Fishery Technology 49 (2012) : 109 - 119

Waste Minimisation in Fishing Operations

M.R. Boopendranath*
Central Institute of Fisheries Technology, P.O. Matsyapuri, Cochin - 682 029, India

Abstract

Sources of wastes in capture fisheries mainly include bycatch discards, processing wastes where catch is processed onboard, plastic wastes due to abandoned, lost and discarded fishing gear, bilges and other wastes from the vessel operations. Fishing systems in general have an associated catch of non-targeted organisms known as bycatch. Non-selective fishing gear that is not modified or equipped to exclude non-targeted organisms, may take a significant quantity of bycatch of non-targeted finfish, juvenile fish, benthic animals, marine mammals, marine birds and vulnerable or endangered species that are often discarded. Average annual global discards, has been estimated to be 7.3 million t, based on a weighted discard rate of 8%, during 1992-2001 period. Trawl fisheries for shrimp and demersal finfish account for over 50% of the total estimated global discards. Plastic materials are extensively used in fisheries, owing to their durability and other desirable properties, contributing to the efficiency and catchability of the fishing gear. However, plastics biodegrade at an extremely slow rate compared to other organic materials. Abandoned, lost or otherwise discarded fishing gear (ALDFG) and related marine debris have been recognized as a critical problem in the marine environment and for living marine resources. Prevention of excess fishing capacity by appropriate management measures could lead to enormous savings in terms of fuel consumption, emissions and bycatch discards from the excess fishing fleet, capital and operational investments and labour deployment in capture fisheries, with significant economic gains. In this paper, wastes originating from fishing operations are reviewed, along with their environmental impacts and possible mitigation measures.

Keywords: Capture fisheries, bycatch discards, bycatch reduction technologies, plastic wastes, garbage, engine emissions, waste minimization

Received 29 May 2012; Accepted 11 June 2012

E-mail: boopendranath@hotmail.com

© 2012 Society of Fisheries Technologists (India)

Introduction

Wastes are substances or objects that are disposed of or are intended to be disposed of or are required to be disposed (Anon, 1989; EC, 2008). Wastes generated in capture fisheries include bycatch discards, onboard processing wastes, plastic wastes due to abandoned, lost or discarded fishing gear, bilges and other wastes from vessel operations. Non-selective fishing gear that is not modified or equipped to exclude non-targeted organisms, may take a significant quantity of bycatch of non-targeted finfish, juvenile fish, benthic animals, marine mammals, marine birds and vulnerable or endangered species that are often discarded. The importance of reducing waste and minimizing ecological impacts of fishing operations has been emphasized by scientists and fishery managers (Laist, 1997; Kiessling, 2003; Brown et al., 2005; Harrington et al., 2005; Brown & Macfadyen, 2007; Boopendranath, 2007; 2008; NRC, 2008; Macfadyen et al., 2009; FAO 2010, Andrady, 2011; Thompson et al., 2011; Suuronen et al., 2012; Boopendranath, 2012). In this paper, an attempt is made to review the sources of wastes from fishing operations, their environmental impacts and possible mitigation measures.

Sources of wastes in fishing operations

Generation of wastes during fishing operations are represented in Fig. 1. Sources of wastes include bycatch discards, processing wastes where catch is processed onboard, plastic wastes due to abandoned, lost or discarded fishing gear, bilges, garbage and other wastes from the vessel operations.

Bycatch discards from harvesting systems

The term bycatch refers to non-targeted species retained, sold or discarded for any reason (Alverson et al., 1994). 'Target catch' is the species or species assemblage primarily sought in a fishery (e.g. shrimps and cephalopods), 'incidental catch' is the retained catch of non-targeted species and 'discarded catch' is that portion of catch returned to the

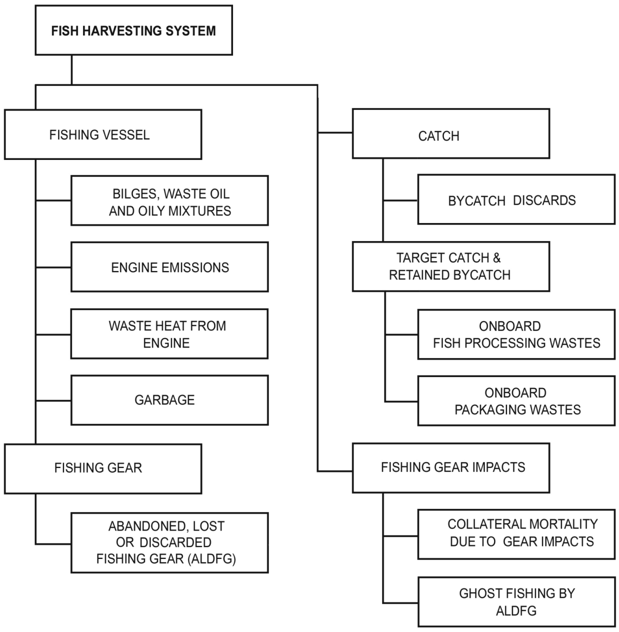

Fig. 1. Waste generation during fishing operations

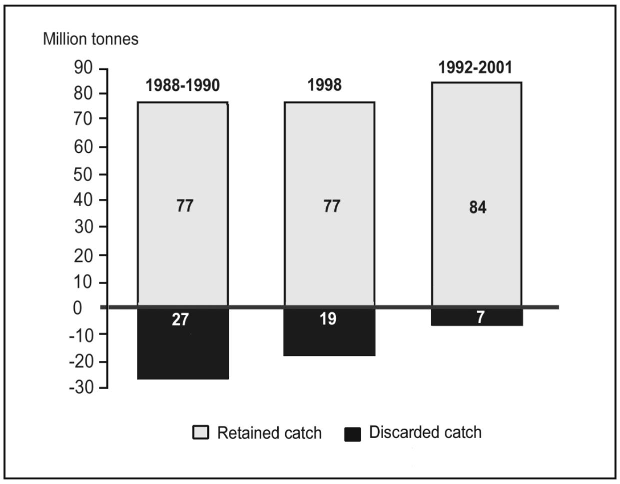

Fig. 2. Bycatch discards in world fisheries (Source: Alverson et al., 1994; FAO 1999a; Kelleher, 2004)

sea because of economic, legal or personal considerations. Bycatch includes both discarded and incidental catch. In addition to the non-targeted finfishes and invertebrates, bycatch also involve threatened and protected species like sea turtles.

