

Trawling and by-catch: Implications on marine ecosystem

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Trawling remains a controversial method of fishing due to the perceived lack of selectivity of the trawl net and the resultant capture of a huge quantity and diversity of non-target species, including endangered species such as sea turtles, coupled with its effect on the marine ecosystem. The impacts of trawling on the physical, chemical and biological environment of the marine ecosystem and the diversity and quantity of by-catch and discards remain poorly documented for the tropical waters. In India, the by-catch landed at fishing harbours are utilized mainly for the production of manure and animal feed. Further, by-catch reduction devices have not been implemented in the field. This review article, besides analysing the impact of trawling, highlights the need for adopting policies and practices that reduce the level of by-catch, the need for ecosystem-based management to ensure long-term sustainability of oceanic resources, and the adoption of a precautionary approach with emphasis on reducing, and if possible avoiding discards.

Keywords: By-catch, discards, fisheries, marine ecosystem, trawling.

THE impacts of fishing gears on the marine environment have been a matter of great concern to the sustainable management of oceanic resources. Trawl nets are designed to catch economically valuable target species such as shrimps and are operated from mechanized boats called trawlers (Figure 1 *a*). As a mobile non-selective fishing gear, the bottom trawl net (Figure 1 *b*) collects every organism in its path and the incidental capture of non-target species – by-catch – has become a major concern allied to trawling. The term ‘discarded catch’ or ‘discards’ denotes the portion of the catch which is returned to the sea and the term ‘by-catch’ means the incidental catch (retained catch) of non-target species plus the discarded catch¹. Intensive fishing activities, besides being detrimental to marine biodiversity, have started affecting the complex ecological processes of the oceans, which in the long term affects the sustainability of marine fisheries that is already in doldrums; 17% of the world’s marine fishery resources is over-exploited, 52% fully exploited and 20% moderately exploited².

Even though a number of explanations have been forwarded to justify the discarding of by-catch, the major reasons include: (i) little or no commercial value for the by-catch, (ii) the cost involved in landing fish, including sorting, storage, and processing (icing), and (iii) storage capacity limitations in trawlers, as this facility is used almost exclusively for target species³. The problem of discarding and by-catch has attracted substantial attention among researchers in the last three decades due to reports on the deleterious impact they have on the marine ecosystem, coupled with documented presence of a colossal amount of biodiversity in the by-catch, particularly eggs and young ones of commercially valuable species and endangered species such as sea turtles. This article analyses reports on the quantum of discards and by-catch due to trawling, physical, chemical and biological implications they have on the marine ecosystem, the present by-catch utilization and research on by-catch reduction devices.

The quantum of discards

The increase in commercial fish production all over the world in the last five decades has been accompanied by

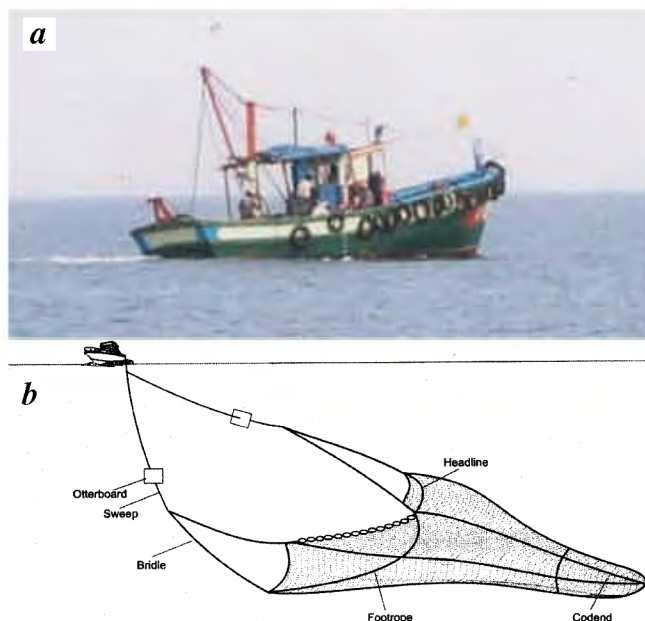


Figure 1. *a*, A trawler in operation. *b*, A bottom trawl net and its parts.

