12. Advances in deep sea and oceanic fishing

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Introduction

Fisheries play a pivotal role in the economic development of all maritime nations. The fisheries sector contributes as foreign exchange earner, ensures nutritional security and generates employment opportunities. With absolute rights on the EEZ, India has also acquired the responsibility to conserve, develop and optimally exploit the marine resources up to 200 nautical miles off our coastline. According to Food and Agriculture Organization (FAO), Deepsea fisheries are those that take place at great depths and many deepsea fisheries take place in waters beyond national jurisdiction (such as the Exclusive Economic Zone [EEZ]), that is in the high seas. In recent years, the deep-sea fishery resources have become the iconic last frontier for the expansion and in forefront of marine fisheries. In general, marine living resources caught in the high seas always pose scientific and technical challenges. Worldwide a number of governmental and non-governmental organizations with mandates relating to conservation of the environment, biodiversity and management of fisheries have expressed concerns about the likely, known or feared consequences of deep-sea fishing in terms of its effects and impacts on target stocks, associated species and habitats. Fisheries play a pivotal role in the economic development of all maritime nations. The fisheries sector contributes as foreign exchange earner, ensures nutritional security and generates employment opportunities. Among the total world fish production India contributes more than 4 per cent. Even though the country unable to reach the annual per capita fish consumption of 11 kg /yr, the present per capita consumption is around 9 kg, it shows the need for an immediate additional nutritional requirement of the country. Indian marine fish harvest mostly centers around coastal waters up to 100 meters depth and about 90 per cent of the catch comes from up to 50 m. A recent revalidation of marine fisheries potential has shown that the fishing pressure on the stock in near shore waters has gone up considerably and signs of over exploitation of species is becoming increasingly evident and further increase in effort in the coastal sector would be detrimental to sustainable yield. The impact of undeterred mechanized trawling and purse seining has also caused resource depletion. Sustainable resources exploitation from this sector is still possible through regulatory management strategies and concerted policy efforts for different species and for different regions.Deep sea fishery over the years has undergone several changes like modernisation of fishing practices along with diversification, intensification and extension of fishing to new grounds and landing from incidental by catch to targeted commercial fishery. In India the coastal fishery sector is now facing challenges like the sustainability, resources conservation and management; therefore, there is an urgent need for looking forward the unexploited or least exploited resources so as to meet demand towards the nutritional security of the country as a whole.

The species composition of oceanic resources include Yellowfin tuna, Skipjack tuna, Bigeye

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tuna, Billfishes, Sharks, Barracuda, Dolphin fish, Wahoo, etc. From the species composition it is clear that the primary objective of exploring oceanic fishery should be to exploit quality Yellowfin tuna resources and complement this with skipjack tuna and other resources such as Bigeye tuna and Billfishes. India is still a small player in global tuna fisheries. Except the Lakshadweep group of Islands, there is hardly any organized tuna fishery in India. Synonymous with tuna fishing, the Lakshadweep Islands abound in skipjack followed by yellow fin. Fish aggregating devices such as 'payao' were introduced in Lakshadweep for increasing tuna catch and have performed well. Similarly, the Lakshadweep Administration is introducing larger fishing vessels for increasing tuna catches from its waters. Baitfish fishing also forms an important component of the pole and line tuna fishing of Lakshadweep and could become a constraint in future if not managed sustainably. In the Bay of Bengal, the Andaman and Nicobar Islands offer some of the best tuna fishing grounds in the Indian EEZ. However, due to lack of capacity and weak forward and backward linkages prevailing in the Islands, tuna resources from the Andaman and Nicobar waters have largely remained unexploited. Since the oceanic tunas are migratory in nature, the tunas that could have been caught by the Indian fleet in the Andaman and Nicobar waters mostly get harvested in the EEZs of the neighbouring countries or in the high seas by the fleet of the distant water fishing nations. Simultaneously, the small-scale fishing sector, especially off the coast of Visakhapatnam and in some coastal districts of southern Tamil Nadu has also ventured into tuna fishing. These initiatives include the targeting of Skipjack and Yellow fin tunas (particularly in Vishakapatnam) using troll line, hand line, gill nets and hook and line. In southern Tamil Nadu (Nagapattinam area), large floating devices are being developed to aggregate tuna and tuna-like species.

Fishing in the marine waters beyond national jurisdiction (the "high seas" covering 64% of the ocean's surface) is dominated by a small number of fishing countries, which reap most of the benefits of fishing this internationally shared area. The rationality of widespread high-seas fishing has been questioned because of its environmental impacts and uncertain economic profitability. Deep-sea bottom trawling can damage fragile habitats containing unique biodiversity including millenary deep-sea corals. Highly migratory species such as tuna and sharks that move between the high seas and countries' jurisdictional waters [exclusive economic zones (EEZs)] tend to be intensely fished and overexploited. Although the International Seafood Sustainability Foundation indicates that 57% of managed tuna stocks are considered to be at a healthy level of abundance, 13% are overfished, and even those that are not overfished show slight declines in biomass over time and may benefit from increases in biomass. Oceanic sharks, of which 44% are threatened, spend a great deal of time in the high seas, where shark fishing is largely unregulated and unmonitored. Here, we characterize the global high-seas fleet in detail and estimate the net economic benefit of high-seas fishing using (i) reconstructed estimates of the global fishing catch and its landed value, (ii) the costs of fishing based on satellite-inferred fishing effort and vessel characteristics, and (iii) estimates of government subsidies per country. We report high-seas fishing profits by fishing gear type, flag state, and Food and Agriculture Organization of the United Nations (FAO) region, with the goal of understanding whether fishing the high seas is economically rational. There are many fishing techniques to exploit deep sea resources of which Gill netting is a age old practice.

Gill Netting

Gillnetting, an age-old fishing practice in the world has shown a spectacular increase in operation in recent years. In recent times the following observations are made on the world gill net fishing:

- The drift: gill net fleet of the world act as curtains of death, land huge quantities of non-targeted species, prevent the salmon from reaching their native spawning sites, and also entangle, mutilate and drown thousands of marine mammals.

