Fishery Technology
2008, Vol. 45(1) pp : 1 - 22

Impact of Bottom Trawling on Benthic Communities: A Review

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The detrimental consequences of trawling on the marine environment have always been a matter of great concern. Bottom trawling causes physical and biological damages that are irreversible, extensive and abiding. The present communication intends to focus the impact on benthic communities caused by bottom trawling. The different methodologies used world wide to study the impact of trawling is depicted here. The quantification and characterisation of bycatch will give an ample evidence of impact of bottom trawling. The interpretation of the available historical data of the trawling grounds is also in practice. The experimental trawling brings to light the physico-chemical and biological impacts. The dietary shifts in benthos are an indirect effect of trawling. Bottom trawling imparts both short term and long-term impacts. The long term effects have not been adequately studied as the impacts are ambiguous and are difficult to interpret. In India, studies on impact of bottom trawling has gained momentum by the establishment of Ocean and Atmospheric Sciences and Technology Cell (OASTC) supported by the Ministry of Earth Sciences. These studies have brought to light the impact of trawling on hydrographical parameters and benthic fauna.

Keywords : Impact, bottom trawling, benthic fauna, India

Fishing is a fundamental cornerstone in the ethnicity of coastal communities and has been persisting for millennia. The conventional system of fisheries management was intended to promote the landings of economically important species. With this motive, the fishing effort increased in the last 100 years with the mechanization of commercial fishing boats, improved harvest technology and advanced navigational know-how. But in the long run, the aim to optimize the catch resulted in the decrease of the targeted species. The Code of Conduct for Responsible Fisheries proposes in article 12, which deals with Fisheries Research, to carry out studies on the environmental impact of fishing gear to aid fisheries management studies and to safeguard the biodiversity of ecosystems (FAO, 1995). The fishing operations contributing to deterioration of marine ecosystem are towed fishing gears like trawling and dredging which over the years have emerged as the most important fishing methods in the world. The detrimental consequences of gears dragged over the seafloor have always been a great concern. The major gears causing impact vary from otter trawls, beam trawls, scallop dredge to even the rapido trawl which is a kind of beam trawl operated in the northern Adriatic Sea (Pranovi *et al.*, 2000).

Studies have shown that bottom trawling is among the most destructive human induced physical disturbances inflicted to seabed and its living communities (Jennings and Kaiser, 1998; Watling and Norse, 1998; Hall, 1999; Kaiser and de Groot, 2000; Kaiser *et al.*, 2000, 2001, 2002; Koslow, 2001; Bhat, 2003; Gowda, 2003; Zacharia *et al.*, 2005 & 2006; Kurup, 2004b; Raman, 2006). The bottom trawls are designed to tow along the sea floor, which on its operation indiscriminately smashes everything on their way crushing, killing, burying and exposing to predators the benthic fauna. Apart from generating enormous bycatch and discards removal of organic matter by dispersion,

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alteration of sedimentation pattern, variations in sediment-water column fluxes, changes in predation rate, transformed population structure of predatory organisms are the other major consequences. A shift in benthic assemblage will have far-reaching consequences such as species replacement; threat to biodiversity and fishery potential and as a whole affecting the entire ecosystem. Thus it causes physical and biological damages that are irreversible, extensive and long lasting (Hall, 1999; Kaiser & de Groot, 2000). Jones (1992) described the impacts inflicted to the benthic realm as direct and indirect effects. The discards, sediment scraping, resuspension of finer particles and damage of benthos by removal and destruction being direct effects and stress suffered by benthos like post-fishing mortality of damaged fauna and the long lasting alterations as indirect effects (Jones, 1992).

Benthic fauna and its significance

Benthos refers collectively to all aquatic organisms that live in, on or near the bottom of a body of water. The benthic community is made of a wide array of plants, animals and microbes, forming an important component of aquatic food web. Based on the functional status, benthos is classified as infauna, epibenthos and hyperbenthos, those organisms living within the substratum, on the surface of the substratum and just above it respectively (Pohle & Thomas, 2001). According to size, benthic animals are divided into three groups (i) macrobenthos (mesh size: 0.5 mm and 1 mm) (ii) meiobenthos (0.5 mm and 63m and (iii) microbenthos (Mare, 1942). The microbenthos are those organisms that are not retained in the finest sieve used for meiobenthos separation and include bacteria and most protozoans. The benthic fauna though of little edible value to humans, occupy key position in the marine food web. They provide food for benthic fishes (Damodaran, 1973), recycle the nutrients, act as indicator organisms and continuously enrich the planktonic community that in turn forms food for pelagic fishes (Levington, 1982).

Methodologies for studying impact of trawling

Jones (1992) reviewing the studies on bottom fishing impacts interpreted that the results of different studies are allied to the weight of the gear on the seabed, its towing speed, the sediment texture and the influence of tides or currents. His view was supported by Lokkeborg (2005) for evaluating the studies on bottom fishing impacts conducted for a period of 15 years.

