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BIODIVERSITY CONSERVATION TECHNOLOGIES IN FISHERIES

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Abstract: Overfishing and irresponsible fishing practices have long been recognized as leading causes that have reduced aquatic biodiversity, along with other causes such as pollution, habitat destruction and fragmentation, non-native species invasions and climate change. The FAO Code of Conduct for Responsible Fisheries and the international instruments pertaining to fisheries and biodiversity conservation stress the need for developing selective and eco-friendly fishing gears in order to conserve resources, protect non-targeted resources and endangered species like sea turtles and minimise environmental impacts of fishing. Various types of bycatch reduction technologies have been developed in the fishing industry around the world, in order to minimise the impact of fishing on non-target resources. These devices have been developed taking into consideration variation in the size, and differential behaviour pattern of shrimp and other animals inside the net. Semi-pelagic trawl system has been developed as an alternative to shrimp trawling in the small-scale mechanized trawlers operating in the tropical waters. Sources of pollution from fishing operations which affect fisheries environment include emissions of greenhouse gases (GHGs) and plastic debris originating from abandoned, lost and abandoned fishing gears. Enforcement of bycatch reduction technologies, promotion of low impact and fuel efficient fishing systems and smart trawling techniques, along with regulation on total fishing effort at sustainable levels and maintenance of Marine Protected Areas will facilitate protection and restoration of biodiversity and enhance the resilience of the fish stocks to fishing pressure. In this paper, various approaches to minimise the impact of fishing operations on biodiversity in fisheries environment are discussed.

Keywords: Biodiversity conservation technology, bycatch reduction, semi-pelagic trawl system, smart trawling, low impact and fuel efficient fishing, pollution from fishing operations

INTRODUCTION

Global capture fishery production has been plateauing and has more or less stabilized at around 80 million t. (FAO, 2012a). Trend in the state of marine fish stocks shows that proportion of overexploited and fully exploited marine fish stocks are increasing with simultaneous decrease in fish stocks that are not fully exploited (FAO, 2011c). In 2009, about 57.4% of the world fish stocks monitored by FAO were fully exploited, 29.9% over-exploited, and only 12.7% were left at levels not reaching full exploitation. Analysis of data from five ocean basins revealed 90% decline in numbers of large predatory fishes such as tuna, blue marlins and swordfish, since the advent of industrialized fishing (Myers and Worm, 2003; Worm *et al.,* 2006). Fishing down effect is pervasive in world fisheries, including Indian fisheries (Pauly *et al.,* 2003; Pauly and Maclean, 2003; Bhathal, 2005; Vivekanandan *et al.,* 2005; Worm *et al.,* 2006; Bhathal and Pauly, 2008). World per capita food fish supply increased from an average of 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009, and preliminary estimates for 2010 point to a further increase in fish consumption to 18.6 kg (FAO, 2012a). With the increasing global population, in order to maintain at least the current level of per-capita consumption of aquatic foods, an additional 23 million tonnes of fish will be required by 2020 (FAO, 2012a).

Positive relationships between biodiversity and ecosystem functions and services were found using experimental and correlative approaches by Worm *et al.* (2006). The principles for sustainable fisheries and conservation of biodiversity have been enshrined in the international instruments pertaining to governance of the oceans, such as the 1948 IUCN Red List of Endangered Species Assessment, the 1975 Convention on International Trade in Endangered Species (CITES), the 1982 UN Law of the Sea Convention (LOSC), the 1992 Convention on Biological Diversity, the 1993 FAO Compliance Agreement, the 1995 UN Fish Stock Agreement, the 1995 FAO Code of Conduct for Responsible Fisheries (FAO, 1995) and related International Plans of Action (IPOAs) (FAO, 2012b,c,d,e), the 1995 Global Plan of Action for the Protection of the Marine Environment from Land based Activities and the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). The 1992 Convention on Biological Diversity (CBD) is an important global agreement on the conservation and sustainable use of biological diversity which focuses on the conservation of biodiversity, sustainable use of the components of biodiversity, and sharing the benefits arising from the commercial and other utilisation of genetic resources in a fair and equitable way (UN, 1992). The conservation measures outlined in CBD which are of particular relevance to marine biodiversity include protected areas, regulation and management of biological resources, protection, rehabilitation, and restoration of degraded ecosystems and habitats.