- Gill net fishing as a major threat to sea-life without curtailment of drift gill net fishing humanity will have little scope to protect its seas for future generations.

- Serious concern that over-exploitation of living marine resources in the high seas adjacent to the EEZ of coastal states is likely to have adverse impact and called for progressive reduction as well as ceasing further expansion of large-scale pelagic drift net fishing.

Drift netting consists of fishing nets set vertically in the water with buoyant floats along the top of the net, and a weighted lead line along the bottom. Fish and any other marine animals in the net zone are caught while swimming along, and fishermen later recover the drifting net. Oceanic drift gillnetting as a commercial enterprise is not in vogue in the Indian EEZ, but in the traditional sector a variety of large mesh drift gillnets are being operated by mechanise and non-mechanised crafts, aiming mainly to catch larger pelagics in the offshore waters up to 50-100 m. These gears have become more popular in view of easy maintenance and economy in operation and the number of these units has been increasing in recent years. According to WWF, the incidental catch of unwanted animals known as bycatch translates into one death every two minutes for small whales, dolphins and porpoises. The use of drift nets is one of the major sources of by-catch. This by-catch threatens 26 species of seabirds. Is also responsible for declining half of global shark catch and harms hundreds of thousands of sea turtles. In an attempt to control the negative impacts of drift nets, the United Nations in 1992 banned the use of drift nets longer than 2.5 kilometers. Drift nets became a popular commercial fishing method due to cost effectiveness, large amounts of fish are caught at once, maximizing the time and efforts of fishermen. The bigger the net, the bigger the catch. During the past two decades, drift nets and gill nets more generally have undergone a revival in their use, especially in traditional and modern small-scale fisheries. Such nets are relatively cheap and easy to use, principally because relatively low-powered vessels can be used to deploy them which make them fuel-efficient. International regulations are outdated, and the damage is still going on in high seas.

High-seas governance

Reducing bycatch would depend on enforcing international rules, like the ban on extra-long drift nets. Indeed, according to the Global Ocean Commission, "the existing high seas governance framework is weak, fragmented and poorly implemented.

Deep sea trawling

Deep-sea fish species are targeted globally by bottom trawling. The species captured are often characterized by longevity, low fecundity and slow growth making them vulnerable to overfishing. In addition, bottom trawling is known to remove vast amounts of non-target species, including habitat forming deep-sea corals and sponges. Therefore, bottom trawling poses a serious risk to deep-sea ecosystems, but the true extent of deep-sea fishery catches through history remains unknown. The landings from deep-sea fisheries are miniscule, contributing less than 0.5% to global fisheries landings. The fisheries were found to be overall under-reported by as much as 42%, leading to the removal of an estimated 25 million tons of deep-sea fish. The extension of bottom trawling to the deep-sea occurred in the second half of the twentieth century, prompted by technological advances and a decline in shallow water fisheries. The fisheries industry, particularly in Europe, North America, and the former Soviet Union, pushed into ever deeper water in search of more fish. In many cases, these fisheries were promulgated on the high seas where there were few. Many of those fisheries, especially those targeting seamounts have been shown to be "boom and bust" fisheries, and lasting from less than a decade to a couple of decades before they are no longer economically viable. The deep sea is an ecosystem different from that of shallower water. Here organisms, including fish, generally live for long times, have low fecundity, mature at older ages, and have lowered metabolism and slow growth. In addition, deep-sea fish may be more vulnerable to the fishery by aggregating on seamounts for mating or taking advantage of trapping of vertically migrating nekton by seamount topography. It is likely that deep-sea fisheries could easily and rapidly, over-exploit fish species living on seamounts and ridges, or along the continental slopes of the world. Fishing in the deep is difficult, and requires large vessels with very heavy gear in order to reach species living at depths of as much as 2,000 m. Deep-sea fishing vessels are often of 80–100 m length, weighing in at 2,000 gross tons or more. In some distant water fisheries, the vessel may be much larger and house crew and capabilities for processing and freezing the catch while at sea. Deep trawl gear is usually in the form of an otter trawl which uses metal "doors" that can weigh up to 5,000 kg in order to get the net to the bottom and keep the net mouth open while being pulled across the seafloor. The trawl can be very wide, with total distance including the sweeps, bridles and ground gear amounting to 80–200 m. The ground gear of a deep-sea trawl is equipped with steel bobbins and/or stiff rubber discs that are designed to allow the net to move over rough bottom without getting "hung up" . This equipment guarantees that bottom trawling is the most efficient fishing method in the deep-sea, but also the most destructive as it permanently removes the benthic habitats, typically comprising long-lived habitat-forming species, such as deep-sea corals and sponges.

Pelagic or mid-water trawling

Fish that live in the upper water column of the ocean are targeted by pelagic/ mid-water trawls. The funnel-shaped trawl nets are hauled by either one or two boats (pair trawls). Pelagic boats generally fish for a single species (unlike the demersal trawls). On very large vessels, fish such as herring and mackerel are pumped onboard the vessel through a large pipe placed in the end of the net. Smaller vessels bring nets onboard. Once captured, the fish is either kept chilled on board or processed and deep-frozen at sea.

Environmental summary

- **Habitat damage** - pelagic trawls don't come into contact with the seabed so are not associated with damage to marine habitat.
- **Bycatch of vulnerable species** - pelagic trawls may unintentionally catch vulnerable species. An example is pair trawls that target seabass in the English Channel. This fishery has been under scrutiny for catching dolphins as they trawl.
- **Discards** - pelagic trawling for a particular species can be associated with capture of non-target fish and other marine life and the accidental catch and discarding of juvenile commercial fish species can impact on these populations. However, bycatch levels are typically lower than in demersal trawls.

