Environmental impacts of fishing and mitigation strategies

Leela Edwin and Yasmi V S

Fishing Technology Division, ICAR- CIFT, Cochin

Introduction

For centuries, humans have depended on the ocean for their existence by harvesting its abundance of fish. In recent decades, new technologies have allowed humans to remove fishes from the ocean on a massive scale to supply the earth's mushrooming population. The world fishing fleet consists of 4.56 million vessels, of which 2.86 million are motorized vessels and 1.7 milloin are non-motorized vessels (FAO, 2020). The marine fisheries resources of India are in terms of 8129 km long coastline, 0.5 million sq. km of the continental shelf, and 2.02 million sq. km of exclusive economic zone contributed by major fish species like oil sardine, mackerel, Bombay duck, pomfrets and shrimp. The marine fishing fleets of India have a total of 0.25 million fishing vessels consisting of 64,760 mechanized boats, 1,22,951 motorized boats and 65,219 non-motorized vessels were operating along the coastal area. The fisheries sector of India provides employment and foreign currency to millions of people. Around the same moment, it is an instrument of life for a wide section of socially backward people of the country (Ayyappan & Diwan, 2006).

There are many issues within the fisheries sector that requires urgent attention including excess capacity in fishing and need for standardization of fishing systems, operational impacts of fishing (bycatch and discards), increasing energy use in fishing, Issues related to synthetic webbing materials, alternate materials for fishing vessels, marine plastic pollution, minimal monitoring, subsidies, continued poverty within coastal communities and impacts of the globalized fisheries trade. The failure of development agencies to adjust their strategies to this new paradigm will have significant social consequences. These include the loss of economic opportunity and food resources for millions of people living in fishing communities, and the loss of national revenues.

Excess capacity in fishing

Fishing capacity is the ability of a stock of inputs (capital) used in fisheries to produce output, measured as either effort or catch, over a period of time (FAO, 1998; 1999a;2000; 2001). Excess fishing capacity has been identified as one of the most inimical problems affecting economic viability of fishing operations and long-term sustainability and biodiversity of fishery resources (Boopendranath, 2007). In Indian Exclusive Economic Zone (EEZ), the marine fishery potential is estimated at about 3.93x106 t. About 58 % of the resources is available at a depth of 0-50 m, 35 % at 50-200 m and 7 % from beyond 200 m depth. In India, the marine fishing fleets consists of non-mechanized (artisanal) sector using country craft and traditional gears, motorized sector using traditional craft with outboard motor(s) (OBMs) (9.9-120 hp) and, more recently, inboard engines (IBM) (89-156 hp); mechanized sector (8.5-16.7 m L_{OA}; 89-156 hp; and deep-sea fishing sector (>16.7m L_{OA}; 156 hp and above) (Boopendranath, 2007). The current existing number of fishing vessels in mechanized sector is 64760 and 122951 number of fishing vessels in motorized sector, which is more than 19048 number of mechanized fishing vessels and 14862 number of motorized fishing vessels of recommended fishing vessel capacity. The present fleet size of India is collected by CMFRI, 2010 for Indian shelf waters (excluding islands) were 35228 mechanized trawlers, 2201 mechanized purse seiners, 20257 mechanized gillnetters, 11794 mechanized bag netters (dol-netters) and 3079 other mechanised boats which are the excess capacity than the optimum fleet size estimated by Devaraj and Kurup (2000).

Unfortunately, there are many pessimistic environmental consequences to different fishing practices and overfishing has been identified as a primary cause of ecosystem collapse in many aquatic systems. Globally, fisheries are regularly overfished and overexploited as a result of weak governance, poor management, perverse subsidies, corruption, and unrestricted access. In addition, destructive fishing practices can rapidly degrade marine ecosystems and contribute to the loss of critical habitats and species. The declining state of fisheries resources will have disproportionately heavy consequences for developing countries. A recent World Bank study indicates that the fisheries sector is losing an estimated US$50 billion annually in lost revenues due to poor management and from illegal, unreported, and unregulated (IUU) fishing.

Operational impacts of fishing

Disturbance to the sea bottom

Trawl is a non-selective fishing gear creating plowing effect on the sea bottom leading to the destruction of benthic ecosystem. Trawl operated on flat sandy/muddy bottom, the sediments might be whirled up into the water masses and suspended. The major negative impact of bottom trawling is the capture and discarding of huge quantity of juveniles of fishes and other aquatic organisms like turtles. Bottom otter trawls interact physically with the bottom sediment, which might result in removal or damage of sedentary living organisms (including seaweed or coral) and in the case of uneven bottom surface displacement of stones or other larger objects (Remsan & Renjith, 2017). In bottom trawling, the trawl is pulled across the seafloor to catch bottom-dwelling fish, decreases the biomass and production of benthic species. The practice also destroys corals, oysters and sponges that form productive marine habitats (Hiddink et al., 2006).

Dredging is one of the habitat devastation practices commonly affecting the sea floor organisms when the large metal scoop drags along the seafloor to pick the clams. The process also churns up sediments along the seafloor, causing them to become suspended in the water column, decreasing water quality. The practice can also dig up burrowing worms from the sediments. These animals are important because their burrows increase contact between sediments and the water (Thrush & Dayton, 2002).

Bycatch and Discards

Trawl nets due to their low selectivity and high efficiency are often implicated with generation of large quantities of bycatch (Madhu, 2018). Globally, shrimp trawling contributes to the highest level of discard/catch ratios of any fisheries, ranging from about 3:1 to 15:1, and the amount of bycatch varies in relation to target species, seasons and areas (EJF, 2003). Midwater trawl fisheries targeting small pelagic are reported to have the least discards among the different trawling systems. Trawl fisheries for shrimp and demersal finfish account for over 50% of the total estimated global bycatch (Madhu & Jha, 2017).

ICAR- CIFT has developed bycatch reduction devices such as Juvenile Fish Excluder cum Shrimp Sorting Device (JFE-SSD), square mesh codends, Big eye BRD, Fish eye BRD, Sieve net BRD, Oval grid BRD and CIFT- TED are for the sustainability of fisheries. The JFE-SSD is an International Smart Gear Prize -2005 winning design (WWF, 2012), which brings down the bycatch of juveniles and small sized non-targeted species in commercial shrimp trawl and at the same time enables fishermen to harvest and retain large commercially valuable fin fishes and shrimp species (Boopendranath et al., 2012). Square mesh codends significantly reduces the bycatch often comprising of the juveniles of commercially important species. In trawl net, use of square mesh codend is benefited with good filtration and reduction in the drag of net.