Overfishing, irresponsible and destructive fishing practices, and illegal, unreported and unregulated (IUU) fishing have long been recognized as leading causes that have reduced biodiversity and modified ecosystem functioning (FAO, 1995; Boehlert, 1996; Jackson *et al.,* 2001; Lotze *et al.,* 2006; Worm *et al.,* 2006; FAO, 2010b). Marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations. Recent studies indicate that investing to achieve sustainable levels of fishing by strengthening fisheries management, financing a reduction of excess capacity on the conventional resources and adoption of a responsible fishing regime are required to rebuild the overfished and depleted conventional fish stocks (Worm *et al.,* 2006, 2009; UNEP, 2011).

MARINE CAPTURE FISHERIES IN INDIA

Marine fish production of India which was only 0.5 million t in 1950, increased to 3.07 million t in 2010 (ICAR, 2011), contributing 38% of the total fish production and 79% of the capture fish production. Marine fishery potential of the Indian Exclusive Economic Zone (EEZ) is estimated at about 3.93 million t (Anon, 2000). 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. The present catch is largely derived from the intensively fished shelf waters. About 1,94,490 fishing crafts of various sizes and classes are under operation in marine fisheries, consisting of 72,559 mechanised, 71,313 motorised and 50,618 non-mechanised fishing vessels (CMFRI, 2012).

Shelf resources are subjected to high intensity of fishing pressure and are exploited at levels close to or exceeding optimum sustainable limit. Problems of juvenile finfish mortality and bycatch discards increased with the intensification of shrimp trawling. Plateuing of catches from mid 1990s, economic and growth overfishing at several centres, and inter-sectoral conflicts in the coastal belt have highlighted the need for regulation of fishing capacity, adoption of responsible fishing practices and caution in marine capture fisheries development. Overfishing and fishing down effect is evident in Indian fisheries (Vivekanandan *et al.,* 2005; Bhathal and Pauly, 2008). Removal of excess fishing capacity and adoption of responsible fishing gear and practices and a conducive fisheries management regime would contribute to the long-term sustainability of the resources, minimise negative environmental impacts, protect biodiversity and facilitate rebuilding of the depleted marine fish stocks.

CCRF and Biodiversity Conservation

The Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995) sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources that give due respect for the ecosystem and biodiversity. Section 6.6 under Article 6 (General principles) prescribes that selective and environmentally safe fishing gear and practices should be further developed and applied, to the extent practicable, in order to maintain biodiversity and to conserve the population structure and aquatic ecosystems and protect fish quality. Where proper selective and environmentally safe fishing gear and practices exist, they should be recognized and accorded a priority in establishing conservation and management measures for fisheries. States and users of aquatic ecosystems should minimize waste, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species. Sub-section 7.2.2 under Section 7.2 (Management objectives) of Article 7 (Fisheries Management) prescribes that biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected. Sub-section 8.4.8 under Article 8 (Fishing operations) prescribes that research on the environmental and social impacts of fishing gear and, in particular, on the impact of such gear on biodiversity and coastal fishing communities should be promoted. Section 12.10 under Article 12 (Fisheries research) prescribes that States should carry out studies on the selectivity of fishing gear, the environmental impact of fishing gear on target species and on the behaviour of target and non-target species in relation to such fishing gear as an aid for management decisions and with a view to minimizing non-utilized catches as well as safeguarding the biodiversity of ecosystems and the aquatic habitat.

