IMPACT OF BOTTOM TRAWLING ON BENTHIC ECOLOGY ALONG THE COASTAL WATERS OF KERALA WITH SPECIAL REFERENCE TO MEIOFAUNA

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BY

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DECLARATION

I, **Sreedevi.C.** do hereby declare that the thesis entitled **"Impact of bottom trawling on benthic ecology along the coastal waters of Kerala with special reference to meiofauna"** is a genuine record of research work done by me under the supervision of **Dr. B.Madhusoodana Kurup**, Professor, School of Industrial Fisheries, Cochin University of Science and Technology, and has not been previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any University or Institution.

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by **Mrs.Sreedevi. C**, under my supervision and guidance at the **School of Industrial Fisheries, Cochin University of Science and Technology**, in partial fulfilment of the requirements for the degree of Doctor of Philosophy and no part thereof has been submitted for any other degree.

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Sreedevi.C.

CONTENTS

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
B.T	Before Trawling
A.T	After Trawling
D.O	Dissolved Oxygen

Chapter 1

GENERAL INTRODUCTION

Fishing is the most widespread human intervention in the marine environment. With the predicted increase in the world population, the demand for fish will definitely exceed the present supply, which definitely results in the further increase in fishing effort, mostly in the coastal waters. Although significant progress has been made in marine research during the last decade, it is only beginning to be understood how fishing activities affect life in the sea. The lack of understanding arises partly because the effects of fishing on marine ecosystems are far more difficult to observe and quantify than the effects of man's activities on land (Kaiser *et al.*, 2000).

Marine ecosystems are complex, adaptive systems composed of interconnected groups of living organisms and their habitats. They are effective at capturing energy, cycling nutrients and producing biomass. Ecosystems have real thresholds and limits, which when exceeded, can effect major restructuring (Holling and Meffe, 1996). Often as stress is applied to an ecosystem, its structure and behaviour may at first not change noticeably. Only after a critical threshold is passed, does the system begin to deteriorate rapidly. When an ecosystem is radically altered, it may never return to its original condition, even after the stress is removed.

Fishing actively removes a percentage of one or several species; it can affect the predator and prey of those species, their physical habitat, which in turn, changes the growth and mortality rates of target and non-target species alike. In short, fishing can and is likely to alter the structure and function of marine ecosystem (Dayton, 1998; Pauly *et al.*, 1998). Seemingly small human perturbations applied at a point in time or in one part of the marine ecosystem may have unforeseen impacts because of the open nature and fluid environment that characterize marine ecosystems. Ecosystems change with time, in response to natural and anthropogenic influences. Critical linkages in marine ecosystems are sustained by key predator-prey relationships. Large, long-lived predators and small, short-lived prey, both contribute in major ways to marine fish catches. Fishing has a number of direct effects on ecosystem because it is responsible for increasing the mortality of target and non-target species, and disturbing the marine environment.

While fishing has a long history, it is a relatively new force in the scales of evolutionary time. Fishing is typically a species-selective and size-selective agent of mortality and therefore, is totally unlike the natural causes of mortality. Most of the fish removed by fishing activities are in the middle or near the top of their respective food webs. With the rapid advances in fishing technology (Eg., vessel power, navigation, sensing-locating, and harvest efficiency), the propensity for fisheries to selectively remove species, the failure to control bycatch, and unintended damage to the physical structure of ecosystems, have cumulatively changed the character of heavily fished ecosystems.

The ecosystem effects of fishing can be classified as direct or indirect effects (Jennings and Kaiser, 1998). It is possible to estimate the area of sea bed that is swept annually by bottom gear, the amount of target species and other biota that are caught, the resulting mortality, the discards and the changes in the physical habitat caused by various fishing practices. It is much more difficult to quantify and predict the indirect and longer term consequences of these impacts. These effects reveal themselves as changes in abundance and structure of affected population with resulting changes in trophic structure. Alarmingly, between 1970 and 1990, the rate of growth in the world wide industrial fishing fleet was twice that of the global catch with both the total tonnage and the number of vessels doubling during that period (Safina, 1995).

Studies on the effects of fishing on the ecosystem is a relatively new research endeavour. There is clear evidence that fishing alters the species composition (Eg. Fogarty and Murawski, 1998). Pauly *et al.* (1998) recently showed that there has been a significant worldwide reduction in mean trophic level of species fished. Several studies have demonstrated that mobile fishing gear alter benthic habitat (Auster and Langton, 1999) but little is known about the implication of these changes.

Mobile demersal fishing gears, which include mostly trawls and dredges are used to capture species that live or feed in benthic habitats, and thus they have been designed to maximize their contact with sea bed. They have been fine tuned to achieve the maximum catch per unit effort. As commercial stocks have diminished, fishing gears have been modified to maintain yield. Thus, larger and heavier trawl gears were put to use, incurring higher fuel costs which have to be offset by higher catches. These financial considerations do not take into account the increase in environmental damage to benthic communities.

Bottom trawling is one of the most disruptive and widespread human induced physical disturbances that impacted the seabed communities and has become a global environmental concern (Engel and Kvitek, 1998). The otter trawl is the most widely used type of bottom gear around the world. The origin of trawling is vested in obscurity, but trawls were certainly known in northwestern Europe in the thirteenth century. As early as the fourteenth century, there were concerns about the effects of fishing on the marine environment (Anon, 1885; Anon, 1921). The existing concerns of fisheries scientists in relation to human activities have largely focused on the dramatic collapse of a few stocks such as the Peruvian anchovy *Engraulis ringens* Jenyn and Atlantic cod *Gadus morrhua* Linnaeus (Idyll, 1973; Myers *et al.*, 1996). The possibility that fisheries have major effects at the ecosystem level, and that the ecosystem should be considered as an assessment and management unit has been expressed by some marine ecologists (Sherman and Alexander, 1986; Sherman *et al.*, 1991, 1993). Many of the key scientists in this field are now assessing the impact of human activities on the structure and function of ecosystems, and the ways in which production processes and ecosystem stability are affected by reductions in species diversity (Kunin and Lawton, 1996; Vane-Wright, 1996).

Fishing has a number of direct effects on ecosystem because it is responsible for increasing the mortality of target and non-target species, and disturbing marine habitats. Thus, fishers may remove some of the prey that piscivorous fishes, birds and mammals would otherwise consume or may remove predators that could otherwise control prey populations.

Trawls generally fall into two categories, beam and otter trawl. The otter trawls are the most prevalent of all gears in the Indian coast. Otter trawls derive their name from the two rectangular boards or doors attached to the towing warps, which act as paravanes to maintain lateral opening at the mouth of the net. The boards can weigh several kilograms in air and are towed at an angle to the seabed (Jones, 1992). Varying numbers of tickler chains are attached between the otter boards (Harden-Jones and Scholes, 1974; Sainsbury, 1987) or the ground rope maybe fitted with metal bobbins or rubber bobbins.

Over the past 25 years, scientists have been gathering data on the effect of fishing gear on habitat. The wider effects of fishing activities on marine ecosystems were eluded prior to this century (de Groot, 1984), but it wasn't until 1950s that Michael Graham undertook the first scientific assessment of the likely effects of fishing on non-target species (Graham, 1956). Preliminary studies on the effects of bottom trawls on seabed and its fauna were published by the International Council for the Exploration of Seas (ICES) in the early 1970's. But these failed to draw attention of the scientific community, and finally, in 1980's reports of the disappearance of once common structural biogenic reefs began to cause concern that fishing might have caused widespread alteration of seabed and the wider marine ecosystem (Reisen and Reise, 1982). Since these findings were reported, research interest in the ecosystem effects of fishing has increased substantially world wide and now encompasses effects on benthic biota, non target fish species, marine reptiles, marine mammals and sea birds (Jennings and Kaiser, 1998). Europe has been a focus of research initiatives that have addressed the ecosystem effects of fishing on the marine environment for the last two decades.

The physical impact of gears on substratum depends on the speed of towing, physical dimensions and weight of the gear, type of substratum, and strength of currents or tides in the area fished. Successive layers of sediments are resuspended (Caddy, 1973; Churchill, 1989). Ripples, detrital aggregations and surface traces of bioturbation are smoothed over by the mechanical action of the trawl and the suspension with subsequent redeposition of the surface sediment and detritus stirred from bottom (Messieh *et al.*, 1991). The physical disturbance of sediment can result in a loss of biological organization and reduce species richness (Hall, 1994).

All mobile bottom gears scrape the surface of or dig into the seabed to varying degrees. Hence it is not surprising that non target fish and benthic invertebrate species comprise a large proportion of catch in some fisheries (Messieh *et al.*, 1991; Andrew and Pepperell, 1992; Robin, 1992; de Groot and Lindeboom, 1994). Significant changes in the abundance of large macroinfauna as a result of fishing disturbance have been reported (Houghton et *al.*, 1971; Bergman and Hup, 1992). In sediment habitats which are characterised by coarser substrata, most infauna is found within the top 10 cm. However, in soft mud, a larger proportion of macroinfaunal communities have been found to live in burrows upto 2 m deep (Atkinson and Nash, 1990) and even these have been found disturbed by the passage of trawl gear.

Sessile epibenthic species are vulnerable to the passage of bottom gears. This observation that epifaunal communities had altered in heavily fished areas have provided some of the first indications of the potential long-term effects of fishing on benthic communities (Langton and Robinson, 1990; Collie *et al.*, 1997). Auster *et al.* (1996) reported a reduction in habitat complexity as a result of trawling and scallop dredging activity at three sites in the Gulf of Maine.

The studies illustrate two main effects of mobile gears on epifaunal communities 1) modification of substrata and 2) removal of biogenic taxa and a decline in the abundance of species and communities associated with them.

Fishing activities also provide source of food for benthic scavengers. Firstly as food falls from discards which are discarded from the trawlers and secondly, the demersal trawls and dredges are dragged across the seabed, they dig up displace, damage or kill a proportion of epi and infaunal organisms in the path of the gear. These latter sources are termed 'non catch' mortality by Bergman and vanSantbrink (1994).

Indirectly, bottom trawling affects marine animals and their associated habitat by resuspending sediments, toxins and nutrients into the water column by scraping and plouging 5-170 mm of the substrate of muddy and sandy bottoms (Rumohr in Krost *et al.*, 1990). Otter board was reported to have a penetration of 100-150 mm depth (Arntz and Weber, 1970). Many marine species including the ones that are commercially caught have young ones that are lithic or benthic in habitat, and depends on the biogenic structures for survival from predators. The removal of these shelters causes increased predation apart from overfishing, the most important criteria for diminishing fish stocks worldwide. Given the rapid, progressive collapse of commercial fish stocks and the less noticed but even more dangerous loss of biodiversity, it is necessary that more research be devoted to ameliorate the impacts of trawling, for future generations to enjoy and benefit from the sea.

Bottom trawling is a source of chronic and widespread disturbance in shallow shelf waters and modifies the diversity, community structure, trophic structure and productivity of macrobenthic invertebrate communities (deGroot and Lindeboom, 1994; Dayton *et al.*, 1995; Jennings and Kaiser, 1998; Lindeboom and deGroot, 1998; Hall 1999; Collie *et al.,* 2000; Gislason *et al.*, 2000; Kaiser and deGroot, 2000). Experimental and field studies have demonstrated that abundance of macrobenthic infaunal and epifaunal species is reduced by trawling, and that fragile species with larger body size and slow life histories are generally more vulnerable than those species with smaller body sizes (Kaiser and Spencer, 1996; Thrush *et al.,* 1998; Tuck *et al.*, 1998; Bergman and vanSantbrink, 2000a & b; Gislason and Sinclair, 2000; Hall-Spencer and Moore, 2000; Kaiser *et al.*, 2000). As a result, trawled communities are increasingly dominated by small infaunal species with fast life histories (Gubbay and Knapman, 1999; Kaiser *et al.*, 2000; Jennings *et al.*, 2000).