Studies on the impact of bottom trawling have quantified bycatch landed and discarded from bottom trawlers. Andrew & Pepperell (1992) estimated a global bycatch of 16.7 million tonnes in world shrimp fisheries. Alverson *et al.* (1994) approximated a world bycatch level of about 29 million tonnes out of which 27 million tonnes were discarded. According to the recent reports of FAO (2004), about 35% of global bycatch is a consequence of trawling and the average annual global discards are around 7.3 million tonnes during 1992-2002. A major portion of the bycatch and discards form epifaunal component of benthic ecosystem (De Groot, 1984; Menon, 1996; Watling & Norse, 1998; Kurup *et al.*, 2004). Bycatch and discards pose a threat to biodiversity and long-term sustainability of fishery resources.

According to Lokkeborg (2005) experimental trawling can be conducted on a site followed by a comparison of the physical and biological parameters at this site before and after the disturbance and / or with an undisturbed control site. Sparks & Watling (2001) investigated the effects of trawling disturbance on a soft-sediment system with experimental trawling in an area that had been closed to shrimp trawling activities for

20 years which altered chlorophyll content. Immediately after the trawling, the number of species, species abundance and diversity decreased and the sensitive species recorded were bivalves and polychaetes.

Lindegarth *et al.* (2000) tested the effects of trawling disturbances on temporal and spatial structure of benthic soft sediment assemblages in Gullmarsfjorden, Sweden which was previously protected. The spatial and temporal variability in the structure of assemblages after one year of trawling was comparatively larger at the trawled sites than at the untrawled sites. A 3-year (1993-1995) otter trawling experiment conducted on a deep-water sandy bottom ecosystem on the Grand Banks of Newfoundland that had not experienced trawling for 12 years (Kenchington *et al.*, 2001; Prena *et al.*, 1999) revealed that the width of the disturbance zones. Samples collected with an epibenthic sledge showed a significant reduction in the biomass of large epifauna. The benthic macrofauna were sampled before and after trawling (Prena *et al.*, 1999) and as an immediate effect of trawling, the abundance and biomass of polychaetes were found significantly lower. According to Kenchington *et al.* (2001) the trawling disturbance appeared to mimic natural disturbance and no distinctive trawling signature was observed.

Many authors mention that historical data is advantageous for the study and interpretation of impacts in a trawled ground. But a suitable control site rarely exists in historical data (Lokkeborg, 2005).According to him a comparative study on commercial fishing grounds that are heavily and lightly fished will bring out the impact. Several studies on impact of trawling have been conducted by comparing the fauna of closed and open areas of fishing in the Gulf of Alaska (Stone & Masuda, 2003), off Devon in United Kingdom (Kaiser *et al.* 2000) and in areas of Emerald and Western banks in Northwest Atlantic Ocean (Fisher, 2004).

Physico-chemical impacts

Turbidity

Experimental trawling in the muddy unfished continental shelf of North Western Mediterranean showed an increase in turbidity of the water column after trawling Palanques *et al.* (2001) . According to Watling & Norse (2003), frequent suspension of sediment will affect the suspension feeders. High levels of suspended sediment will increase the relative abundance of fish that locate food by touch or chemical sensors, and decrease those reliant on vision.

Dissolved Oxygen

The decomposition of enormous amounts of discarded bycatch that settle down to the bottom leads to oxygen depletion, often termed as ground poisoning or spoiling (Alverson *et al.*, 1994). According to Warnken *et al.* (2003), repeated trawling will result in removal of the upper oxic sediment layers and would create anoxic surface sediments. The mixing of reduced products such as methane, hydrogen sulphide and resuspended particulate material like bacteria attached to sediments exert an increased oxygen demand in the water column (Riemann and Hoffmann, 1991).

Kaiser *et al.* (2002) suggested that the effects of low levels of trawling disturbance would be similar to those of natural bioturbators. But intensive trawling would cause sediment systems to become unstable due to large carbon fluxes between oxic and anoxic carbon compartments. In deeper areas with softer sediments where levels of natural disturbance due to wave and tide are low and trawling disturbance at low levels, the macrofauna take the role of natural bioturbators, consume carbon and reduces the magnitude of available carbon fluxes. In contrast to this, chronic trawling intensity *prevents the sediment system from reaching* equilibrium due to large carbon fluxes between oxic and anoxic carbon compartments. (Duplisea *et al.* 2001).

Nutrients

According to Pilskaln *et al.* (1998), the extent of trawling-induced sediment resuspension determines the regional nutrient budgets. The resuspension imparts input of sedimentary nutrients into the water column. The nutrients released will cause abnormal algal blooms, causing further depletion of oxygen and liberation of lethal gases (Churchill *et al.*, 1988).