Big eye BRD is a simple device constructed by making a horizontal slit in the upper part of the codend or hind belly, where the opening is maintained by means of float and sinker arrangement or binding with twine. It is constructed by making a slit on the top of the shrimp trawl codend by cutting a required number of meshes in the twine – wise direction to obtain an opening of about 0.3 m stretched length, across the codend, on the top panel positioned at about 1.5 m from the distal end of the codend. The slit is kept open by means of sinkers and 2-4 floats of sufficient extra – buoyancy. (Boopendranath et al., 2012). The bycatch exclusion from big eye BRDs was about 11.4 -37.3 % and shrimp loss were 2.3-4.1 %.

Fish eye BRD is an important bycatch reduction device facilitating the escapement of actively swimming finfishes which has entered the codend of trawl. It consists of an oval shaped rigid structure with supporting rigid frames made of stainless steel or aluminum rods. Fish eye BRD is 300 ×200 mm semicircular exit of horizontal orientation, fabricated using stainless steel rods of 6 mm dia. Bycatch exclusion rates of 46.6% - 62.7 % with a shrimp loss of 0.8-3.8% obtained from this BRD.

Sieve nets (also known as veil nets) are cone shaped nets inserted into standard trawls which direct the unwanted bycatch to an escape hole cut into the body of the trawl leading to a second codend. The large mesh funnel inside the net guides the fish to a second codend with large diamond mesh netting, while shrimp pass through large meshes and accumulate in the main codend. It is reducing the bycatch rates of 15-50% with shrimp loss of 5-15%.

Oval grid BRD is a rigid grid sorting device developed for separation of shrimp from non-shrimp resources and its catch exclusion rates of 57.8 -58.7 %, with a shrimp loss of 6.1-8.0 %. It consists of an oval grid of 1000×800 mm size, made of stainless-steel rods with grid bar spacing of 26 mm. The grid has one or two horizontal bars attached to provide additional strength to the grid, which also reduces the flexibility of bars thereby maintaining constant bar spacing.

Turtle Excluder Device (TED) is a specialized form of BRD designed for saving sea turtles caught incidentally during shrimp trawling. CIFT has developed an efficient indigenous TED design for commercial shrimp trawling which offers 100% protection to sea turtles with minimal catch loss. CIFT -TED consists of a 1000x800 mm oval frame and is constructed of 10 mm stainless steel rods. Five 8 mm stainless steel rod vertical grid bars are welded to the inside of the oval frame. The distance between the deflector bars is 142 mm and there is a maximum distance of 90 mm between the frame and the adjacent deflector bar. In the TED extension, the frame was fixed at an angle of 45° before the cod end of the trawl net. The device could be manufactured and installed at a cost of about Rs.4000 with minimum training using locally available workshops and net making skills (equivalent to about USD 90) (Boopendranath et al, 2010).

Purse seine is a large wall of netting deployed around an entire area or school of fish. Purse seining is one of the most advanced type of fishing for catching fish shoals. Most fuel is used for purse seining is going to and from fishing grounds and searching for the fishes. The catch effectiveness of purse seine depends on its length, depth, sinking speed, net type, hanging ratio, and the skill in operation. Among which the sinking speed is one of the most important components influencing the catch efficiency. In tuna purse seine fisheries, the purse seine caught tuna shoals at the sea surface, including bycatch species like flocks of birds, cetaceans and whales (Escalle et al., 2015). The purse seine fishery in the Indian ocean is responsible for 0.15% of the fishing mortality of sharks, 0.16% of whale sharks and 0.3% of marine turtles (Garcia & Herrera, 2018).

The CIFT developed and introduced a mini purse seine which came to be known as ring seine, for operation from traditional plank-built canoes (*Thangu vallom*) powered by outboard motors for efficient harvesting of pelagic shoaling fishes. Widespread operation of these ring seiners along Kerala, Karnataka and Goa coasts especially from the eighties had a profound influence on the marine fish production. Edwin (1997) conducted detailed investigations on the catch and effort, energy utilization pattern, gear selectivity, economic efficiency and management aspects of ring seine fishery of south Kerala coast.

Gillnets are low energy fishing gear which are extensively used in the traditional, motorized and mechanized sectors. Mesh size is the most important factor determining gillnet selectivity. Gillnets are considered one of the best gears in terms of size selectivity, species selectivity is quite poor, catching various species and sometimes entangling marine mega fauna and protected species. A high levels of tuna bycatch is occurred in drift gill net results a gradually depletion of tuna fish stocks is another negative impact of gillnet fisheries. Entanglement in massive fishes such as sharks, whale sharks, and dolphins causes gear loss and its destruction. Gillnet depredation and spoilage is caused by a long soaking period of more than 7 hours. The incidental catch of turtle is reported by using of large meshed drift gillnets is a major environmental issue in mechanized fishing sector (Sherief, 2016). Bycatch of sea birds and entanglement of marine mammals by gillnets have resulted in their negative image in the public. Seabird bycatches are common in almost all gillnet types, especially those set near the surface, adjacent to bird colonies, and in shallow waters.

Longline fishing is one of the most significant commercial fishing method practiced in the all-around the world. By catch is higher in longline fisheries in the Indian ocean than in pole and line and purse seine fisheries. By catch includes 87 species or species groups, including sharks, sea birds and turtles, all of which are categorized as vulnerable or endangered by the International Union for Conservation of Nature (IUCN) (Ardill et al, 2013). From Indian EEZ, the incidents of killer whale and shark depredation in longline fishery has been reported by Chinnaduari et al. (2018).

