such as chlorophyll-a, thermocline, SST, SSH and moon phase in the longline catch rates for better understanding of this fishing system.

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Chapter 5

STUDIES ON BAIT EFFICIENCY

Contents

5.1. Introduction

The main components of the longline fishing system are mainline, branchline, hooks and baits and gear handling equipments like line setter, line hauler and mainline spooler. Bait is one of the important factors which determines the selectivity and efficiency of longlines. Fishermen use different types of baits based on the traditional knowledge they have acquired over the years. A good longline bait has to be attractive to the targeted fish and should remain on the hook for the entire duration of fishing or until a fish is hooked. Lokkeborg and Bjordal (1992) documented the species specific effect of baits. Bait preferences may vary seasonally and are affected by previous diet experiences (Sutterlin *et al.*, 1982). Catch rates of longlines depend on type, quality and size of bait, to a large extend (Bach *et al.,* 2000). Bait type is the most important gear parameter affecting the species selectivity of longlines (Shimada *et al.*, 1971; Pajot *et al.,* 1980; Carr *et al.,* 1986; Lokkeborg and Bjordal, 1992).

Fish bait was found to be more efficient than squid bait to reduce the marine turtle bycatch (Yokota *et al*., 2007 & 2009). Watson *et al*. (2005) documented that use of mackerel bait can reduce loggerhead turtle and shark catch rate by 71% and 40%, respectively, compared to squid bait. Squid bait was found to be superior to fish bait in the hook holding properties (Shomura, 1955; Pingguo, 1996; Ward and Myers, 2007). Watson *et al*. (2005) and Gilman *et al*. (2007) demonstrated that fish bait with larger circle hook can minimize the marine turtle bycatch significantly. Bait size is regarded as the most important factor that affects the size of fish caught by longlines (Lokkeborg and Bjordal, 1992; Lokkeborg, 1994). The effect of bait size has been reported to be stronger in pelagic longlines than bottom longlines (Lokkeborg, 1990 & 1994). Increasing the bait size may affect size selectivity in pelagic longline for haddock (Lokkeborg and Bjordal, 1995). Bait quality is an important factor which affects the catch rates significantly. The quality of bait is also understood as how well it remains on the hook. Physical strength and ability of the bait to remain on the hook throughout the soaking time determines the effectiveness of the bait. Natural bait has been reported to be superior to artificial bait (Januma, 1999 & 2003). Brothers *et al*. (1995) found out that adding lead sinkers are useful for increasing the sinking speed of the baited hooks and to reduce the seabird bycatch. The sinking rate of baited hook has been studied by Keith (2003) with Time Depth Recorders (TDR). Bait tenacity is one of the major factors affecting the catch rate and more tenacious bait would provide a longer effective fishing time (Pingguo, 1996). Blue dyed baits are considered as an effective mitigation measure to avoid seabird bycatch (Boggs, 2001; Cocking *et al.*, 2008) and found to be ineffective in reducing turtle bycatch (Swimmer *et al.*, 2005; Yokota *et al.*, 2009). The factors like weather, propeller turbulence, bait shape and thaw conditions have significant effect on the fishing rate (Brothers, 1995; Keith *et al.*, 2003).

The depth at which targeted species are captured is fundamental to understanding the impacts of tuna longline operation on target and bycatch species. Lokkeborg (1991) carried out fishing experiments with an alternative longline bait constituted by surplus fish products and the results indicated species selective effect (Lokkeborg, 1991). Bait loss is a major factor affecting the longline catch rate and the main factors affecting the bait loss are hook design, hook depth, time of operation and bait species (Pingguo, 1996; Ward and Myers, 2007). Loss rate is the number of lost baits divided by the number of baits deployed. Loss rate was reported to be minimum in squid than fish due to the firm nature of flesh (Shomura, 1955; Ward and Myers, 2007). Removal by scavengers or target species, disintegration, and stresses from wave action and longline deployment and retrieval, are the common causes of bait loss (Shomura, 1955). Ward and Myers (2007) opined that soak time, bait species and depth had greatest effect on loss rates.

Seabirds are considered as potential cause to the bait loss and it depends mainly on season and fishing ground (Pingguo, 1996). Sinking rate of baited hooks is an important factor which affects the seabird bycatch (Anderson and Mcardle, 2002). Partially thawed bait has been reported to sink faster than completely thawed bait (Brothers, 1991). Studies on pelagic and demersal longlines show that bait loss tend to increase with soak time (Shomura, 1955; Pingguo, 1996; Ward and Myers, 2007). Bait loss vary depending on bait species and has been found to be higher with increasing water depth (Sullivan and Rebert, 1998). Contrary to this finding, Ward and Myers (2007) reported that bait loss rate decreases with hook depth and possible reason might be decrease in mechanical effect of surface waves. They have reported that loss rates were maximum during rough weather. The bait loss has been reported to be high at night (Ward *et al.*, 2004).

The baiting is carried out manually in smaller vessels and using baiting machines in large vessels. In the manual baiting operation, the crew members attach the bait to the hooks by piercing the bait by the hook at the time of casting the branchlines. The baiting machine is usually located aft of the longliner. The bait is fed into the machine through a spiked conveyor belt. In the automated baiting, the bait should be very firm in order to facilitate good hooking rate. Before the line is set, the bait should be defrozen or thawed partially before use. Baiting machine can bait around 10,000-20,000 hooks per day. Baits that are used by fisherman in India are edible small fishes such as clupeids, small perches, mackerel, mullet, ribbonfish, silverbar, Bombay duck, eels, prawns and cephalopods (Balasubramanyan, 1964). Tuna showed quick response to live baits. Balasubramanyan (1964) reported that the Indian fisherman use neither salted nor frozen fishes as bait. But nowadays, frozen sardine and mackerel are commonly used as baits for tuna longlining in India. The objectives of the study was to find out

- whether bait type affects the hooking rate
- whether bait type influence the species selectivity
- whether baiting pattern affects hooking rate
- the hook holding ability of bait

5.2. Materials and methods

Experiments were conducted from 3 Pablo boats (7.6 to 8.5 m L_{OA}) modified for longlining in the Lakshadweep Sea around Agatti Island (10°38' - 11°07' N; 70°08' - 72°08' E), at a depth range of 35-100 m, from 16 Nov 2009 to 23 April 2011. Mainline and branchlines of the experimental gear were made of polyamide monofilament of 3 mm and 1.8

mm, respectively. Length of the branchline was 22.5 m and floatlines were made up of 4 mm dia polypropylene. Japanese tuna hooks of 3.4 sun with 10° offset were used for the experiments. Data were collected from 19,038 hooks operated during 361 fishing operations. Fishing operations were mostly carried out during the dawn. The duration of soaking time ranged from 1 to 7 h, depending on weather conditions. Shooting and hauling of the lines took approximately 1.30 and 2 h, respectively.

Three bait species, *viz.*, Indian mackerel (*Rastrelliger kanagurta*), Indian oil sardine (*Sardinella longiceps*) and smoothbelly sardinella (*Amblygaster clupeoides*) of 10-25 mm total length were used for experimental operations (Fig. 5.1). During hauling, the type of species, number caught, condition of the fish caught (live or dead), condition of bait (whether bait was retained or not) were recorded. Length and weight of the species were measured onboard. Frozen baits after thawing are used for the fishing operations. The hook holding ability of the bait was determined by counting the percentage of baits which remained on the hook after a given soaking time. The baits which have either detached normally or have been taken away by the fishes were categorized as lost. The condition of the each individual hook retrieved after soaking time was recorded as fish caught, bait remaining (more than 25% of original size remained on the hook), bait lost (less than 25% of the original size remained on the hook), or hook loss (Pingguo, 1996). The bait loss is expressed as a percentage of total number of hooks with no fish catch. Two types of baiting, *viz.*, horizontal and vertical baiting pattern (Fig. 5.2) were used to study the effect of baiting pattern on hooking rate.

The data collected were compiled and analysed using χ^2 for the goodness of fit and ANOVA using SPSS (IBM SPSS Statistics, Version 20) (Prince *et al.*, 2002; Pacheco *et al.*, 2011).

5.3. Results

5.3.1. Selectivity of the baits

The species caught during the experimental fishing operation were grouped in to 4 categories, *viz.*, tuna, shark, sailfish and miscellaneous fishes. The miscellaneous fishes included *Aprion virescens*, *Epinephelus polylepis*, *Lutjanus* spp. and *Caranx* spp. The hooking rates obtained with three different baits, *viz.*, Indian oil sardine, smoothbelly sardinella and Indian mackerel were 31, 22.5 and 23.6 per 1000 hooks, respectively (Fig. 5.3). There was no statistically significant difference in the overall hooking rate when the three different fish species were used as baits (χ^2 = 1.663, P > 0.05, df = 2).

Fig. 5.1 Bait species used for experimental longline fishing
(**A**: *Sardinella longiceps*, **B**: *Amblygaster clupeoides*, **C**: *Rastrelliger kanagurta*)

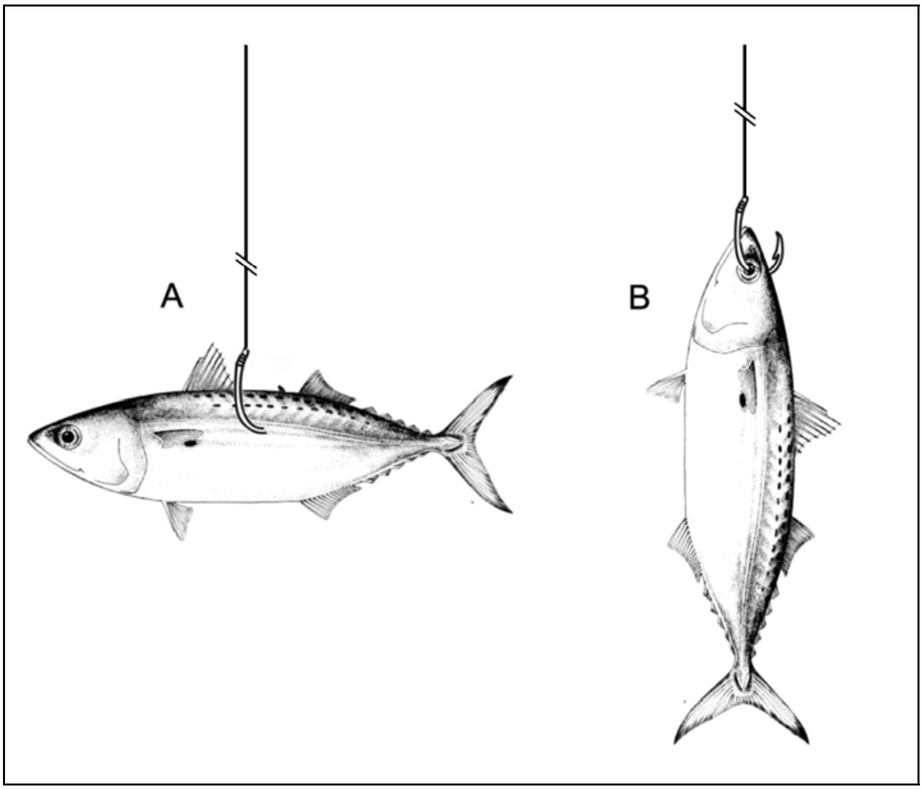

Fig. 5.2 Schematic representation of baiting pattern
(A: Horizontal baiting, B: Vertical baiting)

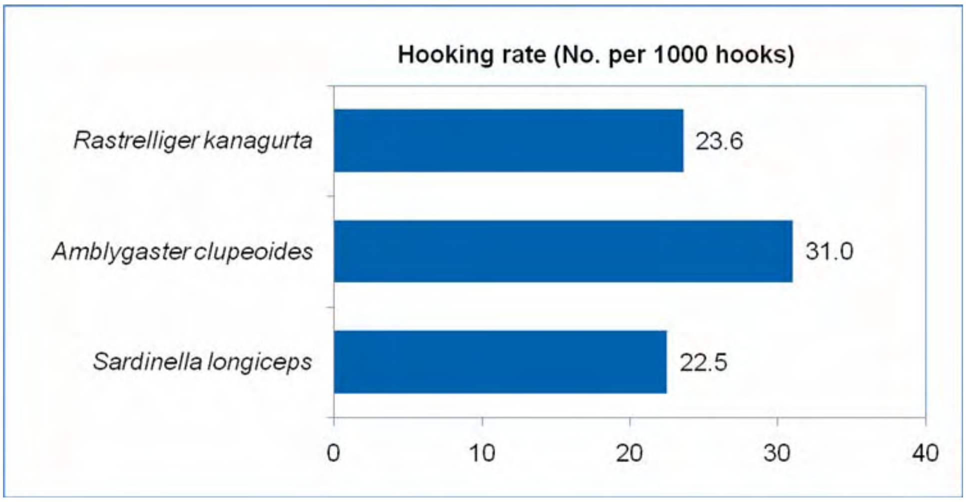

Fig. 5.3 Overall hooking rate using different bait species

Hooking rate obtained by using different bait species for sharks, tuna, sailfish and miscellaneous fishes are given in Fig. 5.4. Hooking rate for sharks while using smoothbelly sardinella as bait was observed to be 12.7/1000 hooks, followed by tuna (5/1000 hooks), sailfish (2.1/1000 hooks) and miscellaneous fishes (2.8/1000 hooks). While using Indian mackerel as bait, hooking rate for sharks was 17.7/1000 hooks, followed by tuna (5.6/1000 hooks), sailfish (0.4/1000 hooks) and miscellaneous fishes (0.4/1000 hooks). Hooking rate for sharks while using Indian oil sardine as bait was observed to be 24.4/1000 hooks, followed by tuna (4.1/1000 hooks), sailfish (0.8/1000 hooks) and miscellaneous fishes (1.6/1000 hooks).

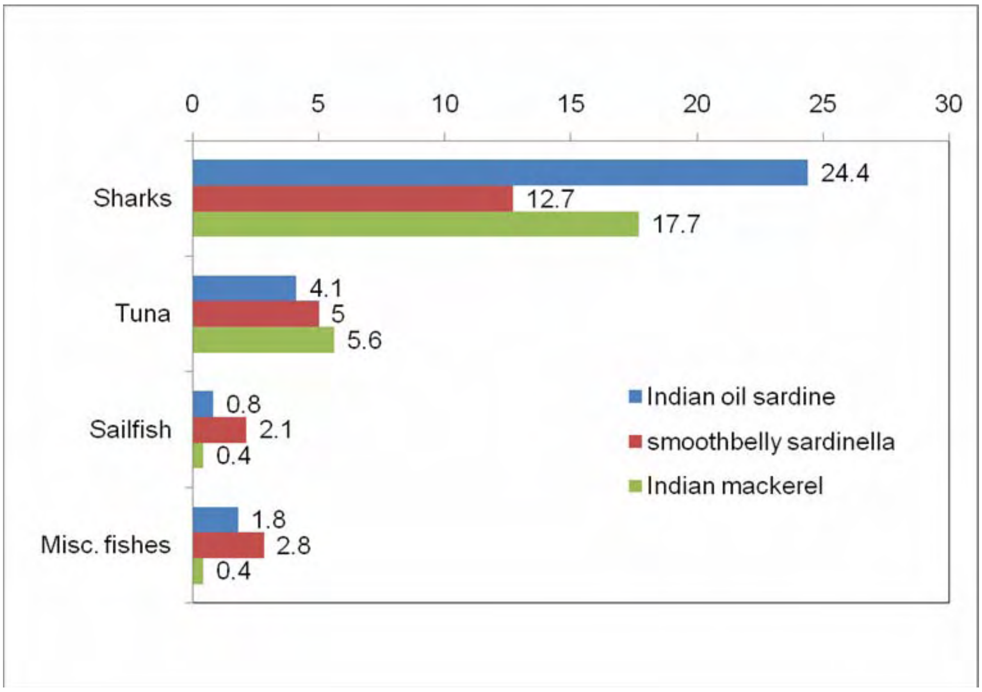

Fig. 5.4 Hooking rates for sharks, tuna, sailfish and miscellaneous fishes, obtained using different bait species

Percentage composition of catch in respect of three bait species used is given in Fig. 5.5. In all cases, sharks predominated in the catch, followed by tuna. Percentage of sharks were 78.5% in the catch of longline operations conducted using Indian oil sardine as bait, 73.4% when using smoothbelly sardinella and lowest (56.2%) when using Indian mackerel. Percentage contribution of tuna was maximum (23.2%) when Indian mackerel was used as bait, immediately followed by smoothbelly sardinella (22.1%) and lowest (13.2%) when Indian oil sardine was used as bait. Percentage contribution of sailfish was maximum (9.3%) when smoothbelly sardinella was used as bait, and between 1.7-2.6% when other baits were used. Miscellaneous fishes were maximum (12.4%) when when smoothbelly sardinella was used as bait, followed by Indian oil sardine (5.8%) and Indian mackerel (1.7%).

