2.1. Introduction

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, 2004; Zacharia et al., 2005 and 2006a&b; 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. It also generates enormous bycatch and discards. The removal of organic matter by dispersion, 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 of incessant operation of bottom trawlers. Many organisms present at the seabed are unable to rebuild. 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. Once the ecosystem is affected there is less opportunity to recover to the pre-trawl conditions. Thus it causes physical and biological damages that are irreversible, extensive and long lasting (Hall, 1999; Kaiser and 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 are the direct effects. The indirect effects comprise of stress suffered by benthos like post-fishing mortality of damaged fauna and the long lasting alterations attributed to the benthic community structure (Jones, 1992).

2.2. 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 and Thomas, 2001). According to size, benthic animals are divided into three groups (i) macrobenthos (ii) meiobenthos and (iii) microbenthos (Mare, 1942). The macrobenthos are organisms that are retained in the sieve having mesh size between 0.5 mm and 1 mm. For meiobenthos, the size ranges between 0.5 mm and 63μ. 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, most of them that may be 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 that reach the sea bottom, improve the oxygenation of sea bottom by burrowing, act as indicator organisms and continuously enrich the planktonic community that in turn forms food for pelagic fishes (Levington, 1982).
2.3. Methodologies used for studying impact of trawling

Jones (1992) on 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, the towing speed, the sediment texture and the influence of tides and currents. His view was supported by Lokkeborg (2005) on evaluating the studies on bottom fishing impacts conducted for a period of 15 years. He ascertained that the studies differ in methodology, scientific approach, gear type, gear design, disturbance regime, bottom texture, intensity of natural disturbance and benthic assemblage.

Studies on the impact of bottom trawling have quantified bycatch landed and discarded from bottom trawlers. Andrew and 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 and Norse, 1998; Kurup et al., 2004). Bycatch and discards pose a threat to biodiversity and long-term sustainability of fishery resources.

Lokkeborg (2005) reviewed the literature of towed-gear fishing impact on benthic habitat and communities. He conferred a critical appraisal of the methodologies applied in different studies. He opined that most studies are far
from fulfilling the criteria of an ‘ideal study’. According to him an ideal study requires analysis over long time extent and comparisons between fished areas and identical untouched control sites.

2.3.1. Experimental trawling

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 and 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. In this study the bottom topography was altered and chlorophyll content of the trawled surface sediments was significantly elevated immediately after the trawling disturbance. Immediately after the trawling, the number of species, species abundance and diversity decreased. 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 Gullmarnsfjorden, Sweden which was previously protected. Three trawled sites and three untrawled (control) sites were sampled before and after experimental trawling. 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 was conducted on a deep-
water sandy bottom ecosystem on the Grand Banks of Newfoundland that had not experienced trawling for 12 years (Kenchington \textit{et al.}, 2001; Prena \textit{et al.}, 1999). The study revealed that the width of the disturbance zones created was on the order of 120 to 250 m. 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 \textit{et al.}, 1999) and as an immediate effect of trawling, the abundance and biomass of polychaetes were found significantly lower. According to Kenchington \textit{et al.} (2001) the trawling disturbance appeared to mimic natural disturbance; no distinctive trawling signature was observed.

Lindegarth \textit{et al.} (2000) opined that having more than one control site in experimental trawling is preferable, as the temporal and spatial variations of different organisms will cause serious problems to the interpretation of experiments, which use only one control and one trawled area.

On reviewing the previous studies Lokkeborg (2005) suggested that experimental trawling ensures, sampling is done in a disturbed site and gives exact data of disturbance level, exact location, size of disturbed area and gear description. When only a narrow corridor is investigated, this method does not replicate the spatial and temporal scale of actual fishing grounds. The impacts interpreted may not be genuine as there is the possibility of migration (disturbed species) or immigration (scavengers) of mobile species into the studied corridor.
2.3.2. Historical data

Many authors mention that historical data is advantageous for the study and interpretation of impacts in a trawled ground. The impact studies based on historical data reflect disturbances in commercial fisheries and the actual intensity of disturbance is not evident as spatial distribution of trawling disturbance and gear configuration is usually unknown. The impact caused will be due to various aspects like dredging, beam trawling, otter trawling or a combination of these. A suitable control site rarely exists in historical data (Lokkeborg, 2005).