Trawl gear without any bottom contact during fishing is certainly not harmful to the bottom habitat. Trawling off-bottom is called pelagic trawling and is conducted in the water column anywhere from the surface to the vicinity of the bottom. Pelagic trawling is primarily used to exploit pelagic fish resources either in schools or in layers. However, some species are known to have seasonal and diurnal vertical migrations and are therefore available for both pelagic and bottom trawls. Catching such species with pelagic trawls when they are off-bottom is thus an option that will reduce the bottom impact significantly. There are several examples of pelagic trawling for species with both demersal and pelagic vertical distribution. In the North Atlantic a major pelagic trawl fishery has developed since 1975 for blue whiting. Prior to 1975 this resource was captured with bottom trawls in the North Sea. Until 1977 cod, haddock and saithe in the Barents Sea were captured with pelagic trawls as well as with bottom trawls. Poor size-selectivity and large catches of small-sized fish was the main reason for the introduction of a ban on pelagic trawling in the Barents Sea in 1977.Alaskan pollock was only captured with bottom trawls prior to 1990. Concerns about the bycatch of crabs and other ground fish species, such as Pacific halibut, initiated a switch to pelagic trawling for the pollock. In recent years, the size-selective properties of trawls have been improved with the introduction of new mesh configurations (square meshes, T-90 meshes and exit windows, etc.) and sorting grids. Pelagic trawl techniques have also become more efficient during the last two decades with the introduction of mega sized large mesh trawls and advanced instrumentation to monitor trawl performance.

Purse seining in high seas

A purse seine is a large wall of netting deployed around an entire area or school of fish. The seine has floats along the top line with a lead line threaded through rings along the bottom. Once a school of fish is located, a skiff encircles the school with the net. The lead line is then pulled in, "pursing" the net closed on the bottom, preventing fish from escaping by swimming downward. The catch is harvested by either hauling the net aboard or bringing it alongside the vessel.

- Purse seines can reach more than 6,500 ft (2,000 m) in length and 650 ft (200 m) in depth, varying in size according to the vessel, mesh size, and target species.
- Finding a school of fish is one of the most difficult steps of this fishing technique and include:
  - Natural cues such as a congregation of seabirds, ruffling of surface water and/or fast-moving groups of dolphins.
  - Helicopters scanning the water for natural cues from the air to direct boats toward schooling fish.
  - Using radar fish finders to help identify the exact location and size of a school.

Target Species

- Schooling pelagic fish of all sizes, from small sardines to large tunas.
- Squids

Risks to Sea Turtles

Purse seining is a non-selective fishing method that captures everything that it surrounds, including protected species. Sea turtles can be captured by a purse seine as it is set and then become entangled in the net mesh as it is hauled in. Entangled turtles may sustain injuries to their flippers and shells due to the force of the net as it is hauled. In a large catch, turtles' risk being crushed under the sheer weight of the tow. Captured turtles can be released alive if they are quickly retrieved and removed from the net.

Risks to Marine Mammals

Purse seines can easily encircle marine mammals along with target species as the net is set. Historically, dolphin pods were even used as a natural cue visually leading purse seiners toward areas of abundant schooling fish (called "setting on dolphins"). Once the netting has been set, encircled marine mammals cannot escape and can become entangled, injured, or stressed. Even with quick retrieval, marine mammals' sensitive bodies and internal organs cannot usually withstand the weight of the catch or the impact of being placed on the vessel.

Bycatch Reduction

Currently no regulations exist for minimizing bycatch of protected species in purse seine fisheries. Employing fisheries observers who scan the water prior to setting nets is the most effective way of minimizing incidental capture.

Squid jigging

Squids *are* most abundant cephalopods attracts hundreds of fishing vessels from around the world to international waters to take home catch. Squids is of high socio-economic importance to communities throughout the region, not just as a source of food security but for income as well. **Squid are migratory and always on the move.** Cephalopods play an important role in the ecology of the high seas act as a linkage between abundant mesopelagic fishes, crustaceans, sea birds and whales. Cephalopods are exclusively marine predators and voracious carnivores with very high metabolic and conversion rates. They feed on live prey throughout their life cycle. The commercially important cephalopods under the phylum Mollusca include nautilus, cuttlefish, octopus and squids. Squid jigging accounts for nearly 40 per cent of the world cephalopod catches followed by trawling, which contributes 25 per cent of the catch. Gillnets are also used for catching the squids, which accounts for nearly 10 per cent of the catch. Gears like shore seines, boat seines, hooks and lines and spearing are the popular methods to catch cephalopods. Cephalopods are considered as an important source of marine fishery resource and many of the species are exploited as bycatch by trawlers along the Indian coast and the fishery forms 4-5 per cent of the total marine fish landings. India government with the association of private trawlers conducted exploratory trawling for the cephalopod resources in the Indian EEZ since 1977-80s. Arabian Sea is considered as one of the richest fishing regions for *Sthenoteuthis oualaniensis*. The preliminary studies on the oceanic squids in the Arabian sea indicated that the area around Lakshadweep Islands is a major spawning grounds for oceanic squids (CMFRI, 2011). These species are known as the masters of the Arabian Seas due to its high abundance and large oceanic squids occupy and monopolise the trophic niche of apex predators in the Arabian Sea.