Previous studies on effects of trawling have focused on macrofauna because they are conspicuous, relatively easy to sample and process, killed directly by trawling gears and provide habitat structure (Currie and Parry, 1996; Bradshaw *et al.*, 2000; Hall-Spencer and Moore, 2000; Pranovi *et al.*, 2000; Rumohr and Kujawski, 2000; Veale *et al.*, 2000). However, meiofauna (animals that pass through a 500 µm mesh sieve but are retained on 63µm -mesh sieve) can make a greater contribution to benthic production than the macrofauna, and their role in the benthic ecosystem should not be overlooked (Kuipers *et al.*, 1981; Schwinghamer *et al.*, 1986). Meiofauna are more productive as a result of their abundance and fast turnover times. Schwinghamer *et al.* (1986) quotes turnover times of 24 days and less for organisms less than 2.1X 10^{-7}g wet weight, an order of magnitude greater than those for most macrofauna.

Meiobenthos is classified by Coull and Bell (1979) as temporary and permanent forms. Temporary meiofauna include polychaetes, gastropods, bivalves and amphipods. The permanent meiobenthos include foraminifera, nematodes, turbellaria, harpacticoida, ostracoda, kinorhynca and gastrotrichs. Meiofauna are known as efficient recyclers of nutrients (Olaffson and Moore, 1990) and as an important food resource for higher trophic levels (Coull, 1990).

In the Indian scenario, the coastal fisheries, limited to a depth of 0-50m, are mainly exploited by mechanized vessels comprising trawlers, purse seiners, drift gill netters, dol netters hooks and lines and boats with OBM (James, 1988). In the southwest coast of India, early trawling operations, till 1950's were concentrated around Cape Comorin region where rich grounds for percoid fishes and elasmobranchs were discovered. The next phase in exploratory fishing started with the establishment of the Indo-Norwegian Project in Kerala in 1953. Exploratory trawling in the continental shelf region revealed rich fishing grounds off Calicut, Cochin and Alleppey –Quilon. Substantial shrimp beds were located in the most productive grounds that existed both north and south of Cochin (PerSandven, 1959). In the shallow grounds off Cochin the dominant species occurring in trawl catches were *Metapenaeus dobsoni*, *Otolithes argenteus*, *Caranx* spp., *Parapenaeopsis stylifera*,*Leiognathus* spp.,*Nemipterus japonicus* and *Penaeus indicus* (Tholasilingam *et al.*,1973). Tholasilingam *et al.* (1973) also reported an uneven distribution of fishing effort and that the fishing pressures in some areas like Cochin was very heavy. In the 1990's about 4500 bottom trawlers were reported to be scouring the Kerala coast (Kurup and Radhika, 2007) against the permissible number of 1145 (Kalawar *et al.*, 1985).

In this context of the heavy fishing pressure and the diminishing trend shown by the demersal fishes and prawn stocks, an attempt was ~~carried out~~ to quantify the impact of bottom trawling along the Cochin –Munambam area, where trawling is done on a regular basis with moderate intensity. The objectives of this endeavour were to study:

1. the effect of bottom trawling on the physico-chemical parameters of sea water,
2. the immediate effect of bottom trawling on the sediment structure of the Cochin-Munambam region,
3. the immediate effect of bottom trawling on the meiofauna.

Chapter 2

REVIEW OF LITERATURE

Marine ecosystem is a complex adaptive system comprising many interconnected groups of living organisms and their habitats (Fluharty, 1998). Holling and Meffe (1996) opined that the ecosystems have real thresholds and limits, which when exceeded, bring about irreversible changes in the ecosystem. Environmental parameters have direct role in the prosperity of the ecosystems and the variations in these parameters are quite suitable for making widespread changes in the survival and subsistence of the marine organisms in the ecosystem (Mooney, 1990). Pillai (1993) has demarcated the major environmental factors that influence the abundance of fauna and flora of marine environment as salinity, dissolved oxygen, turbidity, pH and temperature.

Concern over the possible effects of trawls on the seabed has existed almost as long as the fishing method itself, with early concern being voiced by fishermen themselves as far back as the 14th century (Graham, 1955). Technological advancements in the structure of trawl gear via increase in size and weight as well as increase in number of fishing vessels and engine power paved way for gaining more international public and political importance. This international concern was voiced at the 58th Council meeting in Copenhagen in 1970 at the International Council for the Exploration of the Sea (ICES). Information was requested with regard to the possible impacts of trawls and dredges on the seabed and on the benthic fauna (de Groot, 1984). Unsatisfied with the reports of the member states, an ICES study group on the effect of bottom trawling was convened in 1987 to collect information available since

1972. Based on this movement, many member states initiated national and international studies on the effect of trawling on seabed and the benthic communities (Bergman and Hup, 1992).

Graham (1955) carried out the first attempt to evaluate the effect of trawling on the marine environment. Jennings *et al.* (2001b) described trawling and dredging as the most destructive fishing practices, which cause innumerable direct and indirect changes in the ecosystem. Direct changes in the fish population and in the benthos can occur by the scraping of the trawl gear on the seabed (Riemann and Hoffmann, 1991). The consequence of trawling includes variation in the fish stock and changes in mortality, recruitment/settlement, diversity and production of benthos (Pearson and Rosenberg, 1978). The magnitude of effect depends on the depth of penetration of the gear into the sediment, the frequency with which the area is fished and the structure of the sediment (de Groot, 1984). Penetration of bottom gear has been studied using diverse methods. Bridger (1970) made studies on the penetration of otter boards on the muddy sediment by direct observation. Caddy (1973) used underwater cameras for studying the effect of trawling on sediment. Side-scan sonar was used in the study conducted by Fonteyne *et al.* (1998) on physical impact on sediment due to bottom trawling. Bridger (1972) implanted markers into the seabed and determined which segment had been touched by the tickler chains of a beam trawl passing over them. Main and Sangster (1981) observed the rise of sediment clouds in the trawl track. Ganz (1980) studied the possible effect of sediment clouds generated in the trawl fishing. New~~C~~combe and MacDonald (1991) opined that the turbid clouds definitely affect the survival of larvae and juveniles of fish and other organisms in their study on the effect of sediment clouds in the aquatic systems. Abrupt rise in the turbidity and subsequent reduction in dissolved oxygen may create an unfavorable niche for the animals living in the marine ecosystem (Morgan *et al.*, 1983). Churchill *et al.* (1994) also discussed the adverse effect on shellfish and other benthic organisms due to the rise of turbidity plumes during trawling. Turbidity of bottom water was reported to be increasing during dredging at Cochin harbour (Thressiamma *et al.*, 1998). Banse (1959) reported ~~that~~ the variations on the water parameters during heavy upwelling formed during monsoon months in the west coast of India. Abrupt increase in turbidity was noticed in the upwelled waters (Muraleedharan and Kumar, 1996). Dredging and trawling cause~~s~~ high oxygen demand that has the potential to form a barrier which may hamper the movement of migratory fishes (Eliot *et al.*, 1988a & b).

Riemann and Hoffmann (1991) reported that the decrease in oxygen level after dredging / trawling may be due to the mixing of reduced products such as methane and hydrogen sulphide and/ or because the re-suspended particulate material and bacteria attached to sediments which, in turn, exert an increase in oxygen demand in the water column. Messieh *et al.* (1991) postulated the possible effects of a sudden release of nutrients or contaminants from sediment after trawling. Abnormal bloom~~s~~ formation due to the input of nutrients and minerals at the surface would deplete dissolved oxygen

(De Sousa and Singbal, 1986). Hansson (1985) stated that the hypoxic condition created during dredging or bottom trawling may worsen the conditions at sea bottom by eliminating macrophyte benthos and near-bottom fish that are already close to their limits of tolerance of hypoxia. Dissolved oxygen and salinity play an important role in controlling the distribution of fish and other living organisms in the marine environment (Pillai, 1993). Besides, the natural variations, anthropogenic activities also seem to inflict heavy variations in the environmental parameters in the marine milieu affecting the marine productivity severely (Watling and Norse, 1998).

Banse (1968) studied the effect on demersal fish of cool, poorly oxygenated bottom waters that exist in the Arabian Sea during and after the southwest monsoon. Bhat and Neelakandan (1988) identified 11 environmental parameters that play specific roles in the density variations of macrobenthos in the Kali estuary in the west coast of India. Parulekar *et al.* (1982) noticed that the variations in the physico-chemical parameters in water certainly affect the density, survival, reproduction and distribution of the benthic organisms in the marine environment. Damodaran (1973) studied the role of physico–chemical parameters in the distribution of meiobenthos in the mud banks of Kerala coast.

The increase in turbidity and consequent decrease in the oxygen content in the marine waters due to the bottom trawling activities have been proved to be lethal to the existence of the living communities, especially to the growth and development of eggs, larvae and young ones, on account of the severe sudden alteration of the marine milieu (Mileikovsky, 1970).

Krost (1990) investigated the effects of otter trawling, particularly the otter boards, in Kieler Bucht (Kiel Bay) in the Western Baltic. Trawl boards caused a pressure wave in front of the door as they ploughed through the sediment leading to the generation of sand clouds from suspended sediments (Main and Sangster, 1981). Main and Sangster (1990) recorded suspended sediment plumes as a result of contact of other parts of otter trawl with the sea bottom, such as the bobbins, although these tend to be smaller in volume than those produced by the otter boards. Butman and Noble (1979) noticed heavy sediment clouds during trawling operations. Any hindrance to the penetration of light in the turbid waters, which may be the result of bottom trawling, will definitely affect the coastal water productivity as reported by Mayer *et al.* (1991). Morgan *et al.* (1983) observed poor productivity in the turbid waters due to low penetration of light.

In the wake of large-scale commercial exploitation of prawn resources, the demand for more efficient trawl gear also increased considerably in the Indian waters, which resulted in the introduction of otter trawls in early 60's (John, 1996). Schwinghamer *et al.* (1996) described an in *situ* experiment to quantify the immediate impacts of trawling and studied the recovery of the affected sediments over time. All mobile bottom gears scrape the seabed and inflict heavy damage and disturbance to the bottom structure and organisms (De Groot, 1972). Jennings and Kaiser (1998) reviewed the effect of fishing on marine ecosystem.

Dragging of heavy trawl nets/ dredges along the sea bottom reduce the organic matter present on the top layer of the sediments and also make the surface more coarse which in turn change the natural sediment milieu (Fader, 1991).

Studies pointed out that bottom trawling affect the basic nutrient structure of the sea floor (Churchill *et al.*, 1988). Release of nutrients increases the phytoplankton population in the water column (Reddy *et al.*, 1979). Gray (1992) stated that excessive nutrient supply would negatively affect the benthic fauna and flora. Sediment surface is a rich source of organic matter, nutrients and minerals (Levinton, 1989). Mayer *et al.* (1991) ~~had~~ showed that heavy chain dredges mix surface organic material with subsurface layers of the water column.

Caddy (1973) observed the loss of visibility in the trawled / dredged grounds of Gulf of St. Lawrence due to the rise of sediment clouds. Re-suspension of buried organic material by trawlers increases oxygen demand in the water column in areas where dissolved oxygen is already limiting, significantly affects the growth of plankton and nekton (Watling *et al.*, 2001). Bottom trawling, which is highly destructive to the sea bottom removes the top layer of sediments, leading to the release of embedded nutrients and reduction in the organic matter load (Jones, 1992). Hall (1994) reviewed the indirect changes of bottom trawling on the marine environment. Fonteyne (2000) observed that passage of heavy bottom trawl equipped with heavy otter boards and tickler chains cause depression of sediment mounds, removal of rocky shelter, as well as erected life such as coral and polychaetes. Gislason (1994) stated that bottom trawling causes physical disturbance and re-suspension of sediments as well as increase the exchange of nutrients and pollutants between the sediment and the water column in the study conducted on the ecosystem effects of fishing activities in the North Sea.