2.3.3. Control site

According to Lokkeborg (2005) a comparative study on commercial fishing grounds that are heavily and lightly fished will also bring out the impact of bottom trawling. Several studies on impact of trawling have been conducted by comparing the fauna of closed and open areas of fishing. Such studies were reported by Stone and Masuda (2003) in the Gulf of Alaska, Kaiser et al. (2000) off Devon in United Kingdom and Fisher (2004) in areas of Emerald and Western banks in Northwest Atlantic Ocean.

Open areas of the Central Gulf of Alaska was continuously monitored for 5 years and till 1998, the trawling intensity was estimated to be 11% - 29% per year. The closed areas were prohibited of bottom trawling for 11-12 years. The utility of closed areas in the Gulf of Alaska was brought to light by Stone and Masuda (2003) by collecting samples from areas opened and closed to trawling in cruises of 1998 and 1999. Their study revealed that the sedimentary and
biogeochemical characteristics of the seafloor are altered by bottom trawling.

On comparison of the fauna between the areas closed and open to towed fishing gears off Devon, United Kingdom, Kaiser et al. (2000) found significant dissimilarity apart from the fact that the areas were in close proximity. The closed areas were rich in species diversity and biomass. Areas fished by towed gear were dominated by smaller-bodied fauna and scavenging taxa.

Fisher (2004) studied areas of Emerald and Western banks in Northwest Atlantic Ocean. The area was closed to groundfish trawling in 1987 to conserve haddock (Melanogrammus aeglefinus). The changes in the fish community using multispecies abundance data collected since 1970 were examined and he found differences between the closed area and open reference area. An undisturbed control area is vital for trawling impact studies. Taking into account the natural variations in benthic communities it is necessary to compare the magnitude of temporal changes in fished areas with changes in control site (Lindegarth et al., 2000). To avoid the risk of interpreting the spatial and temporal changes between trawled site and control site as an impact of trawling, replication of control sites is essential. The control site must resemble the disturbed site in depth, currents, sediment characteristics and benthic assemblage (Lokkeborg, 2005).

2.4. Physicochemical impacts

2.4.1. Turbidity

Palanques et al. (2001) conducted experimental trawling in the muddy unfished continental shelf of northwestern Mediterranean. During this study, an
increase in turbidity of the water column was observed after trawling. According to Watling and Norse (2003) the 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. Therefore, those species sensitive to high turbidity may move away from freshly trawled areas.

The sediment plumes are churned up as the weighted nets are ploughed along the ocean floor. The sediment trails caused by trawling could be seen from satellites along Gulf of Mexico (www.neatorama.com; www.foxnews.com), Yangtze River, China (www.treehugger.com) and off Louisiana coast (en.wikipedia.org).

2.4.2. 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) even if moderate trawling activity does not have any adverse effects, 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 at low levels of trawling disturbance, 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. This impact in Northern Sea is illustrated by a generalized soft sediment system by Duplisea et al. (2001).

2.4.3. 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).

2.4.4. 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 and 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.

2.4.5. Pollutants

According to Kaiser et al. (2002) along with the resuspension of the upper layers of sedimentary seabed, bottom trawling remobilize the contaminants into the water column. He suggested that the possible ecological implications like eutrophication, altered biogeochemical cycling need further investigation. 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).