Fish aggregating devices (FADs) are traditionally used by the fishermen to attract and aggregate the fishes closer to the shore. Fishermen from Karnataka started FAD assisted cephalopod fishery in coastal waters of Karnataka. Coastal cephalopod resources in Indian are facing tremendous pressure due to fishing. The exploitation of untapped or under exploited oceanic squid resources from the Arabian Sea will reduce this fishing pressure taking into account the relative huge quantity of the unexploited resources. The total world catch of squids has increased steadily over several decades but there is now evidence in the FAO data that this has been followed by an apparent stabilization over the last ten years. Behind this recent overall stability, however, there has been considerable variation within species. Given the role of squids in marine ecosystems, there are good reasons to monitor the global catch in future and explore the reasons for its behaviour over time. It becomes clear that production has levelled off it should highlight the need for careful management of individual stocks in future and also the need to make maximum use of the catch to avoid waste and maximize the economic benefits from an industry which is reaching the limits of growth. The assessment of squid stocks and management of the fisheries is inconsistent regionally and there would be advantages in moving toward standardizing the approach, especially in the major fisheries. Less attention has been given to the role of squids as predators. They are key prey for vertebrate predators and have substantial seasonal impact on their own prey populations so unsustainable levels of exploitation will have impact through-out much of the food web. The role of squids in ecosystem change includes their response to change caused by overexploitation of ground fish stocks as well as their response to changes in other predator populations and to environmental variability on various timescales, including long-term climate change. An important scientific challenge for the future will be to discriminate between these interactions in order for fishery managers to respond appropriately to changes in squid stocks. It is advisable to use information on large-scale oceanographic processes in the management of the renewable resources including squids of these systems.

Fishing Methods

Cephalopods in general and squids in particular possess ecological and behavioral features that are quite similar to those of fishes. Many nektonic squids migrate in dense schools similar to those of pelagic fishes and fishing methods are common to both groups.

Trawls

Various types of fishing gear based on nets have been used for catching squids since the early days of exploitation. These include the various trap nets, set nets, and purse seines that have mainly been used in artisanal fisheries. The advent of motorized vessels in the early 20th century created opportunities for targeting large schools of pelagic and near bottom squids as well as fish. Trawlers use various types of the trawling gear (pelagic, semi-pelagic, and bottom) which are deployed during daytime to exploit the natural behavior of squids over the continental shelf as they aggregate near the seabed during daylight. The trawling gear used is essentially the same as that used for finfish. Pelagic trawls are used to catch squids near the bottom. Bottom trawls are used mainly to catch near-bottom aggregations of loliginid squids. The commercial otter trawl has two hydrovanes, known as otter boards or doors, one on each side of the net to spread the trawl horizontally. Special cables called bridles and sweeps connect the doors to the trawl wings. The movement of the cables through the water creates disturbance that is sensed by the fish lateral line, herding the fish close to the midline of the net. Unlike fish, squid use mainly vision for their orientation in the water column, and disturbance of water by the door cables has a lesser effect on their behavior in front of the trawl. In order to concentrate squid schools from a wide area into the wings of the trawl, polyvalent oval shaped doors are used. These scrape the seabed, creating clouds of silt that the squids attempt to avoid and so concentrate close to the midline of the net. This method has a negative impact on the sea floor as the trawl doors effectively plough the seabed and damage benthic communities. Trawlers use acoustic target-finding technology to locate aggregations of squids. However, squids provide weak acoustic targets because they lack a swim bladder so the technology has limited use where squid targets are mixed with fish possessing swim bladders. As trawls catch most individuals that are larger than the mesh size of the net, the total catch is very often mixed with the target species. The texture of squid skin is more delicate than that of fish, which is usually covered with scales, so in a mixed catch it becomes damaged and is sometimes completely removed from the body as a result of contact with knots in the mesh of the net and with other elements of the catch. In general, then, squid from trawlers is of inferior quality compared with the catch using methods such as jigging or trapping.

Jigging

Jigging for squid is less damaging to the marine environment and produces a more valuable product. This technology exploits the natural behavior of the squid which moves up in the water column toward the surface at night where they can then be attracted using lights toward the fishing vessel and the jigs. Many large-scale fisheries for both ommastrephid and loliginid squids employ jigging with lights. This method results in a higher value product where the squid can be sold whole because the process causes little or no damage to the skin. Although squid jigging vessels remain stationary in the water there is little or no saving on energy costs because the fuel used to generate the electricity to power the fishing lights is broadly equivalent to that consumed by trawling.

Modern squid jigging vessels have three elements:

- A large parachute drogue deployed as a sea anchor to hold the vessel still in the water.
- An array of incandescent lights to attract the squid at night when the squid naturally migrate upward to feed.
- Jigging machines which lower and raise the weighted lines to which are attached a series of colored or luminescent jigs—each of which is armed with an array of barbless hooks.

Driftnets

The Japanese squid driftnet fishery for neon flying squid, *O. bartramii*, was developed in the northwestern Pacific. From 1974 to 1978, the driftnet fishery operated off the Pacific coast of Japan but it conflicted with the jig fishery. The Japanese squid drift netters were converted from, or were also engaged in, other fisheries such as salmon driftnet fisheries, tuna fisheries, the Pacific saury fishery, squid jigging fisheries, distant water trawl fisheries, the North pacific longline, and gillnet fishery.