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an increase in the landings of by-catch and discards. The trawl net is the most destructive type of mobile fishing gear as it is dragged through the sea bottom, gathering a wide array of organisms as by-catch¹ (Figure 2 *a* and *b*). 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 by-catch varies in

relation to target species, seasons and areas⁴. Andrew and Pepperell⁵ estimated total global discards of 16.7 million tonnes by-catch from shrimp fisheries alone. Alverson *et al.*¹ documented the quantity of fisheries by-catch and discards in various oceans and seas around the world; the report revealed that commercial bottom trawling contributes about 27 million tonnes of discards (based on data from the 1980s and early 1990s), which is more than half of all fish produced annually from marine capture fisheries for direct human consumption. A subsequent report published by the Food and Agriculture Organization (FAO)⁶ suggested a reduced estimate of 20 million tonnes. A recent analysis by FAO² based on the discard data during 1992–2002 estimated the discard rate as 8% of the total catch, represented by 7.3 million tonnes. However, some of the major marine fish-producing countries, including India are under-represented in the discard database, indicating the possibility of higher levels of discards. Majority of the studies in this field were from temperate waters. However, tropical shrimp fisheries have high rate of discards, contributing to over 21% of total discards².

From the Indian waters, there are few reports on the quantity and quality of by-catch due to trawling operations. The first estimation of the quantity of by-catch associated with shrimp trawling by the Central Marine Fisheries Research Institute (CMFRI), Cochin in 1979 showed that 79.18% (315,902 tonnes) of the total landings is represented as by-catch; the percentage of by-catch was maximum in Gujarat (92.58), followed by Tamil Nadu (91.04) and Pondicherry (86.52)⁷. The estimate further showed that the by-catch from shrimp trawlers in India is used either for human consumption or as fish meal and fish manure. Sukumaran *et al.*⁸ made an appraisal of the trawl fishery of Karnataka based on data obtained from Mangalore and Malpe during the fishing seasons 1980–81 and 1981–82, and recorded that shrimps represent only 13% of the annual average trawl catch; the trawl by-catch was as high as 85% during this period. The quantity of by-catch landed by trawlers annually in the South Indian states of Kerala, Karnataka and Tamil Nadu was estimated as 43,000 tonnes⁹. Rao¹⁰ estimated the catches and discards in Visakhapatnam, Andhra Pradesh based on data of shrimp landings and reported that the quantity of by-catch discarded depends on the demand for finfish in the external and domestic markets.

Investigations carried out by CMFRI during 1999 in Karwar, Mangalore, Kochi, Mandapam and Kakinada regions showed the target:by-catch ratios along the southwest and southeast regions of India as 1 : 4.6 and 1 : 1.26 respectively¹¹. The quantity of discards of bottom trawlers in Kerala during 2000–01 and 2001–02 was 2.62 and 2.25 lakh tonnes respectively; the edible portion of the discards during the same periods accounted for 33.3 and 35.5% respectively¹². Except these scattered reports, detailed published reports on the quantity of trawl by-catch is lacking from the Indian waters.



Figure 2. *a*, Catch released from the cod end of the trawl net. *b*, By-catch landings at Neendakara fishing harbour, Kerala.

Ecosystem impacts

Trawl fishing has both direct and indirect impacts on the marine ecosystem as well as on biodiversity, as this method of fishing collects and kills huge amount of non-target species and young ones of commercially valuable species, mechanically disturbs the sea bottom and injures a wide variety of marine benthic creatures. The indirect effects of fishing, though less obvious, are important in defining the structure of benthic communities¹³. Benthic habitats not only provide shelter and refuge for juvenile fish, but the associated fauna provide food sources for a variety of important demersal fish species. Thus frequent alterations in the benthic habitats would result in decline of marine fish landings. A series of studies initiated in the last two decades in various parts of the world notwithstanding, information is limited on the ecosystem impacts of trawling, primarily because of the complex nature of benthic habitats and their large spatial and temporal variations coupled with methodological limitations in research. Absence of control sites, i.e. sites protected from trawling in tropical waters, limit scientific analysis of the results and a better understanding of the impacts of trawling.

In general, the environmental effects of bottom trawling have been found to be more destructive in structurally complex and biodiversity-rich marine habitats such as sea grass meadows, coral reefs, sea mounts and deepwater areas subject to little natural disturbance^{14,15}, than in unconsolidated sediment habitats occurring in shallow coastal waters¹⁶, particularly because of longer recovery trajectories in terms of recolonization of the habitat by the associated fauna. As trawling removes colossal amounts of high biomass organisms in the sea bed, represented mainly by emergent organisms, productivity of the sea bed will be affected considerably¹⁶. Further, sea-bed organisms help in increasing the sea-bed complexity, which offers shelter for young organisms and thus reduces their vulnerability to predation. The bottom trawl net, with its homogenization effect, shears-off bottom vegetation and exposes the organisms to predation and reduces food supply. The benthic faunal composition is critically affected by heavy trawling, mainly through a resuspension of the surface sediment and through a relocation of shallow burrowing infaunal species to the surface of the seafloor. A single passage of beam trawl has been reported to kill 5–65% of the resident fauna and mix the top few centimetres of sediment¹⁷. The non-target species may have key roles in the marine food-webs that fortify ecosystem processes and functioning, which in turn determines the productivity of marine capture fisheries¹⁸. Habitat impacts and by-catches affect stocks of commercially valuable species, the natural biodiversity and ecological services provided¹⁹.