Chlorophyll Content

Aspden *et al.* (2003) observed a significant difference in the chlorophyll *a* content of surface sediment before and after experimental trawling at Lagoon of Venice, Italy. On soft bottom habitat, chlorophyll *content* of the trawled surface sediments significantly elevated immediately after the trawling disturbance (Sparks & Watling, 2001). Smith *et al.* (2000) observed significant differences in sedimentary chlorophyll and phaeopigments between stations during the trawling season along eastern Mediterranean commercial trawl fishing ground.

Pollutants

According to Kaiser *et al.* (2002), along with the resuspension of the upper layers of sedimentary seabed, bottom trawling remobilized the contaminants into the water column. The shrimp trawling experiments conducted in Galveston Bay showed that the pre and post-trawl fluxes of oxygen, ammonium, silicate, manganese, nickel, copper and lead in sediments, did not differ significantly, while the flux of cadmium was affected (Warnken *et al.*, 2003).

Sediment texture

De Biasi (2004) found an increase of the clay percentage immediately after trawling with simultaneous decrease in silt percentage. According to Palanques *et al.* (2001), the sediment texture showed an increase in silt content of the surface sediment during first hour after experimental trawling in the muddy *unfished continental shelf of north*-western Mediterraneanand *this was attrib*-uted to the settling of resuspended particles. The change was temporary as one day after trawling the surface sediment had a grain size pattern analogous to that of before trawling. Schwinghammer *et al.* (1998) could not find any transformation in sediment grain size in sandy areas of Grand Banks of Newfoundland. On conducting experimental beam trawling in the sandy substratum of Belgian and Dutch coast, Fonteyne (2000) found that the resuspension of lighter sediment is pronounced in finer sand substratum. Ball *et al.* (2000) pointed out that undisturbed muddy sediments need longer recovery time than dynamic coarser sediments.

Organic Matter

The sedimentary organic matter forms the basis of energy supply for the marine food web, as it is the abode of nutrition for deposit feeders (Levington, 1982). The studies conducted by Schwinghammer *et al.* (1998) at sandy bottom of the Grand Banks of Newfoundland showed that trawling changed the individual sediment grains to smooth, clean and light in colour. This change was attributed to the reduction in biogenic sediment structure and flocculated organic matter. Smith *et al.* (2000) observed significant differences in sedimentary organic carbon between stations during the trawling season along *eastern Mediterra*nean commercial trawl fishing ground. Contrary to the reduction of sedimentary organic carbon, the carcasses generated from discards and heavy mortality of benthos would in turn elevate the organic matter input into the benthic realm (Frid & Clark, 2000).

Biological impacts

Epifauna

Fishing activities causes direct mortality of benthos as bycatch and net-damaged organisms (Frid & Clark, 2000; Clark, 1999). The complex seafloor habitats of seagrasses, seamounts and coral reefs that provide food, nurseries and shelter for a variety of marine organisms are destroyed by bottom trawling activities. These habitats have the longest recovery rate and take years to recolonise (Kaiser *et al.*, 2002; Gianni, 2004; Rosenberg *et al.*, 2003). Bottom trawling caused elevated fine sediment composition leading to regression of the sea grass *Posidonia oceanica* (Ardizzone *et al.*, 2000; Tanner, 2003) and deep-water corals *Lophelia pertusa* (Fossaa *et al.*, 2002). The benthic fauna of seamounts of Newzealand waters is under the stress of bottom trawling for orange roughy (Koslow *et al.*, 2000; Clark & Driscoll, 2001; Clark *et al.*, 2004). At the 7th Conference of the UN Convention on Biological Diversity (2004), scientists of 69 countries signed a proclamation calling United Nations to ban bottom trawling in high seas, especially where coral reefs were known to occur within their Exclusive Economic Zone (www.mcbi.org). Considering the destruction imposed by bottom trawling to coral reefs, the U.S Government called the North Pacific Fishery Management Council to ban commercial trawling near the Aleutian Islands which is an abode of food resources for the Alaskan fishery (Anon, 2005).

Investigations on the short-term destructions imparted by trawlers in the Gulf of Alaska indicated that 14 - 67% of large sessile epifauna was damaged and densities of these epifauna were significantly higher in unfished reference sites where as the motile invertebrates were not affected. There was a significant decrease in density of sponges and anthozoans in trawled hard-bottom seafloor versus reference transects (Freese *et al.*, 1999, Bergman & van Santbrink 2000b, Ball *et al.* 2000). In muddy habitat epifauna are generally scarce and the effect of trawling is limited when compared to harder sediment habitat. Gastropods suffered the greatest depletion as 95% were removed by the combined effect of 13 trawls on the same track in the Great Barrier Reef of Australia. Ascidians, sponges, echinoids, crustaceans and gorgonians were depleted by 74-86% (Burridge *et al.*, 2003). The epifauna at trawled sites decreased in abundance by 28% within 2 weeks of trawling and by another 8% in the following 2-3 months. Bottom trawling removes predators such as algal-grazing urchins that play a vital role in the food web (Kaiser *et al.*, 2002).