Global bycatch by the world's marine fishing fleets was estimated at 28.7 million t in 1994, of which 27.0 million t (range: 17.9-39.5 million t) were discarded annually and shrimp trawling alone accounted for 9.5 million t (35%) of discards annually (Alverson *et al*. 1994). In 1998, FAO estimated a global discard level of 20 million t (FAO, 1999a). Average annual global discards, has been re-estimated to be 7.3 million t, based on a weighted discard rate of 8%, during 1992-2001 period (Kelleher, 2004) (Fig. 2). The reduction in bycatch discards in recent years could be attributed to (i) increased use of bycatch reduction technologies, (ii) anti-discard regulations and improved enforcement of regulatory measures, and (iii) increased bycatch utilization for human consumption or as animal feed, due to improved processing technologies and expanding market opportunities. 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). Trawl fisheries for shrimp and demersal finfish account for over 50% of the total estimated global discards (Kelleher, 2004). 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 & Sastry, 1993; Sivasubramaniam, 1990; Pillai, 1998; Pravin et al., 1998; Rohit et al., 1993; Menon, 1996; Sujatha, 1995; 1996; 2005). Kelleher (2004) has estimated total bycatch discards in Indian fisheries at 57 917 t, which formed 2.03 % of the total landings. Pramod (2010) has estimated the bycatch discards of Indian trawlers as 1.2 million t. FAO has recently brought out International guidelines on bycatch management and reduction of discards (FAO, 2011).

Bycatch reduction technologies

Different types of bycatch reduction technologies have been developed in the fishing industry around the world (Prado, 1993; Eayrs, 2005; Boopendranath et al., 2006; 2008; 2010; Boopendranath et al., 2007; Kennelly, 2007; Boopendranath, 2009; 2012; Boopendranath & Pravin, 2009; Pravin et al., 2011; Suuronen et al., 2012) (Table 1). 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). These devices have been developed taking into consideration variation in the size, and differential behaviour pattern of shrimp and other animals inside the net. BRDs can be broadly classified into three categories based on the type of materials used for their construction, *viz*., Soft BRDs,

FISHERY TECHNOLOGY

Table 1. Approaches for bycatch reduction

Gear design related approaches

Trawls

- Trawl design improvements
- Mesh size optimisation
- Bycatch reduction devices and turtle excluder devices
- Juvenile and trash fish excluder devices

Purse seines

- Seine design and seine depth, appropriate for schools of target species
- Mesh size optimisation
- Use of aprons in the seine design

Gillnets

- Optimisation of gillnet dimensions
- Optimisation mesh size
- Choice of netting material
- Choice of colour of netting
- Optimisation of hanging ratio
- Use of biodegradable materials in rigging and construction to prevent ghost fishing

Hooks and lines

- Hook design optimisation
- Hook shape and size
- Hook spacing
- Use of circle hook to minimise sea turtle bycatch
- Use of rare earth magnets in the proximity of hooks to deter sharks
- Use of dyed baits, side sets, subsurface line setting chutes and bird scaring steamers to deter birds

*Trap*s

- Trap design optimisation
- Optimised trap mouth
- Escape windows
- Use of biodegradable materials in rigging and construction to prevent ghost fishing

Operation related approaches

- Choice of bait type and bait size appropriate for the target species in hook and line operations; use of dyed baits, side sets, subsurface line setting chutes and bird scaring steamers to deter birds; and deep setting of line to minimize sea turtle bycatch
- Use of scaring devices and acoustic deterrents to prevent cetacean bycatch in gillnets
- Choice of fishing area
- Choice of fishing depth
- Choice of fishing time and season

Hard BRDs, and Combination BRDs. Soft BRDs make use of soft materials like netting and rope frames for separating and excluding bycatch. Hard BRDs are those, which use hard or semi-flexible grids and structures for separating and excluding bycatch. Combination BRDs use more than one BRD, usually hard BRD in combination with soft BRD, integrated into a single system. Juvenile mortality could be reduced by using specially designed BRDs for juvenile exclusion such as Juvenile Fish Excluder cum Shrimp Sorting Device (JFE-SSD) (Boopendranath et al., 2008; WWF, 2009) and Juvenile and Trash Excluder (JTED) (Chokesanguan et al., 2000).

Turtle Excluder Devices (TEDs) are recognized internationally as a convenient and effective measure for preventing trawling-related mortality and

FISHERY TECHNOLOGY

for reducing bycatches of sea turtles in shrimp landings (Mitchell et al., 1995). 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 0.52-0.97% for shrimp and 2.44-3.27% for non-shrimp catch components (Dawson and Boopendranath, 2001; CIFT, 2003; Boopendranath et al., 2003; CIFT, 2007). 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).