Overcapacity in Fisheries

There is a critical overcapacity in the world fishing fleet. Over-fishing can have serious consequences for the entire marine environment. Global fishing fleets are estimated to have a capacity 2.5 times greater than the optimum (Porter, 2008). Devaraj and Kurup (2000) has estimated the optimum fleet size for Indian shelf waters (excluding Islands) as 62,748 consisting of 10,998 mechanized trawlers, 784 mechanized purse seiners, 3,694 mechanized gillnetters, 2,014 mechanised bagnetters (dol-netters), 1558 other mechanised boats and 14,862 motorized crafts. According to these estimates, the existing number (CMFRI, 2012) of mechanised fishing vessels was in excess by a factor of 3.8 and motorized vessels by 4.8. A rights based regulated access system under a co-management regime based on a strong inclusive cooperative movement of stakeholders with built-in transferable quota system and buy-back or rotational right of entry schemes has been suggested for capacity management in the shelf fisheries of Indian states, which need to be implemented in collaboration with the Union Government and the neighbouring states with confluent ecosystems and shared fishing grounds (Boopendranath, 2007a, 2007b).

RESPONSIBLE FISHING TECHNOLOGIES TO MINIMISE BIODIVERSITY LOSS

Reducing bycatch and discards in fishing operations

Trawling

The shrimp trawl is a non-selective gear that commonly has an associated catch of non-targeted organisms such as finfish and miscellaneous invertebrates, designated as bycatch. Kelleher (2004) has estimated total bycatch discards in Indian fisheries at 58,000 t, which formed about 2% of the total landings. Pramod (2010) recently estimated the bycatch of Indian trawlers as 1.2 million t. Trawl bycatch in the tropics is known to be constituted by high proportion of juveniles and sub-adults, particularly of commercially important fishes, which needs serious attention in development and adoption of bycatch reduction technologies (Luther and Sastry, 1993; Sivasubramaniam, 1990; Pravin and Manohardoss, 1996; Pillai, 1998; Pravin *et al.,* 1998; Rohit *et al.,* 1993; Menon, 1996; Sujatha, 1995, 1996, 2005; Dineshbabu *et al.,* 2010). Najmudeen and Sathiadhas (2008) have estimated the annual economic loss due to juvenile fishing made by trawlers, along Indian coast at US$ 15,686 million yr^{-1}. Biju Kumar and Deepthi (2006) have discussed the implications of trawl bycatch on marine ecosystem.

Devices developed to exclude endangered species like turtle, and to reduce non-targeted species in shrimp trawling are collectively known as Bycatch Reduction Devices (BRDs). Turtle Excluder Devices (TEDs) is a specialized form of BRD developed for protecting sea turtles from trawling-related mortality and also for reducing bycatch in shrimp landings. BRDs and TEDs have been developed taking into consideration variation in the size, and differential behaviour pattern of shrimp and other animals inside the net (Prado, 1993; Brewer *et al.,* 1998, 2006; Eayrs *et al.,* 1997; Broadhurst, 2000; CIFT, 2007; Eayrs, 2007; Boopendranath, 2007a, 2009, 2012; Boopendranath *et al.,* 2008, 2010a, 2010b, 2010c, 2012; Kennelly, 2007; Broeg, 2008; Boopendranath and Pravin, 2009; Pravin *et al.,* 2011; Broadhurst *et al.,* 2012; Suuronen *et al.,* 2012). Use of BRDs is one of the widely used approaches to reduce bycatch in shrimp trawls. Some of the advantages in reducing the amount of unwanted bycatch caught in shrimp trawls by using BRDs are (i) Reduction in impact of trawling on non-targeted marine resources, (ii) Reduction in damage to shrimps due to absence of large animals in codend, (iii) Shorter sorting times, (iv) Longer tow times, and (v) Lower fuel costs due to reduced net drag (Boopendranath *et al.,* 2008; Boopendranath and Pravin, 2009). About 50 designs of BRDs and TEDs developed for different resource groups and fishing areas are in vogue either in experimental or commercial operations (Boopendranath *et al.,* 2008).