Bottom trawl can change sediment grain size distribution or characteristics, suspended load and the magnitude of sediment transport processes (Dyekjaer *et al.,* 1995; Pilskaln *et al.*, 1998). Black and Parry (1999) studied the sediment transport rates and sediment disturbance due to scallop dredging in Port Phillip Bay. Currie and Parry (1996) conducted large scale experimental studies on the effect of scallop dredging on a soft sediment community. High-resolution video image studies on sediments showed that trawling reduces the overall surface roughness of the seabed (Schwinghamer *et al.*, 1996). Shelton and Rolfe (1972) revealed that the heavy re-suspension of sediments make the grounds more coarse by the easy settlement of heavy particles. Rasheed and Balchand (2000) reported higher percentage of sand in dredged areas in Cochin harbour in the Southwest coast of India. Langton and Robinson (1990) reported the transport of the re-suspended fine particles resulting in the coarsening of the sediments and thereby changing the natural sediment structure. Clear changes were recorded after trawling in the upper 6 cm of sediments during visual inspection by Pranovi and Giovanardi (1994) in their study on the effect of 'rapido trawling' on the benthic communities in an experimental area formed in the northern Adriatic Sea. Gordon *et al.* (1998) did not find any effect on the grain size of sediments due to the trawling activities even though significant changes were observed on the sediment structure. Smith *et al.* (2000) opined that the passage of the trawl could be responsible for disturbing and re-layering the sediment, causing a change in grain size and affecting the chemical composition. Alterations may also occur in the sediment porosity and chemical exchange processes (McConnaughey *et al.*, 2000). Thomas and Kurup (2005) found extensive variations in the sediment texture and organic matter along the inshore waters of Kerala as a result of impact of trawling. The authors noticed a reduction in the percentage of clay particles, transforming the seabed into a sandy texture, while organic matter showed drastic reduction after trawling.

The soft nature of muddy sediments makes them more susceptible to the physical impacts of trawl gear compared to harder and coarse sediments (Ball *et al.*, 1999, 2000). Wardle (1983) made a study on the effect of trawling, which revealed that when trawl doors were towed under normal fishing speed, they generated intense turbulent wakes capable of creating turbid clouds of suspended sediments. The scale of disturbance on the sea bottom by way of digging up the sediment surface depends on several factors such as gear configuration, towing speed, water depth and the substrate over which the tow occurs (Steele, 2002). Arntz and Weber (1970) measured a depth of 10-15 cm penetration of otter boards in muddy fine sand. Margetts and Bridger (1971) concluded that on sand or muddy sand the trawl did not appear to penetrate deeply into the seabed, but on muddy grounds, the trawl marks lasted for several hours (Schwinghamer *et al.*, 1998).

Based on, measurement made with implanted markers in the seabed, Bridger (1972) concluded that only the surface of sediment would be disturbed by a tickler chain (top 10 mm). Margetts and Bridger (1971) observed sole plate marks 80 -1000 mm deep on muddy sand when compared to a penetration of 15 mm on sandy-ridged ground. Due to the pressure of the trawl gear on the seabed, parts of the gear penetrate to some extent into the sea bottom. The penetration depth largely depends on the nature of the bottom (De Groot, 1972). Fonteyne *et al.* (1998) observed the most distinct disturbance on muddy or soft sandy grounds. Beam trawls marks were detectable for less than 4 days in loose sandy sediments, whereas marks made by otter trawl doors were detectable for over 12 months in more stable sediments (De Groot and Lindeboom, 1994; Krost *et al.*, 1990). Otter trawl leaves more persistent marks on muddy bottom compared to the sandy bottom and the studies conducted in this regard showed that marks persist for up to 5 years on muddy bottoms while on harder sediments they disappear soon after trawling (Hall *et al.*, 1990).

Considerable interest was aroused in the 70's and the 80's concerning the importance of meiofauna. Much of the meiofaunal life and their characteristics have been reviewed by McIntyre (1969), Coull and Bell (1979), Coull and Giere (1988) and Montagna (1995). Meiobenthos is classified by Coull and Bell (1979) as temporary and permanent forms. Temporary forms include polychaetes, gastropods, bivalves and amphipods. The permanent meiobenthos include Foraminifera, Nematodes, Turbellaria, Harpacticoida, Ostracoda, Kinorhyncha and Gastrotrichs. Their numbers and biomass are known to decrease with increasing depths and the highest biomass has been reported from the mud flats (Coull and Bell, 1979). Vertically, the meiofauna get concentrated in the upper layer of sediment, decreasing with increasing depth (MacLachlan, 1977).Tietjen (1971) states that 95% of the total fauna concentrates in the top 5 cm. There is also evidence that meiobenthos plays a role in making the detritus available to the macro consumers (Tenore *et al.*, 1977). It has been suggested that for deriving equivalent biomass, the meiofauna are responsible for about 5 times the total benthic metabolism of the macrofauna (Gerlach, 1978). The author also stated that mineralisation of organic matter is enhanced and bacterial production stimulated by the presence of meiofauna.

Bottom trawling is a source of chronic and widespread disturbance in shallow shelf waters and modifies the diversity, community structure, trophic structure and productivity of macrobenthic invertebrate communities (deGroot and Lindeboom, 1994). Experimental and field studies have demonstrated that abundance of macrobenthic infaunal and epifaunal species is reduced by trawling, and that fragile species with larger body size and slow life histories are generally more vulnerable than those species with smaller body sizes (Kaiser and Spencer, 1996). As a result, trawled communities are increasingly dominated by small infaunal species with fast life histories (Gubbay and Knapman, 1999).

Previous studies on effects of trawling effects have focused on macrofauna because they are conspicuous, relatively easy to sample and process, killed directly by trawling gears and provide habitat structure (Currie and Parry, 1996). However Kuipers *et al.*(1981) and Schwinghamer *et al.*(1986) postulated that meiofauna (animals that pass through a 500 µm mesh sieve but are retained on 63µm –mesh sieve) can make a greater contribution to benthic production than the macrofauna, and their role in the benthic ecosystem should not be overlooked . Meiofauna are more productive as a result of their abundance and fast turnover times. Schwinghamer *et al.* (1986) quotes turnover times of 24 days and less for organisms less than 2.1X 10^{-7}g wet weight, an order of magnitude greater than those for most macrofauna. Sandulli and Nicola (1990) have examined meiobenthos as an indicator to assess environmental conditions of marine benthic ecosystems because of their comparatively shorter generation times and rapid response of population to variable environment. Heip *et al.* (1985) found that nematodes are more resistant to environmental changes than harpacticoid copepods. Varshney *et al.*(1984) studied the meiobenthos of polluted and non polluted environments off Bombay. Harkantra *et al.* (1980) observed high benthic biomass in the near-shore regions due to enrichment of coastal waters due to the riverine flow and land run off.

Bottom trawling causes serious perturbations on the marine ecosystem directly and indirectly (Gislason, 1994). Dragging of heavy otter boards and nets inflict direct changes through digging up the sediments resulting in the resuspension and dispersion of organic rich top layer of the sediments into the subsurface layers as well as removing the epifaunal and infaunal organisms (Holme, 1983).

Bottom trawling inflicts direct changes by way of injury, killing many marine organisms including epifaunal communities such as fishes and other marine invertebrates (Kaiser and Spencer, 1995). Jones (1992) in his review of the impacts of trawling on the seabed reiterated that otter board leaves distinct imprints on the sea floor. McConnaughey *et al.* (2000) made an examination of chronic trawling effects on soft bottom benthos of the eastern Bering Sea. Collie (2000) made a study on the impact of fishing gear on the sea floor in New England. Gordon *et al.* (1998) evaluated the effect of mobile fishing gear on the benthic habitat and communities in Eastern Canada.

Jennings *et al.* (2001b) made systematic research on the impact of trawling/ dredging on the marine ecosystem. The study conducted by Thrush *et al.* (1995) on the short term impacts of bottom trawling on benthos revealed that bottom trawling inflict heavy alterations on the benthic community.

Kaiser and de Groot (1999) have reviewed the various studies conducted in different regions around the globe on the impact of trawling on marine ecosystems. Schwinghamer *et al.* (1996) quantified the impact of trawling on benthic habitat structure using high-resolution acoustics and chaos theory. Auster *et al.* (1996) reported the effect of mobile fishing gear on the seafloor habitats in their study in the Gulf of Maine (Northwest Atlantic) and also highlighted the variations in the fish communities due to bottom trawling.

¶ Impact is determined by the speed of the towing, physical dimension of gear, weight of the gear, depth of penetration into the sediments, the frequency with which the area is fished, type of substratum and strength of currents or tides in the area fished (Redant, 1987). Norse (1993) evaluated the status of increasing bottom trawlers in the continental shelf waters around the world. Black and Parry (1999) reported the mortality and displacement of benthic organisms in the turbulence formed during bottom trawling. Werner *et al.* (1976) studied the consequence of bottom trawling on sandy and muddy bottoms. Jennings and Kaiser (1998) examined the effect of fishing on marine ecosystems. Hall (1999) made thorough studies on the effect of fishing on marine ecosystems and communities. Large number of bivalves and other commercially important and unimportant organisms are damaged by intensive otter trawling (Artnz and Weber, 1970). Eleftheriou (2000) observed large number of less mobile groups such as crabs, starfishes and bivalves in the trawl catches.

Bridger (1970) made direct observation on the sea bottom with a view to analyze the extent of variations on the seabed brought about by the bottom gear. Rijnsdorp *et al.* (1996) compared the changes in abundance of demersal fish species in the North Sea between 1906 and 1909 with that of those of 1990 -1995. Reduced densities of small crustacean, polychaetes and molluscs in trawl and dredge grounds were observed by Thrush *et al.* (1995). Rijnsdorp *et al.* (1998) examined the micro-scale distribution of beam trawl effort between 1993 and 1996 in relation to trawling frequency of the seabed and the impact on benthic organisms. Ehrlich and Wilson (1991) reviewed the impacts of human activities on the structure and function of ecosystems and the way in which the production processes and ecosystem stability are affected by, reduction in species diversity.

The direct effect of trawling and dredging include loss of erect and sessile epifauna, smothering of sedimentary bed forms, reduction in bottom roughness and removal of taxa that produce the biogenic structures (Pickett and White, 1985). Several species might experience reduced fitness as an effect of the trawl disturbance (Gilkinson *et al.,* 1998). Pitcher *et al.* (2000) estimated huge loss of gorgonians and sponges due to prawn trawling in waters of the Great Barrier Reef.

Riesen and Reise (1982) noticed the disappearance of reefs of the calcareous tubiform worm, *Sabellaria spinulosa* and their replacement by small polychaete communities due to the consequence of heavy dredging activity in the Wadden Sea. Frid *et al.* (2000) demonstrated the shift in the composition of benthos after 60 years of inordinate trawling. Bull (1986) observed the decreased survival of scallop spat in the trawled grounds.

Benthos play an important role in the benthic productivity acting as the major food resource of prawns, fishes and other marine invertebrates at bottom waters thereby forming an inevitable link in the benthic food chain (Mohammed, 1995). Varshney *et al.* (1988) opined that the availability of benthos at a region could be an indicator of demersal fishery potential since they form an important food reserve for crabs and fishes.

Vane-Wright (1996) identified priorities for the conservation of biodiversity and mentioned about the measures to be taken to reduce the loss of stability of ecosystems. Hall and Hardings (1997) studied the physical disturbance on marine benthic communities, particularly on infauna. Krost (1990) conducted experimental trawl studies to find out the effect of trawling on the seabed in the Kiel Bay using side-scan sonar. Jennings *et al.* (2001a) found 75 % reduction in total infaunal productivity between unfished and heavily trawled areas. Chicharo *et al.* (2002 a & b) studied the macro and meiobenthic communities in the dredged areas off south Portugal. Freese *et al.* (1999) measured the effect of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska.

Evidence is available which depicts serious damage and mortality in coelenterates, annelid worms, molluscs, echinoderms and crustaceans due to trawling (Bridger, 1970; Margetts and Bridger, 1971). Ball *et al.* (2000) found lower biomass of benthic fauna in trawled areas when compared to untrawled areas. Lower species diversity and species richness have been observed in trawled areas compared to undisturbed areas (Collie *et al.*, 1997). Effect of fishing on diversity was studied by Jennings and Reynolds (2000). Rumohr *et al.* (1998) conducted studies on the long-term trends in demersal fish and benthic invertebrates. Gilkinson *et al.* (1998) studied the impact of otter trawls on infaunal communities. Decreased homogeneity in the benthic assemblages was found after trawling (Prena *et al.*, 1999). Bergman and vanSantbrink (2000b) reported that the total direct mortality varied from 10 % to 80% and fragile or superficial living species experience the highest mortalities during bottom trawling. Short–term experimental studies conducted by Tuck *et al.* (1998) demonstrated that even a confined period of fishing disturbance once per year would be able to maintain a muddy sediment community in an altered state and make profound effects of certain taxa generally shallow growing fragile species. Thomas (2003) studied the impact of trawling on epifaunal community and concluded that the epifauna was being removed from the sea bottom at an alarming rate without replenishment but for the unedible crabs which survived the onslaught of trawling. Thomas *et al.* (2006) studied the variations on infaunal polychaetes along the inshore waters of Kerala and demonstrated that the abundance and biomass of macrobenthos decreased drastically as a result of trawling throughout the year.