Ghost fishing and ALDFG

Ghost fishing is an issue directly dependent on the choice of non-biodegradable type of synthetic materials. Abandoned, lost or otherwise discarded fishing gear (ALDFG) has always been happening during fishing, became an environmental issue for the use of non-biodegradable synthetic fibres mainly includes poly amides. One of the reasons for ALDFG to occur is the use of very low-quality modern fishing gears. Use of low-quality netting material gives chances of more material to be lost in sea and other water bodies when entangling with obstructions or in rough weather (Thomas & Sandhya, 2019). The ghost fishing happens when some passive fishing gears like gillnets, trammel nets, pots and traps are lost or discarded but continue to catch commercially important fish and crustacean species as well as non-commercial species of fishes, crustaceans, birds, marine mammals and marine turtles. The lost gear may also continue damaging benthic habitats through abrasion, plucking of organisms, the meshes closing round them causing translocation of sea-bed features and posing problems as a source of litter or entanglement for birds and mammals when washed ashore. The average amount of net loss per vessel per year in the mechanized sub sectors of deep-sea gillnet fishing is 589 kg, or 24.6 % and 36.2 % in motorized multi-day subsector of the total gear on board. (Thomas, 2020). ALDFG potentially pose safety risks for fishers if they get entangled with the active fishing gear that the fishers use and vessel propulsion systems (Kamei et al., 2014). It is estimated that ALDFG contributes 10% (by volume) in global marine litter and a global figure of 640 000 tonnes per year (Macfadyen et al., 2009). There fore the fishing gear must be operated cautiously to avoid gear loss either accidentally or intentionally. The Share of ALDFG varies across countries are Brazil (46%), Japan (11%) and US (7%). Approximately, the contribution of ALDFG is 6% of all fishing nets, 19% of all traps and pots, and 29% of all fishing lines are estimated to be lost around the world each year (Richardson et al., 2019). .

Gear marking is an effective method to enables the state to take effective action against defaulters in case of Abandoned, Lost and Discarded Fishing Gear (ALDFG). It is an important mechanism for regulating legal and illegal fisheries. If a gear is well marked and has sufficient identification and it can be linked to vessel or gear registers. The basic purpose of gear marking is to determine ownership and to trace back information regarding the gear (Edwin et al., 2020). In the gillnet sector of Veraval, numbering and special markings on thermocole floats attached to the head rope. In Cochin area, there was no marking system for gillnets. In Vishakhapatnam, float colour, shape and arrangement in head rope were used for differentiation. Special knotting on the head rope and float line is also practised, but no marking is seen on the webbing portion. Cement sinkers were marked by carving letters, symbols and numbers. The artisanal fishermen of Kerala operating small gillnets in back-waters use small plastic bottle/piece of polyurethane foam (PUF) sheet as identification marks.

Light fishing

Light fishing is a fishing aggregating method has been found to be environmental-unfriendly due to catching of immature stocks, overfishing, high rate of bycatch and discard and produce green gas emission (Solomon and Ahmed, 2016). The use of artificial light in fishing operation is attract and aggregate fish and eventually capture them using various fishing gears such as hooks, gill net, purse seine, beach seine, and cast net. The major groups of fishes which possess light attraction response are sardines, mackerel, anchovies, carangids and squids (Achari et al., 1998). Light fishing is mainly reported in India, Indonesia, Ghana and East Africa. Due to the introduction of the electric lamps such as incandescent, fluorescent and mercury lamps., the light fishing has been widely spread to the offshore fisheries to the large scale commercial level fisheries. Artificial light is harmful to female sea turtles when searching for a beach hatchery, which can produce unbalanced sex ratio of hatchlings and higher hatchling mortality. The use of artificial lights at night have been shown to increase mass collisions of seabirds, which contributes directly to mortality and the sustainability of seabird populations (Montevecchi, 2006).

In mechanized fishing operations, fishing with artificial light contributes to greenhouse gas emissions. Around 15% more Global Warming Potential (GWP) is estimated in purse seiners using light fishing compared to normal purse seiner (CIFT, 2021). The difference in super structure, extra power generation units for lights, onboard ice making etc. increases GWP. Another potential source of greenhouse gas is the production process that is needed for making fishing lights.

Chemicals and plastics often require significant energy sources in order to be manufactured. A single small low-powered LED light weighing 57.6 g will produce 345.6 g of CO2 to be manufactured (Khanh & Paul, 2019). There are some regulations in light fishing were made by different countries such as India, Thailand, Yemen, Ghana, China and Philippians. In India, prohibits the use or installation or operation of surface or submerged artificial lights/ LED lights, fish light attractors or any other light equipment with or without generator, on mechanized fishing vessel or motorized fishing craft, for trawling, purse seining or gillnetting operations in the Indian EEZ beyond territorial waters. In Thailand, fishing by all types of purse seine nets using light lures was prohibited off the coast of Trat province in the Gulf of Thailand, as they were found to predominantly attract small fish. In Ghana, the chief fishermen in three coastal districts of the Western region have banned light fishing to enable the fingerlings to have enough time to grow and hatch during the off-fishing season. Light fishing is banned from the boundary of Fujian province and Guangdong province of China. The number and candle light power or intensity of superlight and fishing light attractor used in commercial fishing vessels shall be regulated by the Department of Philippines and the use of superlight is banned within municipal waters and bays.

Increasing energy use in fishing

Modern fishing is one of the most energy intensive methods of food production. Fossil fuels used as a dominant energy source in operation of motorised and mechanised fishing vessels. It is a non-renewable resource which releases high amount of carbon dioxide and other greenhouse gases (GHGs) to the atmosphere (Das & Edwin, 2016). Due to the increased level of fuel consumption in fishing vessel operations, emission of GHGs also increased which finally led to climate change (Muir, 2015). Code of conduct for responsible fisheries (CCRF) of FAO highlights the need for efficient use of energy in the fisheries sector. The upper safety limit for atmospheric CO_2 is 350 parts per million (FAO, 1995). A fuel of 1378.8 million litres were consumed by annually and releases about 3.13 million tonnes of CO_2 into the atmosphere. The maximum GWP is contributed by trawler (96.3%), followed by the purse seiner (82.6%) and longliner (61.8%) for the time of fishing operation.

Trawling is an energy intensive fishing method, consumes 1.8 to 11 times more fuel when compared to gillnetting, longlining, ring seining and purse seining for every kilogram of fish produced (Gulbrandson, 1986; Aegisson & Endal, 1993; Boopendranath, 2000). Drag is the most important factor contributing to the fuel consumption and thereby energy efficiency and profitability of fishing operations. The drag of trawl gear components varies considerably according to the design and rigging and depending on the operating conditions. Drag of 18m semi pelagic trawl (HDPE) netting consumes 13779.27 kg fuel compared to the drag of 18m semi pelagic trawl netting (UHMWPE, large mesh) consumes 3713.78 kg fuel. Reduce the amount of netting surface area, knotless netting, large mesh netting and thinner twine are some measures used for reducing drag in trawl systems.

Low drag trawl is an optimized design of trawl net based on empirical calculations and use of Ultra High Molecular Weight Polyethylene (UHMWPE) twines for gear fabrication. ICAR- CIFT designed and fabricated low drag trawls for fish and shrimp of head rope length 24.47 m and 33.0 m respectively. The drag and fuel consumption of low drag trawls are 17% and 10% lower when compared to conventional HDPE trawls (Sayana et al., 2018).