Otter trawling and scallop dredging in gravel sediment habitat of Georges Bank East coast of North America removed the epifauna, thereby reducing the complexity and species diversity of the benthic community (Collie *et al.*, 2000). Jennings *et al.* (2001) studied the effects of bottom trawling on the trophic structure of epifaunal benthic while Jennings & Reynolds (2000) established the impact of fishing on species diversity in the northeast Atlantic. A reduction in fish diversity resulted from the direct mortality of target species and a reduction in invertebrate diversity resulted from the effects of towed gears on the seabed.

Infauna

Other than direct mortality the impact of trawling on the infauna also depends on the alterations imparted to sediment texture. According to Ball *et al.* (2000) bottom trawling resulted in reduction of abundance of large-bodied fragile organisms, an increase in abundance of opportunistic species and a reduction in faunal diversity (Jennings *et al.,* 2001, 2002)

Macrobenthos

The direct mortality due to trawling occurs in the case of gastropods, starfishes, crustaceans, annelids and bivalves in the trawl track (Bergman & van Santbrink, 2000a). McConnaughey *et al.* (2000) examined the impacts of bottom trawling in a shallow, soft-bottom area of the Bering Sea and reported higher densities and diversity of macrofauna in historically unfished areas. They observed drastic variations (both positive and negative) in the abundance of several macrobenthic species between heavily fished and unfished areas. Small-bodied organisms such as polychaetes dominated in heavily fished areas (Kaiser *et al.,* 2002, Simboura *et al.,* 1998).The biomass and abundance of macrofauna decreased significantly after trawling in Gullmarsfjorden, Sweden. The mean abundance of echinoderms, in particular the brittle stars *Amphiura,* decreased significantly after trawling. (Hansson *et al.,* 2000). According to Kaiser *et al.* (1999) no significant changes in composition, size or number were noted in Northeast Atlantic shelf seas that could be attributed to fishing disturbance.

The Silver Pit region of the Central North Sea is regularly fished by beam trawlers targeting sloe and plaice. Jennings *et al.* (2002) investigated the effects of trawling disturbance on the production of benthic infauna. The analyses showed that trawling frequencies of 0.35 to 6.14 times/ year did not have significant effect on the production of small infaunal polychaetes. Since small infaunal polychaetes are a key source of food for flatfishes, they concluded that beam trawling does not have a positive or negative effect on their food supply. While Rijnsdorp & Vingerhoed (2001) reported that intensive beam trawling enhanced the abundance of small opportunistic benthic species such as polychaetes, improving the feeding conditions for flatfishes: plaice (*Pleuronectes platessa* L.) and sole (*Solea solea* L.) Collie *et al.* (1997) revealed that many of the megafaunal species that were identified in the stomach content analysis of demersal fish on Georges Bank, were decreased in abundance at the disturbed sites.Van Dolah *et al.* (1991) studying the effects of shrimp trawling on infaunal assemblages of two estuarine sounds in South Carolina did not have any obvious effect on the abundance, diversity or composition of the soft-bottom communities.

Meiobenthos

Chronic trawling has a significant impact on the composition of meiofaunal assemblages. The number of species, diversity and species richness of the community were significantly lower in the area subjected to high levels of trawling disturbance than in the areas of low or medium levels of disturbance (Schratzberger & Jennings 2002).. The smaller meiofauna that are very productive and have fast generation times are relatively unaffected by trawling disturbance (Schratzberger *et al.,* 2002; Duplisea *et al.,* 2002).

Effects on non-target species

The benthic batoid elasmobranches that feed on benthic organisms like *Dasyatis brevicaudata* and *Himantura jenkinsii* are highly susceptible to capture in prawn trawls and is a bycatch of Australia's northern prawn fishery. Once depleted, the recovery capacity of these species is very low (Stobutski *et al.,* 2002). The beam-trawl fishery for flatfish in the southern North Sea generated huge quantity of dying discards as well as damaged and disturbed benthos (Groenewold & Fonds 2000, Greenstreet &

Rogers, 2000). One third of the total catch produced from bottom trawlers in the northwestern Mediterranean constituted discards, which consisted of 135 species of fishes, 60 crustaceans, 44 molluscs and 70 other invertebrates (Sanchez *et al.*, 2004). Rogers *et al.* (2001) found that the proportion of damaged starfish *Asterias rubens*, increased with intensity of bottom-trawl activity at the Irish Sea and Bristol Channel.

Dietary Shifts

Trawling will definitely result in increased food subsidies in the marine environment. Demestre *et al.* (2000) studied the behaviour of scavengers and predators in response to otter-trawling disturbance in muddy sediments in the North-West Mediterranean. The intensive beam trawl fishery for sole and plaice in the southern North Sea (off the coast of Netherlands) produced large amounts of discards and damage to benthic fauna. Seabirds scavenge on the discards but the major fraction sinks to the sea floor providing additional food source to the benthic scavengers and predators enhancing secondary production (Groenewold & Fonds, 2000). Trawling results in an increased rate of recycling of benthic fauna and fish through the food web due to food subsidies generated to opportunistic scavengers (Fonds & Groenewold, 2000, Ramsay *et al.*, 1998, Laptikhovsky & Arkhipkin, 2003).