Rijnsdorp and Vingerhoed (2001) observed that bottom trawling had augmented the removal of benthic population indirectly by improving the feeding condition of the certain fishes by enhancing the abundance of small opportunistic benthic species such as polychaetes in the heavily trawled areas.

90% of the global fish catch comes from the coastal ocean (Moore,1999). Fishing has a great role in the changes of the marine ecosystem by way of removal of the fish and benthic communities thereby causing harmful environmental effects (Auster and Langton, 1999). Berghahn (1990) studied the impact of bottom trawling on trophic relationship in Wadden Sea. Bergman and Hup (1992) made a study on the effect of beam trawling on macrofauna in the sandy grounds in North Sea. The meiobenthos may play a higher order role as trophic linkage to macrofauna or other predators (eg: fish) or as important structural components of the benthic community (Miller *et al.*, 1992). Kaiser and Spencer (1994) studied the deleterious effect of beam trawling on the infaunal communities. Trawling destroys the tubiforms, which have important role in maintaining the structure and oxygenation of muddy sediment habitats (Reise, 1981). Lindegarth *et al.* (2000) reported large temporal changes in benthos after twelve months of intensive experimental trawling. The increased variability can be interpreted as an indication of decreased homogeneity (Warwick and Clark, 1993). Although the marine ecosystem is undoubtedly influenced by anthropogenic activities, evaluation of the system is difficult because of the complexity of the system (Rijnsdorp and Leeuwen, 1996).

Kaiser *et al.* (1999) studied the importance of benthic habitat complexity for the growth and subsistence of benthic assemblages. Ecosystems with high structural complexity are likely to change most as fishing pressure increases (Auster, 1998). Tilman and Downing (1994) critically evaluated the role of human beings in the variation and reduction in the diversity of ecosystem. Naeem *et al.* (1994, 1995) studied the decline of diversity in the various ecosystems. Many strategies are being worked out to protect the marine ecosystems from being subjected to total degradation by way of fishing, especially bottom trawling.

Chapter 3

MATERIALS AND METHODS

3.1 Description of the study area:

Kerala state, located at the southernmost tip of the Indian subcontinent has a continental shelf area of about 40,000 km^2 of which 15993 km^2 is within the 0-50m depth zone (Kurup , 2001). Cochin has long been recognized as one of the most productive fishing grounds, especially for demersal species. Upwelling is a unique phenomenon along the west coast of India which triggers plankton bloom and results in extremely high productivity in the Arabian Sea (Kumar and Prasad, 1996). The stretch of inshore waters between Cochin and Munambam is the study area (Fig.3.1) selected to carry out the trawling experiments.

This area was selected for the present study due to the following reasons:

a. Proximity of the study area to the institution
b. High productivity of the area as evidenced by the high degree of fishing prevalent in this area
c. The topography of the area lends itself to benthic sampling over a wide range of depth within a limited area.

3.2 Description of Trawler:

A commercial shrimp trawler of 45 feet OAL was hired on contract basis to carry out the onboard sample collection (Plate 3.1). The technical specifications of the fishing boat are given below.

Name of the Vessel	: Lawrence
Registration Number	: MFV ALP 1275

Engine	: Ashok Leyland ALM 402
Facilities onboard	: Echosounder, GPS, Trawl nets and other fishing accessories.

3.3 Selection of stations:

The area between Cochin and Munambam was divided into 5 depth zones, 0-10, 10-20, 20-30, 30-40 and 40-50metres with two stations in each depth zone. Stations were fixed with the help of a GPS, providing a gap of 5 kms between each station. Thus a total of 10 stations were fixed, namely S1, S2, S3, S4, S5.... S10. Trawling was carried about at approximately the mid depth of these stations. For after trawling samplings, these stations were designated as A1 , A2, A3 , A4, A5, ...A10.

3.4 Method of sampling:

Experimental trawling was carried out onboard the fishing vessel "Lawrence" during the period December 2000 to November 2002 (2 years). Commercial trawl nets, otter boards and other fishing equipments were used to accomplish experimental trawling (Plate 3.2). The frequency of experimental trawling was once in every two months, in each of the ten stations, adding upto 12 cruises in a span of 2 years. Thus adequate representation has been given to the seasons viz. premonsoon, monsoon and post monsoon.

3.5 Water sampling:

Upon reaching a predetermined station, "S" the trawler was stopped for collecting water samples in duplicate for determining various hydrological parameters viz. temperature, salinity, pH, dissolved oxygen and turbidity.

Water samples were also collected in duplicate to analyze the nitrite and phosphate content of seawater. The water samples were collected using a 1.5 litre horizontal water sampler (Hydro bios Kiel) (Plate 3.3) from the bottom (lowest layer, just above the sea bed) .

3.6 Sediment sampling:

Sediment was collected in duplicate from each station using a van Veen grab having 0.1 m^2 area (Plate 3.4A). The grab was lowered at each station and as soon as it was hauled onboard, a glass tube of 30 cm length and 30 mm diameter was inserted through one of the grab doors into the undisturbed sediment layers to trap a column of sediment (Plate 3.5). This column was then separated into the upper 5 cm and lower 5cm sections, and packed into separate clean polythene bottles for the analysis of meiofauna. From the rest of the grab sample, the top layer was skimmed and packed into polythene bags for the estimation of sediment organic matter (Plate 3.4B). These samples were then preserved in 4% formalin along with Rose Bengal stain (1%) for subsequent analysis at the laboratory. A portion of sediment was also taken from the grab in duplicate to analyze the sediment grain size distribution of the study area.

3.7 Experimental Trawling:

Upon collection of all the samples, the fishing vessel was propelled rearward for 30 minutes along the station which was sampled. The vessel was then stopped and the trawl net and otter boards were lowered until the gear made contact with the seafloor. Experimental trawling was done through the sampled station, for one hour. The trawl net was then hauled in, and the vessel maneuvered to the original site of sampling, before trawling. From this station, now designated as "A" (after trawling), the entire sample collection protocols were repeated. Thereafter the fishing vessel proceeded to the next station, and the above protocols were repeated to obtain before and after trawling samples from all the ten stations from 0-50m depth (Fig. 3.2). Depth ranges of 0-10 and 10-20 m were covered on the first day of experimental trawling, while 20-30 and 30-40 m zones were sampled on the second. The final zone 40-50 m was sampled on the third consecutive day of trawling.

Depth zone	Stations	Latitude	Longitude	Depth of trawling
0-10 m	S1	9^0 59' 21" N	76^0 10' 36" E	5m
	S2	10^0 01' 19"N	76^0 09' 12" E	
10-20 m	S3	10^0 04' 01" N	76^0 07' 31" E	15m
	S4	10^0 01' 28" N	76^0 09' 01" E	
20-30 m	S5	10^0 02' 47" N	76^0 05' 52" E	25m
	S6	10^0 03' 18" N	76^0 05' 52" E	
30-40 m	S7	10^0 03' 15" N	76^0 03' 08" E	35m
	S8	10^0 01' 03" N	76^0 03' 10" E	
40-50 m	S9	9^0 58' 32" N	75^0 58' 10" E	45m
	S10	10^0 0' 13" N	75^0 57' 46" E	

The samples collected were analysed using standard procedure as given below:

3.8 Analytical procedure:

Temperature: Temperature was measured using a standard thermometer as soon as the water samples were collected onboard.

pH: A portable pH meter (pH Scan 1) was used to measure pH after calibrating with standards at pH 4 and pH 7.

Salinity: Salinity was determined using Knudsen's method, following standard argentimetric technique (Grasshoff *et al.*, 1983).

Dissolved oxygen: Dissolved oxygen was estimated by modified Winkler's method of Strickland and Parsons (1972) with standard iodimetric titration (Grasshoff *et al.*, 1983).

Turbidity: Turbidity was measured using Nephelo turbidity meter, after calibration using standard turbidity suspension. Stock solutions were prepared using hydrazine sulphate and hexamethylene tetramine in the ratio 1:10. The turbidity of this stock is 400 NTU. This solution was diluted to a standard turbidity suspension of 40 NTU and additional standards were prepared by more dilution. The turbidity of the samples was read against that of the standard suspension (APHA, 1992).

Nitrite –Nitrogen (NO_2-N): Nitrite was measured by the method of Grasshoff *et al.* (1983). Nitrite in sea water sample when treated with sulphanilamide in a solution resulted in a diazo- compound which reacts with N-1 naphthyl ethylene dihydrochloride to form an azo dye, the absorbance of this colour complex was measured at 543nm. The cell-to-cell blanks and reagent blanks were determined and the necessary corrections applied.

Phosphate-Phosphorus (PO_4-P): Phosphate –Phosphorus was determined as inorganic phosphate by the formation of a reduced phospho-molybdenum blue complex in an acidic medium containing molybdic acid, ascorbic acid and bivalent antimony. The most popular of the methods relying on this reaction was that given by Strickland and Parsons (1972). A variation of this method described by Grasshoff *et al.*(1983) is adopted in the present study: 0.5 ml of the mixed reagent containing molybdic acid and antimony tartrate followed by 0.5 ml of ascorbic acid reagent was added to 25 ml aliquots of the samples. The absorbance was measured in 5 cm cuvettes at 882 nm within 30 minutes to reduce any possible interference from arsenate.

Sediment organic carbon: The organic carbon of sediment was determined by the wet digestion method of El Wakeel and Riley (1957). Powdered sediment sample was shaken with chromic acid in a water bath and the treated sample was titrated against ferrous ammonium sulphate with ferrous phenanthrolline as indicator. Organic matter in the sediment was estimated by multiplying the organic carbon values by a factor 1.72 (Trask, 1955).

Sediment texture: Sediment sample was thoroughly mixed and a portion subjected to textural analysis (Krumbein and Pettijohn, 1938). Samples were dried at 65°C and bleached with 20% hydrogen peroxide: 20 grams of the dried sample was kept overnight in 0.24 N solution of sodium hexametaphosphate.

Sediment coarser than 63µm is removed by sieving through a 63µm sieve. The coarse fraction retained on the sieve were dried and weighed. The washing was collected in a measuring jar and analysed for silt and clay by pipette method (Carver, 1971). Sieving was done to determine the grain size distribution of sand. The statistical parameters of grain size such as mean, standard deviation, skewness and kurtosis were calculated following Folk and Ward (1957).

Analysis of benthic organisms: Mud samples preserved in 4% formalin and stained with Rosebengal were sieved through a set of 500µ and 63 µ sieves. The organisms retained on the finer sieve were removed carefully and preserved in 4% neutralized formalin for later sorting. The sorting was done after washing off the excess stain. Each organism was categorized into the taxa, after careful examination under a 10X microscope. The organisms were sorted into different taxa and counted (Holme and MacIntyre, 1975).

3.9 Statistical Analysis of Data: Significance of the seasonal variations of the physicochemical characteristics of sea water was tested using ANOVA (Snedecor and Cochran, 1967). Paired t-test was performed to test the significance of the values of all parameters before and after trawling.