A number of BRDs such as Rectangular Grid BRD, Oval Grid BRD, Bigeye BRD, Fisheye BRD, Juvenile Fish Excluder cum Shrimp Sorting Device (JFE-SSD), Radial Escapement Device (RED), Sieve net BRD and Separator Panel BRD have been developed and field tested in Indian waters (Boopendranath *et al.,* 2008, 2012). Among these, Bigeye BRD, Fisheye BRD, Oval Grid BRD, Sieve net BRD and JFE-SSD have been found to be appropriate for introduction in the tropical small-scale mechanised trawl fisheries. Maximum bycatch exclusion and shrimp loss rates in different BRDs, during shrimp trawling operations off southwest coast of India are given in Table 1.

Table 1: Maximum bycatch exclusion and shrimp loss rates in different BRDs, during shrimp trawling operations off southwest coast of India

BRDs	Bycatch exclusion, %	Shrimp loss, %
Bigeye BRD	37	4
Fisheye BRD	63	4
Oval grid BRD	59	8
Sieve net BRD	15	5
JFE-SSD	43	5

(Source: Boopendranath *et al.,* 2008)

Bigeye BRD is a simple device constructed by making a horizontal slit in the upper part of codend or hind belly, where the opening is maintained by means of float and sinker arrangement or by binding with twine (Eayrs, 2007; Boopendranath *et al.*, 2010c; Sabu *et al.,* 2011). Differences in the behaviour of fish and shrimp are utilized in the design of this category of BRDs. Fishes that entered the codend are given opportunity to swim back and escape by providing slits in the netting on the topside of the codend or hind belly, while shrimps are retained in the codend. Size of the slit can be easily adjusted according to the size of the animals, which need to be excluded (Robins *et al.,* 1999). During the field trials using commercial shrimp trawls in Indian waters, bycatch exclusion realised from Bigeye BRDs was up to 37% and shrimp loss was up to 4% (Boopendranath *et al.,* 2008; Sabu *et al.,* 2011) (Table 1). One of the major advantages of the Bigeye BRD is that it is very simple in design and can be easily incorporated in an existing commercial trawl.

Fisheye is an important bycatch reduction device facilitating the escapement of actively swimming finfishes which has entered the codend (Pillai, 1998; Brewer *et al.,* 1998; 2006; Gregor and Wang, 2003; CIFT, 2007; Boopendranath *et al.,* 2008; Burke *et al.,* 2012). It consists of an oval shaped rigid structure with supporting frames made of stainless steel or aluminium rods. This opening facilitates the escape of the fish, which try to swim backward from the codend. The device is suitable for excluding actively swimming juveniles and young fishes while retaining the Big ones. Fisheye can be used either singly or in combination with other BRDs. Bycatch exclusion rates of 63% with a shrimp loss of about 4% have been reported during trawl operations in Indian waters, using 200x300 mm semi-circular Fisheye BRD (Table 1).

Bycatch reduction devices in the form of rigid separation grid were developed in Norway in 1980s, primarily to minimise the bycatch of jellyfish in shrimp trawling (Isaksen *et al.,* 1992; Eayrs *et al.,* 1997; Pravin *et al.,* 2011). Oval grid BRD is a rigid grid sorting device developed for separation of shrimp from non-shrimp resources. The ideal configuration for a sorting grid system includes a funnel that accelerates the water flow, in conjunction with a sorting grate that causes minimum disturbance to the water flow and separate small animals from large and result in little or no loss of target species in trawls. Bycatch exclusion rates up to 59%, with a shrimp loss of about 8% have been reported during trawl operations in Indian waters, using oval rigid grid sorting device with 26 mm bar spacing (Table 1).

Sieve nets, also known as veil nets, are cone shaped nets inserted into standard trawls which direct 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 shrimps pass through large meshes and accumulate in the main codend. Bycatch exclusion rates of 15-50% with shrimp loss of 5-15% have been reported in Sieve net installed trawl operations in different fishing grounds (Polet *et al.,* 2004; Catchpole, 2008; Boopendranath *et al.,* 2008).

The Juvenile Fish Excluder cum Shrimp Sorting Device (JFE-SSD) is a International Smart Gear-2005 price winning design (WWF, 2012) developed at Central Institute of Fisheries Technology (CIFT) (Cochin, India) 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 finfishes and shrimp species (CIFT, 2007; Boopendranath *et al.,* 2008; WWF, 2012). JFE-SSD operations off southwest coast of India have realised bycatch reduction up to 43% with shrimp retention of about 95% (Table 1). Out of a total retained catch (in the lower and upper codends), about 77% was retained in the lower codend and the balance in the upper codend.