Dietary shift in relation to trawling have been noticed for *Diplodus annularis* of sea grass *Posidonia oceanica* and *Diplodus annularis* (Rodriguez *et al.* 2002) and flatfishes (Anon, 2003). Engel & Kvitek (1998) suggested that trawling enhanced the abundance of polychaetes increasing the food resource for commercially important flatfishes off central California while in the North sea the small macrofauna that increased in abundance after trawling do not form food for fishes (Duplisea *et al.*, 2002). As fishing effort intensifies, the depletion of natural prey items and starfish mortality due to fishing cause a reduction (Ramsay *et al.*, 2000). The response to (bream) trawl disturbance varied in behaviour with sympatric species as noted for hermit crab, *Pagurus bernhardus* and *P. prideaux* (Ramsay *et al.*, 1996).

Camphuysen & Garthe (2000) pointed out that any shift in fishing effort or changes in the fishery policy could have unexpected side effects on seabirds. Most North sea seabirds have increased in number over the last century. An additional source of food availability on account of discards from trawls attributes to this spectacular increase. But he also suggested that the gross overfishing of large predatory fish can lead to decline in the seabird population.

A range of epibenthic species like crabs, echinoderms readily utilize invertebrates discarded from trawlers (Groenewold & Fonds, 2000; Collie *et al.*, 1997). In field and laboratory trials, heavy-shelled dead whelks (*Baccinum undatum* and *Neptunea antiqua*) sank very fast making most discards available to the benthos within minutes after discarding (Bergman *et al.*, 2002). In Ebrodelta of NW Mediterranean the consumption of discarded demersal fish increased the level of mercury in seabirds whose natural prey consisted of epipelagic fish (Arcos *et al.*, 2002). The short-lived species are favoured while long-lived species are more adversely affected, with the outcome that the disturbed communities will favour scavengers, predators other than fishery target species (Keegan *et al.*, 1998).

Long-term effects

Thayer (1999) suggested that bottom trawling turns out to cause colossal devastation affecting the long-term sustainability of coastal marine living resources. Most experimental studies have shown that it is possible to detect short-term changes in community structure in response to fishing disturbance. But studies on long-term effects are meager. The long-term impact of bottom trawling on a particular species is difficult to interpret as it will depend on a combination of factors like the direct mortality at each fishing event, the distribution of the fishing effort, the distribution of that species, its life history characteristics such as longevity and fecundity and above all the interference of natural perturbations. Long-living fragile species with a low fecundity and not frequently disturbed by natural events will be affected more than short-living species with high fecundity. The opportunistic species, like members of the polychaete family Spionidae, are characterized by high growth rates, a short life span, a low reproductive age and a large reproductive output (Craeymeersch *et al.*, 2000; Kaiser, 1998). The long-term effects of trawling was ascertained by the experimental trawling in a fine muddy habitat of Scotland for more than 25 years the results showed experimental trawl disturbance over an 18-month period on benthic community structure and also the succeeding patterns of recovery over a further 18-month period were monitored (Tuck *et al.*, 1998). Kaiser & Spencer (1994) suggested that this can lead to alteration of long-term community structure. Kaiser (1998) noted that a survey on organisms that record disturbances of the past in their shells or body structure (eg. bivalves, echinoderms) can give a picture of long-term effects. Effort reductions or permanent area closures should be considered as a management option. This would lead to a single but permanent redistribution of fishing disturbance, with lower cumulative impacts on benthic communities in the long run (Dinmore, 2003).

A three-year experiment to examine the effects of repetitive otter trawling on a sandy bottom ecosystem at a depth of 120-146 m on the Grand Banks of Newfoundland showed that immediate and long-term effect on infauna was minor. The whole biological community recovered from the annual trawling disturbance in less than a year, and no significant effects could be seen on benthic community after 3 years of otter trawling (Gordon *et al.* 2002).

Several studies have accounted for the variations in food resources and dietary shifts of fishes in relation to trawling (Anon, 2003; Rodriguez *et al.*, 2002; Duplisea *et al.*, 2002; Engel & Kvitek, 1998). The bycatch and discards generated from bottom trawlers also adversely affect the fishery (Alverson *et al.*, 1994).