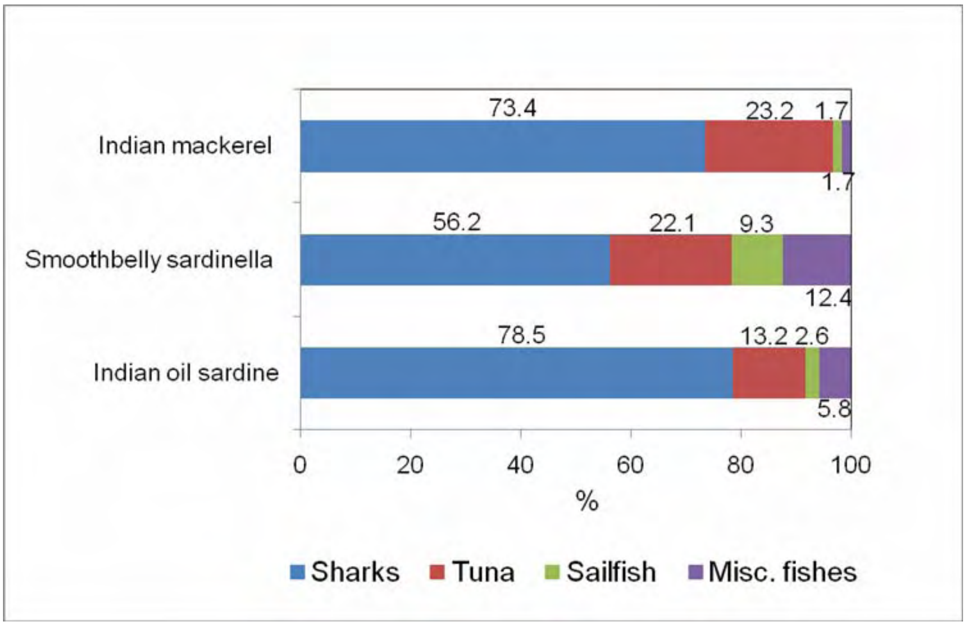

Fig. 5.5 Percentage contribution of sharks, tuna, sailfish and miscellaneous fishes to catch obtained using different bait species

Chi-square test showed that hooking rate of shark was significantly higher with each of the bait is tested.

1) Indian mackerel ($\chi^2 = 33.156$, $P < 0.001$, df = 2)
2) Indian oil sardine ($\chi^2 = 46.768$, $P < 0.001$, df = 2)
3) Smoothbelly sardinella ($\chi^2 = 12.540$, $P < 0.01$, df = 2)

No statistically significant difference was noticed in the species selectivity of the three bait species with Chi-square test ($P>0.05$)

1) Tuna ($\chi^2 = 0.233$, $P > 0.05$, df = 2)
2) Sharks ($\chi^2 = 3.767$, $P > 0.05$, df = 2)
3) Sailfish ($\chi^2 = 1.436$, $P > 0.05$, df = 2)
4) Miscellaneous fishes ($\chi^2 = 1.8$, $P > 0.05$, df = 2)

5.3.2. Effect of baiting pattern

Comparative studies were conducted to understand the effect of baiting pattern on the catch rates in longlining. Comparative catch rates in respect of the two baiting patterns are given in the Fig. 5.6. Hooking rate for all species together obtained using horizontal and vertical baiting were similar and observed to be 23.9 and 24.2/1000 hooks, respectively. Hooking rate for tuna was better when bait was horizontally baited (5.7/1000 hooks), compared to vertical baiting (2.6/1000 hooks). Hooking rate was comparatively better when the hook was vertically baited in the case of sailfish (3.9/1000 hooks), compared to vertical baiting pattern (0.7/1000 hooks). A similar pattern was observed in the case of sharks, with a hooking rate of 17.3/1000 hooks with vertical baiting, compared to horizontal baiting (14.9/1000 hooks). Nearly 87% of the miscellaneous fishes were caught (hooking rate: 2.6/1000 hooks) when the hook was horizontally baited, compared to vertical baiting pattern (0.4/1000 hooks).

There was no significant difference in hooking rate between horizontal or vertical baiting patterns ($\chi^2 = 0.001$, $P > 0.05$, df = 2).

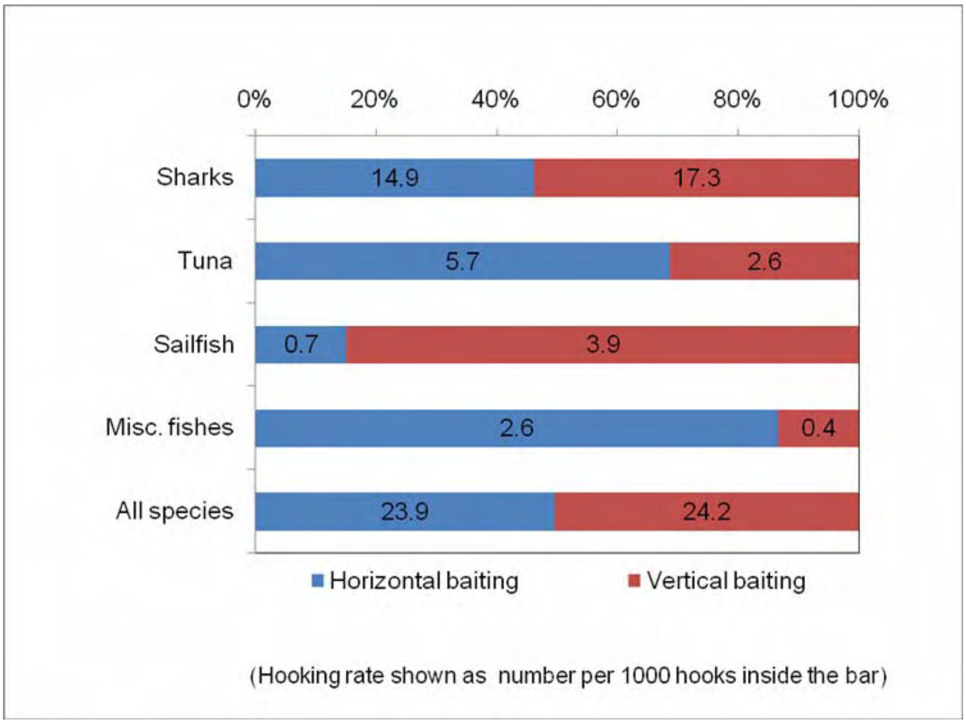

Fig. 5.6 Percentage split of catch obtained using horizontal and vertical baiting (Hooking rate is represented as number per 1000 hooks, inside the bar)

5.3.3. Bait loss

Among the three bait species, bait holding efficiency of indicated that Indian oil sardine was better (52%), compared to smoothbelly sardinella (38%) and Indian mackerel (34%) (Fig.5.7). However, differences in the bait retention among the three bait species was not statistically significant ($\chi^2 = 4.326$, $P > 0.05$, df = 2).

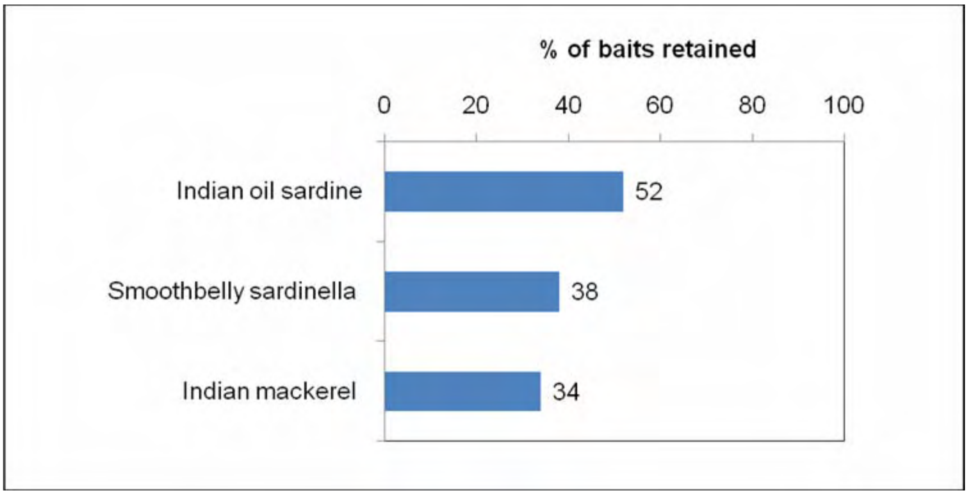

Fig. 5.7 Hook holding efficiency of baits (% of baits retained after fishing operation)

The effect of soaking time on the bait loss is represented in Fig. 5.8. The soaking time was grouped in to three categories (1 to 3, 3.1 to 5 and 5.1 to 7 h) for the comparative analysis. Bait loss was highest for the soaking time range of 5.1 - 7 h (71%), followed by 3.1-5 h (58%) and 1-3 h (36%). The duration of soaking time has a significant effect on bait loss ($\chi^2 = 7.61$, $P < 0.05$, df = 2). The results suggested that bait loss rate increase with soaking time.

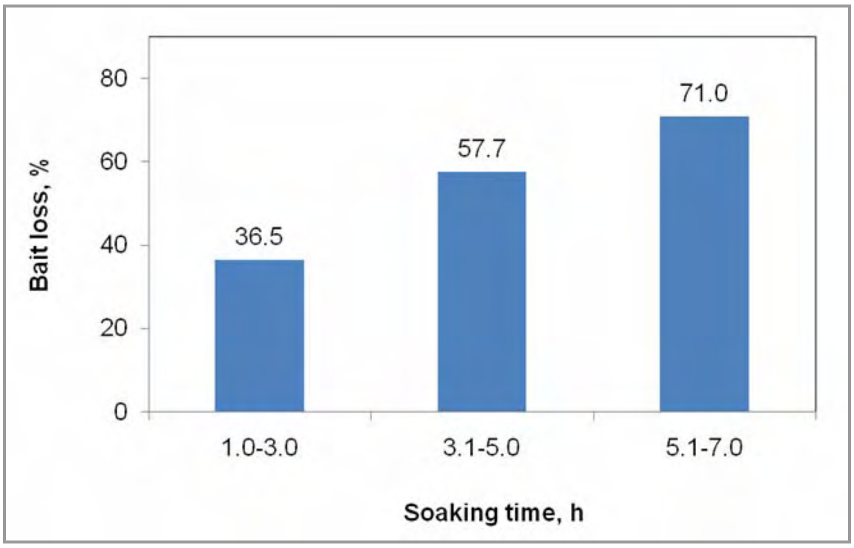

Fig. 5.8 Effect of soaking time on bait loss

The effect of depth of operation on bait loss is represented in Fig. 5.9. The bait loss observed was highest at 35 m depth (59.5%), followed by 60 m depth (46.7%) and 100 m depth (40.4%). The results indicate that bait loss rate decreases with depth of operation. Statistical analysis showed that the depth of operation has no significant effect on the rates of bait loss ($\chi^2 = 3.874$, $P > 0.05$, df = 2).

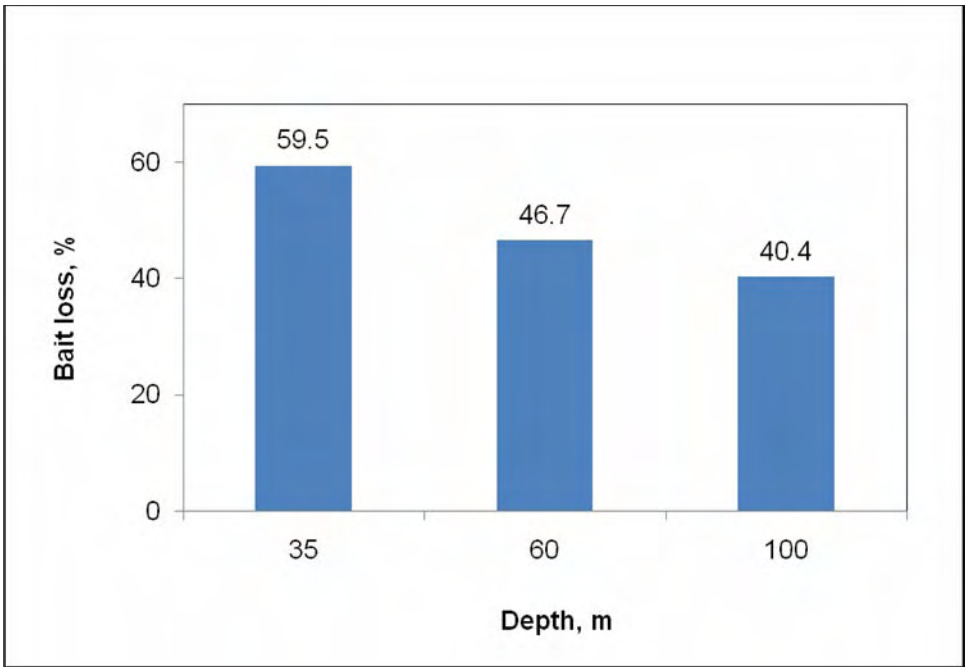

Fig. 5.9 Effect of depth of operation on bait loss

High rate of bait loss was indicated during the period of operations due to scavenging or predation by the small fishes which may increase the rate of drop off of the bait from the hooks (Fig. 5.10). Scavenging may cause partial or complete spoilage of the baits.

Fig. 5.10 Views of bait loss due to scavenging by small fishes

5.4. Discussion

In this study, we have analyzed the influence of three bait species and baiting pattern on hooking rate, and bait loss during experimental longline operations in Lakshadweep Sea. The bait species, *viz*., Indian mackerel, Indian oil sardine and smoothbelly sardinella were selected mainly based on the local availability and as per the prevailing practices of the fishermen. The results suggest that change in the bait type has no significant effect on the overall hooking rate in the longline operations. The results are in accordance with the findings of the work carried out by Yokota *et al.* (2009) which indicated that bait species has little effect on the overall hooking rate. Bach *et al.* (2000) opined that change in bait type has no significant effect on improving the hooking responses. The main bycatch species encountered during the longline fishing operations in Lakshadweep Islands were sharks and sailfishes. Bait type is one of the important gear parameters affecting species selectivity (Shimada *et al.,* 1971; Pajot *et al.,* 1980; Carr *et al.,* 1986; Lokkeborg and Bjordal, 1992). The present study suggest that bait species studied have no significant effect on hooking rates of different categories of catch, *viz.,* tunas, sharks, sailfish and miscellaneous fishes. Shark catch was significantly higher with all three bait species tested. Watson *et al*. (2005) indicated less blue shark catch with Indian mackerel as bait. Watson *et al*. (2005) reported that the catch rate of swordfish was high with mackerel as bait. In the present study, though higher hooking rate for tuna was observed when Indian mackerel was used as bait, compared to Indian oil sardine and smoothbelly sardinella, the differences were not found to be statistically significant. The effect of bait species on the catch rate depend upon many factors like texture and freshness of the bait and it vary seasonally and with previous diet experiences (Atema, 1980; Sutterlin *et al.,* 1982; Bach *et al.,* 2000).

Previous experimental studies have shown that baiting pattern significantly affects the hooking rate (Marquez, 1976). The present study indicated that the differences observed in hooking rate due to variation in baiting pattern (horizontal and vertical) were not statistically significant. Marquez (1976) reported that horizontal baiting pattern showed higher catch rate and higher bait loss. Bait loss is a serious factor which significantly affects the success of fishing operations (Pingguo, 1996; Ward and Myers, 2007). Studies by Ward and Myers (2007) have suggested that tuna catch rate is significantly affected by the bait loss rates. Hook holding ability of the bait is considered as an important property of the bait. Previous studies indicated that loss rate vary among bait species, depending upon the firmness of the meat and freshness of the fish. The variation observed in bait loss among Indian mackerel, Indian oil sardine and smoothbelly sardinella in the present study were not statistically significant. Removal by the scavenging fishes or target fishes, firmness and tenacity of the bait, disintegration due to wave action have been reported as the main causes of bait loss (Shomura, 1955).

Earlier studies have reported that soaking time has a significant effect on the bait loss in longline fishing operations (Shomura, 1995; Pingguo, 1996; Ward and Myers, 2007). In the present study, we have analyzed the effect of soaking time on the bait loss and results showed that rate of bait loss increased with the soaking time. These results are in agreement with the observations of Shepard *et al.* (1975), Skud (1978), Shomura (1995) and Pingguo (1996) which indicated that the loss rate of baits increased with soaking time.