Otter boards contributes about 25 % of the total drag of the trawl system and is responsible for about 16% of the total fuel consumption in trawling operations (Hameed & Boopendranath, 2000). Suberkrub board creates little or no turbulence, have very low drag, which makes this a superior spreading device. Analysis of national level survey results by CIFT showed that the trawls presently in use have drag which is not proportionate to the installed engine power.

For the construction of different type of fishing gears, a certain amount of CO_2 is emitted to atmosphere based on the type materials used for the fabrication of the gear. In trawl net construction, the HDPE contributes 43.8% GWP as higher percentage followed by steel (32.5%), polyethylene (12.6%) and polypropylene fiber (11.1%). In case of gillnet construction, polyamide is contributed by 96.79% GWP followed by Polyvinyl chloride (1.7%) and least contribution by polypropylene (1.5%). In longline construction, the polyamide contributes 94 % GWP as higher percentage followed by Ethylene vinyl acetate (4.63%) and steel (1.2 %). In purse seine fabrication, Polyamide webbing contribute 92.7% of GWP followed by lead (sinker) (5.13%) and 1.45% of GWP is contributed by Polypropylene.

Hull fouling with slime, weeds and barnacles and the propeller covered with marine growth will result in a considerable reduction in boat speed and an increase in fuel consumption. The increase in fuel consumption due to hull fouling can be 7% after only one month and 44% after half a year if antifouling paint is not used (Gulbrandsen, 2012). To save the fuel and decrease the CO_2 emission which is adversely affected to environment, reduce the service speed of fishing vessel, install advanced fish finding equipment, keep the hull free from fouling, use the efficient propeller and change over from a petrol outboard engine to a diesel engine.

Low energy fishing methods

Gillnets and longlines are low energy fishing gears which are extensively used in the traditional, motorized and mechanized sectors. Traps are low energy and eco-friendly harvest technology for the inland fisheries and traditional marine sector. capital investment of trap fishing is relatively low and show high degree of selectivity (Meenakumari, 2009). Barriers, Stow net, Scoop net, Scrape net, Trap net, Aerial trap, Basket trap, Tubular trap, Filter trap, Kalava trap and Lobster trap are coming in this category. Modern lobster traps developed by ICAR- CIFT, which is semi-cylindrical in shape with rectangular frame and semicircular ribs made of rod. Traditional lobster fishermen especially along the southwest coast of India was used this trap which is 2.5 times more efficient than traditional traps in term of catches and also, they last for about 3-4 fishing seasons.

Fish aggregating devices (FADs) are deployed to enhance biological productivity in coastal waters, rehabilitate and conserve the depleting stocks, reduce the scouting time and energy use during harvesting operations and to enhance the income and the standard of living of the fishermen. These make the fishing operations energy efficient and cost-effective, for the benefit of traditional fishermen operating low impact fishing gears such as gill nets and lines.

A 15.5 m multi-purpose deep sea fishing vessel Sagar Kripa with steel hull was designed and developed by ICAR – CIFT with energy saving up to 17%. Fuel efficient multi-purpose IRS class fishing vessel Sagar Harita designed by Fishing Technology Division of ICAR-CIFT and built by Goa Shipyard Limited (GSL) is the latest innovation by CIFT. An optimized hull design made of marine grade steel with a bulbous bow and the cabin and wheel house is made of FRP to reduce weight and to improve the carrying capacity and speed. A 600-watt solar power panel is designed and installed for emergency lighting and navigational aids to promote the utilization of renewable energy resource in the sector. Based on the successful sea trials of the vessel F. V. Sagar Harita and the positive feedback from the fishers and fishing vessel owners, the commercial version of a

“ R ”

of Government of India. Hence ICAR-CIFT joined hands with the largest shipbuilder in the country M/s Cochin Shipyard Limited (CSL) for the design of 22.5 m long liner cum gillnetter and CSL constructed 16 vessels for Tamil Nadu. ICAR-CIFT provided consultancy to these shipyards for the design evaluation and stability testing the vessels constructed by them. Since the successful operation of the research and commercial vessels ICAR-CIFT has been overlooking construction of nearly 200 vessels all over the country.

The use of liquefied natural gas (LNG) as ship fuel has recently gained attention in Europe, but also in Asia and the USA. A marine LNG engine is a dual fuel engine that uses natural gas and bunker fuel to convert chemical energy in to mechanical energy. The natural gas is stored in liquid state (LNG) and the boil-off gas is routed to and burned in dual fuel engines. The use of LNG as ship fuel will reduce sulphur oxide (SOx) emissions by 90- 95%. A lower carbon content of LNG compared to traditional ship fuels enables a 20-25% reduction of carbon dioxide (CO2) emissions. LNG is expected to be less costly than marine gas oil (MGO) which will be required to be used within the Emission Control Areas (ECAs). ICAR-CIFT has already initiated research in this field along with Petronet Kochi LNG terminal (Baiju, 2019).

ICAR-CIFT developed two solar powered FRP boat in 2014 and 2019, which can be used in aqua farms for aqua cultural purposes and for gillnetting, line fishing, transportation and aqua tourism. The twin hull construction gives high stability during the fishing activities and the deck area is wider compared to a similar sized conventional boat. The first vessel 3.63 m Loa FRP solar boat can run in the tribal fishers at Malampuzha reservoir and the second boat 8.0 m Loa solar boat is in use at Fish farm, MATSYAFED, Njarakkal (Baiju, 2019). The solar powerd boat does not burn fuel and not create atmospheric and sound pollution.

Issues related to synthetic webbing materials

Synthetic fibres are the major materials used for gear fabrication. It has greatly extended the endurance of fishing gears, and together with mechanized vessels, have increased the size and complexity of nets. Synthetic fibres are produced entirely by chemical process or synthesis from simple basic substances such as phenol, benzene, acetylene etc. Polyamide is a synthetic fibre, popularly known as nylon. Since the introduction of synthetic webbings in fishing, Polyamide (PA) multifilament were used for the fabrication of gill nets. PA multifilament is the first synthetic material to become popular in India replacing hemp and cotton. The material used for drift gill nets for large pelagics, viz. seer, tuna and shark also has been replaced by PA multifilament. Also, it is used for fabrication of purse seine and ring seine. Recently in many states of India, PA monofilament is replacing PA multifilament, used for the fabrication of gillnet and longline

(Thomas & Hridayanathan, 2002). Among the gear webbing materials, polyamide webbing contributes 77.94% CO_2 emission to environment (Das & Edwin, 2016).