Studies conducted in India

Trawling was introduced and established in India with an active initiative of the Central Institute of Fisheries Technology (CIFT) along with other Government Organisations like erstwhile Indo-Norwegian project. Many designs of two seam trawls, four seam trawls, six seam trawls, multiseam, bulged belly trawls, high opening trawls and large mesh trawls etc. were designed, experimented and developed by the institute. Bottom trawling is in practice in India for nearly 50 years (Pravin & Vijayan, 2002). Even though several studies have been conducted in temperate waters on the impact of bottom trawling, such works in tropical waters remains poor (Bijukumar & Deepthi, 2006). The Ocean and Atmospheric Sciences and Technology Cell (OASTC) supported by Ministry of Earth Sciences initiated five projects in Indian waters covering the coasts of Karnataka (Zacharia, 2003; Bhat, 2003; Gowda, 2003), Kerala (Kurup, 2004b) and Vishakapatanam (Raman, 2006). These studies give a picture of impact of bottom trawling. In all these studies the bycatch and discards generated from commercial trawlers were quantified and characterised. Experimental trawling was conducted at predetermined depths in the commercial fishing grounds to assess the impact after trawling. In Kakinada coast, an untrawled area was sited and unimpeded trawling was conducted for 72 hours. Apart from these studies, the dislocation of non-edible biota by the bottom trawlers was surveyed by Jagadis *et al.* (2003) in the Palk Bay and Gulf of Mannar, along the southeast coast of India while Menon *et al.* (2006) conducted a similar study along the southwest coast of India. The maximum percentage of by-catch in India is from Gujarat (92.58%) (George *et al.*, 1981). The quality of catch has been altered significantly in that the large sized and high value fish is declining and the small-sized and low value fish is dominating the catch. The landings of high value species like lobsters, whitefish, pomfrets, threadfins, eels, penaeid shrimps, etc are declining while low valued croakers, non-penaeids, crabs, etc are supporting the catch (Nair *et al.*, 2003; Zofair *et al.*, 2003).

Physical impacts

Hydrographical parameters

All the studies conducted in India revealed the impact on the environmental parameters immediately after trawling. Significant increase in turbidity is noticed after trawling (Bhat, 2003; Gowda, 2003; Zacharia, 2006; Thomas *et al.*, 2004; Bhat and Shetty, 2005). In bottom waters the dissolved oxygen decreased (Bhat, 2003; Gowda, 2003; Thomas *et al.*, 2004; Bhat and Shetty, 2005) while the concentrations of nitrite- nitrogen, inorganic phosphate and chlorophyll pigments increased (Kurup, 2004b; Thomas and Kurup, 2004). The variations in temperature, salinity and pH due to bottom trawling were found to be insignificant (Thomas *et al.*, 2004; Zacharia *et al.*, 2005; Thomas and Kurup, 2006a & 2006b).

The increase in turbidity is due to the churning up of sediments and may leave the seabed with permanent sediment clouds in the water column. The reduction in dissolved oxygen after experimental trawling was attributed to the churning action of trawl nets on sea bottom (Thomas *et al.*, 2004; Thomas and Kurup 2006a, 2005b). Two fold increase in chlorophyll pigments was ascribed to the release of sediment chlorophyll along with sediment particles dispersed during trawling, decreasing the chlorophyll pigmentation of the sediment (Thomas, 2003).

Sediment characteristics

Owing to a reduction in clay fraction, the sediment texture altered into more sandy and silty after trawling in the muddy bottom of 0-40 m depth (Thomas & Kurup, 2005a, b, c). A reduction was also observed in clay proportion after trawling along Mangalore coast Zacharia *et al.* (2005) and Kakinada along Visakhapatnam coast (Raman, 2006). A reduction in organic matter is also noticed along Cochin coast (Thomas and Kurup, 2005a, b, c; 2006a).

Biological impacts

Epifauna

According to Bhat (2003) and Raman (2006) the mostly affected epifaunal component is the invertebrates. The damage inflicted to epifauna was clearly evident from the enormous amount of dead shells obtained in trawled areas off Vishakapatanam comparing to untrawled areas (Raman, 2006). The most concerned issue in the trawl catches of Karwar coast was the invertebrate shell landed in substantial quantities and disposed (Bhat, 2003; Bhat and Shetty, 2005). In single day fleet off Karwar and Tadri (Karnataka) the major proportion of the total catch was non-targeted bycatch (45%) when compared to the targeted shellfishes (14%) and finfishes (45%) (Menon *et al.*, 2006). Apart from invertebrate shells many other epifaunal assemblage form a major component of discards. The squilla that forms the major discards off Karwar coast is being utilized in the manufacture of fertilizer and poultry feed (Bhat, 2003; Bhat and Shetty 2005). 12% of total trawl landings along southwest coats of India constituted of stomatopods and non-edible biota (Menon *et al.*, 2006). The quantity of epibenthos discarded from the bottom trawlers of Kerala was 1.68 and 1.31 lakh tonnes in the period 2000-01 and 2001-02 respectively. The species composition of the epibenthos discards revealed that crabs (*Charybdis smithii*) were dominant followed by stomatopods (*Oratosquilla nepa*), gastropods (*Turritella maculata*), juvenile shrimps & finfishes (20%), soles, echinoderms, jellyfishes, hermit crab, gorgonids and eggs of squid (Kurup *et al.*, 2004; Thomas and Kurup, 2005b; Menon *et al.*, 2006). Along Mangalore coast the dominant group discarded in single day fishing (SDF) trawlers was stomatopods while finfishes formed the dominant group in multiday fishing (MDF) trawlers (Zacharia, 2006a). The major proportion of bycatch landed in SDF along Mangalore also constituted of stomatopods (90%). The dislocated fauna mainly comprised of the benthic fauna with the non-edible crab forming the dominant group followed by echinoderms, stomatopods, molluscs, sponges and seapens at Rameswaram and Pamban (Jagadis *et al.*, 2003). Quantitative and qualitative data on the discards of bottom trawling are reported by Kurup *et al.* (2003) & Zacharia *et al.* (2006a) which gives a fair picture of the discards.