Deep Sea Long Lining

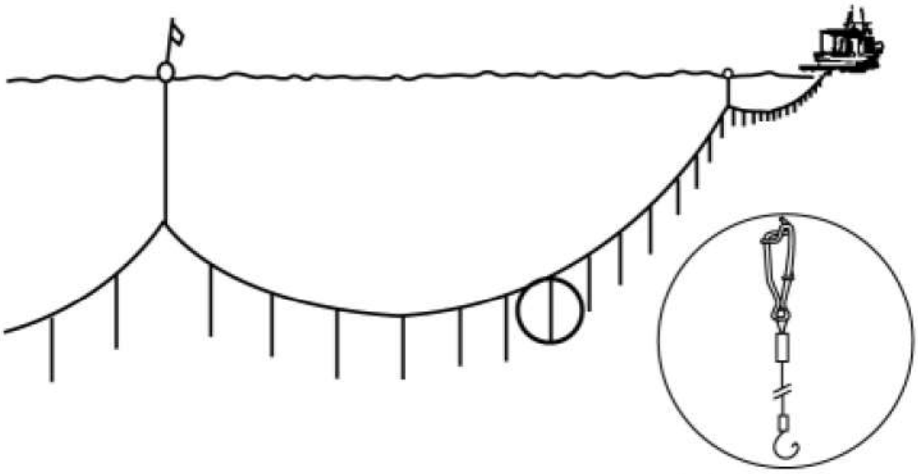
The name of "longline" comes from the length of the lines that are used. In broad terms, a longline consists of a mainline where many branch lines are attached. Each branch line has a baited hook at its end. Longlines are proven to be a good fishing method for catching large, high quality and high value fish. Therefore, it has become a popular method from 1980s. Longline gear is used all over the world, from small-scale fishing to modern mechanised longline operations. The longline is a very simple fishing gear, but there are many variations in gear construction, fishing method and fishing strategy. The high fuel consumption of large-scale fishing has made the fishermen adopt low energy fishing methods. Trawl fishing is very costly in terms of fuel and not environmentally friendly. Longline fishing, on the other hand, does not require much fuel and is environmentally friendly. In order to protect fish resources, trawl and purse seine fishing are not permitted in inshore seas, only in offshore and in open seas, and small-scale fishing is widely practiced in inshore seas. Most of the developing nations are trying to find solutions to increase the catch amount without using trawl and purse seine fishing in inshore waters. One solution is developing longline fishing because it secures sustainable catching with less fuel consumption in inshore areas and protects fish resources. The proportion of crafts engaged in long lining is increasing every year. In the past fishermen mostly used the hand line but nowadays longline fishing is increasing. The vessels used for longline are medium-sized with 120-400 HP engines and small vessels with 14-28 HP engines. The structure of the vessels has been altered for doing small-scale fishing like longline. There are some difficulties in doing longline fishing because it has not been practiced widely in the past. Squid and herring are mostly used for bait to catch demersal and semi pelagic fish. The bait size used in bottom set longline is based on fishermen's experience. Baiting is done by hand and hauling is mostly done by powered haulers. Longline fishing in Indian waters is in its initial stages and problems remain to be solved. The technical information on longline has not yet been widely introduced to the relevant people. Scientific fishing methods are not widely used and the mechanisation of longline is in its infancy. Fishermen use different sizes of bait according to their experience. This may be one of the reasons for the decreasing catch rate. A good understanding on how to study different bait sizes is therefore very important. In longline fishing, several factors such as the hook, bait, branch line and mainline affect catch ability and selectivity.

Classification of Longlines

Based on the structure and fishing method, longlines are classified into four categories: drift longline, bottom set longline, vertical longline and bottom vertical longline (Hameed and Boopendranath 2000). In some cases, longline is grouped into two categories: surface longline and bottom longline, but this categorisation is based on the same principles as the first.

What is long lining?

longline fishing uses a long mainline made of mostly nylon monofilament to which are attached hundreds or thousands of branchlines, each with a single baited hook. The mainline can be from 5 to 100 nm long. The line is suspended in the water by floatlines attached to floats, which may have flagpoles, lights, or radio beacons. Longlines are usually set and hauled once daily and are allowed to drift freely, or soak, for several hours while fishing. Longlines are set, either by hand or mechanically, while the boat steams away from the line and are usually hauled mechanically while the boat steams toward the line. The species targeted are tunas and some billfish.



Structure of Longline

Target Species

The main target species of oceanic longline fishing are tunas and billfish, while other species including sharks can also is an important component of the catch. The catches of long line can be divided into three distinct categories: target, byproduct and by-catch. Tunas are by far the most important target species for longlining. The highest value species are bluefin tuna, followed by bigeye tuna, yellowfin tuna, and albacore tuna, in that order. Some billfish are also targeted, with broadbill swordfish being the most important, followed by striped marlin.

Bigeye tuna:

Bigeye tuna are the most valuable species caught in the longlines and are found throughout the tropical and temperate waters in Pacific, Atlantic and Indian oceans. Fishermen targeting bigeye tuna set their lines deep because bigeye are often associated with the thermocline , which is found between 100 and 350 m, depending on the area and time of year. Bigeye tuna can be caught all year round in equatorial waters but are more seasonal in higher latitudes. The best bigeye catches are usually in the winter months. The most marketable bigeye tuna are those weighing 40 kg or more. Bigeye tuna are usually marketed as fresh chilled fish for sashimi.

Yellowfin tuna:

Yellowfin tuna are also found throughout the tropical and temperate waters of Pacific, Atlantic and Indian oceans, but the stocks change as per the oceans. Although they can be caught in deeper water, longline caught yellowfin are usually taken in water from near the surface down to 250 m above the thermocline. This layer of water is called the mixed and intermediate layer. The preferred temperature range for yellowfin tuna is 18° to 28°C, which roughly corresponds to temperatures found in the mixed and intermediate layer. The best season for yellowfin tuna is in the spring and summer months. The most marketable yellowfin tuna are those that weigh

30 kg or more. Yellowfin are usually sold as fresh chilled fish for sashimi or to be used in cooking. Yellowfin is second to bigeye as a sashimi fish in quality and value.

Albacore tuna:

Albacare tuna are also found throughout the tropical and temperate waters of Pacific, Atlantic and Indian oceans. These fish are schooling fish and are caught seasonally, in the summer and autumn months, at the surface by troll boats, and are smaller than longline caught albacore. Larger fish are caught by longline in deep tropical and subtropical waters down to the depth of the thermocline. Depth and temperature ranges for longline caught albacore are similar to those for bigeye tuna. The season for longline albacore is not as apparent as for other tunas — autumn months in some locations, all year round with peaks in summer and in autumn and winter in other locations, and autumn and winter months in other areas. Longline caught albacore range from 15 to 20 kg and are sold frozen whole to canneries, fresh to export markets, or as frozen quarter-loins.

Striped marlin:

Striped marlins are found throughout the tropical and temperate of Pacific, Atlantic and Indian Oceans. They are usually found in the upper mixed layer or near the surface. In fact, longline caught striped marlin are most often caught on the branchlines nearest the floats, the shallowest branchlines. They are not usually the main target species of longliners, but are caught in association with yellowfin tuna sets. The preferred surface temperature range for striped marlin is 20° to 23°C, although they can also be found in temperatures ranging from 15°to 26°C. The usual size range of striped marlin is 60 to 120 kg, although specimens up to 190 kg have been caught.