2.4.6. Sediment texture

De Biasi (2004) conducted experimental trawling in fished and unfished area of Tuscany coast of Italy. He found that immediately after trawling an increase of the clay percentage occurred in the landward control. A simultaneous decrease in silt percentage was also observed. But, the variations recovered within twenty-four hours. 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 northwestern Mediterranean. This variation was attributed 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. According to him, the physical impacts of otter trawling are moderate and recovery occurs in about a year on a sandy substratum. 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. But he found that the suspended particles would settle down within a few hours. Ball *et al.* (2000) pointed out that undisturbed muddy sediments need longer recovery time than dynamic coarser sediments.

2.4.7. 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 Mediterranean 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 and Clark, 2000).
2.5. Biological impacts

2.5.1. Epifauna

Fishing activities causes direct mortality of benthos as bycatch and net damaged organisms (Frid and Clark, 2000). 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). In Mediterranean Sea bottom trawling caused elevated fine sediment composition leading to regression of the sea grass Posidonia oceanica (Ardizzone et al., 2000). On conducting experimental trawling in the areas that were untrawled for 15-20 years in the Gulf of St. Vincent of South Australia Tanner (2003) noted that the probability of recolonisation of seagrasses were low in trawled sites than untrawled sites. The benthic fauna of seamounts of Newzealand waters is under the stress of bottom trawling for orange roughy (Koslow et al., 2000; Clark and Driscoll, 2001; 2004). Strong decline of fishery is also recorded (Clark, 1999). The corals (Solenosmilia variabilis) that were dominant and diverse in the lightly trawled seamounts of south of Tasmania were absent in heavily fished areas (Koslow et al., 2001). In the mid Norwegian continental shelf the trawlers damage the deep-water corals Lophelia pertusa significantly lowering the inhabitant fishery (Fossaa et al., 2002). 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, 2005b).

Rosenberg et al. (2003) on carrying out experimental trawl study in the northwest Mediterranean found that the epifauna and polychaete tubes were either rare or not observed at all on trawled sediment surfaces.

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. 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 and van Santbrink (2000b) reported the large-scale mortality of invertebrate species either as a result of direct mortality by the passage of the trawl or indirectly owing to disturbance, exposure and subsequent predation. Ball et al. (2000) cited that the destruction of epifauna depends on the sediment texture. 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 experimental trawling conducted in areas untrawled for 15-20 years in Gulf St. Vincent, South Australia showed that most
Chapter 2

taxa of sessile benthic assemblages declined significantly in trawled areas compared with untrawled areas. In contrast to this, the recruitment rates of several taxa into the visible size classes increased after trawling, presumably because of a reduction in competition. 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).

The gravel sediment habitat of Georges Bank (East coast of North America) was an important nursery area for juvenile fish and the site of a productive scallop fishery. The colonial epifauna (bryozoans, hydroids and worm tubes) of this area provided a complex habitat for shrimp, polychaetes, brittle stars and small fish at undisturbed sites. Otter trawling and scallop dredging in this area removed this epifauna, thereby reducing the complexity and species diversity of the benthic community (Collie et al., 2000). There is a direct relationship between the survival of newly settled juvenile fish and the complexity of the benthic habitat to which they settle. According to Lindholm et al. (1997) the epifauna provides a shelter from predation for juvenile fishes and augment their survival, which points out the need to conserve the regions of high epifaunal growth.

Jennings et al. (2001) studied the effects of bottom trawling on the trophic structure of epifaunal benthic communities in two regions - Silver Pit and Hills of the central North Sea. The impacts of fishing were most pronounced in the Silver Pit region, where the range of trawling disturbance was greater. The epifaunal
biomass decreased significantly with trawling disturbance.

2.5.2. Infauna

Other than direct mortality the impact of trawling on the infauna also depends on the alterations imparted to sediment texture. The recovery of infauna in muddy habitats following experimental trawling normally takes longer than other habitats. 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.

The biomass of infaunal bivalves and spatangoids (burrowing sea-urchins) declined considerably in the experimental trawling studies performed in the central North Sea (Jennings et al., 2001) but could not observe change in the biomass of polychaetes. The invertebrate communities have high intrinsic rates of population increase to withstand the levels of mortality imposed by trawling. In another study (Jennings et al., 2002) they found out that the small infaunal polychaetes that form major food of flat fishes in the North Sea have fast life histories and so they are less vulnerable to trawling disturbance.