The depth of hook deployment is reported to influence the bait loss considerably. Though the results of the present study suggested that rate of bait loss decreased with depth, the difference was not statistically significant. Ward and Myers (2007) indicated that loss rates from pelagic longlines decrease with hook depth and the explanation they have given are the possible occurrence of Wahoo (*Acanthocybium solandri*) which scavenge on the bait in the shallower waters. Shomura (1955) has indicated that the bait loss rates are higher in shallow waters due to the physical stress due to wave action which leads to the drop off of the bait from the hooks. Scavenging by the small fishes was frequently observed during the present study which may increase the rate of drop-off of the bait from the hooks.

5.5. Conclusion

The bait species, baiting pattern and bait loss rates are important factors which determine the success of longline fishing operations. In the present study, we have presented results on these aspects, based on experimental longline operations in Lakshadweep Sea. The results suggest that change in bait species, *viz.*, Indian mackerel, Indian oil sardine and smoothbelly sardinella has no significant effect on the overall hooking rate in the longline operations, though variation is observed in catch composition. Dominance of sharks in the longline catch in Lakshadweep Sea is a serious concern. Smoothbelly sardinella and Indian oil sardine may be preferred as the bait species in the longline fishing operations for reducing the shark catch without compromising the overall catching efficiency of the fishing gear. Changes in pattern of baiting (horizontal and vertical) had no significant influence on hooking rate. Bait loss has been considered as a serious issue in the longline fishing operations worldwide which is reported to reduce catch rate and success of fishing operations. The variation in bait loss among Indian mackerel, Indian oil sardine and smoothbelly sardinella were not found to be significant. The soaking time and depth of operation are the two important factors that influence the bait loss in the longline fishing. The results indicated that the depth of operation has no significant effect on the bait loss, within the range of 100 m depth. However, the bait loss was observed to increase with soaking time. Removal by scavengers, disintegration and physical stress from wave action are possible causes for bait loss during the longline deployment. The present study is a pioneering work on the longline fishing operations in the Lakshadweep Sea. The availability of baits is one of the limiting factors in the fishing operations in Lakshadweep Islands. The selection of the bait species mainly depends on the local availability. A steady supply of the bait ensures the smooth fishing operations. The development of artificial baits will be useful in this context and further investigations are needed in this direction.

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Chapter 6

STUDIES ON HOOK EFFICIENCY

Contents

6.1. Introduction

The pelagic longlines are currently used to commercially harvest tuna and tuna like fishes worldwide. Longline is considered as a size selective gear (Bjordal, 1981) and is reported to be an energy efficient fishing gear (Hameed and Boopendranath, 2000). Even though it has been considered as an eco-friendly fishing practice, the gear interact with non-target pelagic species and is described as a threat to seabirds, sharks, marine turtles and dolphins (Belda and Sanchez, 2001; Polovina *et al.*, 2003; Lewison *et al.*, 2004; Diaz, 2005). The accessories of the tuna longline has been undergoing many changes in the shape and structure for improving the fishing efficiency and to reduce the bycatch (Ward and Hindmarsh, 2007). Hooks are the most important part in the gear and it varies in shape and size. Most commonly used hooks are ‘J’ hook, Japanese tuna hook and circle hook. ‘J’ hooks are not advisable because of the injury caused during the capture which reduces the survival rate of the non-targeted animals like dolphin and marine turtles after the release (Huse and Ferno, 1990). Japanese tuna hooks of 3.6 sun has been commonly used in the tuna longlining by most of the tuna fishing fleets in the world (Beverly, 2009). Japanese tuna hook has an intermediate style between ‘J’ hook and circle hook (Whitelaw and Baron, 1995). The overall hooking rate is reported to be very high in ‘J’ hooks compared to circle hooks (Kerstetter and Graves, 2006). Ward *et al.* (2009) concluded that there was no difference between the mean size of the species caught on the circle and Japanese tuna hooks except for striped marlin (*Tetrapturus audax*).

Unintended capture, mortality and discards of non-target species, is a significant issue in current fisheries resource management (Alverson *et al.*, 1994; Harrington *et al.*, 2005). In tuna longlining, a potential technique to reduce unwanted bycatch of marine turtles is deep setting of the line (Beverly *et al.*, 2009; Curran and Bigelow, 2011). Mortality can happen both during capture and post-release. Fishing mortality of bycatch species may be reduced by change in the hook design, decreasing interaction rates, decreasing the mortality during hauling, increase in post release survivals or a combination of these approaches (Kerstetter and Graves, 2006).

Fish caught by longlines are generally hooked in the mouth, particularly in the jaw or in the alimentary tract if the hook is swallowed (Huse and Ferno, 1990). Deep hooking was found to be the main factor influencing the mortality of the fish caught and released (Bartholomew and Bohnsack, 2005). By reducing the rate of deep hooking, it may be possible to increase the overall rate of post-release survival. Fish hooked in sensitive areas such as stomach, esophagus, and gills suffer greater mortality than those hooked in non-critical areas (Aalbers *et al.*, 2004).

The quantity and species composition of fish caught in longline can be influenced by a number of variables such as hook size and design (Erzini *et al.*, 1998). Hook designs are considered as the most effective tool in reducing bycatch (Falterman and Graves, 2002; Piovano *et al.*, 2010). Significant importance is being given to circle hooks which have point turned perpendicularly back to the shank, which helps to reduce the catch of non-targeted species during the lining operations. In the ordinary 'J' hooks the point is parallel to the shank which makes the hook penetrate deeply in to the flesh, affecting post-release survival. In contrast, circle hooks have a tendency to slide over soft tissues and rotate as the eye of the hook exists in the mouth, resulting in jaw hooking (Cooke and Suski, 2004). This results in minimum injury to the animal caught and increased post-release survival (Lokkeborg and Bjordal, 1992; Prince *et al.*, 2002; Skomal *et al.*, 2002; Bacheler and Buckel, 2004; Watson *et al.*, 2004; Watson *et al.,* 2005; Gilman *et al.,* 2006a & 2006b; Kerstetter *et al.*, 2007; Read, 2007; Pacheco *et al.,* 2011; Swimmer *et al.*, 2011). Watson *et al.* (2005) opined that circle hook can considerably reduce the shark catch. Circle hook has been found to be more effective in catching tuna than other form of hooks (Kerstetter and Graves, 2006; Yokota *et al*., 2006; Kerstetter *et al*., 2007 and Ward *et al.*, 2009). The addition of wire appendage which projects posterior from the hook eye at an angle of approximately 45° to the shank was found to be very effective to reduce the hooking of under sized fish and deep hooking (Willis and Millar, 2001). The E-Z baiter hook which is an intermediate form of circle and 'J' hook has been reported to be superior in catching efficiency (Skeide *et al.,* 1986; Gill and Palmason, 2005). Several studies indicate circle hook can produce higher catch rates than traditional 'J' hooks (Peeling, 1985; Montrey, 1999; Falterman and Graves, 2002; Poulsen *et al*., 2004; Kerstetter *et al*., 2007; Ward *et al.*, 2009; Swimmer *et al*., 2011). Studies conducted by Yokota *et al.* (2006) and Pacheco *et al*. (2011) opined that the change in hook design have little effect on the catch composition.

Deep hooking can be significantly reduced by increasing the hook size (Grixtii *et al.,* 2007). Bjordal (1983) and Bertrand (1988) demonstrated that the difference in efficiency between two forms of hooks tends towards zero when the catch rate increases. Large hook size can effectively minimize the bycatch without compromising the catching efficiency for the targeted fish (Shapiro, 1950; Piovano *et al.,* 2010; Curran and Bigelow, 2011). Larger hooks are superior to small hooks for capturing large fish (Lokkeborg and Bjordal, 1992). Cortez-Zaragoza *et al.* (1989) documented that large hook have a positive effect on the size selectivity in handline fishing for yellowfin tuna. Large hook is less readily broken or straightened and its wider gap may allow the hook point to enter more deeply in the mouth cavity thus ensure secure holding of the fish caught (Lokkeborg and Bjordal, 1992).

Considerable research has been carried out on the effect of hook size on the catch and catch selectivity and the results indicated that hook has an optimum catching efficiency for a certain fish length and there is a possibility of fish length increasing with increasing hook size (Koike *et al.,* 1968). Ralston (1982), Bertrand (1988) and Yokota *et al.* (2006) opined that hook size has no effect on size selectivity in line fishing.

Since circle hook cause less physical damage than straight hooks and there is no significant decrease in the catch rates of targeted species, it can be a valuable conservation tool in the fisheries. By decreasing the catch of unwanted bycatch species, the use of circle hooks may save the crew time and overall vessel trip expenses such as replacement of hooks.

There are no reports on the selection properties or catch rate by circle and Japanese hooks from the Indian waters. Objectives of the present study has been to find out

- the influence of hook design on hooking rate
- the influence of hook design on species selectivity
- whether hook design affects the retaining efficiency of bait
- the relationship between hook design and hooking location of fish

6.2. Materials and methods

Fishing operations were conducted off North of Agatti Island (10°57' - 10°58' N and 72°16' - 72°19' E) using converted Pablo boat *Noorjahan* (L_{OA} 7.6 m; 16.5 hp) equipped for experimental tuna longlining operation in Lakshadweep Sea. The depth of longline operation was 60 m. Bait used for this study was *Amblygaster clupeoides.* Line setting started in the dawn and usually took 1 hour to complete. The socking time varied from 2 to 4 h depending on the weather conditions. Maximum number of branchlines shot was 100. Three sets of experiments were conducted to study the selectivity of hooks. A total of 123 hooks were deployed during the comparative fishing operations. Each set carried 25-50 hooks. Hook comparison trials used 14/0 non-offset circle hooks and 3.5 sun Japanese tuna hooks (Fig. 6.1). Each basket contained five hooks and care was taken to ensure alternating positions of each hook within the baskets along the mainline (*i.e.*, one basket would have C-J-C-J-C and the next would have J-C-J-C-J) (Kerstetter and Graves, 2006; Pacheco *et al.*, 2011). During hauling, the species, number, condition (live or dead), and hooking location were recorded. Length and weight of the fish were measured onboard. The catch data were pooled from the each basket by hook design and was used for analysis. The catch rate for each operation calculated as catch per 1000 hooks was taken as the measure of CPUE.

Bait holding efficiency of the hooks were also compared. The bait holding efficiency of the hook was determined by counting the percentage of hooks which have baits left after a given soaking time. The baits which are either detached normally or taken away by the fishes were considered as lost. Hooking pattern of circle hooks and Japanese tuna hooks in the fish's body were analyzed. The favourable hooking locations identified were lip and jaw, and other location like throat and gut and fowl hooking were considered as unfavourable hooking.

The statistical tests were performed using SPSS (IBM SPSS Statistics, Version 20). Catch composition, species selectivity, bait holding efficiency of hooks and hooking location by hook design was compared by Chi-square test (Prince *et al.*, 2002; Pacheco *et al.*, 2011). Catch rate of hooks were analysed using GLMs with hook design and baiting type (Kerstetter and Graves, 2006; Ward *et al.*, 2009; Piovano, 2010). Test results were considered significant at 5% confidence level (P <0.05).

Fig. 6.1 Hooks used for the study - 14/0 Circle hook (left) and 3.5 Japanese tuna hook (right)

6.3. Results

6.3.1. Selectivity of the hooks

Comparative evaluation of CPUE with two different designs of hooks

Hooking rate was expressed as number of fish caught per 1000 hooks. A total of 17 fishes were caught which included 3 species of sharks (*Carcharhinus amblyrhynchos, Carcharhinus falciformis, Galecerdo cuvier*) and 2 species of fishes (*Thunnus albacares* and *Lutjanus* spp.) during the experimental fishing operations. Experiment fishing showed high hooking rate for the Japanese tuna hooks compared to circle hooks. The mean hooking rates for Japanese and circle hooks were 186.44±51.13 and 112.9±40.52/1000 hooks, respectively (Fig. 6.2).

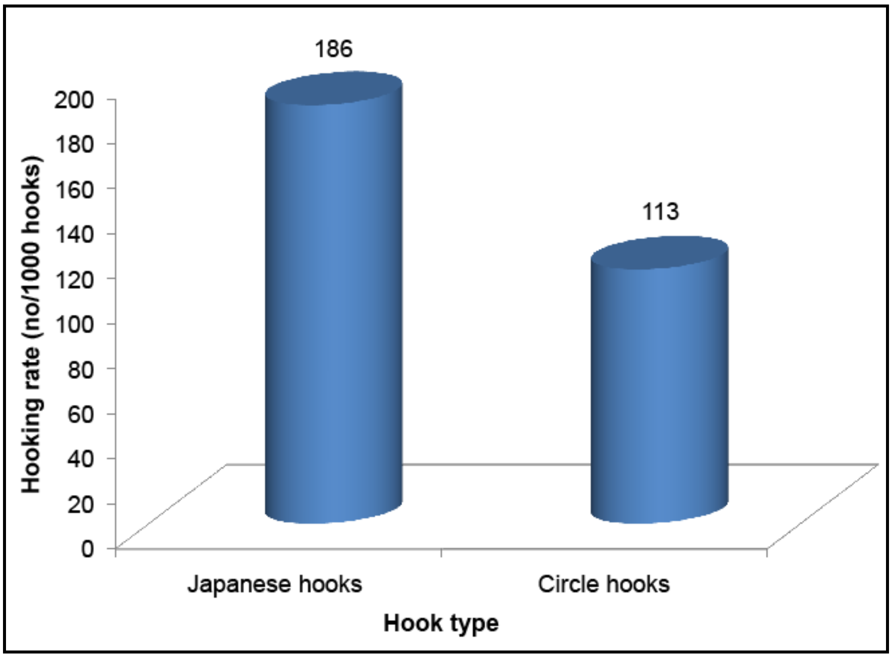

Fig. 6.2 Hooking rate of the two hook designs (the mean hooking rate observed for the different species in Japanese and circle hooks.)

Generalized Linear Modeling (GLM) was carried out to find the influence of hooking rate by three factors reported to influence the hooking rate. The three factors considered were hook designs (circle and Japanese), bait retained or not and the baiting pattern of bait on the hook (vertical or horizontal). Binomial distribution with Probit link was used for the GLM. The results indicated that there was no significant influence of any of these factors on the hooking rate expressed as present or absent.

No statistically significant difference was noticed between the circle hook and Japanese tuna hooks with respect to overall hooking rates observed by the Pearson's Chi-square test ($\chi^2 = 0.83$, $P = 0.36$, df = 1).

Selectivity of the hooks

Hooking rates (number/1000 hooks) observed in Japanese tuna hooks were 0 for tuna, 167 for sharks and 17 for other fishes (Fig. 6.3). The hooking rate observed were 32 for tuna, 64 for sharks, and 16 for other fishes, in the case of circle hooks. The study has indicated the efficiency of the circle hooks in catching more tuna and fewer sharks compared to Japanese tuna hooks. This characteristic of circle hooks can be effectively used for conservation of sharks. The hooking rate of fishes other than tuna and shark was found to be 16/1000 hooks in circle hooks. Both the Japanese tuna hook and circle hook showed almost same hooking rate in catching the fishes other than tuna and sharks (17/1000 and 16/1000 hooks respectively).

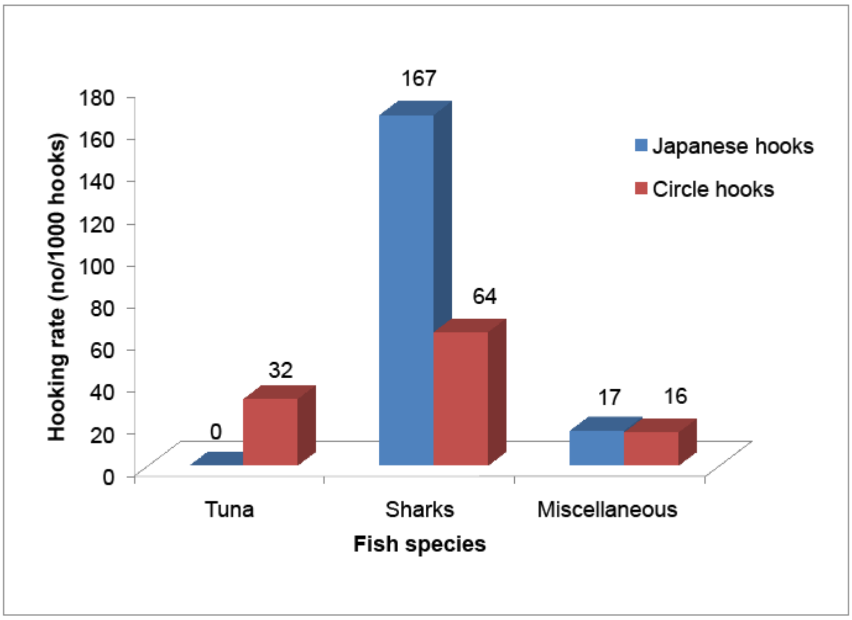

Fig. 6.3 The selectivity of the hook designs (the mean hooking rate observed for the different species in Japanese and circle hooks)

6.3.2. Bait holding efficiency of the hooks

The bait holding efficiency of the hooks was expressed as the percentage of hooks which have baits left intact after a given soaking time. The baits which are either detached normally or taken away by the fishes were considered as lost. Holding the bait when the fish has not either eaten or attended to, was considered as a desirable property of the hook. The bait holding efficiency of the hooks is expressed as a percentage of hooks retaining the bait out of the total number of hooks.