Infauna

The destruction caused to infauna by bottom trawling activities is clearly evident from the results of the studies of Gowda (2003), Zacharia (2003), Kurup (2004a,b), Krishnan *et al.* (2005), Thomas & Kurup, (2005c, 2006b) and Thomas *et al.* (2006).

Macrobenthos

Increase in the abundance and biomass and subsequent decrease in diversity indices of macrobenthos is noted as an immediate effect of trawling (Gowda, 2003; Zacharia, 2003; Kurup, 2004b; Krishnan *et al.*, 2005). The bivalves, gastropods, polychaetes, foraminiferans and scaphopods generally showed an increase after trawling while some of the gastropods like *Cerithium* spp, *Cavolina* spp, and *Strombus* spp. decreased after trawling (Zacharia, 2003, Thomas and Kurup, 2005c; Thomas *et al.*, 2006). The increase in number of polychaetes has been attributed to the survival of opportunistic species in response to bottom trawling (Gowda, 2003; Kurup, 2004b). The experimental trawling operations conducted for a period of 2 years along Kerala coast showed that the abundance, biomass and diversity of the polychaetes increased immediately after trawling. This was attributed to their exposure due to the removal of top sediment. The polychaete abundance decreased in the second year compared to the first year. According to Thomas and Kurup, (2006b) fast growing and continuous breeding species dominated the trawl ban period.

Meiobenthos

Studies conducted at Kerala and Mangalore showed that after trawling there was a significant increase in the density of nematodes and foraminiferans while that of harpacticoids, polychaetes, kinorhynchs and molluscs decreased. The diversity indices reduced after trawling (Zacharia, 2003; Kurup, 2004b). According to Zacharia (2003) the impact on meiobenthos varied with depth.The increase in number of nematodes after trawling has been attributed to the dominance of opportunistic species in response to bottom trawling (Gowda, 2003). Post monsoon seasons of Kerala coast manifested a decline in abundance of nematodes. According to Kurup (2004a), the decline can be attributed to the lift of monsoon ban on trawling during this season.

Long-term impact

The government of Kerala has imposed a ban on trawling throughout Kerala during the monsoon months from 1988 onwards, with a duration varying from 22-61 days. Based on the data published by Central Marine Fisheries Research Institute (CMFRI), Kurup (2001) compared the average landings during the pre-ban (1978-87) and the ban periods (1988-97) and an increase of 70.83% was indicated in the overall landings in the state during the ban period.

Discussion

According to Lokkeborg (2005) the biological impact differs with the gear operated like otter trawl, beam trawl and dredge. The impact also varies with sediment texture and whether the study area is sheltered or protected. The otter trawling on hard bottom habitats with erect structures shows a significant decline in the abundance of large and erect sessile invertebrates like sponges and corals. The hard bottom habitats dominated by large sessile fauna may be severely affected by trawling. But the otter trawling studies conducted on soft bottom confer ambiguous results. This is due to lack of true or replicate control sites and prominence of spatial and temporal variations. The seafloor subjected to natural variations are resistant to trawling or the natural variations may mask the actual disturbance due to trawling as in clayey-silt bottoms. The studies on the intricacy and natural variations of benthic communities are still at the elementary level. This unawareness often puts the investigator in dilemma while interpreting the impact.

The impact of bottom trawling depends on the sediment texture of the area, type of fauna of the area, natural physical disturbances of the area, fishing intensity of the area, fisheries of the area, behaviour of fishing, feeding behaviour of fishes of commercially important species etc. The time taken for recovery or recoupement of the fauna, long-term and short-term changes of trawling, sediment geochemical impact etc varies in different regions of the world. Briefly, the impact of trawling and the extent of impact are area specific and species specific. Therefore the period of closed season and the area to be closed varies with different regions around the globe.

The period of closed days for fishing should be sufficient for recoupment of the benthic fauna (Engel & Kvitek, 1998; Kurup and Thomas, 2005). The implementation of closed areas or seasons without a thorough knowledge on the impact of trawling on benthic community taking into consideration the intensity of trawling and fisheries of the area will have adverse effects (Duplisea *et al.*, 2002). The inappropriate use of closed areas may displace fishing activities into habitats that are more vulnerable to disturbance (Kaiser *et al.*, 2002).