According to Watling and Norse¹⁴, the environmental damage caused by bottom trawling can be substantial and irreversible, and trawling operations have ‘effects on the sea bottom that resemble forest clear-cutting, a terrestrial

disturbance recognized as a major threat to biological diversity and economic sustainability’. However, most of the disturbances in the sea bottom remain unrecorded as they are hidden from direct human observation. Though most of the studies on the impacts of mobile fishing gears on marine biodiversity are currently focused around ecosystems with hard bottoms, such as coral reefs and rocky shores, major part of the seafloor is composed of soft sediments. This warrants further studies on the effect of trawling on coastal waters with soft sediments. Organisms inhabiting the soft sediments, in addition to influencing sediment stability, water turbidity, nutrient and carbon processing and self-purification of ocean ecosystems, help in supplying a variety of raw materials for the growing biotechnology and biomedicine industry¹⁵.

Physical impacts

Trawling is considered as the most important source of human-induced physical disturbance on the seafloor throughout the world¹⁵. Reports on the physical impact of trawl fishing appear more frequently in recent research literature. Bottom-trawl nets can plow deep furrows in the seafloor, remove rock and coral, stir up sediments that smother benthic organisms, and smooth out natural topography, thus resulting in the reduction of structural heterogeneity – an important factor contributing to the abundance of biodiversity at the sea bottom²⁰. The reduction in habitat heterogeneity is a major deterrent in the survival and recruitment of countless marine organisms, including many species that are commercially important. The impact of trawling on the seafloor, which depends upon the speed of towing, the size and weight of the net, type of seabed and strength of currents and tides, may remain as a transitory phenomenon in shallow waters affected by strong tides or persists for several years in deeper areas with lesser disturbance²¹.

Auster *et al.*²² used a remotely operated vehicle (ROV) to obtain video images of the sea-bed in the Gulf of Maine to quantify the physical effects of trawling on the sea bottom. They concluded that both visually and statistically, trawlers greatly reduce the textural complexity of the bottom. According to Auster and Langton¹⁸, the effects of fishing gear must be evaluated not simply in terms of the removal of target and non-target species, but also taking into account other impacts on the environment. The biological and geological implications of the resuspension of sediment due to trawling are not clearly understood, even though it has been proved to reduce photosynthesis.

Impacts on chemical cycles

Trawling activities may affect sediment community function, carbon mineralization and biogeochemical fluxes, because the physical effects of trawling are equivalent to

those of an extreme bioturbator¹⁷. The macrobenthos of the sea bottom are important carbon consumers and their presence reduces the magnitude of available fluxes. Model studies by Duplisea *et al.*¹⁷ showed that in soft-sediment systems, where the level of physical disturbance due to waves and tides is low, intensive trawling disturbance could cause large fluctuations in benthic chemical fluxes and storage.

The dragging of trawl nets may decrease dissolved oxygen, which may be due to the mixing of reduced products such as methane and hydrogen sulphide or the resuspended bacteria attached to sediments exerting an increase in oxygen demand in the water column²³. Formation of sediment clouds in the sea bottom may affect natural balance between physico-chemical parameters in the ocean, further depleting the availability of oxygen²⁴. Trawling was also found to flush out nutrients and contaminants²⁵, and there are possibilities of rise in lethal gases such as ammonia, methane and hydrogen sulphide, affecting the life of organisms in water²⁶.

Studies by Caddy²⁷ have shown that resuspended sediments during trawl fishing hinder the respiratory activity of filter feeders at the sea bottom and result in the resuspension of contaminants, thus enhancing benthic as well as pelagic nutrient flux. Studies in the Gulf of Maine by Pilskaln *et al.*²⁰ recorded that changes in nutrient supply at the sea bottom may have impacts throughout the ecosystem due to nutrient imbalance, affecting phytoplankton growth.

Benthic communities play an important role in remineralization and release of nutrients in marine ecosystems²⁸. Disturbances created by mobile fishing gears temporarily alter the redox state of the system, and thus the rate of remineralization²⁹. Nutrient cycling caused by disturbance of the sediment–water interface, additional organic matter into the system in the form of discarded biomass, continuous transfer of fixed carbon from the marine environment to the terrestrial ecosystem, and changes in the food chain arising from the manipulation of density and size structure of target species may ultimately affect the ecosystem functioning¹³.