Comparative analyses were carried out to understand the bait holding efficiency of two different designs of hooks *viz.*, Japanese tuna hooks and circle hooks. Three sets of experiments have been carried out for the study. From the results, it was found that circle hook is more effective in holding the bait (78%) than the Japanese tuna hooks (73%) (Fig. 6.4).

Chi-square test used to compare circle hook and Japanese tuna hooks with respect to the bait holding properties did not indicate any significant difference between the hook designs (P = 0.67).

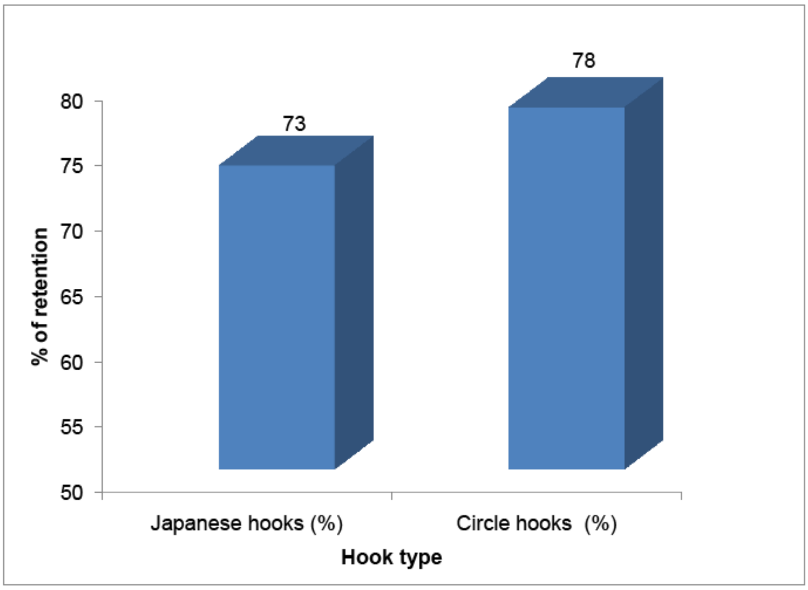

Fig. 6.4 Bait holding efficiency of Circle and Japanese tuna hooks

6.3.3. Hooking location

Hooking pattern of circle hook and Japanese tuna hooks in the fish body were analyzed. The major hooking locations were identified as lip, jaw, throat, gut and foul hooking. The hooking anywhere outside the body is referred as foul hooking. For comparing the effect of hook designs on hooking locations, the observed hooking locations are categorised into two groups *viz.*, preferred and non-preferred hooking locations. Lip and jaw are considered as the preferred hooking location since the removal from the hook is more efficient which enhances the post-release survival rate of the fishes. Throat, gut and foul hooking are considered as non-preferred hooking locations as it may affect the post-release survival of the fishes.

27% of the fish caught by Japanese tuna hooks were hooked in the jaw. Japanese tuna hooks dominate in the hooking of sensitive locations like throat and gut or stomach (deep-hooking) (Fig. 6.5). Throat hooking was found to be more in Japanese tuna hooks (45%) than the circle hooks (0%). 27% of the fish caught by Japanese tuna hook hooked in the deeper locations (gut).

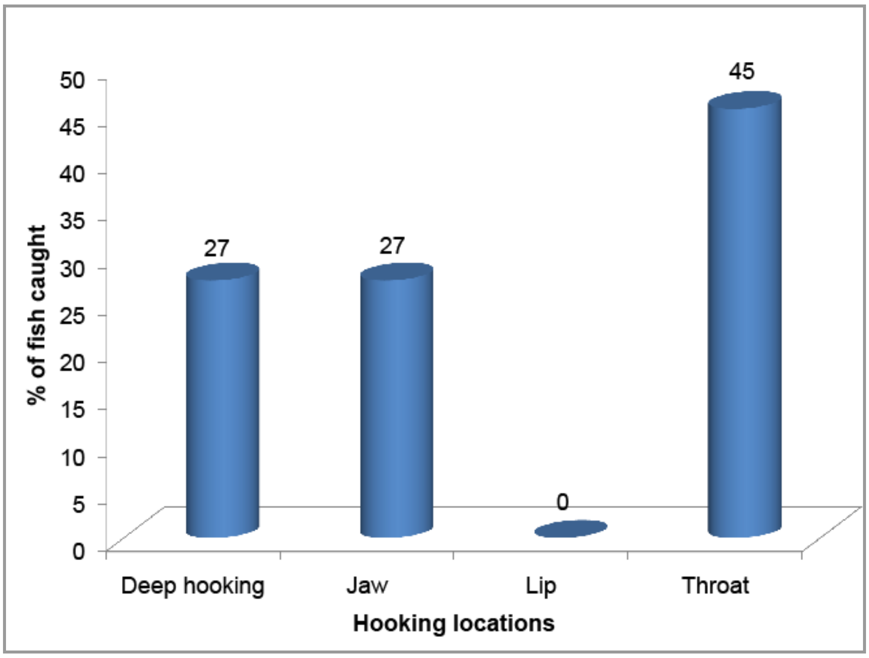

Fig. 6.5 Hooking pattern of Japanese tuna hooks

86% of the fish caught by circle hook were hooked in the jaw followed by lip (14%) (Fig. 6.6). Many workers confirmed the efficiency of the circle hooks to catch the fish in the jaw (Huse and Ferno, 1990; Cooke and Suski, 2004). No throat-hooking and deep-hooking were observed with the circle hook (Yokota *et al.*, 2006; Curran and Bigelow, 2011). No foul-hooking was reported in either of the hook design.

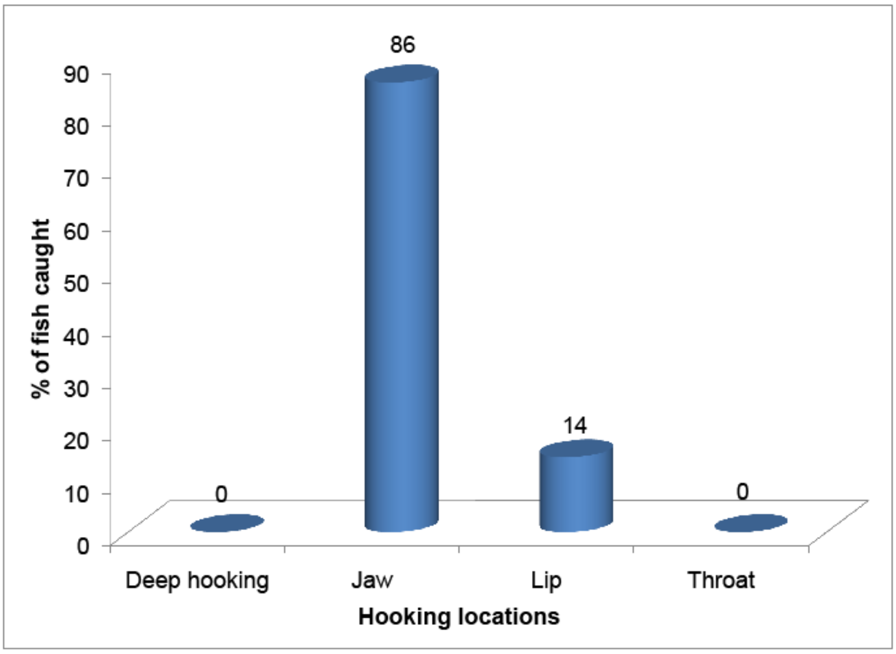

Fig. 6.6 Hooking pattern of Circle hooks

Comparison of the hooking locations for all the species clubbed together with the two hook design is depicted in the Fig. 6.7. Percentage of lip-hooking observed during fishing operations was 100% in the circle hook and no lip-hooking was reported in the Japanese tuna hooks. Jaw-hooking is reported to be high in circle hooks (67%) than Japanese tuna hooks (33%). Throat and deep-hooking is completely absent in the circle hooks. All these results confirms with the previous studies on the effect of hook design on the hooking pattern in longline caught fish (Huse and Ferno, 1990; Skomal *et al.,* 2002; Cooke and Suski, 2004; Beverly, 2006; Ward *et al.,* 2009). Various hooking locations observed during the study are shown in the Fig. 6.8, 6.9, 6.10 & 6.11.

Significant difference was noticed with regard to preferred and non preferred hooking between the two hooks with the Chi-square test (P = 0.02).

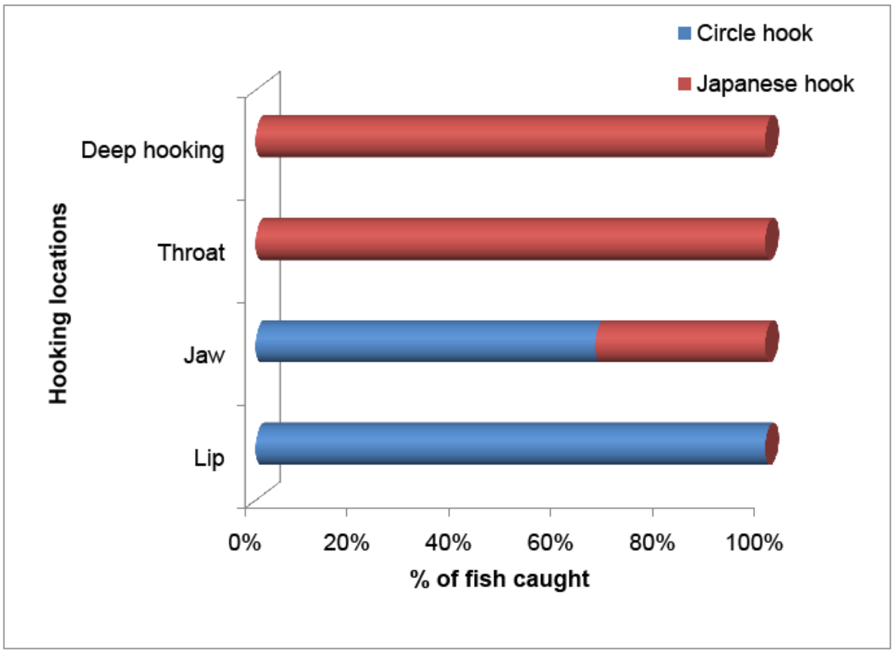

Fig. 6.7 Comparison of hooking pattern of Circle and Japanese tuna hooks (Values expressed as % of fish caught)

Fig. 6.8 Showing jaw-hooking of Japanese tuna hook in *Thunnus albacares*

Fig. 6.9 Showing lip-hooking of circle hook in *Lutjanus* spp.

Fig. 6.10 Showing throat-hooking of Japanese tuna hook in *Thunnus albacares*

Fig. 6.11 Showing deep-hooking of Japanese tuna hook in *Galecerdo cuvier*

6.4. Discussion

The study compared the effect of hook design on the overall catching efficiency expressed as number of fishes per thousand hooks. The mean hooking rate with respect to the Japanese tuna hooks was 186.44±51.13 (SE) and 112.9±40.52 for circle hooks. The comparative analysis showed higher overall hooking rate for Japanese tuna hooks (69%) compared to circle hooks which landed 31% of the total catch. However, the difference in hooking rate was not significant statistically. This is in agreement with studies of Yokota *et al.* (2006) and Pacheco *et al.* (2011) who observed no effect of hook design on the total catch.

Comparative analysis of the species selective ability of hooks has indicated that number and species composition of fish caught in longline can be influenced by the hook design, which is in agreement with observations by Huse and Ferno (1990) and Erzini *et al.* (1998). The tuna hooking rate was observed to be high in circle hooks (32/1000 hooks) compared with Japanese tuna hooks (0/1000 hooks). Circle hooks was found to be more effective in catching tuna than Japanese tuna hooks which was previously reported by many authors (Kerstetter and Graves, 2006; Yokota *et al.,* 2006; Kerstetter *et al.,* 2007; Ward *et al.,* 2009). The shark catch was found to be high in Japanese tuna hooks (167/1000 hooks) than circle hooks (64/1000 hooks). These results agree with the observations of Watson *et al.* (2005) who had confirmed the efficiency of the circle hooks to catch more tuna and fewer sharks, than Japanese tuna hooks. The hooking rate of fishes other than tuna and sharks was found to be 17/1000 hooks and 16/1000 hooks, respectively, for the Japanese tuna hooks and circle hooks. This results indicated that type of hook design do not have any significant effect on catching fish species other than tuna and sharks, in Lakshadweep Sea.

The study compared the bait holding efficiency of the two hook designs. Holding the bait when the fish has not either eaten or attended is considered as a superior property of the hook. The percentage retention of baits for the circle hooks was higher with a value of 78%, compared to 73% observed for the Japanese tuna hooks. Results were found to be statistically not significant. There is not much information available on the effect of hook design on the bait holding properties and hence a comparison of the results with previous work was not possible. Lokkeborg and Bjordal (1992) pointed out that the hook size significantly affects the bait loss, but in this study, only one size of the hook was used and hence a comparison between hook size and bait loss was not possible. Ralston (1982), Otway and Craig (1993) and Grixtii *et al.* (2007) indicated that hook size and bait sizes did not significantly affect bait loss. More studies are necessary with different hooks sizes and bait types to determine the effect of hook design on bait holding capacity.

Comparative analysis showed that the hook design significantly influenced the hooking pattern on the fish (Huse and Ferno, 1990; Skomal *et al.,* 2002; Cooke and Suski, 2004; Beverly, 2006; Ward *et al.,* 2009). Results of the present study confirm the effect hook design on the hooking location in fish. Fish caught in the longline are generally caught in the mouth mainly in the jaw or in the alimentary tract (Huse and Ferno, 1990). Comparative studies showed that circle hooks rank first in the jaw and lip-hooking (86% and 14%, respectively). The jaw and lip-hooking are considered as preferred hooking locations which facilitate the post-release survival rate by making minimum injury to the fish. This finding agrees with the previous works of Huse and Ferno (1990) and Cooke and Suski (2004) which showed the efficiency of circle hooks to hook fish in the jaw and lip areas. Throat-hooking (45%) and deep-hooking or intestinal-hooking (27%) and were found to be very high in Japanese tuna hooks which creates maximum injury to the fish caught. Cooke and Suski (2004); Yokota *et al.* (2006); Curran and Bigelow (2011) have shown that hooking in the more sensitive locations like gut-hooking and throat-hooking can be effectively minimized by use of circle hooks. The results of the present study support the use of circle hooks as a conservation tool to reduce post-release mortality rate in the pelagic longline fisheries recommended by others (Prince *et al.,* 2002; Skomal *et al.,* 2002; Watson *et al.,* 2004; Kim *et al.,* 2006; Yokota *et al.,* 2006; Ward *et al.,* 2009; Curran and Bigelow, 2011; Pacheco *et al.,* 2011).

6.5. Conclusion

The outcome of the study points towards the importance of circle hook as an alternate hook design for use in the longline fishing as a management and conservation tool to make this fishing gear more eco-friendly and sustainable. The results are in concurrence with studies elsewhere which report the superiority of circle hooks over Japanese tuna hooks, in terms of making less injury to the fishes thus reducing the post release mortality of the longline caught fishes. Further studies with large sample size and with different sizes of hooks are needed and seasonal and other factors that could influence the hooking rates also need to be ascertained.