Approaches for bycatch reduction in gillnets, purse seines, hooks and lines, and traps have been recently reviewed by Boopendranath (2009) (Table 1). Bycatch in drift gillnets may include marine mammals, sea turtles and sea birds, in addition to non-targeted fish species. Optimisation of gillnet mesh size and hanging coefficient according to the target species and size group and judicious deployment of gillnet 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 gillnet fisheries. Recent innovations have attempted to make the gillnets detectable by marine mammals having echolocation abilities, using acoustic pingers and specially treated netting (Carretta et al., 2008). Acoustic reflective polyamide netting treated with barium sulphate has been reported to reduce bycatch of harbour porpoise in gillnets (Trippel et al. 2003; Larsen et al., 2007). Lost gillnets continue to gill and entangle fish and other marine organisms leading to unwanted mortality as gillnet material is non-biodegradable. This process known as ghost fishing is a negative characteristic of modern gillnets which is otherwise a simple, energy efficient method of fishing particularly suited for scattered populations, requiring low investment.

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. 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). 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 to minimise gear interaction with other species. 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.

Minimizing wasteful destruction of benthic organisms during bottom trawling

Direct and indirect impacts of bottom trawling on marine environment and benthic communities are well known (Hall, 1999; Kaiser et al., 1998; Kaiser & de Groot, 2000; Barnes and Thomas, 2005; Meenakumari et al., 2008). Gear modifications to achieve the objective of reduced impact on environment include lighter gear construction, semi-pelagic trawling, benthic release panels and minimising contact area of the towed gear with seabed (Carr & Milliken, 1998; CEFAS, 2003; Valdemarsen & Suuronen, 2003; He, 2007; Valdemarsen et al., 2007; Suuronen et al., 2012; Boopendranath, 2012).

Onboard processing and packaging wastes

During onboard processing, wastes are generated due to (i) unwanted catch landed and discarded; (ii) high grading due to limited ice and storage capacity; (iii) processing wastes such as particles of flesh, skin, bones, entrails, shells or liquid stickwater; and (iv) packaging wastes which may include plastics. Processing wastes such as head, viscera, gonad, liver, skin, bones and cartilage from whole fresh fish may range from 30 to 73%, in the case of finfishes and from 22 to 73% in the case of shellfishes, depending on species (Chakraborti, 2006). Appropriate waste management and waste valorisation procedures should be put in place, in fishing vessels that have onboard processing facilities.

Abandoned, lost or otherwise discarded fishing gear (ALDFG) and other plastic wastes

Plastic materials are extensively used in fisheries, as they have very good strength, other desirable properties, and contribute to the high efficiency and catchability of the fishing gear (Ayyappan et al., 2005). Most important synthetic fibres used in fisheries are polyethylene (PE), polyamide (PA), polypropylene (PP) and polyester (PES) and other synthetic materials such as polyvinyl chloride (PVC), polyvinyl alcohol (PVAA) and polyvinylidene chloride (Saran) (PVD) are less widely used (Hameed & Boopendranath, 2000; Meenakumari & Radhalakshmi, 2003). Though valued for their extreme durability, plastics have been considered to be among the most non-biodegradable synthetic materials in existence (Sivan, 2011). The lifetime of a plastic material in the marine environment varies depending on environmental conditions, and may extend to hundreds of years for complete mineralization (Andrady, 2011). Although degradation rates of plastics are extremely low, they break down into less conspicuous microplastics (<5 mm in size) which may further degrade into nano-sizes. Microplastics are pervasive in seawater and marine sediments and are rapidly increasing, long-term threat to the fisheries environment (Moore, 2008; Andrady, 2011; Cole et al., 2011; Thompson, 2011).

Abandoned, lost or otherwise discarded fishing gear (ALDFG), popularly known as derelict fishing gear, cause ecological concerns such as ghost fishing. In 1975, the world's fishing fleets dumped approximately 135 400 t of plastic fishing gear and 23 600 t of synthetic packaging material into the sea (Cawthorn, 1989; DOC, 1990). A recent review of gear loss, abandonment and discard indicators from around the world has shown the ranges to be 0.02-3.2% per boat per year for gillnets, 20-30% for traps and 3% loss of hooks for tuna longline (FAO, 2010). ALDFG and related marine debris is recognized as a critical problem in the marine environment and for living marine resources in terms of the long-term sustainability of fish stocks, due to ghost fishing and habitat loss, safety of navigation, and impact on endangered species such as marine mammals and turtles (Laist, 1987; Jones, 1995; Ayyappan et al., 2005; Macfadyen et al., 2009; FAO, 2010). Approaches to minimize ghost fishing include (i) use biodegradable twines to connect the netting to floats in gillnets whereby floats are separated after a fixed duration due to disintegration of the link and the gillnets loose the fishing attitude and hence the ability to fish and (ii) use biodegradable netting panels in traps (Boopendranath, 2009; Macfadyen et al., 2009).

The deleterious effects of plastic debris on the marine environment have been reviewed by Derraik (2002) and others. A large number of marine species is known to be harmed or killed by plastic debris. Marine animals are mostly affected through entanglement in and ingestion of plastic litter (Laist, 1997; Kiessling, 2003; Brown et al., 2005; Brown & Macfadyen, 2007; NRC, 2008; Macfadyen et al., 2009; FAO 2010; Andrady, 2011; Thompson et al., 2011). A number of measures aimed at the prevention and mitigation of ALDFG and its impacts such as gear recovery programmes and technological measures to prevent ghost fishing by ALDFG have been identified and many have been implemented in different countries (Macfadyen et al., 2009; FAO 2010). Measures such as effort restrictions which are implemented to tackle problems of excess capacity may have the additional benefit of reducing ALDFG.