Ultra-high molecular weight polyethylene (UHMWPE) is a type of polyolefin synthesized from monomer of ethylene. The most important property of UHMWPE fibre is the requirement of a thinner material compared to PA and HDPE, thus developing less drag resulting in fuel efficiency. Due to the light weight property with minimum drag in the water, the material helps fishers to reduce fuel costs by 40%. The trawls incorporating UHMWPE products showed excellent geometric characteristics and a considerably reduced hydrodynamic drag (Sendlak, 2001). In purse seines, the use of UHMWPE facilitates faster sinking due to better filtering and reduced drag. Faster sinking reduces the chances of escape of the fish shoal.

Sapphire PE netting manufactured from specialized polymers available in twisted and braided form is suitable for trawl nets and for cage culture. It has the highest knot breaking strength, knot stability and dimensional uniformity. Braided twine having compact construction restricts mud penetration and provides lesser drag. Sapphire ultracore is a knotless HDPE star netting with an outer layer of heavier sapphire ultracore which features strands of marine grade stainless steel as an integral part of the netting twine. The stiffness and cut resistance enable it to be used as a predator protection net cum cage bag net where the predation problem is very high.

Alternate materials for traditional fishing vessels

The major materials are used for the construction of fishing vessels include wood, fibre reinforced plastic, marine plywood, aluminium and steel. Wood has been used for the boat building sector for ages due to its excellent properties like buoyancy, workability, strength, elasticity, durability, heaviness (480-624 kg m-3 at 12% moisture content), load-bearing capacity, treatability, nail holding power, strength to weight ratio and poor transmission of heat (Lekshmi & Edwin, 2019).The positive environmental impact of a wood, it is a renewable resource, a low energy material and has a negative net carbon footprint (Table. 1) (Bose & Vijith, 2012). The wood is susceptible to deterioration by various biotic and abiotic agents. Chemical preservatives are used to protect the wood against the attack of fungi, insects and marine borers. At the same time, care has to be taken to prevent the leaching of metals from the chemical preservative treated wood which may pollute the marine eco-system (Edwin and Sreeja, 2011). The wood contributes Global

Warming Potential as negative value (-64.52%) compared to other boat building materials (Das &Edwin, 2016).

Table 1. Net carbon emissions in producing 1 tonne of material

Material	Net carbon emissions (kg C/metric) [1]	Net Carbon emissions including Carbon storage within material (kg C/ metric ton)[2]
Framing Lumber	33	-457
Medium Density Fibreboard	60	-382
Steel	694	694
Aluminium	4532	4532
Plastics	2502	2502

(Source: Bose & Vijith, 2012)

Deforestation can result due to the deliberate removal of forest cover for agriculture, urban development sector or it can be an unintentional consequence of uncontrolled grazing and fires. The large quantity of wood used by the fishing industry also adds to deforestation. The utilization of coconut wood and rubber wood as an alternative material for marine purpose, reduces deforestation and it helps in maintaining the ecological stability and conserving the deteriorating environment. ICAR-CIFT has developed canoes using alternate materials like rubber wood and coconut wood for artisanal fisheries sector.

A simple technology has been popularized for development of traditional fishing canoe from rubber wood, which comes as a waste from rubber plantations. Though rubber wood is comparable to many structural timbers in terms of mechanical properties and working qualities, it is highly perishable under marine conditions. The study conducted by ICAR-CIFT proved that the rubber wood is suitable for construction of canoe after upgrading by chemical preservative treatment. Rubber wood can be made durable by treated with chemical preservatives after sheathing it with fibre glass- reinforced plastic. FRP sheathing in the rubber wood canoe provides water proofing, resistance to impact and abrasion and prevents leaching of wood preservative. It also helps to prevent attack of marine woodborers and other decay caused by bacteria and fungi results in less maintenance cost. The important dimensions of the two canoes, one for backwater fishing (6.05 m L_{OA}, 0.77 m breadth and 0.39 m depth) and 6.4 m L_{OA}, 0.83 m breadth and 0.42 m depth rubber wood canoe was used for marine fishing (Edwin, 2003).

Coconut wood is an alternate boat building material that has been zeroed in considering its availability, especially in coastal states and islands of India. ICAR-CIFT has designed and developed a traditional fishing canoe from the coconut wood, which can be used for artisanal fishing like ring seining, gillnetting etc. The preservative treatment on the coconut wood panels were standardized to enhance the physical and mechanical properties. The preservative treatment increases the durability of wood, prevents bio-deterioration and reduces the cost by 35-40%. After standardizing the treatment parameters for increasing the durability of the wood, a canoe of dimension 9.0 m L_{OA}, 1.50 m breadth and 0.70m depth was constructed. The coconut wood canoe is also cheaper when compared to the cost of preferred aini wood canoe.

Fibre reinforced plastics or FRP is used as boat building material due to its low production cost, easiness of fabrication and anticorrosive property. It is also easy and simple to fabricate. The main material components of FRP material are the reinforcing agents like glass fibre in the form of thin fibre and a plastic resin capable of impregnating fibres. For the construction of FRP boat, the primary requirement is a mould. The most popular reinforcement used is a form of glass processed into filaments which are then chopped and supplied in rolls. The thickness depends on the weight of the glass in grams per square meter. The two main types of glass fibres like chopped strand mat and woven rovings and resin are mainly used in FRP vessel construction. The chopped strand mat (CSM) is made up of long fibre glass strands that are randomly oriented and held together with a binder glue. These are available in fabric form as rolls or in small folded packages with varying thickness. Twenty years is often quoted as the lifespan of an FRP vessel. However, there are many vessels are still operating in inland and marine fisheries sector. In coming years more and more boats are going to end of its life and fishers have a tendency to burn these boats. But burning of FRP boats in the beaches leads to emissions of many greenhouse gases (GHG) to the atmosphere. FRP material contributes 75.65% of Global Warming Potential (GWP) for the time of vessel construction. In FRP sheathed wooden fishing vessels, CO2 equivalent was primarily contributed by FRP sheath (41.3%) followed by bronze (23.7%) and copper nail (19.6%).

Marine plywood is extensively used for marine vessels construction due to its commercial feasibility, high economic viability and relatively low damage in aquatic conditions. It is prepared by gluing together a number of thin veneers of wood using a waterproof adhesive such as epoxy or phenol resorcinol. The wooden ply-woods are bonded under high temperature and pressure with phenolic resin glue. Best quality marine grade plywood should have at least 5 layers of veneers.