2.5.2.1. Macrobenthos

The direct mortality due to trawling occurs in the case of gastropods, starfishes, crustaceans, annelids and bivalves in the trawl track (Bergman and 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 heavily fished areas (Kaiser et al., 2002). The increase in opportunistic species was detected in the trawled areas of Aegean Sea also (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 in Gullmarsfjorden, Sweden (Hansson et al., 2000). Serpulids are macrofauna that provide shelter and food for juvenile commercial species and increase benthic biodiversity. They are opportunistic species that rapidly recolonize disturbed areas. 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 sole 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, the authors concluded that beam trawling does not have a positive or negative effect on their food supply. According to Rijnsdorp and Vingerhoed (2001) 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.). The study of 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) studied the effects of shrimp trawling on infaunal assemblages of two estuarine sounds in South Carolina. In this study it was concluded that 5 months of trawling did not have any obvious effect on the abundance, diversity or composition of the soft-bottom communities. Moreover, the natural seasonal variability was more prominent than trawling effects.

### 2.5.2.2. Meiobenthos

Chronic trawling has a significant impact on the composition of meiofaunal assemblages. Schratzberger and Jennings (2002) analysed nematode communities in beam-trawled fishing areas in the central North Sea. 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. The level of disturbance at the ‘low’ and ‘medium’ areas is insufficient to cause marked long term changes in community structure. 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).
2.5.3. Effects on non-target species

The benthic batoid elasmobranchs 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 and Fonds (2000). In the North Sea also, elasmobranchs showed a decline in their population. Even though not targeted, they are taken in the bycatch and were landed (Greenstreet and 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.

2.5.4. 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 repeated trawling with a commercial fishing gear depleted the abundance of commercially important species. However, smaller scavenging and predatory species increased in abundance significantly with time. The aggregate response of scavengers was short-lived and lasted not more than
several days, which indicated that additional food resources made available by the trawling activities were rapidly consumed.

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 and Fonds, 2000). Fish consumes damaged and exposed benthos, while invertebrate scavengers such as crab and starfish mainly consume discarded fish. 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 and Groenewold, 2000). The responses of scavengers to towed beam trawl differed between different communities and between habitat types. In some areas as a result of the disturbance of beam trawling the abundance of starfishes increased, as there was an incursion of starfishes to nosh on damaged benthos. While at some other sites there was no obvious enhancement in scavenger numbers. Moreover, at the site near Walney Island, numbers of Hermit crabs, swimming crabs and starfish (*Asterias rubens*) decreased after trawling (Ramsay et al., 1998).

The seasonal squid trawl fishery of squid in the Falkland Islands shelf altered the feeding spectra of rock cod (*Patagonotothen ramsayi*). The rock cod is a near bottom browser feeding mainly on crustacean plankton, comb jellies and salps. But during the seasonal squid fishery they also scavenge on the discards (Laptikhovsky and Arkhipkin, 2003).
Rodriguez *et al.* (2002) noted the dietary shift of *Diplodus annularis* of sea
grass *Posidonia oceanica* in relation to trawling. The gut content analysis
revealed that *Diplodus annularis* in trawled meadows consumed planktonic
copepods whereas those in untrawled meadows preyed benthos. The studies
conducted at Massachusetts Bay showed that flatfishes consumed spionid
polychaetes more preferentially before trawling while it changed to amphipod
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 does not form food
for fishes (Duplisea *et al.*, 2002).

Ramsay *et al.* (2000) suggested that as fishing effort increases, starfish
numbers also increase until they reach a turning point, after which starfish
numbers decline as fishing effort further increases. As fishing effort intensifies,
the depletion of natural prey items and starfish mortality due to fishing cause a
reduction in the size of starfish populations.