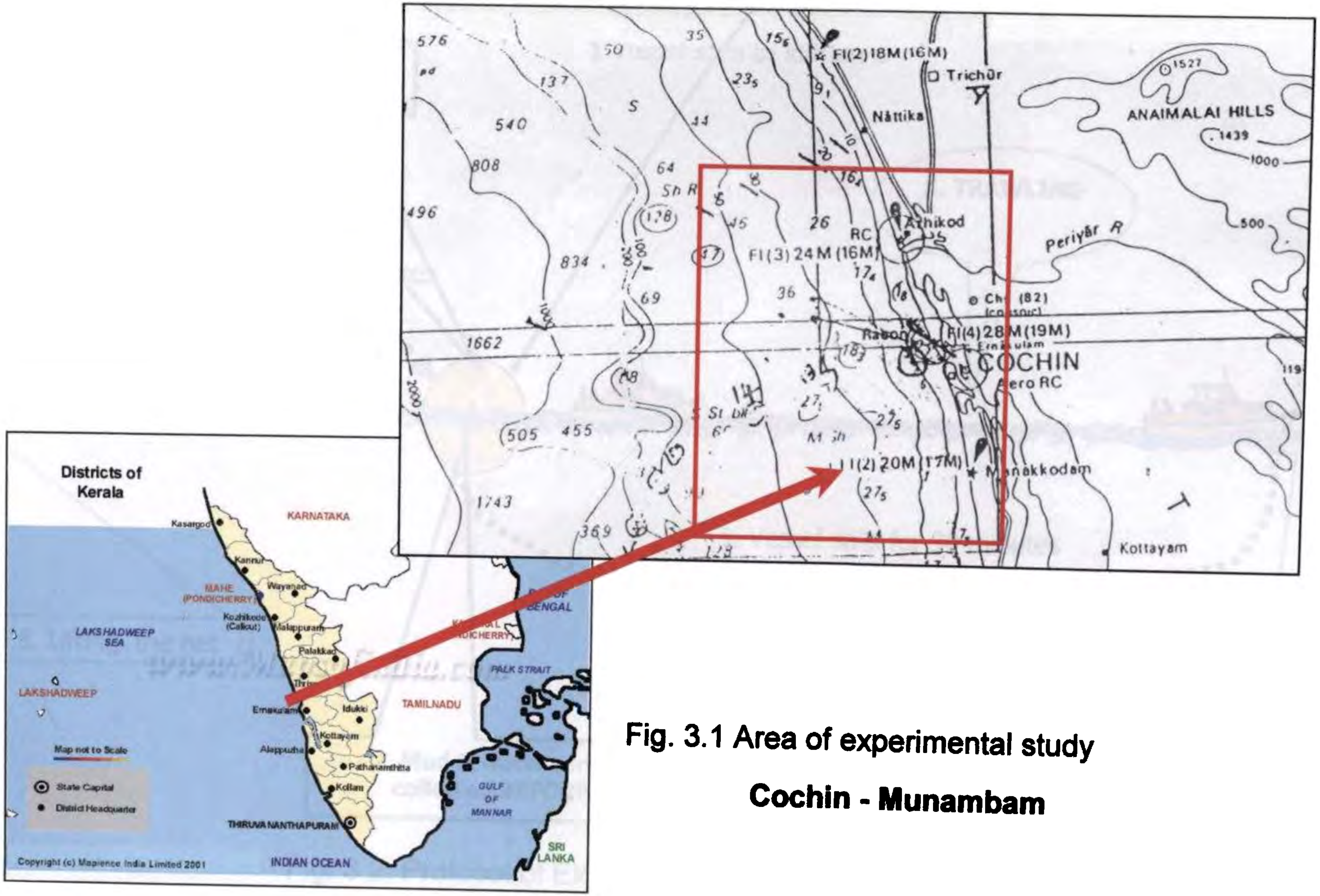


Fig. 3.1 Area of experimental study

Cochin - Munambam

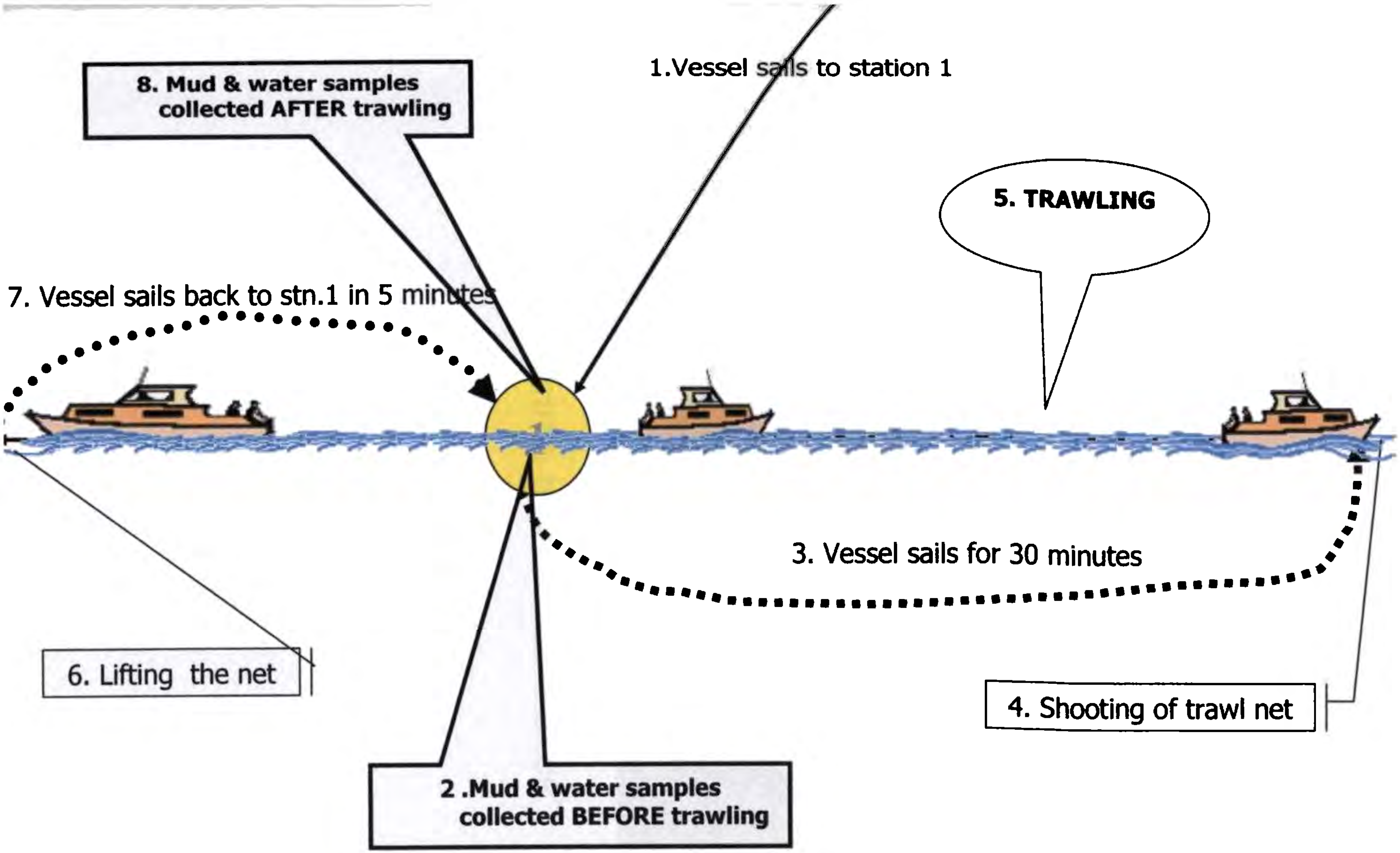


Fig. 3.2. Protocol of Experimental Trawling

Plate 3.1

Commercial shrimp trawler “Lawrence”

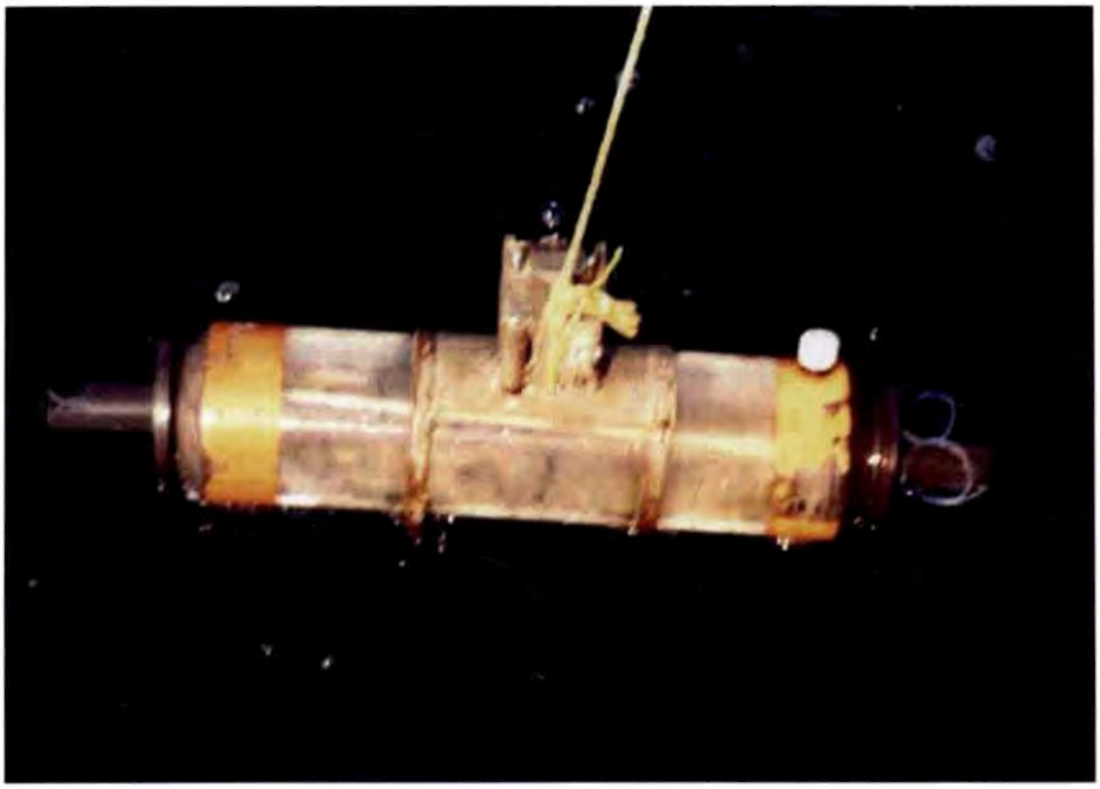
Plate 3.2A

Shooting of the trawl net

Plate 3.2B

Hauling of the net

Plate 3.3



Horizontal Water Sampler

Plate 3.4A

Operation of van Veen grab

Plate 3.4B

Collection of sediment samples

Plate 3.5

Core sampling for meiofauna

Chapter 4

EFFECT OF BOTTOM TRAWLING ON PHYSICO - CHEMICAL PARAMETERS OF SEA WATER

4.1 Introduction

An ecosystem is an integrated spatial entity of interacting and interdependent biotic and abiotic components which are linked by energy flow and material cycling (Kinne, 1978). Temperature, salinity and depth are the major barriers to free movement of marine organisms (Odum, 1959). The Indian Ocean, especially the Arabian Sea, is the seat of high organic production and many oceanographic investigations have been made in this region (SenGupta *et al.*, 1976, 1980; Rao, 1984; de Sousa and Singbal, 1986; de Sousa *et al.*, 1996; Kumar and Prasad, 1996; Naqvi and Jayakumar, 2000). The south west coast of India, owing to its high production (Ryther and Menzel, 1965; Qasim, 1977) has been subjected to studies for its physico-chemical characteristics (Banse, 1959, Ramamirtham and Jayaraman, 1963; Joseph and Kurup, 1990; Pillai, 1993). Detailed studies have been carried out on the hydrological regime in the region of Cochin (Ramamirtham and Jayaraman, 1960; Banse, 1968) and off the Laccadive Islands (Jayaraman *et al.*1959; Varkey *et al.*, 1979). The hydrographic features prevailing along the southwest coast of India play an important role in the distribution of bottom fauna, demersal fishes and prawns (Banse, 1968).

The Arabian Sea is subject to extreme seasonal changes in atmospheric forcing that may be divided into the northeast monsoon and southwest monsoon, and two intermonsoon periods (Morrison *et al.*, 1998). Of the two monsoons, the southwest monsoon endures longer period, and is stronger and steadier than the northeast one. These differing atmospheric regimes produce dramatic physical chemical and biological changes in the upper layers of the water column. Strong seasonal influence can be seen on almost all physical and chemical characteristics of the coastal waters. The phenomenon of upwelling is a regular feature off the west coast of India from 8^{O} to atleast 15^{O} N during the whole of south west monsoon season ,for about 5 months (Banse, 1959) . Both the current pattern (Banse, 1959) and wind stress (Morrison *et al.*, 1998) are reported to be responsible for this phenomenon. Upwelling and the accompanying horizontal advection will markedly alter the distribution of physical and chemical properties of water involved. Though many water masses have been identified in the Arabian Sea, in the coastal regions upto 50 m, no distinct water masses are seen, but the waters are mixed vertically, with intense seasonal variations (SenGupta *et al.*, 1976). In addition to the monsoons and upwelling, the present study area is also influenced by the Cochin backwater system, which is a typical tropical estuary permanently connected to the Arabian Sea and fed by five major rivers (Joseph, 1974).