The immediate effect of bottom trawling on the physico-chemical parameters in the inshore waters of Kerala³⁰, recorded increase in temperature and nitrates and decrease in dissolved oxygen, organic matter and organic carbon due to the churning action of the trawl net on the sea bottom. The long-term impacts of trawling on biogeochemical processes of the benthic ecosystems remain to be investigated in detail, particularly in tropical waters, with appropriate modelling studies.

Impacts on biodiversity

The seawater–benthic habitat interface is similar to any ecotone in the terrestrial realm. The mechanical penetra-

tion of the sea bed by the ground rope and tickler chains of the trawl net upsets the delicate physical and chemical properties of the habitat, leading to direct mortality of the benthic fauna¹⁴. Several organisms that occur in the path of the net are killed as a result of direct contact with the gear and exposure to predators³¹. The impacts are more severe with beam trawl because of its deeper penetration; even the low impact of trawling may significantly affect sensitive infaunal and epifaunal species inhabiting the upper zones of the sea bed³².

Organisms inhabiting the soft sediments, particularly the biogenic structure-forming creatures creating mounds, tubes and burrows, develop much of their habitat's structure and play a critical role in many population, community and ecosystem processes; the decline and/or elimination of these species and the disturbance to their habitats may affect both structural and functional biodiversity¹⁵. Intensive trawling has been recorded to decrease the density and abundance of sea grasses, polychaetes, molluscs and echinoderms³¹. Depletion of polychaete fauna due to trawl fishing was observed in Kerala coast, India³³. Excessive trawling has also resulted in decline in the proportion of larger size groups of commercial species of shrimps in the Indian coast³⁴.

The trawl net, being an efficient but unselective fishing gear with a small cod end mesh size, captures numerous small-sized species as well as juveniles of larger species, compared to any other fishing gear. The increase in prawn landings in Kakinanda, Andhra Pradesh, during 1970s had been due to the gradual reduction in cod end mesh size of trawl nets; this ultimately results in the reduction of average size of the prawns³⁵. The quantity and quality of juveniles and subadults in the by-catch depends upon the type of trawl net used. In the South Indian states, an annual average of 6200 tonnes of juveniles/young fishes was recorded to be landed by trawl nets. The annual economic loss generated due to catching of juvenile fishes by a single trawler in Kerala coast was estimated as 28.3 lakhs³⁶. The discarding and wastage of huge amounts of juveniles is ultimately a loss to the fishery of the state. Further, intensive trawling during the breeding season of fish and shellfish may affect total marine fish landings³⁷.

In tropical waters, trawl nets can catch over 400 species in their nets⁴. The diversity of species discarded due to trawling in tropical waters would be considerably higher than that in the temperate waters. However, there are only a few studies to substantiate this. Menon⁹ studied the by-catch landings of trawlers in Karnataka, Kerala and Tamil Nadu during 1985–90 and recorded 20 genera of fishes, 26 genera of crustaceans, 23 genera of gastropods, 15 genera of bivalves, 10 genera of echinoderms, polychaetes, anemones, sponges, gorgonids, ascidians and echiuroids, besides a large number of juvenile young fishes and cephalopods. Studies on the impact of bottom trawling on the ecology of fishing grounds and living resources of the Palk Bay and the Gulf of Mannar have shown

the presence of 185 species as by-catch, represented mainly by ground fish, stomatopods, undersized prawns, gastropods, bivalves, inedible crabs, echinoderms, sea weeds and sea grass³⁸. According to Kurup *et al.*¹², the discards of bottom trawlers in Kerala coast were represented by 103 species of finfishes, 65 gastropods, 12 bivalves, 8 shrimps, 2 stomatopods, 12 crabs, 5 cephalopods, 3 echinoderms and 4 jelly fishes; the discards were represented mainly by epifaunal species and juveniles of commercially valuable species. When the by-catch landed at harbours and discards are considered together, biodiversity would be substantially higher. Extensive research is needed in this area to arrive at better conclusions on the effect of trawling on biodiversity. Such an ongoing study on the biodiversity associated with the trawl by-catch (considering both discards and by-catch of trawlers) of Kerala coast shows the presence of five species of reptiles, 262 species of finfishes, 12 species of echinoderms, 140 species of molluscs, four species of prawns, 42 species of crabs, five species of stomatopods, many species of hermit crabs, three species of lobsters, several species of annelids, one species of sipunculid worm, one species of bryozoan, seven species of cnidarians, and three species of sponges (A. Bijukumar, unpublished data).