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Chapter 7

STUDIES ON BYCATCH AND DEPREDATION

Contents

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, 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 (Sivasubramanium, 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 (L_{OA} 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 χ^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

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

*IUCN (2012)

Fig. 7.1 Shark species encountered as bycatch (A: *Carcharhinus falciformis,* **B:** *Sphyrna lewinii,* **C:** *Alopias. pelagicus,* **D:** *Carcharhinus amblyrhynchos,* **E:** *Galeocerdo cuvier,* **F:** *Negaprion acutidens)*

Fig. 7.2 Sailfish and lagoon fishes caught as bycatch (**A:** *Istiophorus platypterus,* **B:** *Lutjanus gibbus*, **C:** *Aprion virescens,* **D:** *Epinephelus polylepis)*

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.

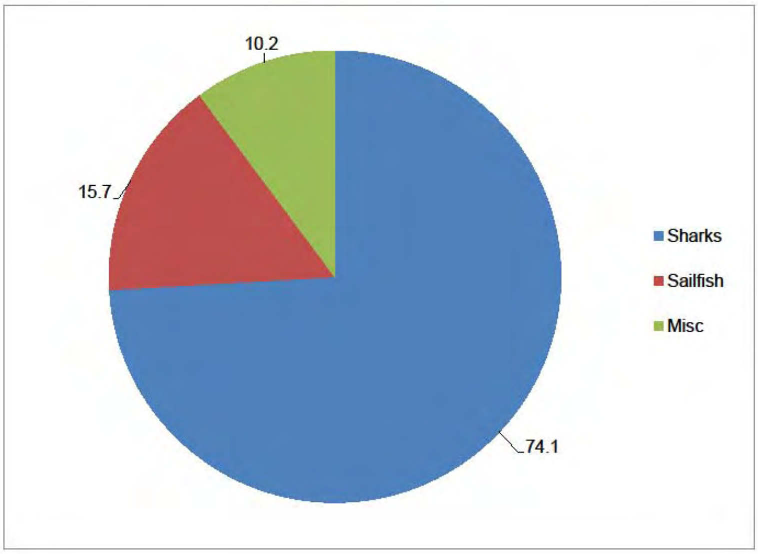

Fig. 7.3 The percentage composition of bycatch species

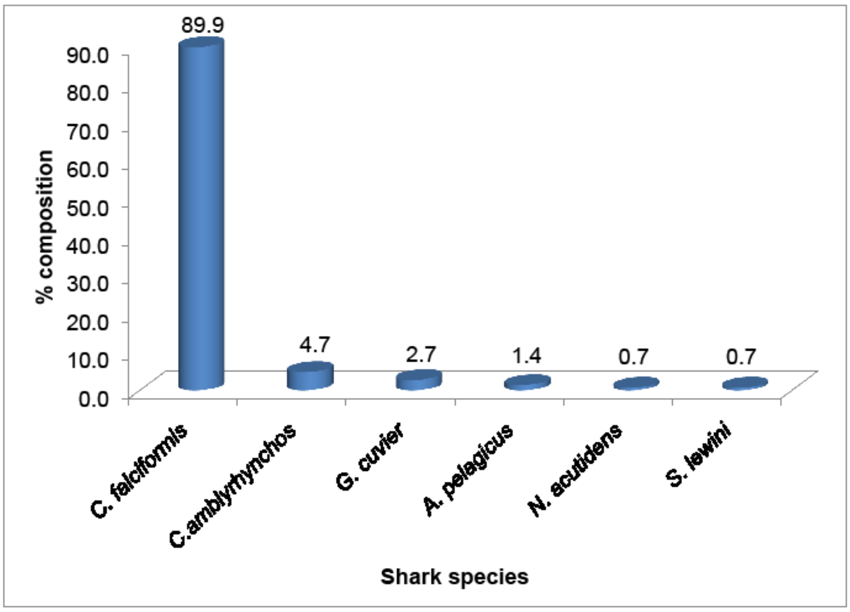

Fig. 7.4 Percentage composition of different shark species contributing to the bycatch

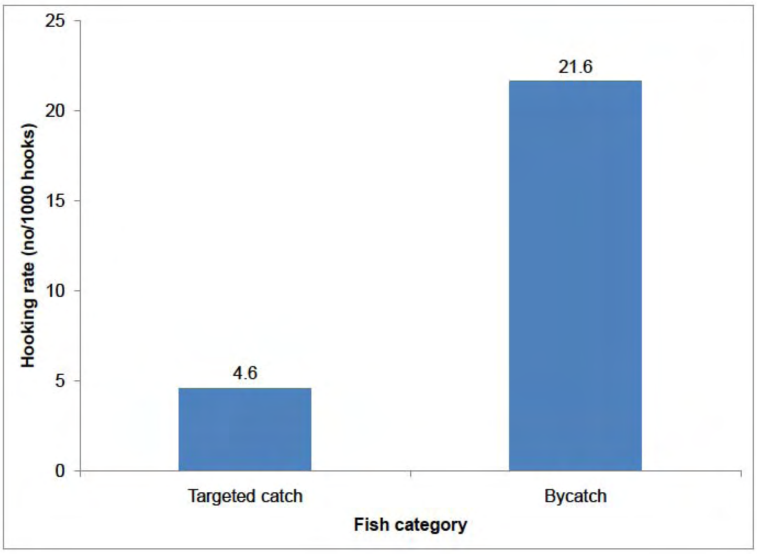

Fig. 7.5 The hooking rate reported for targeted catch and bycatch

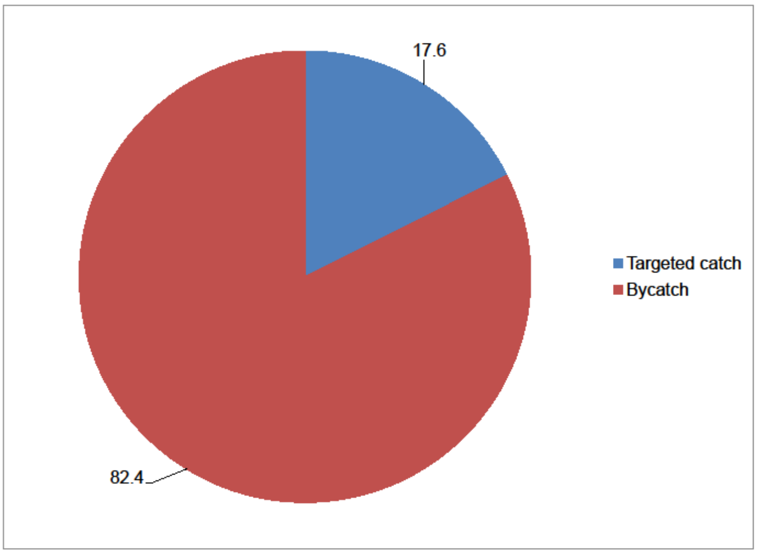

Fig. 7.6 The percentage composition of targeted catch and bycatch

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).

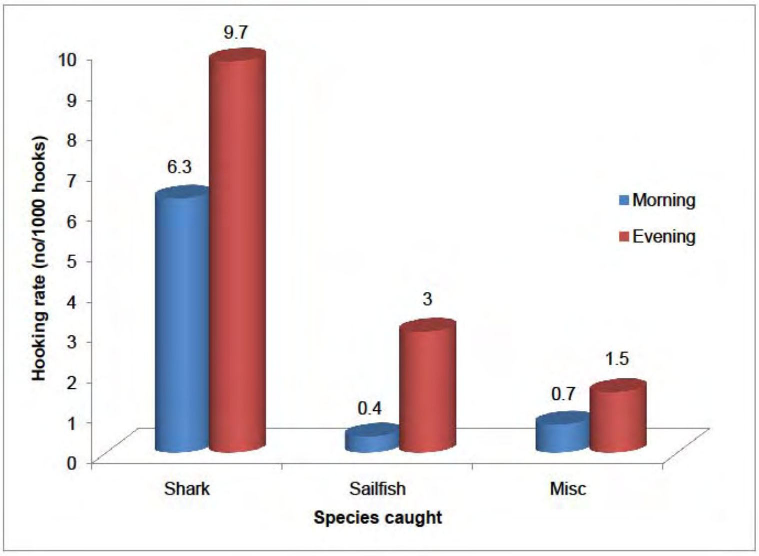

Fig. 7.7 Species- wise hooking rate in morning and evening contributed to bycatch

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 in to 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 in the overall bycatch rate and depth.

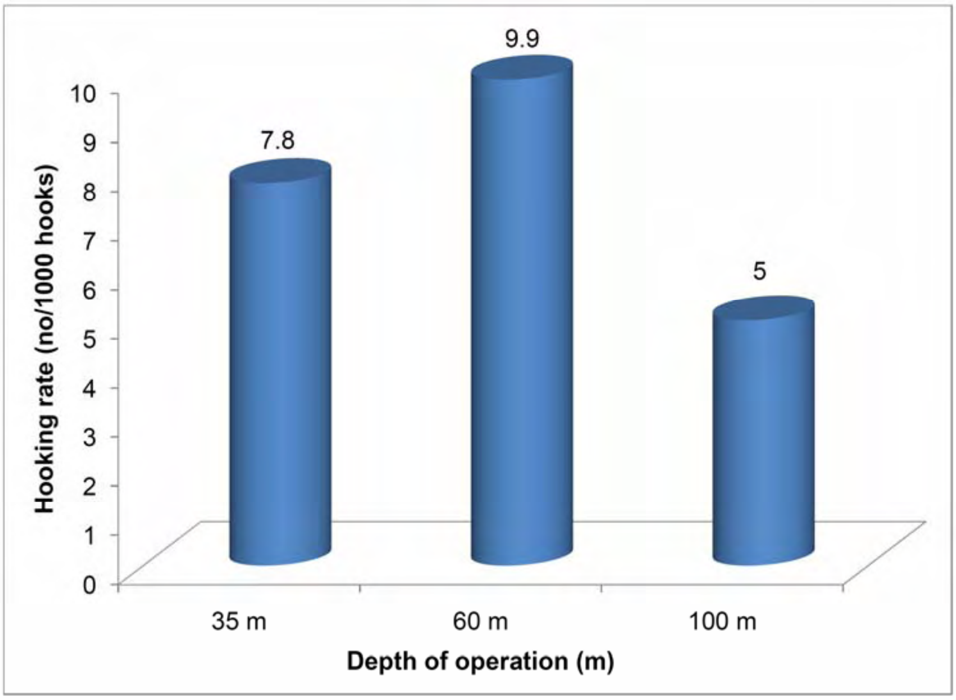

Fig. 7.8 The overall bycatch rate at three different depths

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 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.

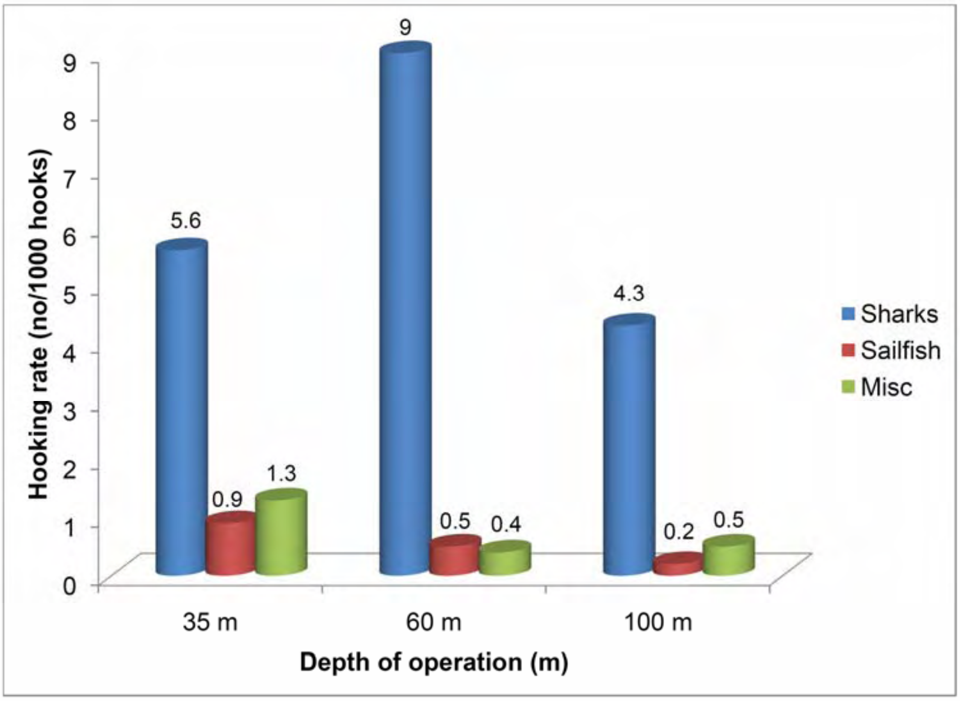

Fig. 7.9 Species wise hooking rate in three different depths

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

Source	SS	df	ms	F	P value
Total	17.4436	11			
Seasons	8.5881	1	8.5881	74.42	P< 0.01
Months	8.2786	5	1.6557	14.35	
Error	0.5769	5	0.1154		

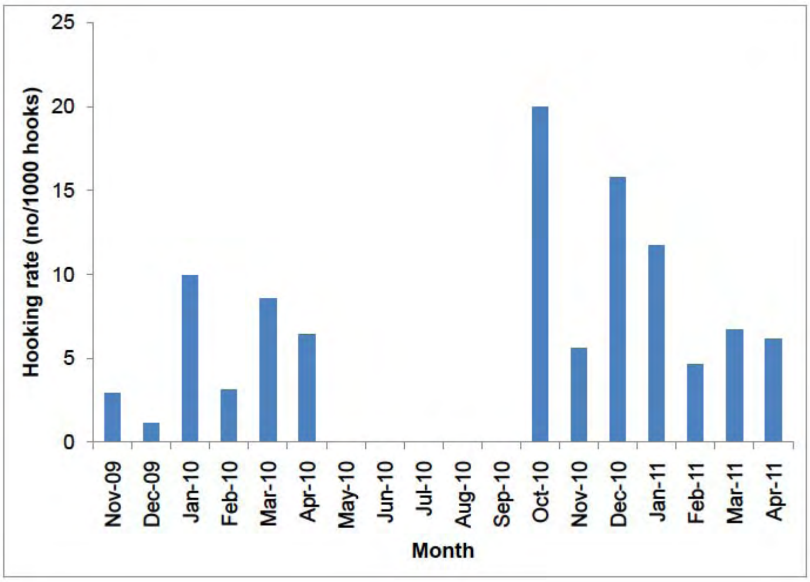

Fig. 7.10 Month-wise overall bycatch rate

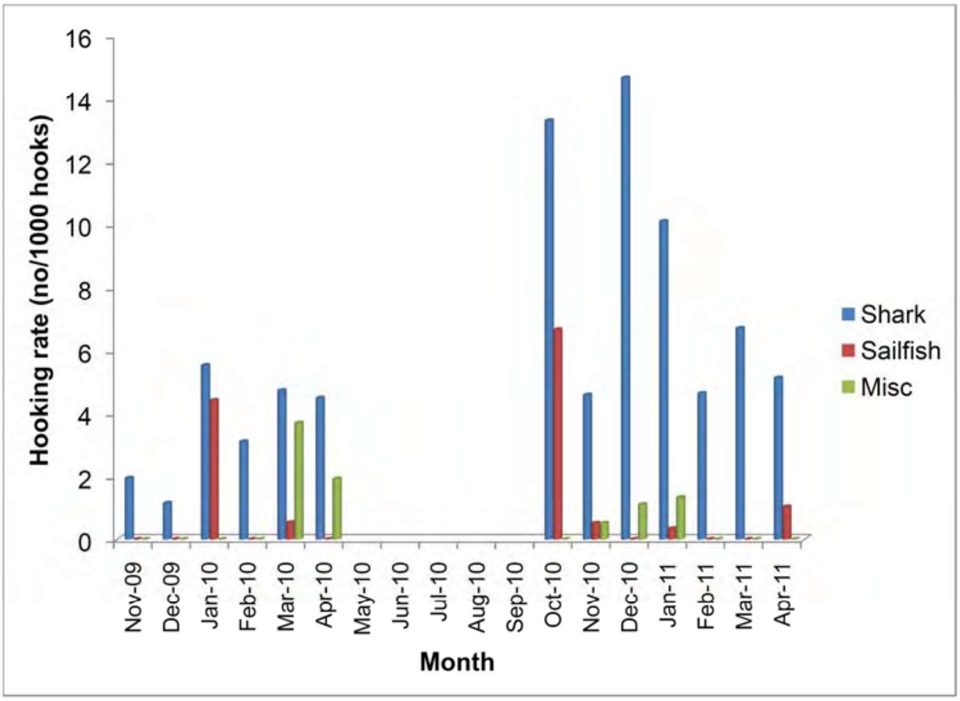

Fig. 7.11 Month-wise hooking rate of different bycatch species groups (the values expressed as no/1000 hooks)

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.