The occurrence of benthic species is controlled to a great extent by physical factors viz. depth, temperature, intensity of light, turbidity of water, chemical factors such as salinity, dissolved oxygen and available elements, biological factors namely available food supply and character of bottom sediments. Natural disturbance events are important wherein the various dynamic forces play a role in determining the structure of benthic communities (Grassle and Sanders, 1973; Kaiser *et al.*, 2000). Fishing is one of the most important anthropogenic disturbance sources to marine benthic ecosystems and has been occurring for centuries (deGroot, 1984). Trawling significantly alters the benthic environment by disturbing the ambient physico chemical features of the habitat (Thrush *et al.*, 1998; Bonsdorff *et al.*, 1995; Simboura *et al.*, 1995; Telesh *et al.*, 1999) and sediment characteristics. Studies on impact of trawling are very scanty in the Indian waters though otter trawling is the most prevalent fishing method used along the Indian coast, and especially along Kerala coast.

4.2 Results

4.2.1 Temperature:

Before trawling: Distribution of temperature in the bottom waters upto 50 m depth shows a distinct seasonal pattern with lowest during monsoon and highest during post monsoon. The bottom water temperature of the 10 stations during two years of study has been depicted in Fig. 4.1. Temperature during the first year ranged from 23.2°C in July 2001 to 31.3°C in November 2001. Almost uniform temperature was found during each sampling at the ten stations, except in July 2001 which showed a significant ($P<0.05$) lowering of temperature along the bottom. The range of temperature during the second year was from 23.2°C in July 02 to 31.5 °C in January 2002. During the second year also, significant ($P<0.05$) lowering of temperature took place as anticipated during the monsoon period and the temperature minima (23.2°C) was recorded in July2002 while the warmest bottom waters during the second year were recorded in January 2002 with 31.5°C. Two way ANOVA performed on temperature recorded before trawling did not yield significant differences between treatments (P>0.05, Appendix I, Table 1).

After trawling: Temperature recorded in the samples collected after trawling showed more or less similar values as obtained before trawling (Fig.4.2). The range of temperature during the first year was from 23.3°C in July 2001 to 31.9°C in November 2001 at station 5. Significant (P<0.05) lowering of temperature took place in the monsoon period, while the post monsoon months showed an increasing trend (Appendix I, Table 2). The range of temperature during the second year showed more or less the same trend as noticed in samples collected before trawling, with a lowest of 23.2°C in July 2002 and highest of 31.6°C in March 2002. Comparing the values obtained before and after trawling there was no significant variation (P>0.05) in the temperature of bottom waters in relation to trawling (Fig.4.3 a & b, Table 4.1).

4.2.2 Salinity:

Before trawling: Salinity variations in the area between Cochin and Munambam were closely related to the monsoon season. Significant seasonal variations were observed in the salinity recorded in the samples collected before trawling during the first and second year (P<0.05). An annual range of 28.1 to 36.3 ppt was recorded in the year 2001 where the lowest was measured at station 7 in July 2001 while the highest was at station 3 in December (Fig.4.4). An average of 36 ‰ was observed at all stations for the rest of the year. Salinity of bottom waters showed very slight fluctuations during the second year (January to November 2002), except during monsoon. The values ranged between 29.1 ppt at station 4 and 36 ppt at station 7 with lowest in July and highest in November 2002. Seasonal variations of salinity were found significant (P<0.01, Appendix I, Table 3). There was no marked variation in salinity as one moved offshore, except during July where an average of 30.16 and 31.5 ppt in the first and second year respectively was observed. Near shore stations (0-30m) showed relatively lower salinity concentrations when compared to stations located at higher depths (40-50m) (Fig.4.4).

After trawling: The annual range of salinity during the first year was 27.6%o at station 9 in July 2001 to 36.1%o at station 2 in December 2000 (Fig.4.5). Stations 1 to 10 showed almost uniform salinity, for most part of the year, except in July 2001, during when significantly lower salinity (P<0.01) was observed.. Similar trend of salinity variation was noticed during the second year also with characteristic drop in values at all stations in July 2002. The values ranged from 28.4 in July 2002 to 36 ppt at stations during September, May and November 2002. Salinity values showed significant reduction during monsoon (Appendix I, Table 4). Bottom water samples collected immediately after trawling did not show any significant (P>0.05) changes in salinity when compared to that collected before trawling (Fig.4.6 a& b, Table 4.1).

4.2.3 pH:

Before trawling: Seawater was found to be slightly alkaline for the major part of investigation, and was found to be influenced by the monsoon. The pH values observed before trawling has been depicted in Fig.4.7. The annual range of pH fluctuated from 6.9 at station 6 and 7 in September 2001 and station 6 in July 2001 to 8.2 in December 2000 at stations 8 and 10 during the first year. The fluctuation in pH of the bottom waters towards the offshore regions was very slight, and this feature was noticed during the sampling in the succeeding year also. The annual range of pH of bottom waters during the second year was 7.1 in station 5 in July 2002 to 8.0 at stations 9 and 10 in January 2002. Higher pH values were recorded during post monsoon season, which decreased slightly during premonsoon showing the lowest during monsoon. The reduction in pH of bottom waters during monsoon was found to be significant ($P<0.05$, Appendix I, Table 5) during both the years of observation.

After trawling: pH of the bottom waters varied between 6.9 and 8.2 with the lowest at stations 7 and 9 in July 2001 and the highest of 8.2 at station 6 in December 2000 during the first year. The fluctuation during the second year was from 7.1 at station 5 in July 2002 to 8.0 in a few stations in January 2002 and at station 8 in November 2002 (Fig.4.8). Significant seasonal variations were noticed in samples collected after trawling ($P<0.05$, Appendix I, Table 6). When the pH of bottom waters before trawling and after trawling were compared (Fig.4.9 a & b), no significant difference was noticed ($P>0.05$) leading to the conclusion that trawling had no immediate effect on the pH of bottom waters (Table 4.1).

4.2.4 Dissolved oxygen:

Before trawling: The dissolved oxygen content of bottom waters ranged between a high value of 5.83 mlL^{-1} in April at station 1 and a minimum of 2.56

mlL^{-1} at station 3 in July 2001 during the first year. In the second year, the highest was found in May 2002 with 5.14 mlL^{-1}, while the lowest was encountered in July2002 with 2.43 mlL^{-1} at station 10 (Fig.4.10). The horizontal distribution of dissolved oxygen content showed a decreasing trend towards offshore, with the stations near the coast registering higher values compared to those offshore. Higher values of dissolved oxygen were encountered during premonsoon and post monsoon seasons ,whereas in the monsoon season a significant lowering in the dissolved oxygen during both the years of observation ($P<0.01$, Appendix I, Table 7) was noteworthy.

After trawling: The values for dissolved oxygen observed before trawling have been plotted in Fig.4.11. During the first year, the range observed was between 2.22 mlL^{-1} at station 3 in July 2001 and 5.12 mlL^{-1} at station 1 in April 2001. During the second year, the dissolved oxygen concentration ranged between 2.13 mlL^{-1} at station 10 in July 2002 and 4.88 mlL^{-1} at station 7 in May 2002. A marked seasonal variation was observed in the after trawling in the concentration of dissolved oxygen showing drastically lower values during monsoon season ($P<0.01$, Appendix I, Table 8). The highest variation at a station was observed in July 2001 during the first year of sampling when 5.10 mg L^{-1} before trawling declined to 3.98mg L^{-1} after trawling at station 2. Dissolved oxygen concentration was found decreased significantly immediately after trawling when compared to that of samples collected before trawling ($P<0.05$, Table 4.1) (Fig.4.12 a & b).

4.2.5 Turbidity

Before trawling: The turbidity of bottom waters showed distinct seasonal variation in the samples collected before trawling and the values are depicted in Fig.4.13. The values during the first year ranged between 2 and 80 NTU, the former was registered at station 7 in November while the latter was at station 1 in July. During the second year, the lowest of 1 NTU (January 2002) and the highest of 38 NTU (July 2002) were observed at station 5 and 1 respectively. It was interesting to note that turbidity of seawater at bottom was on a higher range in stations 1 to 5 which were in close proximity to the terrestrial environs. The bottom waters were much less turbid in all the other stations indicating that land run off played an important role in creating turbid waters. The monsoon season also played a major role in creating turbid waters along the sea bottom. During both the years of observation, the month of July (monsoon) registered the highest turbidity, followed by September, which corresponds to the monsoon season along the west coast. The turbidity values when compared monthwise showed a significant variation ($P<0.01$, Appendix I, Table 9), with the lowest during premonsoon season.

After trawling: The seawater samples collected from bottom manifested a perceptible increase in turbidity during all seasons and at all depth zones. The highest value of 96 NTU was registered at station 1 and 2 in July and September 2001 respectively in the initial year. The minimum turbidity recorded during the preceeding year was at 10 NTU, at station 10, during April. During the second year also, the same pattern of distribution of turbidity was recorded, and fell within the range 8-62 NTU, the highest being recorded at 5 m and the lowest at 35 and 45 m depth (Fig.4.14). Seasonwise, there was a highly significant increase (P<0.01, Appendix I, Table 10) in turbidity which could be attributed to the monsoon. It appears that trawling played an important role in elevating the turbidity levels of bottom waters, irrespective of the seasons and depths. Highest variation was recorded at station 8 when 38 NTU was recorded after trawling from 10 NTU in the samples collected before trawling, thus showing a 4 fold increase in turbidity due to trawling. A comparison of the turbidity values registered both before and after trawling are shown in Fig.4.15 a & b. Significant variations were observed when the turbidity of bottom waters were compared both before and after trawling (P<0.05, Table 4.1).

4.2.6 Nutrients

4.2.6a Nitrite:

Before trawling: Nitrite values before trawling showed prominent variations with different depths zones and seasons (Fig.4.16). The lowest nitrite value (0.45µ moles per litre) was recorded at station 4 in April 2001 while the highest of 3.47µ moles per litre at station 1 was recorded in July 2001 during the fist year of sampling. In the second year, nitrite values showed a range 0.10 – 3.93µ moles per litre in March and September 2002 respectively at stations 8 and 5. Seasonwise, the highest nitrite concentration in the bottom waters occurred in the month of July 2001 and 2002, with an average of 2.19 and 2.27 µmoles per litre respectively, while lower values were observed during premonsoon and post monsoon. Significant variation was observed in the nitrite content of bottom waters collected before trawling ($P<0.01$, Appendix I, Table 11). The stations in the inshore area upto 35 m depth showed a higher content of nitrite compared to those beyond it, obviously due to the presence of silty clay sediment enriched with organic matter.

After Trawling: The nitrite values ranged from 0.87 (station 4, April 2001) - 4.20 (station 1, July 2001) during the first year, and 0.47 (station 3, March2002) -4.78μ moles per litre (station 8, July2002) during the second year (Fig.4.17). Significantly ($P<0.1$, Appendix I, Table 12) enhanced values were noticed when seasons were taken into consideration, and among them, the monsoon season showed the highest average nitrite value as observed in July .The nitrite concentrations were found to be increased significantly immediately after trawling ($P<0.05$,Table 4.2) while comparing the samples collected both before and after trawling (Fig.4.18 a & b). Around two - fold increase has been noticed at station 8 in September 2002 with a high value of 4.78 μ ML^{-1} after trawling against 2.78 μ ML^{-1} before trawling.

4.2.6b Phosphate:

Before trawling: The values of Phosphate phosphorus observed during the period of study are depicted in Fig.4.19. During the first year of trawling, the inorganic phosphate of bottom waters ranged between 0.04 (station 2) and 5.83μ moles per litre (station 9) in July and November 2001 respectively. In the second year it varied from 0.21 to 6.56μ moles per litre at station 6 and 1 respectively. Between stations, the highest concentration was found in those stations which were in close proximity with land, indicating that river/ land run-off was a major source of this nutrient. Interseason comparison revealed that phosphate levels began to increase in July, maintaining high values in September, thenceforth a drop in concentration was discernible. Two-way ANOVA showed a significant variation in the phosphate values ($P<0.01$, Appendix I, Table 13) obviously due to significant variations observed during monsoon.