The response to beam trawl disturbance varied in the behaviour of two
sympatric species of hermit crab, *Pagurus bernhardus* and *P. prideaux*. The
proportion of crustaceans and polychaetes were enhanced in the stomachs of
*P.bernhardus* collected from trawled grounds. This domino effect recommended
that *P.bernhardus* migrated into recently trawled areas because they were capable
to benefit from feeding on the damaged or disturbed fauna engendered by beam
trawling. *P.prideaux* apparently neither moved into the trawled area nor
responded to the additional food source if already present, even though they have akin dietary characteristics to *P. bernhardus* (Ramsay *et al.*, 1996).

Camphuysen and Garthe (2000) have 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 even decline in the seabird population. The feeding ecology, foraging strategies, functional responses of feeding seabirds and factors influencing prey availability has to be studied to bring out the population trends of piscivorous seabirds in relation to fishing effort.

A range of epibenthic species like crabs, echinoderms readily utilize invertebrates discarded from Clyde Sea Nephrops trawlers. 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). Groenewold and Fonds (2000) pointed out that the beam-trawl fishery for flatfishes in North Sea created enormous mutilated benthos that increased the amount of food available to the benthic scavengers. This led to shortcut in trophic relationships. The disturbed sites of Georges Bank were dominated by scavenging crabs and echinoderms (Collie *et al.*, 1997).

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).

2.5.5. Biodiversity

Jennings and Reynolds (2000) enumerated the impacts 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. He has pointed out that diversity is not a particularly sensitive measure of fishing effects. So we have to identify indicator species that are vulnerable to fishing. Studies of the abundance and distribution of these species would aid in identifying areas impacted by fishing.

2.5.6. 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. These characteristics enabled them to adapt rapidly to environmental perturbation and quickly recolonise disturbed habitats. (Craeymeersch et al., 2000; Kaiser, 1998). The long-term changes are ambiguous in habitats where seasonal changes in benthic community occur (Kaiser et al., 1998).

Craeymeersch et al. (2000) enumerated the long-term changes of beam trawling on the Dutch Continental Shelf since 1993 to 1996. The total density of members of the polychaete family Spionidae increased with increasing fishing disturbances. This impact may not be solely due to trawling effort but also due to differences in environmental factors like eutrophication, pollution and fisheries.

The long-term effects of trawling was ascertained by the experimental trawling that was carried out in a fine muddy habitat of Scotland that has been closed to fishing for more than 25 years. The results of repeated 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. After 18 months of recovery the physical effects were not distinguishable but the changes in benthic community were still apparent signifying that even fishing during a restricted period of the year may be ample to maintain communities occupying fine muddy sediment habitats in an altered condition (Tuck et al., 1998).
Fishes rapidly migrate into beam-trawled areas to feed on benthic fauna that are mutilated by trawling or on scavenging invertebrates. The food resource for opportunistic fish species will be increased. Kaiser and Spencer (1994) suggest that this can lead to alteration of long-term community structure.

Frid and Clark (2000) suggested reduced abundances of long-lived bivalves and increased abundances of scavenging crustaceans and sea stars in the German Bight. Kaiser (1998) found 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.

According to Dinmore (2003), in the Central North Sea seasonal closures increased the homogeneity of overall disturbance and led to the redistribution of trawling activity to environmentally sensitive or previously unfished areas. Therefore 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.

Gordon et al. (2002) conducted 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. The most pronounced impacts were the immediate effects on physical structures and direct removal of epifauna like snow crabs, basket stars, sand dollars, brittle stars, sea urchins and soft corals. The 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.

The long-term changes in the benthos on a heavily fished ground off the NE coast of England provided some evidence for the role of direct effects of fishing in determining the abundance and composition of coastal macrofauna. Long-term monitoring of 2 benthic stations off the Northumberland coast was carried out since 1971. One station was located within a *Nephrops norvegicus* fishing ground, while the other station was located outside of the main fished area. At the heavily fished station the increase in fishing effort did not alter the abundance of the taxa predicted to decline, but the abundance of individuals in taxonomic groups predicted to increase did change (Frid et al., 1999).