There are studies that showed changes in community composition of marine benthic communities as a result of trawling. Communities in the areas closed for trawling in European waters were dominated by higher biomass and emergent fauna that increased habitat complexity, while areas of the sea frequently fished by trawl net were dominated by smaller-bodied fauna and scavenging taxa (opportunistic species) such as crabs, star fish, sea urchins, whelks, etc.³⁹. Continued subtraction of target species from the ecosystem and abundance of food in the form of discarded biomass coupled with reduced predation and competition increase the abundance of non-target species, particularly scavengers⁴⁰. Trawling results in increased rate of recycling of macrobenthic fauna and fish through the food web and removes large predators from the ecosystem, resulting in increased populations of small commercially less important fishes such as gobies³⁴. The impacts of frequent removal of benthic organisms due to trawling on the complex marine food web have not been understood in detail.

The incidental capture of endangered species as by-catch is a matter of great concern for the future of the fisheries. Perhaps the issue of greatest concern in warm water shrimp fisheries is the accidental capture of sea turtles in shrimp trawl nets. In the Orissa coast of India alone, more than 100,000 dead olive ridley turtles have been reported since 1994, mainly due to fisheries-related mortalities, resulting in possible decline in their population⁴¹. Reports on cetacean mortalities associated with trawling are not available from the coastal waters of India. According to Hanfee⁴², the landings of elasmobranchs as by-catch in India are high, but absence of reliable data on the levels of by-catch, survival rate of discards, and on the popula-

tions of deep sea sharks handicaps their conservation in Indian waters, even though many of these species are protected under the Indian Wildlife (Protection) Act (1972).

By-catch utilization in India

While in the West almost all the by-catch is discarded, in countries like India by-catch is brought back to the landing centres because of its economic utilities. For example, in Gujarat, the largest producer of marine fishes in India, the by-catch is utilized mainly for fish meal and fish manure production⁴³. Recent publications, particularly by the experts associated with the FAO, unambiguously admit to the lack of scientific information on the issue of by-catch and its utilization^{2,3}. The Code of Conduct for Responsible Fisheries calls on states to 'encourage those involved in fish processing, distribution and marketing to improve the use of by-catch to the extent that is consistent with responsible fisheries management practices'⁴⁴.

In India, the total catch is deposited in the deck of the trawler after each haul is sorted and economically valuable species such as shrimps, lobsters, large crabs, large cuttle fishes, edible fishes, gastropod molluscs such as *Babylonia* sp. and *Turbinella pyrum* (sacred chank) are separated and stored in ice. In large trawlers performing 'stay-in fishing', the target species are stored in refrigerated fish holds, and non-target species are thrown back into the sea. Some of these trawlers bring back the last day's by-catch to the landing centre to be used as food, manure and animal feed (Figure 1). Larger, economically valuable fish and shell fish in the by-catch are marketed fresh. Smaller varieties or larger species present in abundance (soles, *Lactarius*, lizard fishes, anchovies, carangids, sardines, mackerels, etc.) are either sun-dried or salt-dried. Major quantity of the sun-dried specimens is used for local consumption, while some quantity is exported⁷.

Several improved fish processing methodologies have been perfected by the Central Institute of Fisheries Technology (CIFT), Cochin, for by-catch species. A variety of speciality products such as fish paste, fish sausages, fish pappads, fish wafers, fish spirals, fish save, fish diamond-cuts, fish jam, fish noodles and canned fish paste products have also been prepared from the by-catch species usually wasted. CIFT has also standardized a method for preparing fish silage (poultry and animal feed) from cheaper by-catch fish species.

During 1971–79, CIFT had conducted a detailed study under an all-India co-ordinated research project on transportation of fresh fish and utilization of trash fish. Several products were prepared from the by-catch species, and some of the technologies have been transferred for development of value-added products. One such example is preparation of fish protein concentrate from different trash fish species in the by-catch. Bacteriological peptone from threadfin bream was also developed and put to com-