Intensive trawling is going on in shallow water depths targeting prawns all over the coast of India. The decline in landings per trip of different kinds of fishing units, alteration in species, decrease in the fish size etc have been attributed to the rise in the number of trawlers (Sathiadas, 1998). Many of the demersal marine finfishes of India are on the verge of extinction due to overfishing and irrational bottom trawling demolishing benthic ecosystems (Bensam & Menon, 1994). In the Indian background lack of control sites or sites protected from trawling is methodological limitation (Bijukumar & Deepthi, 2006).

Bijukumar & Deepthi (2006) suggested that except scattered reports detailed publishing on the quantity of trawl by-catch and its benthic faunal composition is lacking from the Indian waters. A major limitation for carrying out studies on the impact of trawling on benthic fauna in India is the inadequacy of taxonomic studies of benthic fauna of coastal and marine waters of the country. The studies conducted in India on this aspect are generally confined to estuaries (Hussain & Mohan, 2001; Khan & Murugesan, 2005), intertidal beach (Rao & Srinath, 2002) and mangrooves (Saravanakumar, 2002; Serebiah, 2002; Chinnadurai & Fernando, 2003). The published reports on the benthic studies of continental shelf, slope and deepsea are limited to the ecological aspects. The benthos of continental slope and deepsea has been explored only by Parulekar *et al.* (1982) during the cruises onboard *INS Darshak* (1973-74) and *RV Gaveshani* (1976-80). In this study, the benthic production has been assessed relating it to the demersal fishery resources of the Indian Seas (Arabian Sea, Bay of Bengal, Andaman Sea and Lakshadweep Sea). The depth zones of continental shelf, continental slope and deepsea were covered. In the 2nd, 12th and 13th cruises of *RV Gaveshani* during 1976-77, Harkantra *et al.* (1980) recorded the benthic biomass, sediment organic carbon, nature of substrata, demersal fish catch, distribution and abundance of faunal groups of west coast continental shelf at a depth of 10-70m. It has been established that the quantitative distribution of benthic fauna showed a direct relationship to the exploited demersal fisheries, in particular the shrimps. Sajan and Damodaran (2005) have reported the vertical distribution of nematodes on the continental shelf off Dabhol, Coondapore and Vadanappilly during the cruises onboard the FORV *Sagar Sampada* in 2001. The recent reports on the different species of polychaetes (Joydas, 2002; Jayaraj, 2006) and nematodes (Sajan, 2003) of shelf of west coast of India is giving some insight into the obscure benthic taxonomy of Indian marine waters. In view of the paucity of adequate information, more focused research on the taxonomy of benthic fauna of continental shelf, slope and deep sea is required for interpreting the impact of bottom trawling.

The bottom trawling should ensure bottom contact to achieve catch efficiency. So it is not possible to completely avoid the mortality of benthic organisms (Van Merlen, 2000). As bottom trawling should be continued as a livelihood for fishermen the impact caused by bottom trawling has to be assessed using different methodologies along east and west coast of India taking into account the variations in fishing gears used, fishing behaviour, substrate characteristics and taxonomy of resident benthic fauna. The taxonomy of benthic fauna of fishing grounds has to be documented along Indian coast. The benthic habitat and communities and trophic relationships of benthic fauna with the fishery have to be periodically checked. The monitoring of benthic habitat as a whole along the shelf areas and impact of bottom trawling is the need of the hour. This field of research offers vast opportunities for the upcoming scientific activities. The results of these studies would generate information useful for the fisheries managers in the execution of measures to reduce the impact of trawling.

The prospect for implementation of artificial reefs to prevent the illegal trawling of ships (Munoz- Perez *et al.*, 2000) has to be investigated. Based on impact studies, issues like extent of usefulness of the closed season or reduction in fishing pressures are important. Adoption of technical modifications like water jet injection or electrical stimulation at the foot rope instead of tickler chains, provision for more floats (Keegan *et al.*, 1998; Van Merlen, 2000) to reduce the bottom impact and incorporation of release holes at the codends and incorporation of benthos release panels (Revill & Jennings,

2005) to reduce the by catch so as to protect the biodiversity, provide scope for future studies.

This review emerged as a part of the project entitled "Investigations on the effect of bottom trawling on the benthic fauna off Saurashtra coast (Gujarat)" initiated by Ocean and Atmospheric Sciences and Technology Cell (OASTC). The authors gratefully acknowledge the Ministry of Earth Sciences for the financial assistance rendered for the project. They are thankful to Dr. K. Devadasan, Director, Central Institute of Fisheries Technology (CIFT) for encouragements and permission to publish the paper and to Dr. M.R. Boopendranath, Principal Scientist, CIFT for going through the manuscript and for the valuable suggestions.

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