Many uses of plywood in boats involve laminating fiberglass over a plywood boat component. The fiber glass coating protects the underlying plywood from abrasion and wear during landing and launching of boats. Marine plywood boats can ensure protection in severe conditions if it is made of durable or treated veneers. The life of a marine plywood boat is 5-7 years. The end life of disposal of FRP sheathed marine plywood boats is a common phenomenon in tropical developing countries. This adds to the marine debris and later if not properly recycled can turn to micro plastics and enters to the food chain.

Aluminium is selected as a boat building material due to its lightweight with high strength, durability and easiness to repair. Since it is lightweight, it has more carrying capacity and greater speed. The use of aluminium for fishing craft construction offers a number of advantages that includes improved stability, reduced displacement and therefore improved maneuverability and increased cargo carrying capacity, increased speed and increasing operating range, decreased engine size, decreased fuel consumption, reduced maintenance therefore less idle time. A 5.22 m L_{OA} aluminum alloy boat was designed and constructed by ICAR -CIFT for fishing and related activities in reservoirs and rivers. This material avoids expenditure on paints etc. and gives good re-sale value.

Steel has good strength, elasticity and durability and it is mainly used to construct hulls of large vessels mainly beyond 50 m in length. Mild steel is commonly used to construct fishing vessels where the carbon content is 0.15 to 0.30%. Steel vessels have good strength, elasticity and durability. Steel can be easily bent and twisted so that larger designs/sections can be fabricated easily with less wastage. The specific gravity of steel is 7.84 where the weight is comparatively more than wood, aluminium and FRP vessels. Steel is prone to corrosion and anticorrosive paints are essential for the hull protection. Steel material produces 82. 8% of Global Warming Potential (GWP) for the time of vessel construction. In steel vessels, CO_2 equivalent was contributed maximum by steel plates (65.8%) followed by bronze (24.1%) and welding arc (4.6%) (Jha et al., 2021).

Marine plastic pollution

Micro-plastics in seawater and marine sediments are rapidly increasing, and are entering into the food chain becoming a long-term threat to the mankind. Over 300 million tons of plastic are produced every year for use in a wide variety of applications. At least 8 million tons of plastic end up in our oceans every year, and make up 80% of all marine debris from surface waters to deep-sea sediments. Marine species ingest or are entangled by plastic debris, which causes severe injuries and deaths. Plastic pollution threatens food safety and quality, human health, coastal tourism, and contributes to climate change.

Advanced Technologies in fisheries sector

Potential Fishing Zone (PFZ) is a reliable and short-term forecast on the fish. This is the first advisory service started by INCOIS. This service was started by the Ministry of Earth Sciences with the help of the Department of space and several institutions under the Ministry of Agriculture. These organizations are collaborating with the State Governments of the beneficiary states to offer these services to the end users. The backbone of this service is the real-time data for ocean color and SST(sea surface temperature) provided by the OCEANSAT and NOAA (National Oceanic and Atmospheric Administration) respectively. Features such as oceanic fronts, meandering patterns, eddies, rings, Upwelling areas etc. are identified sites for fish accumulation. These features can easily be identified from Sea Surface Temperature and Chlorophyll data. The validation of PFZ helps in finding fish schools and productive fishing areas that can minimize the fuel consumption and time expended in commercial fisheries. Another feature of PFZ service is the generation of species-specific advisory to enable the fisher folk to distinguish between the exploited and under-exploited species in the potential fishing zones. This enables them to have sustainable fishery management by targeting only the under-exploited species in the fishing zones. This approach enables them to avoid fishing the over-exploited species over and over again. One such species-specific advisory is Tuna Fisheries Forecasting System that enables the fishing community to adequately prepare for the Tuna catch (Kamai et al., 2014).

Technological and digital advances would allow innovative monitoring equipment to be attached to traditional sampling gear and collect more data such as ecosystem in formation, in order to better manage fish stocks and tackle IUU fishing. For instance, visual inspections in complex habitats using imaging systems installed on robotic and autonomous underwater vehicles (AUVs) can contribute to the advancement of marine science and better knowledge of fish stocks. Collaborative monitoring, control and surveillance (MCS) tools depend on the willingness of a captain of vessel; non-collaborative tools rely on the decisions taken by the authorities in control (on when and where the vessel is monitored).

Collaborative tools include Vessel Monitoring System (VMS) and Automatic Identification System (AIS). Non-collaborative tools include optical or radar satellites. New data processing technologies in fisheries includes big data, block chain, smart weighing at sea, Radio-frequency identification (RFID), smart phones for monitoring, artificial intelligence, drones, and on-board cameras (Girard & Payrat, 2017).

Vessel Monitoring System (VMS) was originally a satellite-based system that provided data on the time-stamped location, course and speed of vessels to fisheries authorities at regular intervals.VMS are implemented nearly worldwide with various ranges of transceivers. Some countries (e.g., Algeria) only equipped tuna-seiner vessels or specific vessels for fishing in the high seas in order to comply with recommendations by Regional Fisheries Management Organizations (RFMO).

Automatic Identification System (AIS) is a ship-reporting system based on messages broadcasted by vessels carrying transponders. It was developed primarily as a tool for maritime safety to avoid vessel collision by Vessel Traffic Services (VTS) and as a means for coastal states to receive information on vessels operating near their coasts. AIS transponders send and receive signals, using a very high-frequency (VHF) transmitter, broadcast to receiver devices on other ships or to land-based systems. By sending and receiving regular communications about their identity and course, vessels can avoid collisions and navigate safely in low visibility.

Electronic Recording and Reporting System (ERS) is commonly referred to as E-Logbook, in comparison with former paper-based logbooks. E-logbook data (logs records) contribute to better management of fish stocks by keeping track of catches (origin and volume) and gearused.ERS collects information on species, volume and areas of catches, important data for fisheries. On-board logbooks are mandatory requirements for high sea fishing vessels in some RFMOs such as the Indian Ocean Tuna Commission.

Facing tremendous increase of data for fisheries monitoring, control and surveillance, the Big Data can help in sorting out data coming from new technological tools. It offers an alternative to traditional database and requests tools. Large fishing vessels currently use motion-compensated weighing system at sea in order to directly measure and store raw weight of the catch. The movement of vessel at sea does not allow determining the exact weight of the catch. Thus, the smart weighing system at sea calculates the weight of catches while taking into account movement of vessel. Data is then regularly sent to fish market and ports by satellite support to update landing forecast.