Byproducts and By-catch of longlining:

Byproduct and by are species that are caught incidentally (not targeted) during longline fishing, that have a commercial value and are retained for sale. These species include opah, black marlin, Indo-Pacific blue marlin, shortbill spearfish, sailfish, skipjack tuna, mahi mahi, wahoo, pomfret, escolar and barracuda, amongst others. A range of shark species are also taken as byproduct, although they are mainly prized for their fins (finning is probably going to be phased out as more and more countries are adopting a policy where the entire shark must be retained). Black marlin, Indo-Pacific blue marlin, sailfish, skipjack tuna, mahi mahi and wahoo are distributed throughout the subtropical and tropical Pacific Ocean and are caught near the surface on the shallowest hooks in a set, near the floats. Conditions for catching these species are similar to conditions for catching yellowfin. Byproduct species such as pomfret, escolar and opah are usually found in deeper waters and are associated with bigeye catches. The most common species of shark taken by longlining include the blue shark, oceanic white tip shark, short-finned mako shark, silky shark, thresher shark and tiger shark. These are all pelagic or oceanic sharks. Sharks are mainly caught on the shallower set hooks during normal tuna longlining activity.

By-catch:

Bycatch are the unwanted species that are taken incidentally during longlining, and are discarded as they have no commercial value. These species include snake mackerel, lancetfish, pelagic rays, seabirds and sea turtles, amongst others. Snake mackerel, lancetfish and pelagic rays can be taken at various depths on a longline, and are not really associated with a particular type of longline set. The fish are generally small in size. Seabirds, such as albatross, and sea turtles are sometimes caught on longlines. The seabirds attack the baits on the gear as it is being set, while the sea turtles are taken on the shallow hooks, generally near the floatline. The catch of seabirds and sea turtles by longliners has become an environmental issue as the animals are protected. This is an area of concern to all longline fishermen. Another form of bycatch are fish, both target and byproduct species, that have been damaged by sharks or toothed whales. In some cases, shark damaged fish may be retained for crew consumption or sale if the damage is limited. However, when toothed whales take fish, they only leave the heads, and these are discarded.

Bait used in longline fishing

Bait used for longline fishing is usually frozen whole finfish such as sardines, saury, or mackerel and scads. Frozen whole squid is often used for tuna longlining but is more important as bait for swordfish. Live milkfish is also used for tuna longlining. The average bait weighs about 80 to 100 g. If the bait is much bigger than 120 g it is likely that some target fish will be missed. The principle of line fishing is to lure fish to bite the bait. Therefore, bait is one of the most important factors in line fishing. The catch rate depends to a large extent on bait type, quality and size (Bach *et al*. 2000). Fishermen use different types of bait from their experience accumulated over the years. The type of bait is chosen with regard to the target species. Bait quality is one of the important factors, which affect the catch rate. Bait must also be suitable to the target species. What attracts the fish is the odour from the bait. As the odour gets stronger, the more it attracts fish. The quality of bait is also measured by how well it remains on the hook. In addition to the attractiveness of the smell and taste stimuli, the efficiency of bait is determined by its physical strength and ability to remain on the hook throughout the soaking time. The bait loss is more important for hooks on the bottom. Bait size is also an important factor affecting the fish size and catch rate. As bait in mid-water is more easily seen than bait on the seabed, the effects of bait size are more pronounced for pelagic or semi pelagic longline than for bottom longline. The bait size also affects the size of the fish caught, as small fish prefer small size prey because of their mouth size and ability to bite and handle the prey.

Bottom set longline

Bottom set longlines operate close to the sea bottom for demersal species such as shark, sea beams, sea bass, goupers, snapper, cod, haddock, halibut, hake and flat fish. As the bottom longlines are set near the sea bottom, they are easily damaged by obstacles on the bottom. When using bottom longlines, the ground must be fairly regular since rocks or corals may entangle the lines and break them. Where muddy bottoms are found, the longlines are not set to remain on the bottom and are held off the seabed by floats. They can be set so that the bait is suspended at any desired distance from the bottom. In bottom longline fishing, the main concern is the selection of optimum branch lines because of the character of the fishing operation. The bottom set longlines which have the branch lines set at wider spacing catch fish better than those with the branch lines set more closely together, and they also need less bait for the same area. The length of the branch line must be selected correctly. The branch line cannot be too short because short branch lines are less effective than long branchlines. The length of the branch line is related to the hooking space and the free space of the vessel used in longline fishing. The branch lines are knotted to the mainline. They can also be connected to the mainline by using removal clips or swivels. Using swivels has many advantages in handling. The branch lines can be easily changed and stored separately and also the distance between branch lines on the mainline can be adjusted whenever it is needed. It also has the advantage in eliminating entanglements of the branch lines, thus reducing the labour of gear handling. Branch lines are mostly made of monofilament and multifilament. In some longline fisheries, particularly for catching different sharks, branch lines made of steel wire or chain are used because fibre branch lines are easily cut by the sharp teeth. Bottom longline fishing is mostly carried out at depths from 100 to 800 m. The longline fleets are set on the bottom with anchors, buoy lines, buoys and/or marker buoys at either end. The anchor is made of stone, steel, lead or chain with a weight from 5-10 kg up to 80 kg. The purpose of buoys is to keep the gear in a certain position with anchor. It is made of synthetic fibre with different buoyancies. The buoy line is a rope somewhat stronger than the mainline, because it must have the high strain that is often needed to pull the anchor. In the middle, buoys with buoy lines and anchors are also used in order to save time and prevent the risk of losing gear if the mainline breaks during hauling. In case the line breaks, instead of moving to the end buoy, which might be far away, the middle buoy which is close to the vessel is picked up and the hauling is done continuously after short time. The purpose of the marker buoy is to mark the ends of the longline fleet so that fishermen can easily find the longline from a distance. It consists of a pole (3-4 m long) and a weight at the bottom end to keep it floating in an upright position. Marker buoys usually carry one or two flags at the top end in order to make it more visible and a battery-light package or radar- light reflector in the marker buoy is used to identify the gear easily in darkness. In addition to the marker buoy, there are normally one or more surface floats, the main function of which is to keep the strain off the buoy line. The amount of lines depends on the capacity of the vessel, topography of the bottom, and the distribution and density of fish. Fishing is done by setting in stern, soaking, and hauling in starboard and handling gear. Before setting, baiting is done by auto baiting machines on boat or manually on land. Soaking times are different depending on the fishing operation, normally two to three hours. Hauling is done by powered machines in the starboard. Different methods are used for storing longlines. In auto longline fishing, hooks with the mainline and branch line hang on racks. Basket, tubes and wooden or plastics boxes are used for keeping hooks with branch lines.