Of the retained catch of non-shrimp resources, about 70% was retained in the lower codend and nearly 30% in upper codend. The sorting effect was most pronounced in the shrimp species. Out of the retained shrimp catch, nearly 99% was retained in the lower codend (Boopendranath *et al.,* 2008).

Turtle Excluder Devices (TEDs) are recognized internationally as a convenient and effective measure for preventing trawling-related mortality and for reducing bycatch of sea turtles in shrimp landings (Mitchell *et al.,* 1995; Boopendranath *et al.,* 2010c). CIFT-TED is an efficient turtle excluder device developed at Central Institute of Fisheries Technology (Cochin, India) with focus on reducing catch losses, which is a cause of concern for trawler fishermen in adopting the device. Catch losses during the experimental operations due to installation of CIFT-TED were in the range of 0.5-1.0% for shrimp and 2-3% for non-shrimp catch components (Dawson and Boopendranath, 2001; CIFT, 2003; Boopendranath *et al.,* 2003, 2010c; CIFT, 2007).

Purse seining

Purse seines like other surrounding nets are not selective. However, operational selection is possible, if schools are judiciously selected after evaluating the presence of bycatch species and juveniles (Boopendranath, 2009). Special escape panels known as Medina panels, which are sections of fine mesh that prevent dolphins from becoming entangled in the gear, and back down manoeuvre have been deployed to prevent capture of dolphins in purse seines (Ben-Yami, 1994). Selection of mesh size for the purse seine appropriate for the target species, proper choice of fishing area, depth and season could also lead to better selectivity of purse seines.

Gillnetting

Bycatch in drift gill nets may include marine mammals, sea turtles and sea birds, in addition to non-targeted fish species. Optimisation of gill net mesh size and hanging coefficient according to the target species and size group and judicious deployment of gill net in terms of fishing ground, fishing depth and season in order to minimise the gear interaction with the non-targeted species are important bycatch mitigation measures for gill net fisheries. Recent innovations have attempted to make the gill nets detectable by marine mammals having echolocation abilities, using acoustic pingers and specially treated netting (Carretta *et al.,* 2008). Acoustic reflective polymaide netting treated with barium sulphate has been reported to reduce bycatch of harbour porpoise in gill nets (Trippel *et al.* 2003; Larsena *et al.,* 2007). Lost gill nets continue to gill and entangle fish and other marine organisms which is generally termed ghost fishing. One approach to minimise ghost fishing by lost gill nets, is to use biodegradable natural fibre twines or time release elements to connect the netting to floats (Hameed and Boopendranath, 2000; FAO, 2010a). When floats are separated due to the disintegration of these links, the gill nets lose their fishing attitude and consequently lose the ability for ghost fishing. Another approach to prevent ghost fishing is to locate and retrieve lost fishing gear.

Hook and line fishing

Optimized hook design and size and selection of bait type and bait size appropriate for the target species and size class, proper choice of fishing ground, depth and time of fishing are approaches for mitigation of bycatch issues in hook and line fisheries and minimise gear interaction with other species. Interaction with sea birds during long line operation are minimised using dyed bait, deploying bird scaring devices (streamers) in the area where bait is set and by using sub-surface setting chutes for deployment of branch lines. Sub-surface setting chutes, blue-dyed bait, weighted baits and side-sets were reported to have reduced the bycatch of seabirds in the longline fisheries (Gilman *et al.,* 2003; Boopendranath, 2009; FAO, 2010a).

Trap fishing

Traps generally have high species specificity and size selectivity and offer high potential for survival of discarded non-targeted species and low energy requirements in operations (Boopendranath, 2009). The disadvantages of trap fishing are relatively high loss rate during operations and ghost fishing by lost traps (Hameed and Boopendranath, 2000; Macfadyen *et al.,* 2009; FAO, 2010a). Approaches to reduce bycatch in trap fishing include optimised trap design and trap mouth configuration according to the target species and provision of escape windows for juveniles and non-target species in the design side and appropriate choice of bait type, fishing area, fishing depth, fishing time and season in the operational side to minimise gear interaction with non-target species.