After trawling : The range of phosphate concentration showed conspicuous increase after trawling, the values ranged between 0.39(station 2) and 7.76 µML^{-1} (station 4) in February and July 2001 respectively (Fig.4.20). During the second year it varied between 0.54 and 6.46 µ moles per litre at stations 10 and 1 during January 2002 and November 2002 respectively. The concentration of phosphate in the samples collected after trawling followed the similar pattern of seasonal variations observed before trawling with high values in monsoon and comparatively low values in premonsoon and postmonsoon period. The month of July during both the years of study was characterized by a sudden increase in phosphate concentration, which can primarily be attributed to summer monsoon. But these values were significantly higher ($P<0.01$, Appendix I, Table 14) than that recorded during monsoon in the samples collected before trawling. A phosphate concentration of 5.36µ moles per litre recorded before trawling showed a rise to 7.76 at station 4 after trawling during July 2001. In July 2002, all the stations showed an increase in the concentration of phosphate content immediately after trawling. Highest variation was noticed in December 2000 with 5.21 µ ML^{-1} in the samples collected after trawling from 1.21 of that of before trawling at station 6, thus showing almost a four-fold increase. Highly significant variation was noticed (P<0.01, Table 4.2) in the phosphate-phosphorus concentrations recorded after trawling samples when compared to that of before trawling (Fig.4.21a & b).

4.3 Discussion: Several studies have been conducted in the Indian Ocean, Arabian Sea and especially on the Southwest coast of India regarding the physico-chemical parameters (Banse, 1972; SenGupta *et al.*, 1975; Suresh *et al.*, 1978; Babu *et al.*, 1980; deSousa and Singbal, 1986; Muraleedharan and Kumar, 1996; Kumar and Prasad, 1996).

Relationship between nutrients and physical parameters were also studied well in Indian waters, which brought to light the important role of these parameters in the productivity of water (Naqvi *et al.*, 1978; Sen Gupta *et al.*, 1979, 1980; deSousa and Singbal, 1986; Rivonker *et al.*, 1990).

Variations in the temperature-salinity regimen are recognized to be of direct influence on the marine organisms. Monsoon has been identified to be the most important cause for producing variations in the physico-chemical parameters of the coastal region (Banse, 1959, 1968). In the present study, all the parameters were found to be influenced to a great extent by the monsoons, especially the south west monsoon. Upwelling off the west coast of India has a profound influence on the distribution of physical and chemical properties of water (Sharma, 1978). Temperature of the bottom waters remained almost the same towards the offshore regions, as manifested by the characteristic temperature shown by each station representing the season. High bottom temperatures were found during the premonsoon and post monsoon, while it plummeted invariably during the monsoon season (Banse, 1959). This tendency registered during the first year of investigation was found to be identical in all respects to that observed during the second year. Varkey *et al.* (1979) recorded a 29°C isotherm at about 50 m depth off Cochin while characterizing the physical conditions of the Laccadive Sea, during a cruise conducted in March /April. During the present study also, temperature range of 29.0 to 31.3°C was observed in April which represented the highest temperature range of this region during premonsoon period. The temperature – depth profile in May 1959, of stations near the coast in the latitude 10°N also reflected similar values at 0-50 m depth (Darbyshire, 1967). Along the southwest coast, rainfall usually starts during the final week of May and extends upto August, thereafter showing a decrease in rainfall. Sharp variations in temperature of bottom waters were noticed during the onset and withdrawal of southwest monsoon. An average temperature of 23.8 °C was observed during the first year, while the same in respect of second year was 23.4 °C, in July. Lowest average of 25 °C was recorded in July/ August off Cochin in the hydrographic studies conducted by Seshappa and Jayaraman (1956) and Kasturirangan (1957). The sudden decrease of temperature during the onset of monsoon in the southwest coast of India is not caused by turbulence due to the increased wave action but due to upwelling (Banse, 1959). Upwelling was strongly recommended to be mainly responsible for lowering of seawater temperature during the southwest monsoon season along the west coast of

India (Banse, 1959). At 20 m depth, Banse(1959) recorded 23.4 °C during upwelling period off Cochin. Two temperature maxima have been recorded in the present study, one in November and the other in March. Hydrographic studies on the near shore waters off Mangalore coast on the west coast of India also revealed maxima in October and April (Gopalakrishnan and Nair, 1998). At bottom, the highest and lowest temperature recorded during the above study were 30.4 and 23.1 °C respectively, which correspond to the maxima and minima reported in the present study. Significant changes were not noticed in the temperature recorded after trawling. Trawling activities did not create any disturbance in the temperature regime of the coastal waters which was obvious from the similar readings of temperature both before and after trawling samples.

The bottom water samples at stations 1 to 10 showed only slight fluctuations in salinity throughout the year, except during monsoon season (June – August). Higher values of bottom salinity were recorded during months when conditions were favourable for net evaporation and vertical mixing of surface and subsurface waters. Lower values of salinity occurred with the occurrence of rainfall. During the rainy season, the waters of the shelf become diluted by rainfall, land drainage and increased outflow of river water through the backwater opening into the sea near Cochin (Babu *et al.*, 1980). The salinity range during July 2001 was 27.6 ppt at station 9 to 32.8 ppt at station 10 and that in 2002 was 27 ppt at station 4 to 33.1 ppt at station 10. It can reasonably be concluded that southwest monsoon had perceptible influence on salinity variation during the second year, when compared to the first. In

November 2001, there was very little difference in salinities of the bottom waters which concurs with the observation by Darbyshire (1967) off Kerala coast. The characteristics of bottom waters immediately after trawling with respect to salinity are almost identical, with the plummetting during monsoon. Salinity values thus do not reflect any immediate impact of trawling in these waters. Towards the end of upwelling period, an increase in the near bottom salinity was observed by Seshappa and Jayaraman (1956) off Calicut. This feature was also observed in the present study after the southwest monsoon, when the bottom salinity increased to an average of 34.9 from 30.1 ppt during first year and 35.1 from 31.5 ppt during the second year.

The pH of seawater is relatively constant, falling within the range 7.8 to 8.3 (Skirrow, 1975). The pH of seawater in the study area also conforms to this range except during southwest monsoon period when the pH drops considerably. Park *et al.* (1958) also recorded a dip in pH from 8.41 to 8.03 during three hours of rainfall. The average pH during monsoon in the first and second years was 7.51 and 7.29 respectively, which represented the lowest average for both the years. Carbon di oxide, due to its acidic character, affects the pH of the oceans through respiration and photosynthesis causing a decrease and increase of sea water pH respectively (Naqvi and Jayakumar, 2000). Traces of organic acids and other substances potentially capable of giving rise to weak acids are known to occur in the sea but their concentrations are negligible (Skirrow, 1975). During the southwest monsoon, maximal emission of carbon di oxide to the atmosphere occurs from the Arabian Sea

(Goyet *et al.*, 1998) which is due to the effect of strong winds. This in turn might decrease the partial pressure of the gas in the sea (Naqvi and Jayakumar, 2000), leading to a decrease in pH during monsoon. Traces of organic acids and other substances potentially capable of giving rise to weak acids are known to occur in the sea but their concentrations are negligible.

As in the case of temperature, salinity and pH, the distribution of oxygen is decisively influenced by the southwest monsoon (Jayaraman *et al.*, 1959). The monsoon season showed significantly lower values of dissolved oxygen at the bottom waters. Pillai (1993) observed that the shelf waters were well aerated during most of the year except during the southwest monsoon (July – September). Banse (1968) also reported low oxygen content of the cool water entering the shelf , off west coast of India. The reasons for the decrease have been attributed to the phenomenon of upwelling which occurs along the south-west coast of India during monsoon (Banse, 1968). The depletion has also been attributed to the higher flux of organic matter from the surface layer. The distribution of bottom fauna, demersal fishes and prawns would be affected by this depletion (Banse, 1959). During the rest of the year fairly high values of dissolved oxygen have been observed in the bottom waters, which is in conformity with the observation of Ramamirtham and Patil (1965). From the present study it was also evident that more or less uniform distribution of oxygen existed upto 50 m depth in the Cochin Munambam belt. Jayaraman *et al.* (1959) who studied the vertical distribution of dissolved oxygen in the Arabian Sea has also made similar observation.

Turbidity of sea water especially at bottom is directly proportional to the sediment load higher the sediment the more turbid the waters become. The shelf waters become highly turbid due to increased river and land run off and the increased wave action of the sea. Another phenomenon responsible for increased turbidity in the south west coast of India is upwelling, which usually occurs along with southwest monsoon (Nair and Balchand, 1992).

Phosphate-phosphorus and nitrate-Nitrogen are two most important nutrients found in the marine environment. Nitrogen has been highlighted as the nutrient that controls primary production in coastal ecosystems (Ryther and Dunstan, 1971; Codispoti, 1989). Nitrite ions are created by the process of denitrification when practically all oxygen has been utilized and nitrate is used as an alternative source of energy. SenGupta *et al.* (1976) observed that very low oxygen values are associated with nitrite values, with an average of 0.1 µg-at /L in the northwestern Indian Ocean. In a study conducted in the estuarine complex which lies adjacent to the area under study, it was reported that during April, nitrite was found only in traces. Lower values of nitrite were observed in the bottom waters during premonsoon season of both the years. Nitrite content was found to be enhanced in the bottom waters during the peak of monsoon season, as observed during both July 2001 and 2002.

The nitrite–N concentration showed conspicuous seasonal variation. The concentration increased from June onwards with the introduction of land run off and was found to be maximum in July / September. Similar observation was made by Gouda and Panigrahy (1995) in Rushikulya estuary on the east coast of India. Manikoth and Salih (1974) recorded high nitrite concentration during the monsoon season in the Vembanad estuarine complex during the southwest monsoon. Spatially, the stations close to the shore had slightly higher nitrite content when compared to those of offshore. Manikoth and Salih (1974) have discussed the nutrient content of the estuary and observed that the nutrients come into the backwaters via freshwater discharge, which is ultimately drained into the sea. Kamykowski and Zentoura (1991) points out that accumulation of nitrite in the near bottom samples depends on diffusion from sediment as well as mechanisms such as nitrification near the sediment water interface. Active regeneration of nutrients takes place within the sediment, resulting in a marked concentration gradient between interstitial water and overlying water, which leads to enrichment of the latter by diffusion (Rittenberg *et al*, 1955).

The only significant input of phosphorus to the oceans comes via river water. It sinks to the ocean floor as organic debris and becomes incorporated into the sedimentary rocks (Tyrrel, 1999). The conversion of organic phosphorus to phosphate occurs with bacterial decomposition of organic matter (Reddy and Sankaranarayanan, 1972). In the estuarine and coastal environments, where sedimentary inputs are large, microbially mediated benthic remineralisation of debris is a major recycling pathway and it can supply a significant fraction of nutrients to the overlying water. The bottom water samples show a higher quantity of phosphate compared to nitrite during all months, showing high regenerative action and incorporation into the overlying waters (Sarala Devi *et al.*, 1991). Seshappa and Jayaraman (1956) also observed that during the south west monsoon, the interstitial phosphate was very low. However, simultaneous observations made on the phosphate content of water close to seabed showed higher values (Rao *et al.*, 1982).

Bottom trawling is a fishing practice used to catch species living on or in the sea floor. From the present study it was clear that bottom trawling has little effect on the temperature, salinity and pH of bottom waters. These parameters show constancy in values even after trawling. But significant changes were noticed with regard to dissolved oxygen and turbidity when before and after trawling samples were compared. Dissolved oxygen was found to be reduced due to trawling, while turbidity showed a significant increase.