Approaches to minimize plastic debris and measures aimed at the prevention and mitigation of ALDFG and its impacts include the following:

- Use twines, ropes, netting, connectors and shackles of correct specifications and breaking strength, in fishing gear fabrication.
- Introduce a system of marking fishing gears and procedures for reporting of lost fishing gears and their retrieval.
- Compliance of MARPOL regulations (IMO, 2010) that prohibit at sea disposal of plastics and other synthetic materials.

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

Garbage, waste oil and oily mixtures and emissions are generated during the vessel operations. Pollution of the marine environment by ships of all types, including fishing vessels, is strictly controlled by the MARPOL 73/78, the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978. Different annexes of MARPOL deals with Oil (Annex-I), Noxious Liquid Substances carried in Bulk (Annex II), Harmful Substances carried in Packaged Form (Annex III), Sewage (Annex IV), Garbage (Annex V) and Air Pollution (Annex VI) (IMO, 2010).

In accordance with regulation 9 of Annex V of the MARPOL 73/78, a record is to be kept of each discharge of garbage at sea, to reception facilities or

FISHERY TECHNOLOGY

to other ships. The garbage includes all kinds of food, domestic and operational wastes excluding fresh fish and parts thereof, generated during normal operation of the vessel and are liable to be disposed continuously or periodically except those substances which are defined or listed in other annexes to MARPOL 73/78 (Table 2). Every vessel of 12 m or more in length overall shall display placards which notify the crew and passengers of the disposal requirements. Fishing vessels of 400 gross tonnage and above need to carry a Garbage Management Plan providing procedures for collecting, storing, processing and disposing of garbage and maintain a Garbage Record Book giving details of discharge operations. The discharge of oily mixtures into the sea is prohibited. The only allowable discharge of an oily mixture is where a discharge rate of 15 ppm is achieved through oil filtering/separating equipment. All vessels over 400 tons are required to be fitted with this type of equipment.

World capture fisheries consumes about 50 billion litres of fuel annually (1.2% of the global fuel consumption) releasing an estimated 134 million t of CO_2 into the atmosphere at an average rate of 1.7 t of CO_2 per tonne 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 which formed about 1% of the total fossil fuel consumption in India in 2000 (122 billion 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 tonne of live-weight of marine fish landed (Boopendranath, 2008) (Fig. 3). CO_2 emissions per kg of fish landed in India have been estimated to range from 0.3-1.02 kg in traditional motorised operations undertaking ring seining and mini-trawling, 0.17 to 0.99 kg in small-scale mechanised operations undertaking purse seining, gillnetting-cum-lining and bottom trawling, to 0.87-3.52 kg in large-scale mechanised operations undertaking aimed midwater trawling and bottom trawling (Boopendranath, 2008) (Fig. 4). Other pollutants from vessel operations include nitrogen oxides (NO_X) and sulphur oxides (SO_X) from engine emissions and ozone depleting substances from refrigeration plants and fire fighting systems. A typical fishing vessel utilizes only about 40% of the inherent energy of the fuel used onboard for propulsion and generation and energy and 60% is lost in waste heat. Technologies to convert the waste heat into electricity or cooling systems, if developed, could potentially lead to savings of 15-20% in fuel consumption of the vessel (Anon, 2006).

Approaches for energy conservation and minimization of GHG emissions from fishing fleet have been reviewed by Gulbrandson (1986), Wileman (1984), Aegisson and Endal (1993) and Boopendranath (1996; Wilson, 1999; Boopendranath, 2009). The approaches include appropriate adoption of (i) low energy fishing techniques; (ii) low drag trawls; (iii) pair trawling; (iv) economic vessel speed; (v) hull

Table 2: MARPOL 73/78 Garbage disposal regulations

Garbage type**	Disposal outside special areas*
Plastics including synthetic ropes, synthetic fishing nets and plastic garbage bags and incinerator waste from plastic products, which may contain toxic or heavy metal residues.	Disposal prohibited
Dunnage, lining and packing materials, etc, which will float	> 25 nm offshore
Paper products, rags, glass, metal, bottles, crockery and similar refuse	> 12 nm
All other garbage including paper products, rags, glass, metal, bottles, crockery and similar refuse comminuted or ground	> 3 nm
Food wastes not comminuted or ground	> 12 nm
Food wastes comminuted or ground	> 3 nm

* Special areas (MARPOL Annex V) include the Mediterranean Sea, the Baltic Sea, The Black Sea, the Red Sea, the Gulf Area I, the north Sea, the Antarctic Area and Wider Caribbean Sea, where it is illegal to discharge any garbage except food waste which may only be discharged beyond 12 nm offshore.

** Mixed refuse types: When garbage is mixed with other discharges having different disposal requirements, the more stringent disposal requirements shall apply.

FISHERY TECHNOLOGY

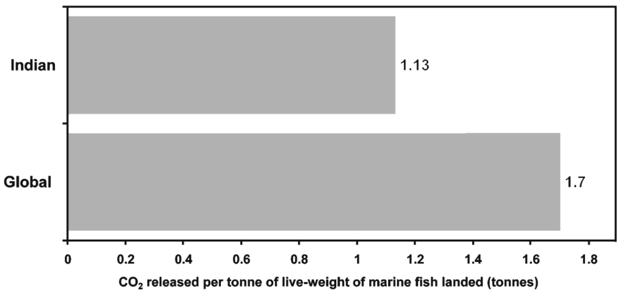

Fig. 3. GHG emissions from Indian and global fishing fleet (Source: Tyedmers et al., 2005; Boopendranath, 2008)