The long term changes in benthic community due to trawling was tested by Frid and Hall (1999) using a data set comprising stomach contents for fish (*Limanda limanda*) collected in early 1950s and a matched sample from 1996-97. The results of the test were consistent with the hypothesized effects of fishing, with an increased prevalence of scavengers and decreased occurrence of sedentary polychaetes in the diet.

Information on benthic communities within the North Sea was compiled by Frid et al. (2000) to assess the long term changes in the marine benthos on fishing grounds over 60 years. In two sites, Dogger Bank and Inner Shoal, he could not observe significant difference in community composition between the early 1920s and late 1980s. In the remaining three areas, Dowsing Shoal, Great Silver Pit and Fisher Bank, significant differences were observed.
In spite of clear short-term effects, the long-term effects of trawling and scallop dredging have not been adequately studied so far and little trawling impact is revealed in areas exposed to natural stress (Lokkeborg, 2005).

2.5.7. Fishery

Whether the impact on benthic ecosystem is reflected in the fishery is obscure. Martin et al. (1995) studied the abundance and distribution of small demersal fishes in the Gulf of Carpentaria, Australia. They recorded significant correlations between the presence of benthos and both the species diversity and abundance of fishes. They pointed out that the changes to benthic community resulting from trawling would affect fish community composition. Major alteration in benthic habitat can lead to changes in the composition of the resident fish fauna (Kaiser et al., 2002). Fishes rapidly migrate into beam-trawled areas to feed on benthic fauna that are mutilated by trawling or on scavenging invertebrates. The food resource for opportunistic fish species will be increased which can lead to alteration of long-term community structure (Kaiser and Spencer, 1994).

The gut content analysis of commercially important species will bring forth the indirect effect imposed to fisheries. 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 and Kvitek, 1998). The bycatch and discards generated from bottom trawlers also adversely affect the fishery (Alverson et al., 1994).
2.6. 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 and 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 (Kumar and Deepthi, 2006). The Ocean and Atmospheric Sciences and Technology Cell (OASTC) supported by Ministry of Earth Sciences initiated 5 projects in Indian waters. The coasts of Karnataka (Zacharia, 2004; Bhat, 2003; Gowda, 2004), Kerala (Kurup, 2004b) and Vishakapatnam (Raman, 2006) were studied. 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.
2.6.1. Physical impacts

2.6.1.1. 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, 2004; Zacharia, 2004; Thomas et al., 2004; Bhat and Shetty, 2005). In bottom waters the dissolved oxygen decreased (Bhat, 2003; Gowda, 2004; 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 & 2006b; Thomas and Kurup, 2006a).

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).

2.6.1.2. 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 and Kurup, 2005a, b, c; 2006a). A reduction was also observed in clay proportion after trawling along Mangalore coast (Zacharia et al., 2005) and Kakinada along Visakhapatnam coast (Raman, 2006). During trawling the lighter particles of clay will get suspended and as sand resettle faster, more sandy sediment is found immediately after trawling. A two-fold reduction in organic matter was also noticed due to the loss of sediment surface during the scraping of otter boards and nets (Thomas and Kurup, 2005a, b, c; 2006a). The reduction in organic matter is concurrent with the studies conducted at Kakinada along Visakhapatnam coast (Raman, 2006) and off Mangalore coast (Zacharia et al., 2005).

2.6.2. Biological impacts

2.6.2.1. 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 coasts 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 trawlers were stomatopods while finfishes formed the dominant group in multiday fishing trawlers (Zacharia, 2006a). The major proportion of bycatch landed in single day fishing trawlers 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).

2.6.2.2. Infauna

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

Increase in the abundance and biomass and subsequent decrease in diversity indices of macrobenthos is noted as an immediate effect of trawling (Gowda, 2004; Zacharia, 2004; 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, 2004). Polychaete, which is the most dominant macrofauna, increased in abundance and biomass during July when there is a ban on bottom trawlers in Kerala. This shows that the ban is useful for the regeneration and recoupement of polychaetes (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, 2004; 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.