Reducing bottom impacts of towed gears

Bottom trawling caused direct and indirect impacts on marine environment and benthic communities (Hall, 1999; Kaiser and de Groot, 2000; CEFAS, 2003; Barnes and Thomas, 2005; Valdemarsen *et al.,* 2007; Meenakumari *et al.,* 2009). Approaches to minimise environmental impacts of bottom trawling such as semi-pelagic trawl systems, benthic release panels and ground gear modifications in bottom trawls, otter board designs with narrower footprint, smart trawling techniques and low impact and fuel efficient (LIFE) fishing have been discussed by Brewer et al. (1996), Fonteyne and Polet (2002), CEFAS (2003), Valdemarsen and Suuronen (2003), Shenker (2005), He (2007), Valdemarsen *et al.* (2007), Boopendranath (2009), FAO (2012a) and Suuronen *et al.* (2012).

Semi-pelagic trawls have comparatively low impact on the benthic biota, as it operates a little distance above the sea bottom (Brewer *et al.,* 1996; He, 2007). CIFT Semi-pelagic Trawl System (CIFT SPTS) has been developed as an alternative to shrimp trawling in the small-scale mechanized trawler sector, after extensive field-testing (CIFT, 2007, 2011). Benthic release panels are large square mesh drop out windows provided ahead of the codend, to release unwanted benthic organisms (Fonteyne and Polet, 2002; He, 2007). Use of lighter ground gear and use of rollers, wheels and bobbins with their axes perpendicular to the direction of towing has been known to reduce bottom impact during trawling, without significantly affecting the catch rates (He, 2007). High aspect ratio vertically cambered otter boards typically have lower angle of attack and narrower footprint compared to traditional otter boards (He, 2007). The area of seabed affected by high aspect ratio otter boards is typically 40% of the area affected by low aspect ratio otter boards with similar board area. Use of shorter and lighter bridles and sweeps, where herding effect is not important in the catching process, could reduce the impact on seabed. Smart trawling systems have been under development in which the distance of otter boards and ground gear from the sea bed is constantly and automatically measured and adjusted by special instrumentation. (CEFAS, 2003; Valdemarsen and Suuronen, 2003; Shenker, 2005).

Pollution from Fishing Operations GHG emissions of fishing systems

World capture fisheries consumes about 50 billion litres of fuel annually releasing an estimated 134 million t of CO_2 into the atmosphere at an average rate of 1.7 t of CO_2 per t of live-weight landed product (Tyedmers *et al.,* 2005). Annual fuel consumption by the mechanized and motorized fishing fleet of India has been estimated at 1220 million litres releasing an estimated 3.17 million t of CO_2 into the atmosphere at an average rate of 1.13 t of CO_2 per t of live-weight of marine fish landed (Boopendranath, 2008). Tyedmers et al. (2005) estimated that about 0.53 t of fuel is consumed for every tonne of fish landed, globally. However, fuel consumption varies widely according to the type of fishing operations

(Boopendranath, 2000; World Bank and FAO, 2009; FAO, 2012a). Fuel consumption and CO_2 footprint in selected fish harvesting systems operated in Indian waters are given in Table 2.

Table 2: Fuel consumption and CO_2 footprint in selected fish harvesting systems in India

Fishery sector and methods of capture	kg fuel per kg fish	kg CO_2 per kg fish
Traditional motorised operations		
Ring seining	0.12	0.30
Mini-trawling	0.41	1.02
Small-scale mechanised operations		
Gillnetting-cum-lining	0.31	0.82
Bottom trawling	0.38	0.99
Purse seining	0.07	0.17
Large-scale mechanised operations		
Aimed midwater trawling	0.33	0.87
Bottom trawling	1.34	3.52

Source: Boopendranath (2000, 2008)

Various approaches to energy conservation in fish harvesting in areas such as (i) fishing gear and methods; (ii) vessel technology; (iii) engines; (iv) reduction gear, propeller and nozzle; (v) sail-assisted propulsion; (vi) alternative fuels (vii) adoption of advanced technology in fish detection, navigation and fishing operations; and (viii) conservation, management and enhancement of resources, have been discussed by May *et al.,*'1981'; Gulbrandson (1986), Wileman (1984), Aegisson and Endal (1993), Boopendranath (1996, 2000, 2009), Sterling and Goldsworthy (2007) and Chokesanguan (2011).