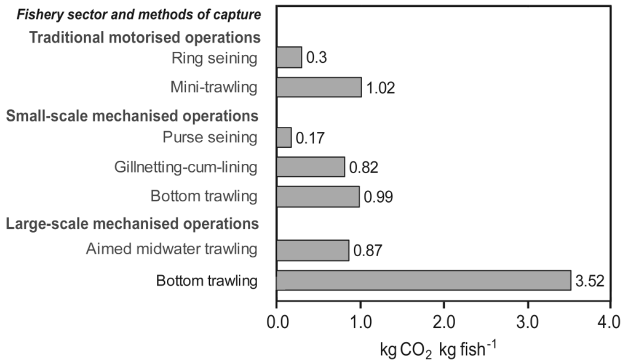

Fig. 4. GHG emissions according to fishery sector and methods of capture (Boopendranath, 2008)

design and displacement optimisation; (vi) effective anti-fouling measures; (vii) appropriate choice of engines; (viii) right sizing of engines; (ix) emission standards and fuel quality; (x) preventive maintenance of engines, (xi) appropriate reduction gear, propeller size and propeller nozzle; (xii) energy management system; (xiii) sail-assisted propulsion, where applicable; (xiv) use of advanced technology such as acoustic fish detection devices (echosounder, sonar and gear monitoring system), Global Positioning System (GPS), Potential Fishing Zone (PFZ) information based on remote sensing, and Geographical Information System (GIS); (xv) Fish Aggregating Devices (FADs); (xvi) effective fleet management and voyage optimisation; and (xvii) removal of excess fishing capacity.

Resource waste due to excess fishing capacity

Excess fishing capacity has been identified as a major problem affecting long-term sustainability and biodiversity of fishery resources and economic viability of fishing operations (FAO, 1995; 1999b; 2001; Boopendranath, 2007; Arnason et al., 2008). Significant economic gains could be achieved by eliminating excess capacity, in addition to attaining objectives of resource sustainability and waste minimisation in capture fisheries. Estimates of optimum fleet size by Devaraj & Kurup (2000) for Indian shelf waters (excluding Islands) were 62748 consisting of 10998 mechanized trawlers, 784 mechanized purse seiners, 3694 mechanized gillnetters, 2014 mechanised bagnetters (*dol*-netters), 1558 other mechanised boats and 14862 motorized crafts. According to these estimates, the existing number (CMFRI, 2012) of mechanised trawlers were in excess by a factor of 3.2, mechanised purse seiners and ring seiners by 2.8, mechanised gillnetters by 5.5, mechanised bagnetters by 5.9, other mechanised boats by 2.0 and motorized vessels by 4.8 (Fig. 5). These estimates suggest that the present level of marine capture fish production could be maintained by deploying about one-fourth of the presently deployed fleet of mechanised and motorised vessels, saving enormous amount of wasted resources in terms of fuel consumption, emissions and bycatch discards from the excess fishing fleet, capital and operational investments and labour deployment in capture fisheries. 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 seems to hold potential 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, 2008).

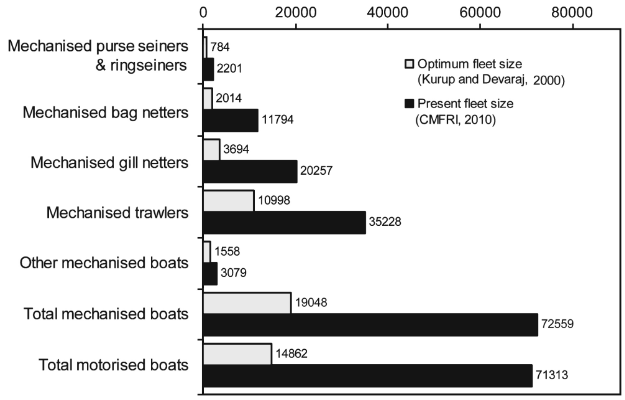

Fig. 5. Present (CMFRI, 2012) and estimated optimum fleet size (Kurup & Devaraj, 2000) for marine fisheries of India

Conclusion

In capture fisheries, waste is generated mainly due to bycatch discards; onboard processing; abandoned, lost or otherwise discarded fishing gear (ALDFG); garbage; waste oil and oily mixtures and emissions from the vessel operations. A wide range of proven technologies and procedures are readily available for reduction of bycatch discards in harvesting operations. 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. Procedures for minimization of plastic waste originating from abandoned, lost or discarded fishing gear need to be adopted. Fishing vessels must make every effort to retrieve all lost or damaged fishing gear. A system of marking of fishing gear and reporting of lost fishing gear facilitating its retrieval has to be in place. Technologies and procedures for minimization of GHG emissions from the fishing fleet need to be promoted through legislation, stakeholder education and training. Strict compliance of MARPOL regulations for safe disposal of garbage, oil, oily mixtures and other residues originating from fishing vessel operations need to be promoted and implemented. Appropriate processing waste management and waste utilisation procedures should be put in place, in fishing vessels with onboard processing facilities. Harbours and landing centres need to be provided with reception facilities for wastes from fishing vessels and procedures put in place for their safe disposal. Elimination of excess fishing capacity by appropriate management measures could entail in enormous savings in terms of fuel consumption, emissions and bycatch discards from the excess fishing fleet, capital and operational investments and labour deployment in capture fisheries.

Acknowledgement

The author is thankful to the Director, Central Institute of Fisheries Technology, for granting permission to publish this paper.