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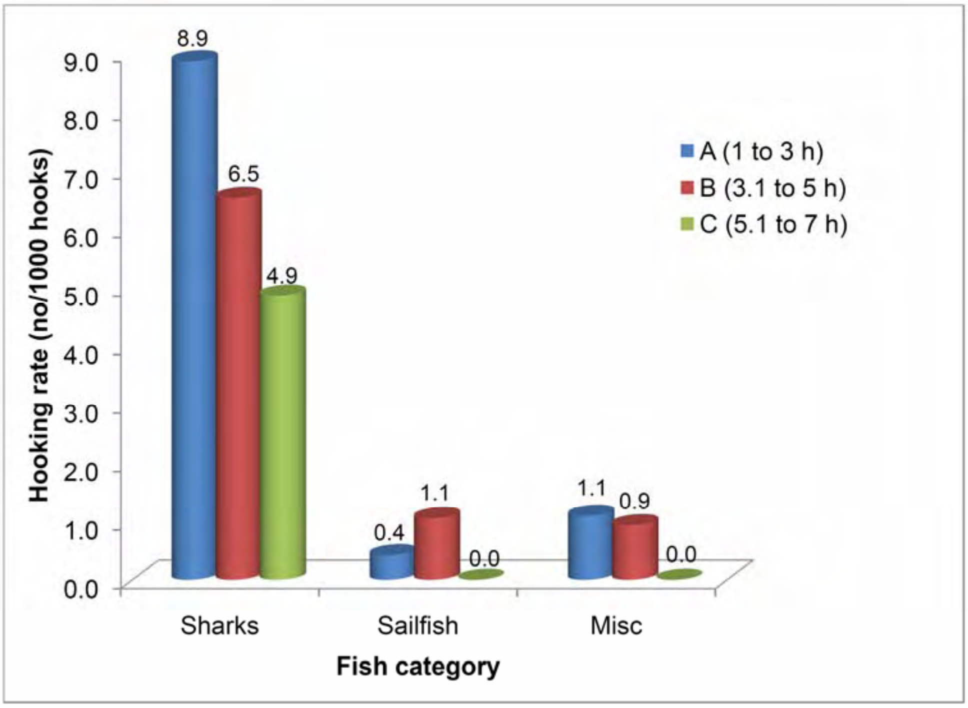

Fig. 7.12 The effect of soaking time on bycatch rates

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 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 conservations 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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Chapter 8

SUMMARY AND RECOMMENDATIONS

Longlines are passive fishing gears which are meant to catch sparsely distributed large pelagic fishes like tunas, billfishes and sharks. The main principle behind this fishing method is foraging behaviour of the targeted fish. This fishing method is considered as highly energy efficient, eco-friendly and species and size selective compared to other fishing methods such as trawling and purse seining. Longline vessels accounts for approximately 14% of the world tuna production. Majority of the catch in terms of weight is taken by purse seines. Skipjack tuna are the major group of tuna species landed from the world oceans in terms of quantity and major portion utilized for canning. Skipjack tuna and yellowfin tuna contributed nearly 80% of the tuna landed from the Indian Ocean waters. Skipjack and yellowfin are the major tuna species landed, in the Indian EEZ.

Hooks are considered as the heart of the longline fishing gear. Most commonly used hook designs in longline fishing operations are 'J' hooks, Japanese tuna hooks and circle hooks. Previous studies reported that a change in hook design can be used as an effective management and conservation tool to reduce the bycatch rate without compromising the targeted catch. Types of bait have profound influence on the selectivity and efficiency in the longline fishing operations. Natural baits are found to be more superior in the catching efficiency, compared with artificial baits.

Tuna longlines has been reported to catch many other species such as marine turtles, seabirds, sharks and cetaceans apart from targeted species. Discarded catch pose serious threat to the global efforts for the conservation of already depleted marine biodiversity. Shark catch has been reported to be one of the major concerns in the longline fishing operations. Most of these bycatch issues have been effectively mitigated by certain adjustments and modifications in the fishing gear and fishing operations. Alarming decrease in the tuna stock, poor management and conservation measures, IUU fishing and bycatch of marine turtles, seabirds, sharks and cetaceans are the major bottlenecks for the further expansion of the fishing operations. The content of the thesis is organized into 7 chapters.

Chapter - 1

The first Chapter deals with the introduction to the topic of the study. The chapter mainly discussed (i) marine fisheries of India, (ii) fisheries in Lakshadweep, (iii) fishing boats and gears of Lakshadweep, (iv) line fishing, (v) horizontal longline fishing - world scenario, (vi) horizontal longline fishing - Indian scenario and (vii) rationale and objectives of the study. India is blessed with a coastline of 8128 km, 2.02 million square km of EEZ and continental shelf area of 0.5 million sq. km. Substantial development has been witnessed during the last decade due to the innovative and efficient fishing practices, government policies, development in the harvest and post-harvest technologies and increased demand for fish and fish products in the international and domestic markets. Lakshadweep group of Islands has one of the largest oceanic territories, contributing immensely to the fisheries sector of our country. Pole and line fishing operation for catching skipjack tuna is the mainstay of the Island economy. Apart from the pole and line fishing, other major livelihood activity is the coconut cultivation. The most popular fishing methods in the Lakshadweep Islands includes pole and line, gillnets, hook and line, troll lines, shore seines and traps. Lakshadweep Sea has very rich resources of tunas, sharks and billfishes. Recent studies showed that there is a scope for the further expansion of capture fisheries of the high value oceanic fishery resources. Detailed description of the fishing crafts and gears are given in this Chapter. Wood is the most popular boat building materials in the Islands. Mechanisation of boats in the early sixties and extension of pole and line fishing from the Minicoy Islands to other Islands made significant developments in the fisheries sector of Lakshadweep Islands.

A detailed description on the various line fishing methods such as handlines, pole and lines, troll lines, jigging, longlines are given in this Chapter. Present scenario of the longline fishing operations carried out worldwide and India have been discussed in detail. The objectives of the present study have been:

- studies on the operational performance of tuna longline in Lakshadweep Sea
- studies on the efficiency of hooks in the longline operation
- studies of the efficiency of baits in the longline operation
- studies on bycatch in longline operation
- studies on depredation of the longline catch and hook loss encountered during the fishing operation

Chapter - 2

Chapter 2 is dedicated to the literature review in connection with the study. The available literature under (i) historical evolution of tuna longlining, (ii) longline fishing, (iii) classification of longline gears, (iv) tuna longline performance, (v) hooks and hook loss in tuna longlining, (vi) baits and bait loss in tuna longlining and (vii) bycatch issues and mitigation measures in tuna longlining have been reviewed. From the literature, it was evident that the first form of longline was originally developed in Japan. This fishing operation spread outside Japan after the Second World War. The longline operations in the Indian Ocean waters were started by the Republic of Korea and Taiwan. Today, Sri Lanka and Maldives are the two main coastal countries that have well developed tuna longline fleets in the Indian Ocean, neighbouring India. Longline is a passive fishing gear which can be operated as horizontal and vertical longlines. Horizontal longlines are also known as drift longlines used to catch sparsely distributed large pelagic fishes. The use of monofilament longlines and light sticks are some of the recent developments in the longline fishing operations. Bottom set longlines are used to catch predatory demersal fishes such as sharks, seabreams and groupers. Vertical longline are effective when the bottom conditions are rough. FAD assisted vertical longline operation has been found to be very effective in catching large tunas by exploiting the vertical range of distribution of the target species. Another modified longline is bottom vertical longline which has been designed to catch demersal fishes in rough fishing grounds.

Catch per day and catch per 1000 hooks are considered as the better indicators of apparent abundance than catch per trip. The fishing efficiency of the longlines are usually expressed as number or average weight of the fish per 1000 hooks. The hooking rate reported for tuna in various longline fleets from the world oceans is discussed in the Chapter.

Hooks are considered as the heart of the longline fishing gear. Earlier studies confirm the effect of hook design on the catching efficiency and species selectivity in the longline fishing operations. Studies on the effect of different designs of hooks on the catching ability, species selectivity and bycatch rate are reviewed in the Chapter. Available information indicated that a shift from the 'J' hooks or Japanese tuna hooks to circle hooks can help to reduce the bycatch rate considerably.

Catch rates and species selectivity depend to a large extend to the type, quality and size of the bait used. The selection of the bait mainly depend upon the preference of the targeted fish, local availability and firmness to hold to the hook. The natural bait is superior to artificial baits on the catching efficiency. Squid is considered as an effective bait for longline fishing. A detailed review of previous studies carried out on catching efficiency and selectivity of various bait types is given in this chapter. Bait loss is a serious issue which hinders successful fishing operations. The bait loss vary among bait species and has been reported to increase with depth. Various factors affecting the bait loss have been discussed.

Tuna longline not only catch targeted species but also many other species which are accidently caught during the fishing operations. The non-targeted species is known as bycatch. Turtles, cetaceans, sharks and seabirds are the main species which are discarded as bycatch and pose serious threat to the biodiversity conservation programmes. A detailed review on the bycatch issues facing by the longline fishing operations is made in this Chapter. A change in hook design, bait type, time of operation, depth of operation are considered as potential mitigation measures to reduce the bycatch rate. The bycatch issues facing the longline fishing operations and the effective mitigation measures for reducing the bycatch rate is discussed in detail.

Chapter - 3

Chapter 3 deals with the methodology adopted for the studies. Fishing area, fishing systems, fishing operations and aspects of field trials, data collection and analysis have been presented. The experimental longlining operations were carried out in the Lakshadweep Sea around Agatti Island. The fishing operations were carried out from 3 modified Pablo boats selected from the Agatti Island. All these boats were mechanised and were previously used for pole and line fishing for catching skipjack tuna. These Pablo boats were suitably modified with minor alteration in the deck layout. The alterations and modification of the Pablo boats are also discussed in detail. A detailed description and specifications of the longline gear and the method of fishing operations carried out are also discussed in this Chapter. Two different designs of hooks *viz*., Japanese tuna hooks and circle hooks were used for the selectivity studies. *Rastrelliger kanagurta*, *Amblygaster clupeoides* and *Sardinella longiceps* were the three different bait species used for studying the effect of bait type on longline catch rates and species selectivity. A general description on the methodology used for data collection and analysis has been furnished in the Chapter. Detailed description of the methodology adopted for the data collection, data analysis and statistical analysis used for the analysis are discussed in the respective Chapters. Data collected were compiled and analysed using χ^2 for the goodness of fit and ANOVA using SPSS (IBM SPSS Statistics, Version 20).

Chapter - 4

The fourth Chapter deals with operational performance of experimental tuna longlines. The main objectives of the study have been (i) to study the catch composition, size frequency and CPUE in the longline operation, (ii) to study the depth of operation and catch rates, (iii) to evaluate the effect of time fishing operation on the catch rates, (iv) to understand the monthly and seasonal variations in the longline catch rates, and (v) to study the effect of soaking time on catch rates. CPUE and various factors affecting the catching performance of experimental longline fishing operations in the Lakshadweep Sea are discussed in detail. The catch comprised of two species of tuna, six species of sharks, one species of sailfish and four species of lagoon fishes. Sharks were the dominant species contributing to the catch, followed by tunas, miscellaneous fishes and sailfishes. The size frequency of the main species caught, are discussed in the Chapter. Studies carried out to understand the effect of time of fishing on the hooking rate revealed that time of operation has significant effect on the overall catching performance with no significant change in the species composition. The fishing operations could not be carried out during monsoon season due to the bad weather conditions. The overall hooking rate was found to be high during the month of October. There was significant difference in the species composition with respect to the month of fishing operations. Shark catch ranks first when compared to other group of fishes every month. High shark catch was reported during the month of October. The results indicated that there was no significant difference in the hooking rate during pre-monsoon and post monsoon seasons. Studies were carried out to understand the effect of hook depth on the hooking rate and species selectivity in the longline fishing operations. There was significant association between the depth of operation (35-100 m) on overall catching ability and species selectivity. Further studies at deeper depths (>100 m) are needed for establishing the effect of hook depth on the catch rates and species selectivity. Comparative studies showed that soaking time did not have any significant effect on the hooking rate of different species.

Chapter - 5

The fifth Chapter deals with studies on bait efficiency in longline operations in the Lakshadweep Sea. The main objectives of the study were (i) to understand the effect of bait type on the hooking rate, (ii) to study the effect of bait type on the species selectivity, (iii) to understand the effect of baiting pattern on the hooking rate, and (iv) to find the hook holding ability of different types of baits. Three different types of baits *viz.*, *Sardinella longiceps*, *Rastrelliger kanagurta* and *Amblygaster clupeoides* were used for the experiments. The results indicated that there was no statistically significant difference in the overall hooking rate with three different baits. The results confirm that bait species have no significant effect on the species selectivity. The studies carried out to understand the effect of baiting pattern on the hooking rate indicated that there was no significant difference in the hooking rate between horizontal or vertical baiting pattern. Results of experiments conducted to understand the rate of bait loss in the fishing operations indicated that there was no significant difference among three different baits. Experiments carried out to understand the effect of soaking time on the bait loss rate revealed that bait loss tended to increase with soaking time. Further studies are required to be carried out with squids and artificial baits to evaluate their efficiency in the longline fishing operations. Studies carried out to understand the effect of depth of operation on the bait loss indicated that depth of operation has no significant effect on the bait loss. Very high rate of bait loss due to scavenging, predation or partial removal by small fishes was observed during the fishing operations which may hinder the successful fishing operations.

Chapter - 6

The sixth Chapter deals with studies on hook efficiency during longline operation in Lakshadweep Sea. The main objectives of the study were to find out (i) the influence of hook design on the hooking rate, (ii) the influence of hook design on species selectivity, (iii) the effect of hook design on the retaining ability of the baits and (iv) the relationship between hook design and hooking location of the hook. Two hook designs were tested during the fishing trials *viz.*, Japanese tuna hooks (3.5 sun) and circle hooks (14/0 non-offset). A detailed description on the experimental set up and methodology for data collection adopted for the selectivity studies have been furnished in the Chapter. The bait holding ability of two hook designs and baiting pattern were also studied. The results indicated that a change in hook design has significant effect on the species selectivity. The studies have also indicated that hook design has no effect on the bait holding ability. Experiments were carried out to understand the effect of hook design on the hooking pattern in the fishes caught. The hooking locations were categorised into two groups *viz.*, preferred hooking and non-preferred hooking. Jaw and lip hooking were considered as preferred hooking locations and throat and deep hooking were considered as non-preferred hooking. The preferred hooking locations are considered as a mitigation measure to reduce the post-release mortality due to accidental hooking of the untargeted species. Significant difference was noticed with regard to preferred and non-preferred hooking between the two different hook designs.

Chapter - 7

The seventh Chapter deals with studies on bycatch and depredation during longline fishing operations carried out in the Lakshadweep Sea. The main objectives of the study included (i) hooking rate and composition of bycatch, (ii) monthly variation in the bycatch rates, (iii) effect of depth on the bycatch rates, (iv) variation in the bycatch rates with respect to time of operation, (v) effect of soaking time on the bycatch rates and (vi) depredation in longline fishing in Lakshadweep Sea. Bycatch rate is the proportion of non-targeted species in the total catch that is caught in fishing operations. The studies indicated that the fishing is free from bycatch species usually encountered during the fishing operations in other fishing areas, such as marine turtles, seabirds and cetaceans. The major group of species constituting the bycatch, which need special measures for their conservation, are sharks. A total of six species of sharks, one species of sailfish and four species of lagoon fishes were caught as bycatch. The species which contributed to the bycatch were grouped into three categories *viz.*, sharks, sailfishes and miscellaneous fishes. The comparative studies indicated that there was a significant difference in the hooking rate of different species and the shark catch was found to be significantly higher. The studies carried out to assess the effect of time of fishing operation indicated that there was no significant difference in the species-wise hooking rate between morning and evening hours. The season and month of operation had no significant effect on the species selectivity except for sailfish. High sailfish hooking rate was observed during post-monsoon and among months, January registered higher hooking rate compared to other months. The results indicate that shark catches declined with increase in soaking time which need to be substantiated by further experiments. Observations were made to understand the rate of depredation and resultant hook loss. A few incidents of depredation, presumably by sharks, were noticed and it was not possible to identify the exact species responsible for the depredation.