Drones (fully or partly unmanned vehicles) is one of the prominent fields of application of new technology for sustainable fisheries. Three main types of drones may be distinguished are UAV (Unmanned Aerial Vehicle), USV (Unmanned Surface Vehicle) and UUV (Unmanned Underwater Vehicle). Drones can be used for fish stock assessments and monitoring and controlling of MPAs (Marine protected areas). Electronic Monitoring loosely consists of a closed video or photographic system, integrated with a sensor system that can be used to view changes in fishing activity and to trigger or coordinate detailed viewing. The camera and sensor systems do not allow external or manual inputs or manipulation of data. On-board survey cameras may identify interactions with bycatch species and are especially useful when recording bycatches of protected species. The viewed data can also provide a secondary source of data, for example, to validate catch and bycatch log sheets (Girard & Payrat, 2017).

Tiny microprocessors and sophisticated remote sensing systems is possible to explore the lives of marine animals and the open ocean from the perspective of individuals equipped with smart tags. Satellite tags provide researchers with information about migratory routes and internal physiological processes such as digestion. smart tags are especially useful in tracking highly migratory species like sharks, tuna, and albacore, Sea turtles, Sea lions, seals and Whales. Underwater vehicles are used to study life in the ocean, including autonomous underwater vehicles (AUVs), manned submersibles, and remotely operated vehicles (ROVs). ROVs are tethered to a surface vessel, whereas AUVs operate independently. AUVs receive commands from an operator-controlled computer as to where, when, and what they sample. They also carry equipment for sampling and surveying such as cameras, sonar, and depth sensors.

Developments in acoustic fish detection satellite-based remote sensing techniques and the overall awareness of the need for responsible fishing to ensure long-term sustainability of the resources, protection of the biodiversity, environmental safety and energy efficiency. The most well-known and widely used acoustic instruments for fish detection are echo sounder and sonar. Echo sounders are used for depth recording for navigation purposes and position fixing, ground or sea bed discrimination, determination of sea bed contour, location of wrecks and hazardous areas, and location of fish and determination of its depth of occurrence. Sonar is an indispensable tool aimed trawling and purse seining.

Conclusion

Fisheries should be managed to ensure that fishing are conducted in ways that minimize negative impacts on the environment. Encourage diversification of excess capacity into low energy fishing methods. Future of sustainable fisheries depend on less fishing effort, lower exploitation rates, larger fish stocks, gradual reduction of bycatch, concern about the ecosystem impacts of exploitation and elimination of destructive fishing practices. The diversity of different fishing gears and crafts and its intensity and efficiency of fishing operations have increased significantly during the recent decades in India. Different type of fishing operation has created a significant negative impact on ecosystem. The minimization of the environmental impacts on fishing, ICAR-CIFT developed a vast number of technologies for sustainable fishing and fisheries conservation.

Reference

Achari, R B., Joel, J J., Gopakumar, G., Philipose, K K., Thomas, K T and Velayudhan, A. K. (1998) Some observations on light fishing off Thiruvananthapuram coast. Marine Fisheries Information Service, Technical and Extension Series, 152: 9-12.

Aegisson, G. and Endal, A.(1993) Energy conservation programme in Indian fisheries–report from the Preparatory Phase, pp 1-93.

Ardill, D., Itano, D. and Gillett, R. (2013) A review of bycatch and discard issues in Indian ocean tuna fisheries. *Indian Ocean Commission and Smart Fish*, 55p.

Ayyappan, S. and Diwan, A. D. (2006) Fisheries research and development in India, *Fish. Chimes*, 26(1), pp 19-23.

Baiju, M.V. (2019) Energy efficient fishing vessels and use of alternate energy for fishing, ICAR Winter School Manual- Responsible Fishing: Recent advances in resource and energy conservation. 21 Nov. – 11 Dec. ICAR-CIFT, Kochi, pp143-150.

Boopendranath, M.R., 2007. Fishing capacity management. *Integrated Fisheries Project Souvenir 2007*, pp.7-14.

Boopendranath, M.R., Sabu, S., Gibinkumar, T.R. and Pravin, P. (2010) Soft bycatch reduction devices for bottom trawls: A review, *Fish. Tech. Vol*, 47(2) pp99-110.

Boopendranath, M.R. and Shahul, H.M. (2000) Studies on energy requirement and conservation in selected fish harvesting systems, Ph.D. Thesis, Cochin University of Science and Technology, Cochin, India, 233p.

Boopendranath, M. R. (2012) Basic principles of fishing gear design and classification. Fish harvesting systems for resource conservation, ICAR-Central Institute of Fisheries Technology, Cochin, pp 125-151.

Bose, S. and Vijith, V. (2012) Wooden Boat Building for Sustainable Development, *Int. j. innov.*, 1(10), pp.345-360.

Chinnadurai, S., Jha, P.N., Renjith, R.K., Remesan, M.P. and Thomas, S.N. (2018) Depredation in gillnets operated along the south west coast of India, *Indian J. Fish., 6*5(4): pp 154-156.

CMFRI. (2010) Marine fisheries census, Central Marine Fisheries Research Institute, Kochi.110p

Das, D.P.H. and Edwin, L. (2016) Comparative environmental Life Cycle Assessment of Indian oil sardine Fishery of Kerala, *India. Fish. Tech.,* 53, pp. 273 – 283.

E.J. F (Environmental Justice Foundation).(2003) Squandering the Seas: How shrimp trawling is threatening ecological integrity and food security around the world. *Environmental Justice Foundation*, London, UK.45p

Edwin, L. (1997) Studies on the Ring Seine Fishery of South Kerala Coast, Ph.D. Thesis, Cochin University of Science and Technology, Cochin, India, 138 p.

Edwin, L. (2003) Rubber wood for marine applications – A success story – CIFT Special Bulletin 13, Central Institute of Fisheries Technology, Cochin-29.

Edwin, L. and Sreeja, A. (2011) Ecological impact of chromated copper arsenate (CCA) treated wood for marine applications: A review, *Fish. Tech.* 48(1), pp 1 – 12.

Edwin, L., Antony, V., Das, D.P.H., Joseph, R. and Prajith, K.K. (2020) Fishing Gear Marking: A technique for traceability of lost gears,*Fish Tech Rep.* 6 (1), pp1-2.