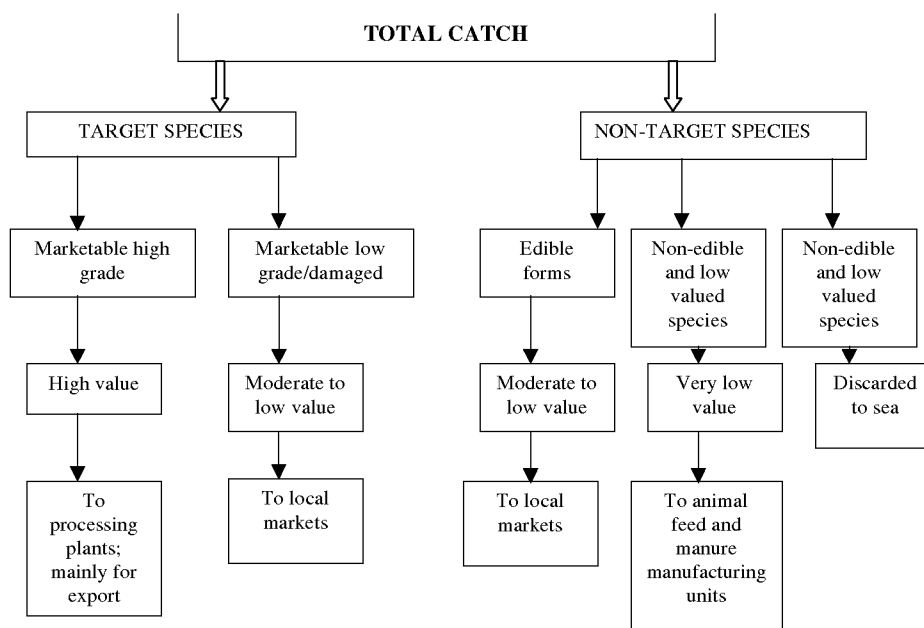


Figure 1. Utilization of the catch of trawlers in India.

mercial production for use as a growth-supporting compound in microbiological media formulations⁷. Pickled fishery products hold promising prospects as substitutes for canned products for domestic and international markets and also have the advantage that cheaper by-catches may be used for this method of preservation⁴⁵. Many species landed in India as trawl by-catch could be effectively utilized for the production of value-added products⁴⁶.

In countries like India, where per capita protein availability is below the recommended level, proper utilization of by-catch from trawlers is important, as it is found to be a good source of protein and minerals⁴³. Since for many species the 'appearance' is not flattering for consumers, production of value-added products from the by-catch should be given priority. Further, the technologies/methods developed by the research centres have not been implemented in large scale by entrepreneurs. As a result, a lion's share of the by-catch finds its way to manure and animal feed manufacturing units, denying the rich protein sources to the malnourished populace.

By-catch reduction: Devices and policies

The high economic value of shrimps has been the primary reason for the expansion of trawl fishing throughout the world. When we consider the fact that a third of the production from modern fisheries is destined for use as fish meal or other secondary products, it could be considered as a loss for human food security. This also involves the export of fishmeal and oil from the developing countries where malnutrition is an unembellished issue, to the wealthy developed world. Even though it can be argued that better

utilization of by-catch is a solution to the problem, its impact on the fish stock and traditional fishers remains to be investigated, particularly when taking into account the mammoth amount of juveniles of economically valuable species caught in the trawl net. Further, there is a total hiatus in scientific information in tropical waters with regard to the ecosystem services and functions rendered by the species wasted along with trawl by-catch, as well as their role in the complex food web of the ocean. While majority of the phyla in our planet is represented in oceans, more attention needs to be focused on the impact of modern fishing methods on marine biodiversity as well as ecosystem functioning.

The relation of the efficiency of the trawl net with its contact with the sea bottom is the major bottleneck in reducing mortality of benthic organisms due to bottom trawling. Occurrence of high quantities of by-catch demands immediate interventions in trawl designs, so that the amount of by-catch retained in the trawl nets could be brought down considerably. A variety of techniques have been developed in many parts of the world to improve the species selectivity and size selectivity of trawl nets and to reduce the by-catch levels, particularly aimed at bringing down the mortality of juveniles and young ones of commercially important species. One of the major issues associated with trawling is incidental capture of endangered sea turtles in the trawl net. Devices developed to eliminate sea turtle by-catch and reduce the non-target species and other unwanted catch in shrimp trawling are collectively known as by-catch reduction devices (BRDs) and those meant for excluding turtles are called turtle excluder devices (TEDs). While technological innovations such as TED have been proved to reduce by-catch considerably, their

use has not been made legally binding in many countries and in countries like India, the proven technologies for by-catch reduction have not been put into practice. For example, CIFT has developed indigenous square-type window attachment, radial-type escapement device, fish eye, grid with guiding funnel and escape opening, etc. to reduce by-catch in trawl nets⁴⁷. The juvenile fish excluder cum shrimp sorting device, a system of angled metal grids and net meshes that work to reduce by-catch of undersized shrimp and fish in trawls, developed by CIFT has been awarded at the International Smart Gear Competition 2005. The TED developed by CIFT (CIFT TED), has been distributed by Marine Products Exports Development Agency (MPEDA) and this has been made mandatory in Orissa.

Even though better designs have been forwarded by researchers which facilitate by-catch reduction in trawl net, policy makers often fail to make use of these technologies because of various reasons, primarily anticipating resistance from mechanized fishing sectors. This situation warrants more awareness programmes, highlighting the need for reducing by-catch levels and conserving endangered species such as sea turtles often caught in trawl nets. Any attempt to implement the by-catch reduction strategies without the support of fishermen and boat owners will become a futile exercise.