Recommendations

i). The present study highlights the scope for developing longline fishing operations for catching under-utilised large pelagic fishes from the Lakshadweep Sea and indicates the possibility for diversification of fishing activities from the conventional pole and line fishing which targets skipjack tuna to longlines targeting large high value yellowfin tuna, with a precautionary approach.

ii). The existing fishing vessels used for pole and line fishing can be effectively modified for the operation of longlines. It is recommended that a few vessels from each Island may be modified for longline operations targeting large pelagic fishes.

iii). The locally available bait species can be used effectively for the longline operations in the Lakshadweep Sea. However, attention needs to be given for the development of alternate baits including artificial baits, for longlining.

iv). The use of circle hook can be promoted to minimise injuries and hence reduce the post-release mortality of unwanted species and also to reduce the bycatch.

v). Insufficient infrastructural facilities such as cold storage and ice plants and transportation facilities are major constraints for a successful value chain based on longline landings, which need to be addressed in Island fisheries development schemes.

vi). Mother vessel-catcher vessels concept will be helpful to overcome the logistical issues which will ensure the proper storage, processing and transportation of the fishes caught.

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Papers published

1. **Kumar, K. V. A**., Khanolkar, P. S., Pravin, P., Madhu V. R. and Meenakumari, B. (2013) Effect of hook design on the longline catches in longline fisheries in Lakshadweep Sea, India. *Indian Journal of Fisheries* 60(1): 21-27.

2. **Kumar K. V. A**., Khanolkar, P. S., Pravin, P., Meenakumari, B. and Radhakrishnan, E. V. (2012) First record of the pelagic thresher shark *Alopias pelagicus* (Pisces: Alopiiformes Alopiidae) from the Lakshadweep Sea, India. *Marine Biodiversity Records*, Journal of Marine Biological Association, Cambridge University Press, UK, 5(16): 1-2: doi:10.1017/S1755267211001114

3. **Kumar K. V. A**., Khanolkar P. S., Pravin, P., Meenakumari, B. and Radhakrishnan, E. V. (2012) First Record of the Grey Reef Shark *Carcharhinus amblyrhynchos*, (Bleeker, 1856) (Carcharhiniformes: Carcharhinidae) from the Lakshadweep Sea, India. *Journal of Threatened Taxa* 5(1): 3580-3582: 3580-3582; doi:10.11609/JoTT.o3223.987

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First record of the pelagic thresher shark *Alopias pelagicus* (Pisces: Alopiiformes: Alopiidae) from the Lakshadweep Sea, India

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The pelagic thresher shark Alopias pelagicus *is a large, wide-ranging Indo-Pacific Ocean pelagic shark. In this paper, the first record of the pelagic thresher shark, caught from the Lakshadweep Sea is reported. The shark 275 cm in total length was caught by drift longline operation at depth of 60 m in the Lakshadweep Sea (10°52N latitude 72°13E longitude).*

Keywords: *Alopias pelagicus*, Lakshadweep Sea

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INTRODUCTION

Family Alopiidae includes three species of thresher sharks viz., pelagic thresher *Alopias pelagicus* (Nakamura, 1935), bigeye thresher, *A. superciliosus* and thresher shark *A. vulpinus*. Distribution of pelagic thresher is largely restricted to the Indian and Pacific Oceans (Compagno, 2001). The pelagic thresher is highly migratory inhabiting in both coastal and oceanic waters in temperate and tropical seas. It can grow very large in size (L_{max} = 365 cm total length (TL)) and the growth rate is comparatively very low (K = 0.10 year^{-1}) showing late sexual maturity (8.0–9.2 years for females and 7.0–8.0 years for males) and usually producing about two embryos per litter (Liu *et al.*, 1999).

The occurrence of this species in the Indian Ocean has been documented by Pillai & Honma (1978), John & Varghese (2009), Huang & Liu (2010), Romanov *et al.* (2010) and others. Shark distribution is said to be high in the north of the equator (Pillai & Honma, 1978). This species is reported from the Indian Exclusive Economic Zone by Vijayakumaran (1994), Pillai & Parakkal (2000), Bhargava *et al.*, (2002), Manojkumar & Pavithran (2006), Kizhakudan *et al.* (2007) and Joshi *et al.* (2008), and contributes considerably to the elasmobranch fishery of India. *Alopias vulpinus* is the only species of thresher shark previously reported from the Lakshadweep Sea (Jones & Kumaran, 1980). In this paper, evidence of the occurrence of *Alopias pelagicus* in the Lakshadweep Sea is presented.

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MATERIALS AND METHODS

A male pelagic thresher shark *Alopias pelagicus* was landed during longline operation in the Lakshadweep Sea by fishermen from Agatti Island on 4 April 2011 (Figure 1). The shark was caught on the 3.4 Sun Japanese tuna hook and the location of capture was recorded as 10°52N latitude; 72°13E longitude. The morphometric measurements of the shark were made with a measuring tape to the nearest millimetre (Compagno, 1984) and weight was measured to the nearest gram. The species identification was carried out based on Compagno (1984).

RESULTS

The morphometric measurements of the specimen are given in Table 1. The TL of the specimen was 275 cm and standard length was 160 cm. The size of the shark was bigger than earlier reported from the Arabian Sea by Joshi *et al.* (2008).

Fig. 1. Pelagic thresher shark, *Alopias pelagicus*.

Table 1. Morphometric measurements of *Alopias pelagicus.*

Measurements	Cm	% of total length
Total length	275	100
Standard length	160	58.2
Snout to mouth	13	4.7
Snout to eye	11	4
Snout to 1st gill-slit	36	13.1
Snout to pectoral	44	16
Snout to 1st dorsal	75	27.3
Snout to pelvic	110	40
Eye diameter	4.7	1.7
Between dorsal bases	35	12.7
Pectoral to pelvic	51	18.5
Pelvic to anal	20	7.3
Inter-nasal distance	5	1.8
Mouth width	11	4
1st dorsal base	15	5.3
2nd dorsal base	2	0.7
Anal base	1.9	0.7
Pectoral base	20	7.1
Caudal upper lobe	141	51.3

The species has moderately large eyes reaching up to the dorsal surface of the head. Head is convex and the forehead is moderately convex in the lateral view. An inconspicuous horizontal groove is present on each side of the head above the gills. Labial furrows are absent. Snout is moderately long and conical. Pectoral fins are not falcate and the tips are broad and straight. Terminal lobe of the caudal fin is very small. Ventral side is white in colour and is not extending beyond the pectoral fin bases.

DISCUSSION

The pelagic thresher shark is a large, wide-ranging Indo-Pacific Oceanic species, which is highly migratory, with low fecundity and a low annual rate of population increase. The thresher sharks are listed as 'Vulnerable' globally because of their declining populations (IUCN, 2011). Our study presents the first record of *Alopias pelagicus* from the Lakshadweep Sea.

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NOTE

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First Record of the Grey Reef Shark *Carcharhinus amblyrhynchos*, (Bleeker, 1856) (Carcharhiniformes: Carcharhinidae) from the Lakshadweep Sea, India

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Grey Reef Shark *Carcharhinus amblyrhynchos* (Carcharhiniformes: Carcharhinidae) is a widely distributed requiem shark in the Pacific Ocean, and has an extensively scattered distribution in the Indian Ocean (Compagno 1984; William 2006). Indian elasmobranch fishery is one of the largest in the world (Vannuccini 1999) but information available on this species is very scanty (Raje et al. 2007). Pillai & Parakal (2000) and Joshi et al. (2008) have reported the presence of *C. amblyrhynchos* landings from Indian waters. Grey Reef Shark is a typical 'reef shark', found in clear tropical waters often from 10–50 m around coral reefs, in shallow water near coral slopes of islands and continents particularly near drop-offs, passes of fringing reefs and relatively common in atolls (Wetherbee et al. 1997; Economakis & Lobel 1998). The IUCN Red List of Threatened Animals categorizes *C. amblyrhynchos* as Near Threatened (Smale 2009), possibly due to its restricted habitat, site fidelity, inshore distribution, small litter size, and relatively late age at maturity, along with increasing fishing pressure.

Information available on the diversity and abundance of carcharhinid sharks in Indian waters is very meager though they contribute a major portion of the fishery. No scientific information is available on the presence of Grey Reef Shark in Lakshadweep waters which are known for coral reef biodiversity. In this paper, evidence for the occurrence of *C. amblyrhynchos* in Lakshadweep Sea is presented.

A female Grey Reef Shark *C. amblyrhynchos* was landed by fishermen from longline operation off Agatti Island in Lakshadweep Sea on 25 November 2010 (Image 1). The shark was caught by 3.4 Sun Japanese tuna hook and the location of capture was recorded as 10°47'N & 72°09'E (Image 2). The morphometric measurements of the shark were made to the nearest millimeter and weight was measured to the nearest gram. The species identification was based on Compagno (1984).

Image 1. Grey Reef Shark *Carcharhinus amblyrhynchos* (TL 126cm)

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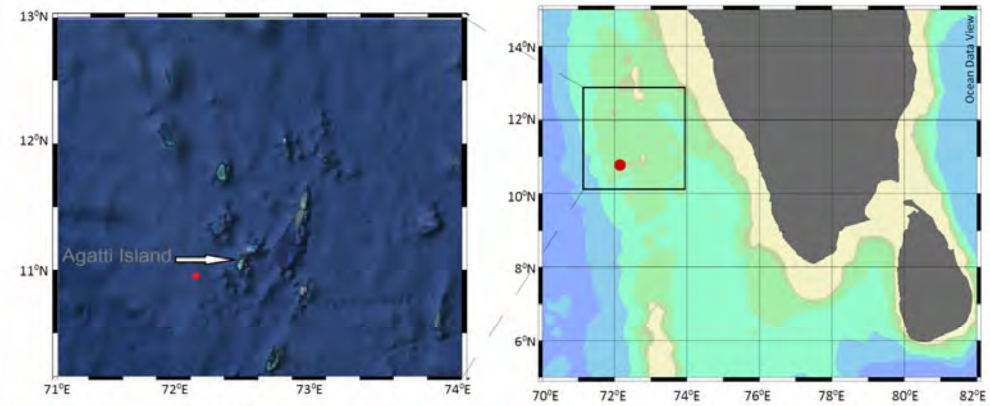

Image 2. The location of capture of a Grey Reef Shark from the Lakshadweep Sea.

Results and Discussion

The morphometric measurements of the specimen are given in Table 1. The total length (TL) of the specimen was 126cm and standard length (SL) was 106cm. The Grey Reef Shark is a moderately stocky species, distributed in the coastal and pelagic waters of Indo-Pacific. *Carcharhinus amblyrhynchos* can be identified by the following characters: dusky grey color above and white below; first dorsal fin irregularly to prominently white edged (Image 3); posterior margin of the caudal fin with a conspicuous broad black margin; pectoral, second dorsal, anal and pelvic fins with blackish or dusky tips and prominent blackish margin (Image 4). The First dorsal fin is moderately large and semifalcate with a narrowly pointed apex. Second dorsal fin is moderately large and high. Pectoral fins falcate. Snout fairly long and broadly rounded. Eyes are round and fairly large. Upper labial furrows short and inconspicuous. Inter dorsal ridge absent. Upper teeth are narrow and serrated (Image 5). The species inhabits continental and insular shelves preferably on coral reefs and in shallow lagoons. The area from where the specimen is reported was near the coral ridge in Lakshadweep Sea. Present record is the first report of *Carcharhinus amblyrhynchos* from the Lakshadweep Archipelago.

Table 1. Morphometric measurements of *Carcharhinus amblyrhynchos* (female, 126cm TL) from Lakshadweep Sea

Measurements	cm	% of total length
Total length	126	100.0
Standard length	106	84.1
Snout to eye	11	8.7
Snout to pectoral	33.5	26.6
Snout to first dorsal	43	34.1
Snout to pelvic	76.5	60.7
Eye diameter	2.5	2.0
Eye to pectoral	20	15.9
Between dorsal bases	25.2	20.0
Pectoral to pelvic	34.5	27.4
Pelvic to anal	8.5	6.7
Pre first dorsal length	43	34.1
First dorsal base	13	10.3
First dorsal anterior margin	17	13.5
Second dorsal base	4	3.2
Pectoral anterior margin	24	19.0
Pectoral base	8.5	6.7
Dorsal caudal margin	34.5	27.4
Anal base	5.5	4.4
Preventral caudal margin	19	15.1
Lower postventral caudal margin	11	8.7

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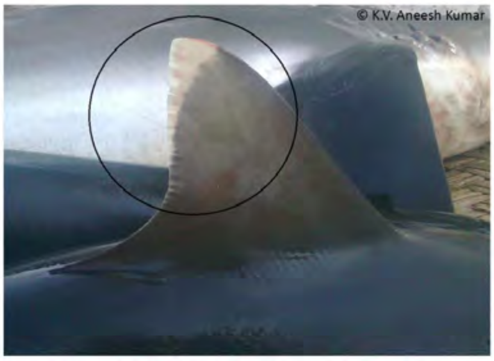

Image 3. Irregular white edge of the first dorsal fin margin

Image 4. Blackish margins in the pelvic, second dorsal, anal and caudal fins

Image 5. Upper and lower teeth

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Effect of hook design on longline catches in Lakshadweep Sea, India

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ABSTRACT

Tuna longlining is considered as an ecofriendly, economical, species-selective and size-selective fishing technique suitable for harvesting sparsely distributed large predatory fishes. Many non-targeted and protected species like marine turtles, seabirds, cetaceans and sharks are also caught as bycatch in the pelagic longline gear. Investigations were undertaken to evaluate the effect of hook design on the longline catches in Lakshadweep Sea by comparing the species selection efficiency, bait holding efficiency and hooking pattern of the Japanese and circle hook designs. The results indicated that hook design has no effect on the catching efficiency, species selectivity and bait holding ability in pelagic longline fisheries in Lakshadweep Sea. The hooking pattern was found to be significantly different, indicating favorable hooking locations in the case of circle hooks. The results of the present study, indicated the positive effects of circle hooks in minimising the impact of bycatch by hooking on the fish favouring post-release survival of the species.

Keywords: Hook design, Lakshadweep Sea, Longline, Selectivity

Introduction

The pelagic longlines are currently used to commercially harvest the tuna and tuna like fishes worldwide. Longline is considered as a size selective gear (Bjordal, 1981). Even though it has been considered more eco-friendly than other fishing practices, the gear also interacts with non-target pelagic species and can be a threat to birds, sharks, turtles and dolphins (Belda and Sanchez, 2001; Polovina *et al.,* 2003; Lewison *et al.*, 2004; Diaz, 2005). Tuna longlining has been undergoing many changes in the shape and structure for improving the fishing efficiency and to reduce bycatch (Ward and Hindmarsh, 2007). Hooks are the most important part in the gear and it varies in shape and size. Most commonly used hooks are 'J' hook, Japanese tuna hook and circle hook. 'J' hooks are not advisable because of the injury caused by deep hooking during the capture which reduces the post-release survival rate of the nontargeted animals like dolphins and turtles (Huse and Ferno, 1990). Japanese tuna hooks of 3.6 sun are commonly used in the tuna longlining by most of the tuna fishing fleets in the world (Beverly *et al.,* 2009). Japanese tuna hook has an intermediate style between 'J' hook and circle hook (Whitelaw and Baron, 1995). The overall hooking rate is reported to be very high in 'J' hooks (Kerstetter and Graves, 2006).

In tuna longlining, a potential technique to reduce unwanted bycatch of turtles is deep setting of the line (Beverly *et al*., 2009). Fishing mortality of bycatch species can be reduced by change in the hook design, hook size, decreasing interaction rates, decreasing the mortality during hauling, increase in post-release survival or by a combination of these approaches (Shapiro, 1950; Koike *et al.,* 1968; Ralston, 1982; Cortez-Zaragoza *et al.,* 1989; Lokkeborg and Bjordal, 1992; Erzini *et al*., 1998; Falterman and Graves, 2002; Kerstetter and Graves, 2006; Gilman *et al.,* 2006; Piovano *et al*., 2010; Curran and Bigelow, 2011).