Drift longline and Pelagic longline:

Drift longline is operated close to the surface in middle water layers for pelagic fishes such as tuna, marlin, billfish, mackerel and shark. The fishing method is similar to the bottom set longline. The setting work is done from the stern. The speed of the vessel in setting differs according to the fishing conditions, but is normally around 5-6 knots. At first, marker buoys with flags, radio buoys and light buoys are thrown in and the mainline is released. The marker buoy, light buoys and radio buoys are connected at proper intervals. In case of auto line, hooks are baited when the mainline is released. After setting, the vessel stays for six hours near the line. In hauling, the line is hauled by a powered hauler and when the branch line comes onboard the fish is removed. For traditional drift longlines, the mainline carrying the branch lines is coiled and kept in a basket. In modern large-scale drift longline, mainline is continuously pulled and kept on a powered reel or rack with branch lines. There are some cases that on hauling branch lines are removed from the mainline and kept separately. But nowadays lines with branch lines are usually kept on racks after hauling. To locate the potential fishing ground and to position the line in deep seas, it is important to know the correlation between fish distribution and sea surface temperature or the thermocline. Distribution of fish is determined by temperature and feed organisms. Thermocline is the temperature continuity layer where temperature changes rapidly with depth, between mixed surface waters and cooler deeper waters. Fish like tuna are generally found in the thermocline layer. The swimming layer of the yellow fin tuna and albacore is in the mixed layer and thermocline. Big eye tuna occupies lower layers of the thermocline and the cooler waters below. Information on the swimming layer of target fishes and their association with the thermocline is used by fishermen for fishing the target species. Sea surface temperature and ocean colour charts are used to locate potential fishing grounds based on the temperature preference regimes of target species and the aggregation of feed organisms in the thermal front. The most common drift longline in fisheries is the tuna longline. The tuna longline was introduced by Japanese fishermen about 300 years ago and they have been a leading nation in terms of longline fisheries along with China and Taiwan. The tuna longline, like most of other longlines consists of many sets. Each set ranges from 150-400 m in length. Typical branch lines for tuna longline consist of three sections and each branch line is attached with a special snap-on metal clip to the mainline. Each set is stored in a basket. Japanese fishing boats, ranging from 200 to 800 gross tonnages in size, usually carry 350- 400 baskets of longline. The tuna longline is not only an effective fishing method but also a very labour intensive one. Mechanisation and automation for both bottom and drift longline are successfully under way. While setting, the hooks are baited by drawing them through an automatic machine. Mechanical hydraulic line haulers are now widely used in drift longline fishing. This system includes de-hooking of fish, twist removal of branch lines, hook cleaning and handling lines. This has decreased the manpower required dramatically.

Vertical longline

Vertical longline is used to catch fish with a wide vertical distribution. Vertical longline is effective on steep shelves. Vertical longline is used in deep waters up to 1,200 m and in shallow areas having rough bottom conditions or in areas where fish aggregating devices are deployed. Gear construction has a little difference to drift longline. It consists of a single line with a float at one end and a weight at the other. The mainline extending across the vertical range of the swimming layer of the target species is attached to the buoy line with a swivel. Branch lines are attached to the mainline through three way swivels or snap clips, at intervals of around 2 m. The mainline is set vertically with the upper end joined to a large float and flagpoles, and the lower end is provided with a sinker. Branch lines are attached at approximate intervals to the mainline. The fishing operation is similar to drift longline. When the vessel arrives at the fishing ground, the anchor, marker buoy and radio buoy with the connected end mainline are thrown overboard. The line is set over the stern when the vessel moves ahead. The hooks are baited before setting the line. After soaking for a period, the lines are hauled up using a line hauler. The soaking time depends on fish distribution and density. Fishes are removed when the branch lines come up, mainlines and branch lines are arranged and stored, and accessories are removed and stored. Bottom vertical longline combines the properties of the bottom set longline and vertical longline, using their advantages. Many hooks are attached at suitable intervals less than 2 m by polyamide monofilament lines less than a meter in length to the branch lines. Branch lines are designed to be directed vertically during operation by adding floats at the top and sinkers at the bottom end. Branch lines are hung from the mainline by means of snap clips at interval of 20-25 m. The mainline is positioned at an appropriate height from the bottom by adjusting the buoyancy. When the mainline does not touch the ground the gear is particularly suitable for rough grounds.

Pelagic longline

Pelagic longline is normally not anchored but drifts freely in the sea. Pelagic longlines are mainly used in high seas longline fisheries for pelagic species such as sword fish, tuna, shark and salmon, but are also in coastal waters for species such as haddock during periods when the fish are feeding on pelagic prey. The fishing operation is similar to drift longline. Between the ends (marker) buoys, the mainline is suspended in the sea by floats attached at intervals. Sometimes the branch lines are weighted, but this method usually relies on the mainline sinking under its own weight to get to the required depth.

What are the problems in longline fishing?