Garbage, waste oil and oily mixtures and emissions from the vessel operations

Pollution of the marine environment by ships of all types, in terms of garbage, waste oil and oily mixtures and engine emissions is strictly controlled by the International Convention for the Prevention of Pollution from Ships (MARPOL)(IMO, 2006). The discharge of oily mixtures having oil content above 15 ppm, into the sea, is prohibited and all vessels over 400 tons are required to be fitted with oil filtering/separating equipment to comply with this regulation.

Abandoned, lost or otherwise discarded fishing gear and related marine debris

Abandoned, lost or otherwise discarded fishing gear (ALDFG), generally known as 'derelict fishing gear' and related marine debris of plastic origin are recognized as a critical problem in the marine environment and for living marine resources in terms of the long-term sustainability of fish stocks and biodiversity conservation, due to ghost fishing and habitat loss and impact on endangered species such as marine mammals and turtles (Laist, 1987; Jones, 1995; Derraik, 2002; Ayyappan *et al.,* 2005; Macfadyen *et al.,* 2009; Boopendranath, 2012, CBD, 2012). Approaches to minimize plastic debris due to abandoned, lost or discarded fishing gear include (i) use twines, ropes, netting, connectors and shackles of correct specifications and breaking strength, in fishing gear fabrication; (ii) introduction of a system of marking fishing gears and procedures for reporting of lost fishing gears and their retrieval; and (iii) compliance of MARPOL regulations which prohibits at sea disposal of plastics and other synthetic materials (IMO, 2006; Macfadyen *et al.,* 2009; FAO, 2010a, 2010 a,b. Boopendranath, 2012). Approaches to minimize ghost fishing include (i) use biodegradable twines to connect the netting to floats in gillnets, so that when floats are separated due to disintegration of the link, the gill nets loose the fishing attitude and hence the ability to fish, (ii) use biodegradable netting panels in traps, and (iii) salvaging lost fishing gear (Hameed and Boopendranath, 2000; Macfadyen *et al.,* 2009; FAO, 2010 a,b; Boopendranath, 2012).

CONCLUSIONS

Adoption of ecosystem based fisheries management which incorporates responsible fishing practices along with strict regulation of fishing capacity at sustainable levels and establishment of marine protected areas (MPAs) would facilitate protection and restoration of biodiversity and enhance the resilience of the fish stocks and ecosystem services. A wide range of proven technologies and procedures are readily available for minimizing the direct and indirect impacts of harvesting operations on biodiversity. Adoption of such technologies may only be successful with the active involvement of stakeholders in the process, supported by a system of incentives and disincentives and training, under a participatory management regime. BRDs and TEDs need to be adopted and enforced legally, under a participatory management regime, in order protect the biodiversity and prevent trawling induced sea turtle mortality. Semi-pelagic trawling can be promoted as an alternative to shrimp trawling in small mechanised trawl sector in India, to minimize environmental impacts. Ecofriendly practices are to be promoted in purse seining, gillnetting, lining and trap operations, to minimize the impact on non-target species and environment. Technologies and procedures for minimization of GHG emissions from the fishing fleet need to be promoted through legislation, stakeholder education and training. Procedures for minimization of plastic waste originating from abandoned, lost or discarded fishing gear, need to be adopted. Strict compliance of MARPOL regulations for safe disposal of garbage, oil, oily mixtures and other residues originating from fishing vessels operations, need to be promoted and implemented, for protecting the health of fisheries environment.

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