Recently, attention has been given to circle hooks, having the point turned perpendicularly back to the shank as a means of bycatch mitigation. Fish caught by longlines are generally hooked in the mouth, particularly in the jaw or in the alimentary tract if the hook is swallowed (Huse and Ferno, 1990). Fish hooked in sensitive areas such as stomach, esophagus, and gills suffered greater mortality than those hooked in non-critical areas (Aalbers *et al*., 2004). Deep hooking can be significantly reduced by increasing the hook size (Grixtii *et al.,* 2007). Circle hooks have a tendency to slide over soft tissues and rotate resulting in the hook catching in the jaw (Cooke and Suski, 2004) causing minimum injury to the fishes resulting in enhanced post-release survival (Lokkeborg and Bjordal, 1992 ; Prince *et al.,* 2002; Skomal *et al*., 2002; Watson *et al*., 2004; Watson *et al.,* 2005; Bacheler and Buckel, 2006; Gilman *et al.,* 2006; Kerstetter *et al*., 2007; Read, 2007; Pacheco *et al.,* 2011; Swimmer *et al*., 2011). Several studies indicated that circle hooks can produce higher catch rates than traditional 'J' hooks (Peeling, 1985; Montrey, 1999; Falterman and Graves, 2002; Poulsen, 2004; Yokota *et al*., 2006; Kerstetter and Graves, 2006; Kerstetter *et al*., 2007; Ward *et al*., 2009; Swimmer *et al*., 2011). Studies conducted by Yokota *et al.* (2006) and Pacheco *et al*. (2011) indicated that change in hook pattern have little effect on the catch composition.

Bait holding effect of the hooks is an important factor for the successful fishing operation. It is very important that the baits should be remaining in the hook until the fish approached. Although, large number of studies have been conducted on the effect of hook design on the longline catches in the international waters, there are only limited works carried out in Indian waters. Hence, the present study was undertaken with the objective to find the effect of Japanese and circle hooks on overall hooking, species selection, bait holding ability and hooking locations by experimental longlining operations in Lakshadweep waters.

Materials and methods

Fishing operations were conducted off north of Agatti Island (10° 57' to 10° 58' N and 72° 16 to 72° 19' E) employing a converted pablo boat (*Noorjahan*, L_{OA} 7.6 m; 16.5 hp) equipped for experimental tuna longlining operation in Lakshadweep Sea. The depth of longline operation was 60 m. Bait used for this study was *Amblygaster clupeoides*. Line setting started in the dawn and usually took 1 h to complete. The soaking time varied from 2 to 4 h, depending on the weather conditions. Maximum number of branchlines shot was 100. Three sets of experiments were conducted to study the selectivity of hooks. Each set carried 25-50 hooks. Hook comparison trials used 14/0 non-offset circle hooks and 3.5 sun Japanese tuna hooks (Fig. 1). Each basket contained five hooks and

Fig. 1. Hooks used for the study- 14/0 circle hook (left) and 3.5 Japanese tuna hook (right)

care was taken to ensure alternating positions of each hook within the baskets along the mainline (*i.e.*, one basket would have C-J-C-J-C and the next would have J-C-J-C-J) (Kerstetter and Graves, 2006; Pacheco *et al.*, 2011). During hauling, the species, number, condition (live or dead), and hooking location were recorded. Length and weight of the fish were measured onboard. The catch data were pooled from each basket by hook type and was used for analysis. The catch rate for each operation was calculated as catch per 1000 hooks and expressed as the measure of catch per unit effort (CPUE).

Bait holding efficiency of the hooks were also compared. The bait holding efficiency of the hook was determined by counting the percentage of hooks which have baits left after a given soaking time. The baits which are either detached normally or taken away by the fishes were considered as lost. Holding the bait when the fish has not eaten or attended to, was considered as a desirable property of the hook.The bait holding efficiency of the hooks is expressed as a percentage of hooks retaining the bait out of the total number of hooks deployed. Hooking pattern of circle hooks and Japanese tuna hooks in the fish's body were analysed. The favourable hooking locations identified were lip and jaw, and other locations like throat, gut and foul hooking were considered as unfavourable hooking patterns

Statistical tests were performed using SPSS (IBM SPSS Statistics, Version 20). Catch composition, species selectivity, bait holding efficiency of hooks and hooking location by hook type was compared by chi-square test (Prince *et al.*, 2002; Pacheco *et al.*, 2011). Catch rate of hooks were analysed using generalised linear modeling (GLMs) with hook type and baiting type (Kerstetter and Graves, 2006; Ward *et al.*, 2009; Piovano, 2010). Test results were considered significant at 5% confidence level.

Results and discussion

Comparative evaluation of catch per unit effort (CPUE)

The data set had observations from a total of 123 hooks. Hooking rate was expressed as number of fish caught per 1000 hooks. A total of 17 fishes were caught during the experimental fishing operations which included three species of sharks (*Carcharhinus amblyrhynchos, Carcharhinus falciformis, Galecerdo cuvier*) and two species of bony fishes (*Thunnus albacares* and *Lutjanus* sp.). Experimental fishing showed very high hooking rate for the Japanese hooks compared to circle hooks. The mean hooking rates for Japanese and circle hooks were 186.44 ± 51.13 and 112.9 ± 40.52 (mean ± SE), respectively (Fig. 2).

Generalised linear modeling (GLM) was carried out to find the influence of hooking rate by three factors

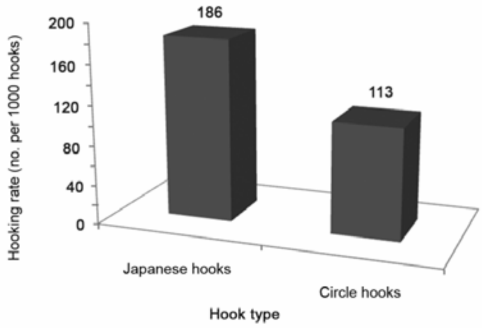

Fig. 2. Hooking rate of the two hook designs (mean hooking rate) observed for different species

reported to influence the hooking rate. The three factors considered were hook type (circle and Japanese), retention of bait and baiting pattern on the hook (vertical or horizontal). Binomial distribution with probit link was used for the GLM. The results indicated that there was no significant influence of any of these factors on the hooking rate expressed as present or absent. No statistically significant difference was noticed between the circle hook and Japanese hooks with respect to hooking rates observed by the Pearson's chi-square test with Yate's continuity correction ($p = 0.36$).

Selectivity of the hooks

Hooking rates (number per 1000 hooks) observed in Japanese hooks were 0 for tuna, 167 for sharks and 17 for other fishes (Fig. 3). Hooking rates observed were 32 for tuna, 64 for sharks, and 16 for other fishes, in the case of circle hooks. The study indicated the efficiency of the circle hooks in catching more tuna and fewer sharks compared to Japanese hooks. This characteristic of circle hooks can be effectively used for conservation of sharks. Both the Japanese hook and circle hook showed almost same

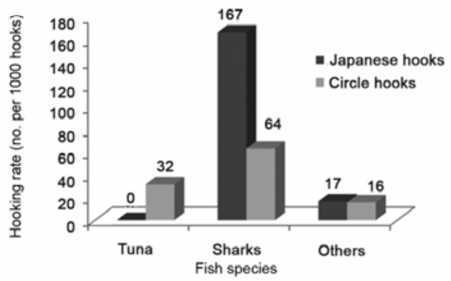

Fig. 3. The selectivity of hook design (mean hooking rate) observed for the different species in Japanese and circle hooks

hooking rate in catching fishes other than tuna and sharks (17/1000 and 16/1000 hooks respectively). No statistically significant difference was noticed in the species selectivity of the two hooks, using chi-square test ($p = 0.515$).

Bait holding efficiency of the hooks

Comparative analyses were carried out to understand the bait holding efficiency of the two different type of hooks. Three sets of experiments were conducted for the study using a total of 123 hooks. From the results, it was found that circle hooks were more effective in holding the bait (78%) than the Japanese hooks (73%) (Fig. 4). Chi-square test performed to compare circle hooks and Japanese hooks with respect to the bait holding properties showed no significant difference between the hook types ($p= 0.67$).

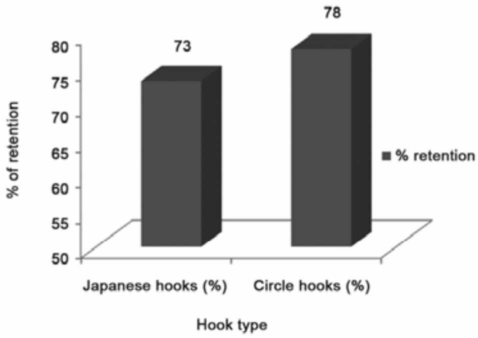

Fig. 4. Bait holding efficiency of circle and Japanese hooks

Hooking location

The major hooking locations were identified as lip, jaw, throat and gut, in addition to foul hooking. Hooking anywhere outside the body is referred as foul hooking. For comparing the effect of hook types on hooking locations, the observed hooking locations were catogorised into two groups *viz*., preferred and nonpreferred hooking locations. Lip and jaw were considered as the preferred hooking location since the removal of fish from the hook from these locations is more efficient which enhances the post-release survival rate of the fishes. Throat, gut and foul hooking are considered as non-preferred hooking locations as it may adversely affect the post-release survival of the fishes.

Twentyseven percent of the fish caught in Japanese hooks were hooked in the jaw. No lip-hooking was observed in the Japanese hooks. Japanese hooks dominated in the hooking of sensitive locations like throat, gut or stomach (deep-hooking) (Fig. 5). Throat hooking was found to be more in Japanese hooks (45%) than the circle hooks were (0%) and 27% of the fish caught by Japanese hooks were hooked in the deeper locations (gut).

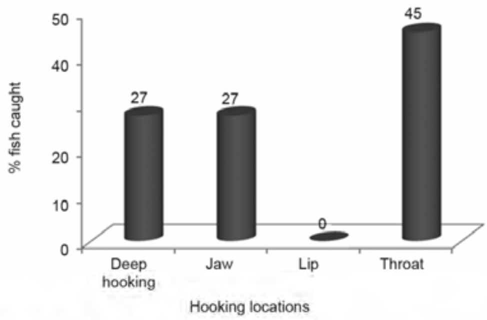

Fig. 5. Hooking pattern of Japanese hooks

About 86% of the fish caught by circle hook were hooked in the jaw followed by lip (14%) (Fig. 6). Many workers confirmed the efficiency of the circle hooks to catch the fish in the jaw (Huse and Ferno, 1990; Cooke and Suski, 2004). No throat-hooking and deep-hooking were observed with the circle hook (Yokota *et al.* 2006; Curran and Bigelow, 2011). No foul-hooking was recorded in either of the two hook types.

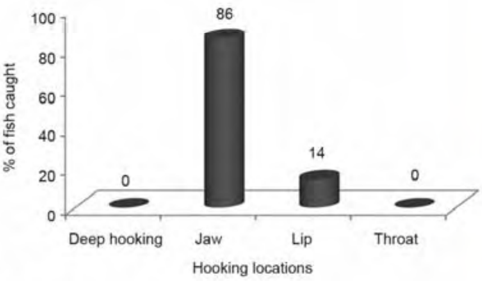

Fig. 6. Hooking pattern of circle hooks

Comparison of the hooking locations for all the species clubbed together with the two hook designs is depicted in the Fig. 7. Hundred percentage lip-hooking was recorded in the circle hook while no lip-hooking was observed in the Japanese hooks. Jaw-hooking was found to be high in circle hooks (67%) than Japanese hooks (33%). Throat and deep-hooking were not observed in the circle hooks. All these observations are in agreement with the previous studies conducted elsewhere on the effect of hook design on the hooking pattern in longline fish catch (Huse and Ferno, 1990; Skomal *et al.*, 2002; Cooke and Suski, 2004; Beverly, 2006; Ward *et al.*, 2009). Various hooking locations observed during the study are depicted in Fig. 8 to 11. Significant difference was noticed with regard to preferred and non-preferred hooking between the two hooks in Chi-square test ($p = 0.02$).

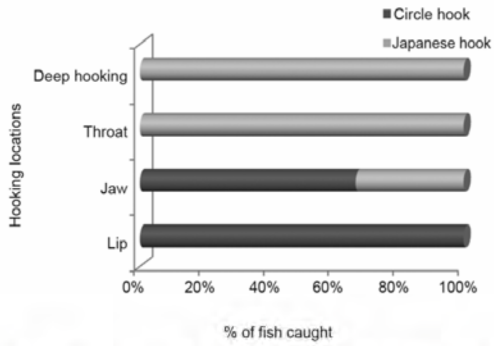

Fig. 7. Comparison of the hooking pattern of circle and Japanese hooks

Fig. 8. Jaw-hooking by Japanese hook in *Thunnus albacares*

Fig. 9. Lip-hooking by circle hook in *Lutjanus* sp.

The study compared the effect of hook type on the overall catching efficiency expressed as number of fishes per thousand hooks. The mean hooking rate with respect to the Japanese hooks was 186.44 ± 51.13 and

Fig. 10.Throat-hooking by Japanese hook in *Thunnus albacares*

Fig. 11.Deep-hooking by Japanese hook in *Galecerdo cuvier*

112.9 ± 40.52 (mean ± SE) for circle hooks. However, the difference in hooking rate was not significant statistically. This is in agreement with studies of Yokota *et al.* (2006) and Pacheco *et al.* (2011) who observed no effect of hook type on the catch.

Comparative analysis of the species selection ability of hooks indicated that the number and species composition of fish caught in longline can be influenced by the hook design, which is in agreement with observations by Huse and Feno (1990) and Erzini *et al.* (1998). The tuna hooking rate was observed to be high in circle hooks (32/1000 hooks) compared with Japanese hooks (0/1000 hooks). Circle hooks have been reported to be more effective in catching tuna than Japanese hooks (Kerstetter and Graves, 2006; Yokota *et al.,* 2006; Kerstetter *et al.,* 2007; Ward *et al.,* 2009). Shark catch was found to be high in Japanese hooks (167/1000 hooks) than circle hooks (64/1000 hooks). These results agree with the observations of Watson *et al.* (2005) who confirmed the efficiency of circle hooks to catch more tuna and fewer sharks, than Japanese hooks. The hooking rate of fishes other than tuna and sharks was found to be 17/1000 hooks and 16/1000 hooks respectively for the Japanese and circle hooks and the results indicated that, type of hook design do not have any significant effect on catching fish species other than tuna and sharks in Lakshadweep Sea.

Holding the bait when the fish has not either eaten or attended, is considered as a superior property of the hook. The percentage retention of baits for the circle hooks was higher with a value of 78%, compared to 73% observed for the Japanese hooks. However the differences observed were found to be statistically not significant. There is not much information available on the effect of hook type on the bait holding properties and hence a comparison of the results with previous work was not possible. Lokkeborg and Bjordal (1992) pointed out that the hook size significantly affects the bait loss, but in this study, only one size of the hook was used and hence a comparison between hook size and bait loss was not performed. Ralston (1982); Otway and Craig (1993) and Grixtii *et al.* (2007) indicated that hook size and bait sizes did not significantly affect bait loss. More studies are necessary with different hook sizes and bait types to determine the effect of hook type on bait holding capacity.

It has been reported that the hook type significantly influenced the hooking pattern on the fish (Huse and Ferno, 1990; Skomal *et al.*, 2002; Cooke and Suski 2004; Beverly, 2006; Ward *et al.,* 2009). Results of the present study confirm the effect of hook design on the hooking location in fish. Fish caught in the longline are generally hooked in the mouth mainly in the jaw or in the alimentary tract (Huse and Ferno, 1990). Circle hooks ranked first in jaw and lip-hooking (86% and 14% respectively) which are considered as preferred hooking locations which facilitate the post-release survival rate by making minimum injury to the fish. This finding agrees with the previous works of Huse and Ferno (1990) and Cooke and Suski (2004) which showed the efficiency of circle hooks to hook fish in the jaw and lip areas. Throat-hooking (45%) and deep-hooking or intestinal-hooking (27%) were found to be high in Japanese hooks, which creates maximum injury to the fish caught. Cooke and Suski (2004), Yokota *et al.* (2006) and Curran and Bigelow (2011) have shown that hooking in the more sensitive locations like gut and throat can be effectively minimised by use of circle hooks. The results of the present study support the use of circle hooks as a conservation tool to reduce post-release mortality rate in the pelagic longline fisheries, as has been recommended by several workers (Prince *et al.,* 2002; Skomal *et al.,* 2002; Watson *et al.,* 2004; Kim *et al.,* 2006; Yokota *et al.*, 2006; Ward *et al.,* 2009; Curran and Bigelow, 2011; Pacheco *et al.,* 2011).

The outcome of the study clearly indicated that the circle hooks are superior to the Japanese hooks in terms of reduction in bycatch and the results are in concurrence with studies elsewhere which report the efficacy of circle hooks in bycatch reduction. The study suggests the use of circle hooks as a technical measure in the longline fisheries, to make this fishing gear more eco-friendly and sustainable. Further studies with large sample size and with different sizes of hooks are needed, The probable influence of seasonal and other factors on the hooking rate also needs to be investigated.

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