References

Aegisson, G. and Endal, A. (1993) Energy Conservation Programme in Indian Fisheries – Report from the Preparatory Phase, Report No. 402009.00.01.93, MARINTEK, Norwegian Marine Technology Research Institute, Trondheim, Norway

Alverson, D.L., Freeberg, M.K., Murawski, S.A. and Pope, J.G. (1994) A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No 339, FAO, Rome

Andrady, A.L. (2011) Microplastics in the marine environment, Mar. Pollut. Bull. 62: 1596-1605

Anon (1989) Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal adopted by the Conference of The Plenipotentiaries on 22 March 1989 (Entry into Force - May 1992), http://archive.basel.int/text/con-e.pdf (Accessed 1 May 2012)

Anon (2006) The Future of Energy and Environmental Issues, VS Project No 3299, 12 p. Vik-Sandvik, Norway

Arnason, R., Kelleher, K. and Willmann, R. (2008) The Sunken Billions: The Economic Justification for Fisheries Reform. 100 p, Joint publication of the World Bank, Washington, DC and the FAO, Rome

Ayyappan, S., Devadasan, K. and Boopendranath, M.R. (2005) Plastics in Fisheries. Souvenir: International Conference on Plasticulture and Precision Farming - 2005, 17-21 November 2005, New Delhi: 32-37

Barnes, P.W. and Thomas, J.P. (Eds) (2005) Benthic Habitats and the Effects of Fishing, American fisheries Society, Symposium 41, Bethesda, Maryland: 890 p.

Ben-Yami, M. (1994) FAO Purse Seining Manual. Fishing News Books Ltd., UK

Boopendranath, M.R. (1996) Approaches to energy conservation in fishing, Regional Training Course in Commercial Fishing Technology, Training Department, Southeast Asian Fisheries Development Centre, Thailand

Boopendranath, M.R. (2007) Fishing capacity management, In: Spearheading Quality Fish Processing (S. Girija, Ed.), pp. 115-122, Integrated Fisheries Project, Cochin

Boopendranath, M.R. (2007) Possibilities for bycatch reduction from trawlers in India. In: Indian Fisheries – A Progressive Outlook (Vijayan, K.K., Jayasankar, P. and Vijayagopal, P., Eds.), pp. 12-29, Central Marine Fisheries Research Institute, Cochin

Boopendranath, M.R. (2008) Fishing practices in the context of climate change impacts, Paper presented during the Meeting on Climate Change and Fisheries, 15 December 2008, ICAR, New Delhi

Boopendranath, M.R. (2009) Responsible fishing operations. In: Handbook of Fishing Technology (Meenakumari, B., Boopendranath, M.R., Pravin, P., Thomas, S.N. and Edwin, L., Eds), pp. 259-295, Central Institute of Fisheries Technology, Cochin

FISHERY TECHNOLOGY

Boopendranath, M.R. (2012) Technologies for Responsible Fishing, In: Advances in Harvest and Post-harvest Technology of Fish (D.D. Nambudiri and K.V. Peter, Eds.), Chapter 2, pp. 21-47, New India Publishing Agency, New Delhi

Boopendranath, M.R. and Pravin, P. (2009) Technologies for responsible fishing - Bycatch Reduction Devices and Turtle Excluder Devices. Paper presented in the International Symposium on Marine Ecosystems-Challenges and Strategies (MECOS 2009), 9-12 February 2009, Marine Biological Association of India, Cochin

Boopendranath, M.R., Dawson, P., Pravin, P., Remesan, M.P., Prakash, R.R., Vijayan, V. Mathai, P.G., Pillai, N.S., Varghese, M.D. and Ramarao, S.V.S. (2003) Design and development of Turtle Excluder Devices for Indian fisheries. In: Marine Turtles of the Indian Sub-continent (Shanker, K. and Choudhury, B.C., Eds.), pp. 244-267, Universities Press (India) Pvt. Ltd., Hyderabad

Boopendranath, M.R., Pravin, P., Gibinkumar, T.R. and Sabu, S. (2006) Development of bycatch reduction devices and turtle excluder devices in the context of sustainable seafood production. Paper presented at National Seminar on Seafood Production: Reflections, Alternatives and Environmental Control, 23-24 February 2006, Goa

Boopendranath, M.R., Pravin, P., Gibinkumar, T.R. and Sabu, S. (2008) Bycatch Reduction Devices for Selective Shrimp Trawling, Final Report on ICAR Ad-hoc Project, Central Institute of Fisheries Technology, Cochin

Boopendranath, M.R., Sabu, S., Gibinkumar, T.R. and Pravin, P. (2010) Soft bycatch reduction devices for bottom trawls. Fish. Technol. 47(2): 99-110

Brown, J. and Macfadyen, G. (2007) Ghost fishing in European waters: Impacts and management responses. Mar. Policy 31(4): 488–504

Brown, J., Macfadyen, G., Huntington, T., Magnus, J. and Tumilty, J. (2005) Ghost fishing by lost fishing gear. Final report to DG, Fisheries and Maritime Affairs of the European Commission, Fish/2004/20, 132 p. Institute for European Environmental Policy/Poseidon Aquatic Resource Management Ltd. Joint Report.

Carr, H. A., and Milliken, H. (1998) Conservation engineering: Options to minimise fishing's impacts on the sea floor, In: Effects of fishing gear on the sea floor of New England (Dorsey, B.M. and Pederson, J., Eds.), pp. 100–103, Conservation Law Foundation, Boston, Massachusetts

Carretta, J.V., Barlow, J. and Enriquez, L. (2008) Acoustic pingers eliminate beaked whale bycatch in a gillnet fishery. Mar. Mammal Sci. 24: 956-961

Cawthorn, M. (1989) Impacts of marine debris on wildlife in New Zealand coastal waters. In: Proceedings of Marine Debris in New Zealand Workshop, 9 March 1989, wellignton, New Zealand, Department of Conservation, Wellington, New Zealand, pp. 5-6

CEFAS (2003) A study on the consequences of technological innovation in the capture fishing industry and the likely effects upon environmental impacts, The Centre for Environment, Fisheries and Aquatic Science (CEFAS), Final Report submitted to Royal Commission on Environmental Pollution, Westminster, London, 181 p.