Declining sea turtle stocks:

Sea turtle populations are declining worldwide due to human activities including: destruction or disturbance of nesting beaches; hunting for food and sale; and incidental catches related to some fishing activities such as trawling, gillnetting, purse seining and tuna longlining.

Perceived overfishing:

There is worldwide concern about the catch and use of pelagic sharks and, to a lesser extent, marlins and other pelagic fish species by longline vessels. Some concerns are related to a belief that these species are being overfished.

Seabird interactions:

The incidental take of seabirds by longline vessels (both pelagic and demersal or bottom-set) has been widely publicised, although this mainly occurs with albatross in higher latitudes.

What can be done to make longline fishing sustainable?

- Minimizing the incidental catch of unwanted bycatch species. Keeping good data in logbooks on all fishing activities, including the recording of byproduct and bycatch taken or interactions with protected species.
- Setting pelagic longline gear deeper than 100 m will reduce the incidental catch of many bycatch species (especially sea turtles).
- Setting deep, using a line setter, puts the bait in the zone where catches of albacore and bigeye (target species) will be maximised.
- Not using squid for bait on shallow-set hooks (those closest to the float and floatline) will lessen the chance of hooking sea turtles, as this is a favourite food of theirs.
- Not using a branchline under the float to target sharks.
- Setting pelagic longlines at least 12 nm from a reef or island, and ensuring they drift offshore, will minimise interactions with reef sharks (not pelagic sharks) and some turtle species, as they do not venture far from the reef.
- Using monofilament leaders (not wire) directly onto the hook will allow sharks to bite off the hook and escape.
- The bycatch of sea turtles by pelagic longlining is an issue of great concern. If a turtle is caught, steps should be taken to give it the best possible chance of survival.

Avoiding seabirds and bait loss

The issue of tuna longline gear interacting with seabirds, causing incidental takes, is an issue in some regions in longline fishing. There is a problem though at times with bait loss through seabirds attacking baited hooks as they are set. In areas where seabird interactions have occurred, mitigation measures have been developed and introduced. These measures also work to reduce bait loss, by making it difficult for the seabirds to get to the baited hooks, or getting the baited hooks to sink faster. Setting tuna longline gear at night is by far the simplest and easiest way to avoid bait loss to seabirds, as most seabirds are day feeders. However, in some fisheries the setting time is dictated by the main feeding time of the target species and night setting of the gear may result in lower catch rates.

Depredation by toothed whales

'Depredation' is the term used when unwanted species such as cetaceans or sharks consume hooked fish, while predation refers to one species preying on another. Toothed whales sometimes attack and eat tuna and swordfish that are caught on longlines. When a pod of these whales finds a longline with fish, they follow the line eating everything except the head of the hooked fish. Some dolphin species have been associated with the loss of bait from longline gear. Some whales have interacted with the longline gear itself and become caught, putting the whale at risk and damaging the gear. Given there are no foolproof mitigation measures available at present, the following measures can avoid or minimise the chance of interactions or depredation.

- Reducing vessel noise, possibly through vessel design.
- Managing gear noise through its operation (turn off echo sounders when not in use, reduce noise of deck machinery, propeller noise etc.).
- Considering changes to gear and setting and hauling practices.
- Considering changing fishing areas and fishing seasons.
- Avoiding areas where cetaceans are known to congregate.
- If cetaceans are sighted during the set, discontinue the set, haul the line, and move to another location.
- Use acoustic equipment to try to locate and subsequently avoid cetaceans.
- Avoiding discarding of offal and used bait in the vicinity of fishing locations.

Concluding remarks

Longlining is one of the main fishing methods that holds potential for economic development in many countries and territories. The method targets the larger, deeper swimming tunas and other oceanic resources that command high prices in export markets if they are handled carefully and quality is maintained throughout the catching, processing and exporting processes. The costs for local operators to set up a longlining operation are high, but the potential returns are also great. While promoting longline fishing focus should be on sustainable and responsible fishing practices. longlining has 1.5 times more advantages than trawl and fewer drawbacks. However, it should be noted that longline fishing has the clear drawback of needing to use additional biological resources, ie. squid, fish, shellfish, etc, as bait for its hooks. This negative characteristic of longline fishing, however, is compensated for by the much more sparing fishing qualities it has in comparison with other fishing methods. Despite the few drawbacks of longline fishing, its advantages over other fishing methods are very clear. The large-scale development of the sustainable longline fishery is one of the means of optimizing the exploitation of tuna and other oceanic resources. At the same time, it is necessary to state that the development of the longline fishery must not only be aimed at increasing the size of the fleet, but also at increasing the working efficiency of existing vessels. Tunas and other oceanic resources can be caught very effectively using the longline, but remain inaccessible to the bottom trawl which is the most common fishing method. For promoting longline, it will be necessary to avoid shifting preference over to longlines entirely. It is should be borne in mind that some stocks of fish, bottom resources such as shrimps are difficult for the longline to access and their exploitation is only possible using trawl fishing gears. Therefore, it is essential to ensure that only the combined use of these fishing gears will allow for the optimal utilisation of the all the resources. There should be a rational distribution of fishing efforts according to fishing areas and seasons and the taking into account the various biological peculiarities of the fish being exploited

Although the environmental impacts of fishing on the high seas are well studied, the lack of transparency and data has precluded reliable estimates of the economic costs and benefits of high-seas fishing. Fisheries data suggest that fish catch in this vast area amounted to around 6% of global catch and 8% of the global fishing revenue in 2014 (see www.seaaroundus.org/data/#/global). However, the high level of secrecy around distant-water fishing has impeded the calculation of fishing effort and associated costs. Nevertheless, recent technological developments in machine learning and satellite data now allow us to obtain a far more accurate picture of fishing effort across the globe at the level of individual vessels (*9*). This capability provides a more transparent and novel method to examine high-seas fisheries and answer key questions such as whether fishing in the high seas is profitable and whether government subsidies enable current levels of fishing.