Escalle, L., Capietto, A., Chavance, P., Dubroca, L., De Molina, A.D., Murua, H., Gaertner, D., Romanov, E., Spitz, J., Kiszka, J.J. and Floch, L. (2015) Cetaceans and tuna purse seine fisheries in the Atlantic and Indian Oceans: interactions but few mortalities, *Mar. Ecol. Prog. Ser.* 522, pp255-268.

FAO. (1995) Code of conduct for responsible fisheries. Food & Agriculture Organisation, Rome, 41p.

FAO. (1998) Report of the FAO Technical working Group on management of fishing capacity, 15-18 April 1998, La Jolla, USA, FAO Fisheries Report No. 586, FAO, Rome

FAO (1999a) Managing fishing capacity: selected papers on underlying concepts and issues, FAO fisheries Technical Paper No. 386, FAO, Rome

FAO (2000) Report of the technical consultation in the measurement of fishing capacity, 29 Novemner-3 December 1999, Mexico, FAO Fisheries Report No, 615, FAO, Rome.

FAO (2001) Managing fishing capacity: a review of policy and technical issues, FAO technical Paper 409, FAO, Rome: 63 p.

FAO. (2020) The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en., 224p.

Garcia, A. and Herrera, M. (2018) Assessing the contribution of purse seine fisheries to overall levels of bycatch in the Indian Ocean, IOTCY2108YWPDCS14-26_Rev1. Retrieved January, 24 p.

Girard, P. and Du Payrat, T. (2017) An inventory of New Technologies in Fisheries: Challenges and opportunities in using new technologies to monitor Sustainable fisheries, Norwegian Ministry of Trade Industry & Fisheries, 26p.

Gulbrandsen, O. (1986) Reducing the fuel costs of small fishing boats. Bay of Bengal programme BOBP/WP/27, Development of Small-Scale Fisheries, India, 26 p

Hameed, M.S. and Boopendranath, M.R. (2000) Modern fishing gear technology. Daya publishing house, ISBN – 817035223-1, Delhi, 183 p.

He, P. (2006) Gillnets: gear design, fishing performance and conservation challenges. *Mar. Technol. Soc. J.* 40(3), pp.12-19.

Hiddink, J.G., Jennings, S., Kaiser, M.J., Queirós, A.M., Duplisea, D.E. and Piet, G.J. (2006) Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. Canadian journal of fisheries and aquatic sciences, 63(4), pp.721-736.

Jha, P.N., Antony, V.T., Baiju, M.V., Yasmi, V.S. and Edwin, L. (2021) Carbon Footprint and Associated Environmental Impacts in Construction of Fishing Vessels: A Preliminary Study, *Fish. Tech*. 58: pp.18-24.

Kamei, G., Remesan, M.P., Devi, H.M., Tok, N.C., Gangmei, K. and Panmei, S. (2014) Ghost fishing impacts and management, *Fish. Chimes*, 34(4), 45-46.

Kamei, G., Felix, J.F., Shenoy, L. and Shukla, S.P. (2014) Trends of potential fishing zones (PFZs) along the Mumbai coast, Maharashtra, *Indian J. Fish*., 61(2): 140-142.

Khanh, Q.N. and Paul, D.W. (2019) Artificial Light in Commercial Industrialized Fishing Applications: A Review, Reviews in Fisheries Science & Aquaculture, 27:1, 106-126.

Lekshmi, M. N. and Edwin, L. (2019) Boat building materials with special reference to environmental impacts. ICAR Winter School Manual- Responsible Fishing: Recent Advances in Resource and Energy Conservation. 21 Nov. – 11 Dec. ICAR-CIFT, Kochi, pp.87-94.

Macfadyen, G., Huntington, T. and Cappell, R.(2009) Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No. 523. Rome, UNEP/FAO. 2009. 115p

Madhu, V.R. and Jha, P.N. (2017) By-catch reduction devices in trawling. Recent trends in harvest and post-harvest technologies in fisheries, Central Institute of Fisheries Technology, Kochi, India, 73-80.

Madhu, V.R.(2018) A review of trawl selectivity studies carried out along Indian coast. *Fish. Tech*, 55: 1 - 18

Meenakumari, B. (2009) Traps and their operation. Handbook of Fishing Technology, Central Institute of Fisheries Technology, Cochin: 226-236.

Montevecchi, W. A (2006) Influences of artificial light on marine birds. Ecological consequences of artificial night lighting, Catherine Rich and Travis Longcore, Eds. Washington: Island Press, pp. 94–113.

Muir, J. F. (2015) Fuel and energy use in the fisheries sector Approaches, inventories and strategic implications. FAO. 1-95.

Remesan, M.P. and Renjith, R.K.(2017) Design and operation of trawls, Recent trends in harvest and post-harvest technologies in fisheries, Central Institute of Fisheries Technology, Kochi, India, pp 57-72.

Richardson, K., Hardesty, B.D. and Wilcox, C., 2019. Estimates of fishing gear loss rates at a global scale: A literature review and met - *Fish and Fisheries*, *20*(6), pp.1218-1231.

Sayana, K.A., Remesan, M.P. and Edwin, L. (2018) Low drag trawls for fuel saving. *Fish Tech Rep*. 4 (1), pp 1-3.

Sherief, M.P.S., Thomas, S.N. and Edwin, L. (2016) Large Pelagic Mechanised Gillnet Fishing Systems of Odisha Coast, India. *Global Journals Inc*, pp 1 -8.

Solomon, O.O. and Ahmed, O.O. (2016) Fishing with light: Ecological consequences for coastal habitats. *Int. j. fish. aquat*. 4(2), pp474-483.

Thomas, S.N. and Hridayanathan, C. (2002) Substitution of polyamide multifilament by polyethylene twisted monofilament in large mesh gill nets. *Fish. Tech*., 39(2), pp.100-106.

Thomas, S.N. and Sandhya, K.M. (2019) Netting materials for fishing gear with special reference to resource conservation and energy saving. ICAR Winter School Manual- Responsible Fishing: Recent Advances in Resource and Energy Conservation. 21 Nov. – 11 Dec. ICAR-CIFT, Kochi, pp.55-70.

Thomas, S. N., Edwin, L., Chinnadurai, S., Harsha, K., Salagrama, V., Prakash, R., Prajith, K. K., Diei-Ouadi, Y., He, P. and Ward, A. (2020) Food and gear loss from selected gillnet and trammel net fisheries of India. FAO Fisheries and Aquaculture Circular No. 1204. Rome, FAO. https://doi.org/10.4060/ca8382en., 52 p.

Thrush, S.F. and Dayton, P.K. (2002) Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annual Review of Ecology and Systematics, p. 449-473.