Chakraborti, R. (2006) Enzymatic bioprocessing of tropical seafood wastes, In: Food Biotechnology (Chapter 3.12) (Shetty, K., Paliyath, G., Pometto, A. and Levin, R.E., Eds.), pp. 1605-1630, CRC Press, Boca Raton, FL

Chokesanguan, B., Ananpongsuk, S., Siriraksophon, S. and Podapol, L. (2000) Study on Juvenile and Trash Excluder Devices (JTEDs) in Thailand. SEAFDEC Training Department, Samut Prakan, Thailand, TD/RES/47

CIFT (2003) CIFT-TED for Turtle-safe Trawl Fisheries - A Success Story in Responsible Fisheries. CIFT Special Bulletin No. 12 (English), Central Institute of Fisheries Technology, Cochin

CIFT (2007) Responsible Fishing - Contributions of CIFT. CIFT Golden Jubilee Series, Central Institute of Fisheries Technology, Cochin

CMFRI (2012) Marine Fisheries Census 2010, Part-1. 97 p, Central Marine Fisheries Research Institute, Cochin

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S. (2011) Microplastics as contaminants in the marine environment: A review. Mar. Pollut. Bull. 62(2): 2588–2597

Dawson, P. and Boopendranath, M.R. (2001) CIFT-TED Construction, Installation and Operation. CIFT Technology Advisory Series – 5, Central Institute of Fisheries Technology, Cochin

Derraik, J.G.B. (2002) The pollution of the marine environment by plastic debris: a review. Mar Pollut Bull 44: 842–852

DOC (1990) Marine Debris. Department of Conservation, Wellington, New Zealand

Eayrs, S. (2005) A Guide to Bycatch Reduction in Tropical Shrimp Trawl Fisheries. FAO, Rome

EC (2008) Waste Framework Directive. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certainDirectives, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do? uri= CELEX: 32008L0098:EN:NOT (Accessed 1 May 2012)

FISHERY TECHNOLOGY

EJF (2003) Squandering the seas: How shrimp trawling is threatening ecological integrity and food security around the world. 45 p, Report of the Environmental Justice Foundation, London

FAO (1995) Code of Conduct for Responsible Fisheries. 41 p, FAO, Rome

FAO (1999a) The State of World Fisheries and Aquaculture, 1998. FAO, Rome

FAO (1999b) International Plan of Action for the management of fishing capacity, FAO, Rome

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

FAO (2010) Abandoned, lost or otherwise discarded fishing gear, In: State of World Fisheries and Aquaculture Part 3: Highlights of Special Studies, pp.126-133, FAO, Rome. http://www.fao.org/docrep/013/i1820e/i1820e.pdf

FAO (2011) International Guidelines on Bycatch Management and Reduction of Discards. 73 p, FAO, Rome

Gulbrandson, O. (1986) Reducing Fuel Cost of Small Fishing Boats. BOBP/WP/27, Bay of Bengal Programme, Madras

Hall, S.J. (1999) The Effects of Fishing on Marine Ecosystems and Communities. 274 p, Blackwell Science Ltd., Oxford

Hameed, M.S. and Boopendranath, M.R. (2000) Modern Fishing Gear Technology, Daya Publishing House, Delhi

Harrington, J.M., Ransom A Myers, R.A. and Rosenberg, A.A. (2005) Wasted fishery resources: discarded by-catch in the USA, Fish and Fish. 6: 350–361

He, P. (2007) Technical measures to reduce seabed impact of mobile fishing gears, In: By-catch Reduction in the World's Fisheries (Kennelly, S., Ed.), pp. 141–179, Springer, The Netherlands

IMO (2010) International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 1973/78). International Maritime, Organisation, http://www.imo.org/Conventions (Accessed 10 May 2010)

Jones, M.M. (1995) Fishing debris in Australian marine environment. Mar. Pollut. Bull. 30: 25-33

Kaiser, M.J. and de Groot, S.J., (Eds.) (2000), The Effects of Fishing on Non- target Species and Habitats: Biological, Conservation and Socio-economic Issues, 399 p. Blackwell Science Ltd., Oxford, England

Kaiser, M.J., Edwards, D.B., Armstrong, P.J., Radford, K., Lough, N.E.L., Flatt, R.P. and Jones, H.D. (1998) Changes in megafaunal benthic communities in different habitats after trawling disturbance. ICES J. Mar. Sci. 55: 353-361

Kelleher, K. (2004) Discards In The World's Fisheries Marine - An Update. FAO Fisheries Technical Paper 470, Food and Agriculture Organization of the United Nations, Rome

Kennelly, S.J. (Ed.) (2007) Bycatch Reduction in the World's Fisheries, Reviews: Methods and Technologies in Fish Biology and Fisheries Vol. 7, 288 p. Springer, The Netherlands

Kiessling, I. (2003) Finding Solutions: Derelict fishing gear and other marine debris in Northern Australia, Charles Darwin University, 58 p. National Oceans Office, Australia

Kurup, K.N. and Devaraj, N. (2000) Estimates of optimum fleet size for the exploited Indian shelf fisheries, Mar. Fish. Inf. ser. T&E No. 165: 2-11

Laist, D. (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Marine Debris: Sources, Impacts, and Solutions, (Coe, J.M. and Rogers, D.B., Eds. pp. 99–139, Springer, New York

Laist, D.W. (1987) Overview of the biological effects of lost and discarded plastic debris to marine environment, Mar. Pollut. Bull. 18: 319-326