Increase in cod end mesh size will increase the selection factor and retention of juvenile fishes and smaller species could be considerably reduced⁴⁸. The present cod end mesh size of trawlers operating from Indian waters is as low as 8–10 mm, against the 35 mm stipulated by law⁴⁹. Absence of effective surveillance systems promotes frequent violation of rules by trawlers and facilitates their entry into inshore waters and use of trawl nets with lesser cod end mesh size. Ironically, researchers established that large-meshed trawl nets perform better in the Indian coast without much reduction in catch⁵⁰.

The quick release of non-target species back to the sea may also help in reducing their level of mortality. However, detailed scientific studies are needed in the tropical waters to assess the survival rate of organisms within the net and on-board, before they are being discarded back to the sea. As higher occurrence of by-catch and their mortalities are recorded during night hours, night trawling should be banned, as stipulated in the Kerala Marine Fishing Regulation Act.

Individual quota system practised in the West is not suitable in India, considering the free access to oceanic resources and the larger number of fisherfolk involved in fisheries. Further, fixing the size of by-catch to be caught by individual trawlers has become counter productive in real terms, as this is reported to enhance discarding⁵¹. Seasonal closure of trawling, particularly during the breeding season of most of the valuable fishery items, would help conservation of marine fishery resources. The expert committee appointed by the Government of Kerala recommended

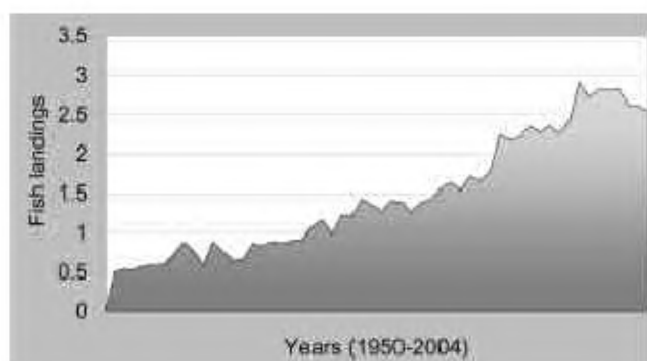
a total ban on trawling by all types of vessels in the territorial waters of Kerala during June–August⁵². The Government of Kerala had imposed a ban on monsoon trawling since 1988 in the Kerala coast, with a duration of 21 to 71 days. Many of the maritime states in India have adopted this strategy in order to sustain the availability of fishery resources. The marine fishery landings in the post-trawl ban period had increased substantially in Kerala⁵³; marine fish and shellfish landings had increased from an average of 3.5 lakh tonnes in the pre-trawl ban period to 5.7 lakh tonnes in the post-trawl ban period⁵³ (Table 1). According to Sreedevi and Kurup³³, monsoon trawl ban in the Kerala coast for 45 days helped in the recoupment and regeneration of polychaete fauna up to 50 m depth in the Cochin–Munambam area. As the breeding season of commercially valuable species varies in the east and west coast of India and around the islands, a similar trawl ban during the peak breeding season of commercially valuable exploited marine species would help in sustainable utilization of fishery resources in India. This demands further research on the breeding biology of all the major commercially valuable species in Indian coastal waters.

The marine fish landings in India increased from 0.5 metric tonnes (mt) in 1950 to 2.54 mt in 2004 (ref. 49) (www.cmfri.com) (Figure 3). The significant increase in marine fish landings during this period is primarily due to the introduction of fishing methods such as trawling; about 50% of the total marine capture fisheries in India is the contribution of trawlers. Estimates of the Ministry of Agriculture (1991), Government of India showed that the annual catchable potential (the biomass that could be exploited annually without depleting the stocks) of marine fisheries of Indian waters is 3.9 mt (2.22 mt from inshore and 1.7 mt from offshore waters). However, the catch from the inshore waters (<50 m depth) reached the catchable potential during 1995–2000 (ref. 49). While India still has the potential to exploit the offshore fishery resources, majority of the trawlers are currently operating from the inshore waters. This would further put pressure on inshore fishery resources, when we consider the fact that marine organisms such as eels, catfishes, sciaenids, pomfrets, Indian mackerel and cephalopods have already been overexploited from coastal waters⁴⁹. The Marine Fisheries Regulation Act has been framed by the Government of India with a view to regulate exploitation of marine fish stocks in territorial waters. The maritime states enacted various laws, particularly concerned with marine fishing regulation, following the Government of India directions. Despite the fact that all these regulations spell out the importance of regulating fishing, no serious efforts were made in reducing the by-catch levels and in controlling the number of trawlers, especially those operating within the inshore waters.