2.6.2.2. 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, 2004; Kurup, 2004b). According to Zacharia (2004) the impact on meiofauna varied with depth. The numerical density and biomass of meiofauna increased at 10 and 20 m depths after trawling while a decrease was noted at 30, 40 and 50 m depths. The increase in number of nematodes after trawling has been attributed to the dominance of opportunistic species in response to bottom trawling (Gowda, 2004). 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.

2.6.2.3. Biodiversity

The discards of bottom trawling pose a threat to marine biodiversity. Kurup et al. (2003) quantified the discards generated from 375 bottom trawlers operated from six major fisheries harbours such as Sakthikulangara, Neendakara, Cochin, Munambam, Beypore and Puthiyappa. The annual discarded quantity during 2000-01 was 2.62 lakh tonnes and that of 2001-02 was 2.25 lakh tonnes. The major groups of discards were edible finfishes, non-edible finfishes, edible crabs, non-edible crabs, cephalopods, juvenile shrimps, gastropods, jellyfish, echinoderm, stomatopods and squid eggs. Temporal, seasonal and depthwise variations in discards were observed.

Zacharia et al. (2006a) assessed quantitatively and qualitatively the by-catch and discards of bottom trawlers along Karnataka during 2001-2002. The quantity of by-catch was estimated as 56,083 t in 2001 and 52,380 t in 2002 forming 54% and 48% of total trawl catch respectively. The quantity of discards
was estimated as 34,958 t in 2001 (33.8% of total catch) and 38,318 t in 2002 (35.1% of the trawl catch). The dominant stomatopods group discarded in single day fishing trawlers and finfishes in multiday fishing trawlers also contribute to biodiversity loss. The amount of discarded catch generated is higher in shallower waters.

2.6.2.4. 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). An increase of 70.83% was indicated in the overall landings in the state during the ban period. This long-term comparative study revealed that the imposition of trawl ban was very effective in providing some respite for fish stocks in the coastal waters of Kerala.

2.7. 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.

Intensive beam trawling causes reduction of infauna and epifauna as short-term changes. Long-term effects of beam trawling have not been studied. In prevalence of the temporal and spatial changes the short-term reduction in species density and abundance attributable to dredging impact was negligible. The dredging impacts were not evident in areas exposed to natural stress, e.g., wave action, eutrophication and salinity fluctuation (Lokkeborg, 2005).

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.
Many authors (Engel and Kvitek, 1998; Kurup and Thomas, 2005) have stressed the need of sufficient time to be given for the revival of the benthic fauna. 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 and Menon, 1994). In the Indian background lack of control sites or sites protected from trawling is a methodological limitation (Kumar and Deepthi, 2006).

Kumar and 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. Knowledge of seasonal, annual and spatial variations in the benthic fauna is a prerequisite for interpreting the impacts of trawling (Lokkeborg, 2005). The studies conducted in
India on this aspect are generally confined to estuaries (Hussain and Mohan, 2001; Khan and Murugesan, 2005), intertidal beach (Rao and Srinath, 2002) and mangroves (Saravanakumar, 2002; Serebiah, 2002; Chinnadurai and 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.
2.8. Conclusions

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. 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 prospects for implementation of artificial reefs to prevent the illegal trawling of ships (Munoz-Perez et al., 2000) have to be investigated. Based on impact studies issues like extent of usefulness of the closed season or reduction in fishing pressure, advantages of adoption of technical modifications like incorporation of release holes at the codends, water jet injection or electrical stimulation at the foot rope, provision for more floats and tickler chains (Keegan et al., 1998; Van Merlen, 2000), incorporation of benthos release panels (Revill and Jennings, 2005) to reduce bycatch as to protect the biodiversity, provide scope for future studies.