Larsen, F., Eigaard, O.R. and Tougaard, J. (2007) Reduction of harbour porpoise (*Phocoena phocoena*) bycatch by iron-oxide gillnets Fish. Res. 85: 270-278

Luther, G. and Sastry, Y.A. (1993) Occurrence of spawners, juveniles and young fish in relation to the fishery seasons of some major fishery resources of India - A preliminary study. Mar Fish Infor. Serv T&E Ser 122

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, 115 p. UNEP/FAO, Rome

Meenakumari, B. and Radhalakshmi, K. (2003) Synthetic Fish Netting Yarns, CIFT Special Bulletin 11, 39 p. Central Institute of Fisheries Technology, Cochin

Meenakumari, B., Bhagirathan, U. and Pravin, P. (2008) Impact of bottom trawling on benthic communities: a review, Fish. Technol. 45(1): 1-22

Menon, N.G. (1996) Impact of bottom trawling on exploited resources. In: Menon NG and Pillai CSS (eds.) Marine Biodiversity, Conservation and Management, pp. 97–102, Central Marine Fisheries Research Institute, Cochin

FISHERY TECHNOLOGY

Mitchell, J.F., Watson, J.W., Foster, D.G. and Caylor, R.E. (1995) The Turtle Excluder Device (TED): A Guide to better Performance. NOAA Technical Memorandum NMFS-SEFSC-366

Moore, C.J. (2008) Synthetic polymers in the marine environment: A rapidly increasing, long-term threat, Environ. Res. 108(2): 131–139

NRC (2008) Tackling Marine Debris in the 21st Century. Publication draft. Committee on the Effectiveness of International and National Measures to Prevent and Reduce Marine Debris and Its Impacts, 224 p. National Research Council, Washington, DC

Pillai, N.S. (1998) Bycatch reduction devices in shrimp trawling, Fishing Chimes 18(7): 45-47

Prado, J. (1993) Selective shrimp catching devices: a review, INFOFISH International 1/93: 54-60

Pramod, G. (2010) Illegal, Unreported and Unregulated Marine Fish Catches in the Indian Exclusive Economic Zone, Field Report (Pitcher, T.J., Ed.), Policy and Ecosystem Restoration in Fisheries. 29 p, Fisheries Centre, University of British Columbia, BC, Vancouver, Canada

Pravin, P., Remesan, M.P. and Manoharadoss, R.S. (1998) Trends in landings by trawls of five designs off Veraval coast, Fish.Technol 35: 50-54

Pravin, P., Sabu, S., Gibinkumar, T.R. and Boopendranath, M.R. (2011) Hard bycatch reduction devices for bottom trawls – a review. Fish. Technol. 47(2): 107-118

Rohit, P., Gupta, A.C. and Bhat, U.S. (1993) Increased exploitation of juvenile fish population by bull trawlers during the early post-monsoon fishing season of 1992 along the Dakshina Kannada coast, Karnataka. Mar Fish Infor Serv T&E Ser 122, pp. 9-12

Sivan A. (2011) New perspectives in plastic biodegradation, Curr. Opin. Biotechnol. 22(3): 422-426

Sivasubramaniam, K. (1990) Biological aspects of shrimp trawl bycatch, Bay of Bengal News 40: 8-10

Sujatha, K. (1995) Finfish constituents of trawl bycatch off Visakhapatnam, Fish Technol 32: 56-60

Sujatha, K. (1996) Trash fish catch of the trawl fishery off Visakhapatnam. J Aquat Biol 11: 17-23

Sujatha, K. (2005) Finfish bycatch of trawls and trammel nets off Visakhapatnam, Andhra Pradesh In: Sustainable Fisheries Development – Focus on Andhra Pradesh, Society of Fisheries Technologists (India), Cochin, pp. 87-94

Suuronen, P., Chopin, F., Glass, C., Lokkeborg, S., Matsushita, Y. Queirolo, D. and Rihan, D. (2012) Low impact and fuel efficient fishing—Looking beyond the horizon, Fish. Res. 119-120: 135-146

Thompson, R.C., La Belle, B.E., Bouwman, H. and Lev Neretin, L. (2011) Marine Debris: Defining a Global Environmental Challenge, Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility, GEF/C.40/Inf.14

Trippel, E.A., Hol, N.L., Palka, D.L., Shepherd, T.D., Melvin, G.D. and Terhune, J.M. (2003) Acoustic reflective net mesh reduces harbour porpoise bycatch. Mar Mammal Sci 19: 240-243

Tyedmers, P.H., Watson, R. and Pauly, D. (2005) Fuelling global fishing fleets. Ambio 34: 635–638

Valdemarsen, J.W. and Suuronen, P. (2003) Modifying fishing gear to achieve ecosystem objectives. In: Responsible Fisheries in the Marine Ecosystem (Sinclair, M. and Valdimarsson, G., Eds.), FAO and CABI International Publishing: 321–341

Valdemarsen, J.W., Jorgensen, T., Engas, A. (2007) Options to mitigate bottom habitat impact of dragged gears. FAO Fisheries Technical Paper No. 506. 29 p, FAO, Rome

Wileman, D.A. (1984) Project Oilfish: Investigation of the Resistance of Trawl. The Danish Institute of Fisheries Technology, Denmark

Wilson, J.D.K. (1999) Fuel and Financial Savings for Operators of Small Fishing Vessels. FAO Fish. Tech. Paper 383, FAO, Rome

WWF (2009) Modifying shrimp trawls to prevent bycatch of non-target species in the Indian Ocean, www.smartgear.org/smartgear_winners/smartgear_winner_2005/ smartgear_winner_2005 (Accessed 20 May 2009)

FISHERY TECHNOLOGY