In 1998, the Indian coast had 30,979 trawlers ranging from 9 to 17 m overall length and with engines of 40–150 HP capacity, in addition to few offshore registered

Table 1. Marine fish and shellfish landings in Kerala during pre-trawl ban (before 1988) and post-trawl ban (after 1988) periods

Fishery items	Pre-trawl ban	Post-trawl ban	Impact
Marine fish and shellfish	3.5 lakh tonnes	5.7 lakh tonnes	70%
Prawn	33,000 tonnes	55,000 tonnes	60%
Squids and cuttle fish	10,000 tonnes	40,000 tonnes	400%
Perches	20,000 tonnes	54,000 tonnes	150%
Sceanids	30,000 tonnes	90,000 tonnes	300%
Demersal fishes	1,36,000 tonnes	2,62,000 tonnes	70%
Catch in trawl net/unit (kg)	492	702	210

Source: Kurup⁵³.**Figure 3.** Marine fish landings (metric tonnes) in India during 1950–2004.

trawlers of 17–30 m length and 150–400 HP engine capacity⁴⁹. Even though the Kalawar committee appointed by the Government of Kerala⁵⁴ had recommended limiting the number of mechanized trawlers in the Kerala coast to about 1145, there are about 4550 trawlers operating in state⁵⁵. While there is still scope for exploitation of under-utilized deep-sea resources in Indian waters, the number of trawlers should be maintained at optimum level.

Declaration of certain coastal areas closed for trawling would also help in reducing the amount of by-catch as well as conservation of marine organisms from complete exploitation. The concept of no-fishing zones is now gaining popularity in many parts of the world. The Marine Protected Areas (MPAs) in India, represented by National Parks, Sanctuaries and Biosphere Reserves, form only 0.3% of the 8000 km long coastline of India⁴⁹. Even within the MPAs, only a limited fraction is currently protected from fishing. The marine sanctuaries in Gahirmatha, the Gulf of Mannar and the Gulf of Kachch prohibit trawling. Further, the Central Empowered Committee of the Supreme Court of India and the Fisheries Department of Orissa have banned trawling in the offshore areas of the sea-turtle nesting beaches at Devi and Rushikulya, Orissa. Considering the importance of marine biodiversity, more areas should be declared as MPAs, with the involvement of local communities in conservation and management coupled with regulation in fishing.

Fuller utilization of the by-catch, particularly when it is dominated by juveniles, may lead to increased pressure on some stocks of species. Clucas³ discussed several critical points relevant to this issue, showing that much more is involved in conserving marine resources than just utilizing everything that is caught. Since the monetary value of by-catch can be less than a twentieth of the catch of commercial species, there is often little economic incentive for marketing non-target species. Even if efficient at-sea by-catch collection procedures are developed, the availability of fish stocks from the inshore waters may be affected, further augmenting the conflicts between traditional and mechanized sectors, as seen in India.

Hence an ecosystem approach aimed at reduction in fishing effort and modification in the fishing gear to maximally reduce the by-catch would be ideal as the major factor contributing to the by-catch has been identified as ‘systematic overfishing’⁵⁶. The major action that will help in decreasing the by-catch and discard problem in trawling would be the reduction of fishing efforts. The Exclusive Economic Zones (EEZs) of the coastal states embrace about 90% of the world’s marine fishery resources. Adoption of the United Nations Convention of the Law of the Sea in 1982 outlined the rights and responsibilities for the management of the resources within the EEZ of the coastal nations. The Code of Conduct for Responsible Fisheries by FAO⁴⁴ has clearly spelt out the principles and international standards of behaviour for responsible practices in order to ensure long-term sustainability of the marine fishery resources. The fundamental objective of responsible fisheries is to maximize economic returns to the fishermen, without affecting the long-term sustainability of the fisheries resource and with minimum impact on the ecosystem. This code emphasizes the need for developing and adopting suitable trawl nets in order to reduce the loss of non-target species, and considers marketing and utilization of by-catch only as a last resort in the management initiatives. Considering the severe ecological and ecosystem damages caused by trawling, adoption of a precautionary approach by regarding ‘no discards’ as a norm² would be appropriate for the conservation of marine biodiversity and ecosystem.

Conclusion

The impacts of trawling on the marine ecosystem, though relatively well researched in temperate waters and reported to hamper the marine ecosystem, remains poorly studied in the tropical waters. In countries like India, the absence of benchmark data on the quantity and quality of by-catch and lack of information on the biology and ecosystem roles of by-catch species coupled with methodological limitations such as absence of control sites or sites protected from trawling, handicap defining strategies and policies aimed at reducing by-catch. However, for ensuring sustainability of oceanic resources, we need to have a precautionary approach which envisages reducing by-catch rather than efforts to fully utilize the by-catch.

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