Owing to the pressure of trawl gear on seabed, parts of the gear penetrate upto some extent into the sea bottom; the penetration largely depends on the nature of sea bottom (Margetts and Bridger, 1971, Bridger, 1972). The disturbance is most distinct on muddy / soft sandy grounds (Fonteyne, 2000). Successive layers of sediment are brought into suspension which creates a zone of high turbidity in the water column (deGroot, 1984, Redant, 1987). Bottom waters have been reported to be lesser in oxygen content compared to the surface waters (Damodaran, 1973). The heavy influx of organic matter further depletes the oxygen content of the bottom waters. This situation can further be aggravated by the turbulent churning of sediments during trawling, creating a zone of very low oxygen. Along Kerala coast, where trawling pressure is very high immediately after monsoon, the above said conditions might exist in the bottom waters. The hypoxic condition might prove to be hazardous for the survival of eggs, larvae, and juveniles of fish as observed by Morgan *et al.* (1983). An abrupt rise in turbidity and subsequent reduction in dissolved oxygen may create an unfavourable niche for organisms in the marine ecosystem. Studies along the southwest coast of India revealed that bulk of pelagic fish population constituted by oil sardine, mackerel and white bait avoided temporally areas of intense upwelling activity due to low oxygen concentration (Pillai, 1993). High turbidity level may reduce larval survival (Morgan *et al.*, 1983), smother sessile organisms, impair the filter feeders and impair growth of bottom flora due to lessened light penetration (Newcombe and MacDonald, 1991). The hazardous effect of rise in turbidity plumes on shellfish and other benthic organisms have also been discussed by Churchill *et al.* (1994).

From the results of this study, it is clear that trawling can increase the nitrite content of the bottom waters to a significant extent. Main and Sangster (1981) have observed that those parts of the trawl net that come into contact with seabed will cause bottom sediments to be resuspended, but the turbulence created by trawl door suspend the most material and plays an important role herding the fishes towards the net. This resuspension may have resulted in an increase in nutrients in the bottom waters immediately after trawling. The interstitial water may also contribute to an increase in the nitrite content of sea water. Moreover a decrease in oxygen content as observed in the present study has been found associated with bottom trawling. The unavailability of oxygen may also promote the production of nitrite ions in water. Pilot studies in the

Western Moreton Bay (Eyre and Ferguson, 2002) suggests lower denitrification rates in the trawled areas of the Bay compared to the untrawled areas.

After trawling , there was a notable significant increase in the phosphate content, which can be attributed to the churning and mixing of sediment and interstitial water into the overlying water column (Rittenberg *et al.*,1955), due to the action of the trawl gear. An additional amount of phosphate is thus released into the overlying waters by way of bottom trawling. Phosphate concentration was found to be amplified after trawling at almost all stations throughout the experiment, indicating that the event was independent of the seasonal changes in concentration. Along Kerala coast, the ban imposed on trawling during the monsoon lifts by the 31st of July, thus permitting the trawlers to fish in the coastal waters. The after trawling concentration of phosphate was found to be significantly high in September also, which is indicative of the heavy trawling pressure along the area. Seabed is a major supplier of the nutrients into the water column and any disturbance on the sea bottom releases the nutrients into the water along with the other minerals and gases trapped in sediment (ICES, 1992).

Among the physico chemical parameters investigated, the salinity, pH and temperature of bottom waters were unaffected by bottom trawling. On the other hand, oxygen distribution and turbidity underwent rapid changes immediately after trawling while a reduction in oxygen level and a significant elevation in turbidity was detected. Nair and Balchand (1992) observed a depletion of oxygen in the bottom waters during the mud bank period in

Alleppey, on the southwest coast of India and attributed this phenomenon to upwelling. According to them, oxidation of organic matter may further reduce the oxygen content of the subsurface waters during this period. Trawling resusupends sediments, thus increasing the organic load of the bottom waters. The low original oxygen content is further depleted , so that the bottom waters become badly aerated . Banse (1959) discusses the possibility of the demersal fishes and prawns being forced to migrate against the shore or into the deeper waters. Riemann and Hoffmann (1991) has discussed the effects of trawling and dredging and the possibility of increasing the nutrient loads, oxygen consumption and primary production.

Increased turbidity can lead to a reduction in the production and diversity of species. It can reduce the amount of light available for photosynthesis which may decrease the phytoplankton biomass and therefore result in increased dissolved nutrients in the water column. It can smother benthic organisms and habitat (ANZECC/ARMCANZ, 2000). Further it can cause mechanical and abrasive impairment to the gills of fish and crustaceans. It can transport contaminants (particulate nutrients, metals and other potential toxicants), and can lead to the dissolved oxygen depletion in the water column if it is caused by particulate organic matter. Bottom trawling can remobilize substantial amounts of bottom sediments, including associated nutrients and contaminants, smothering filter feeders and adding to the pollution load and biological oxygen demand.

The direct effects of trawling on the physical and chemical properties of water have been demonstrated in this chapter. However, the potential ramifications of these changes on the sea floor communities are yet to be considered (Thrush and Dayton, 2002). They play an important role in the marine ecosystem so that the extent and intensity of human disturbance to the natural ecosystem is a threat to both structural and functional diversity of the ecosystem.

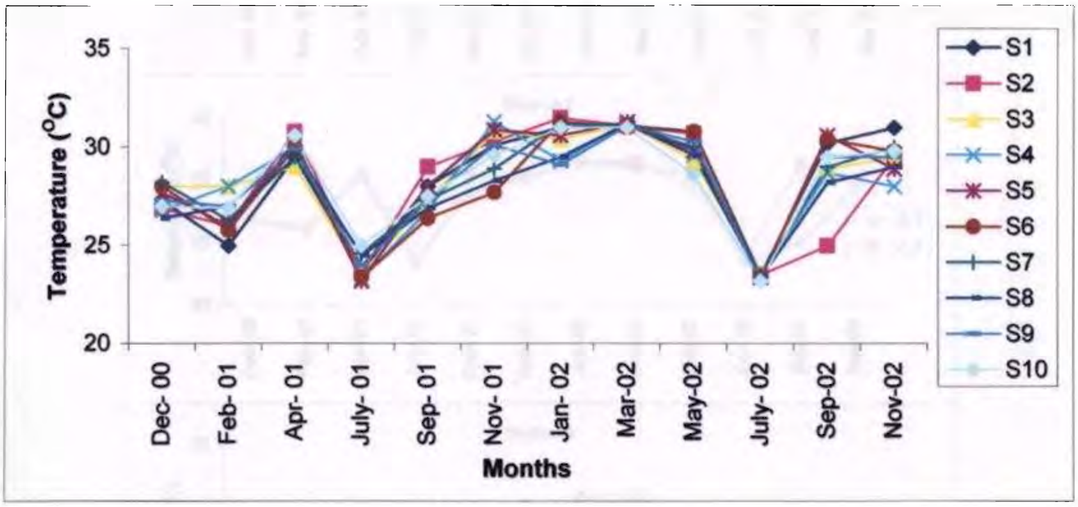


Fig.4.1 Seasonal variations in temperature of bottom waters during December 2000 to November 2002 at stations 1 to 10.

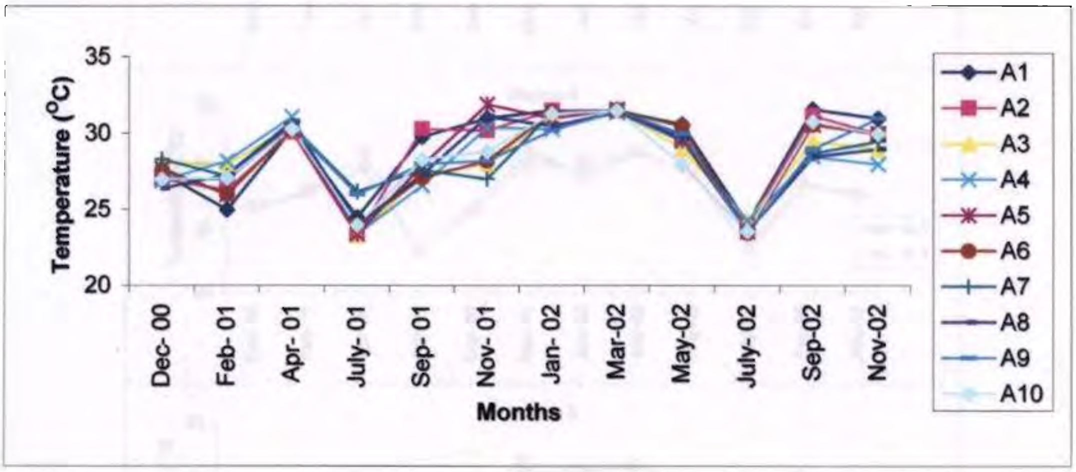


Fig.4.2 Temperature of bottom waters after trawling during December 2000 to November 2002 at stations 1 to 10.

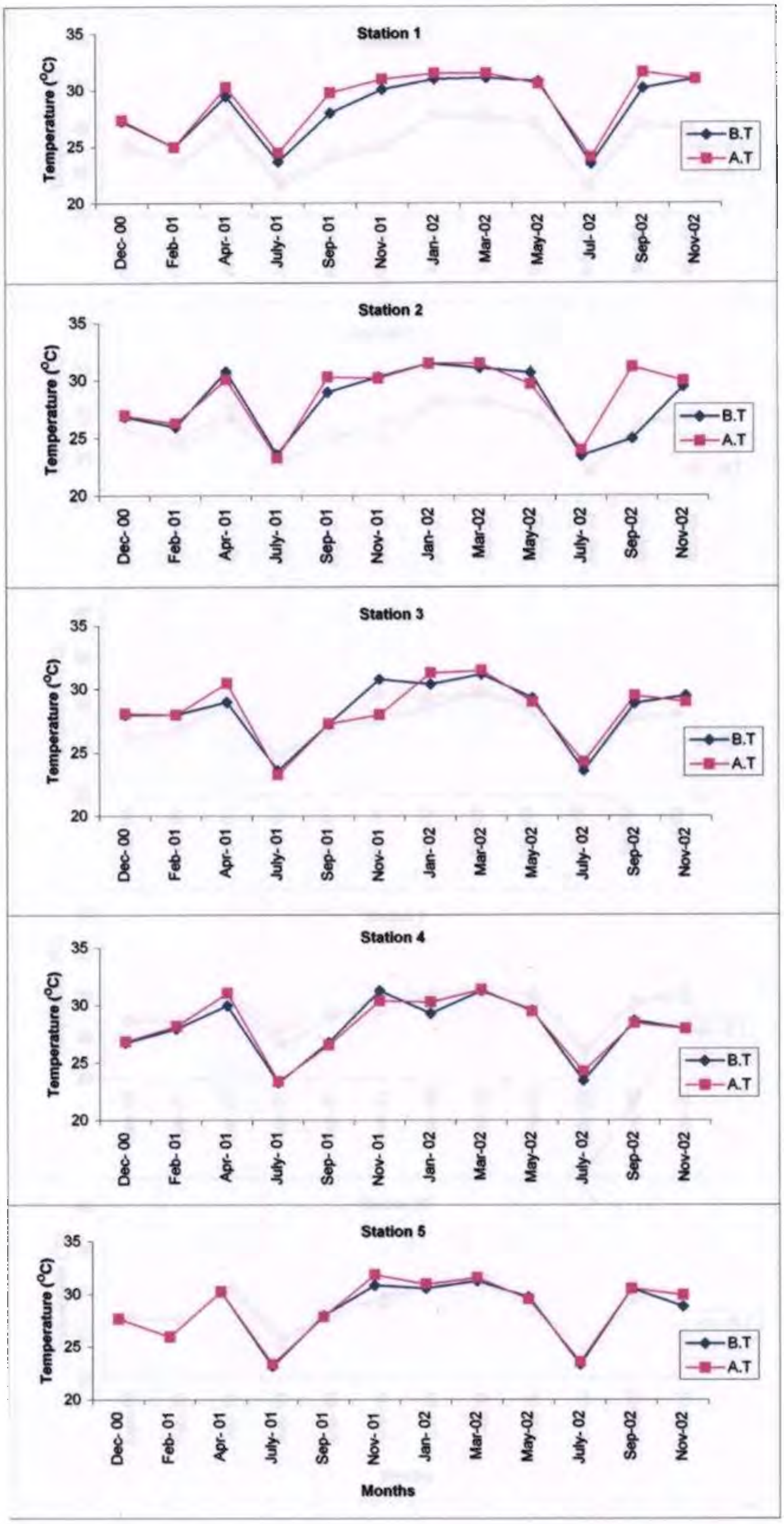


Fig.4.3a Pattern of variations in temperature of bottom waters before and after trawling during December 2000 to November 2002

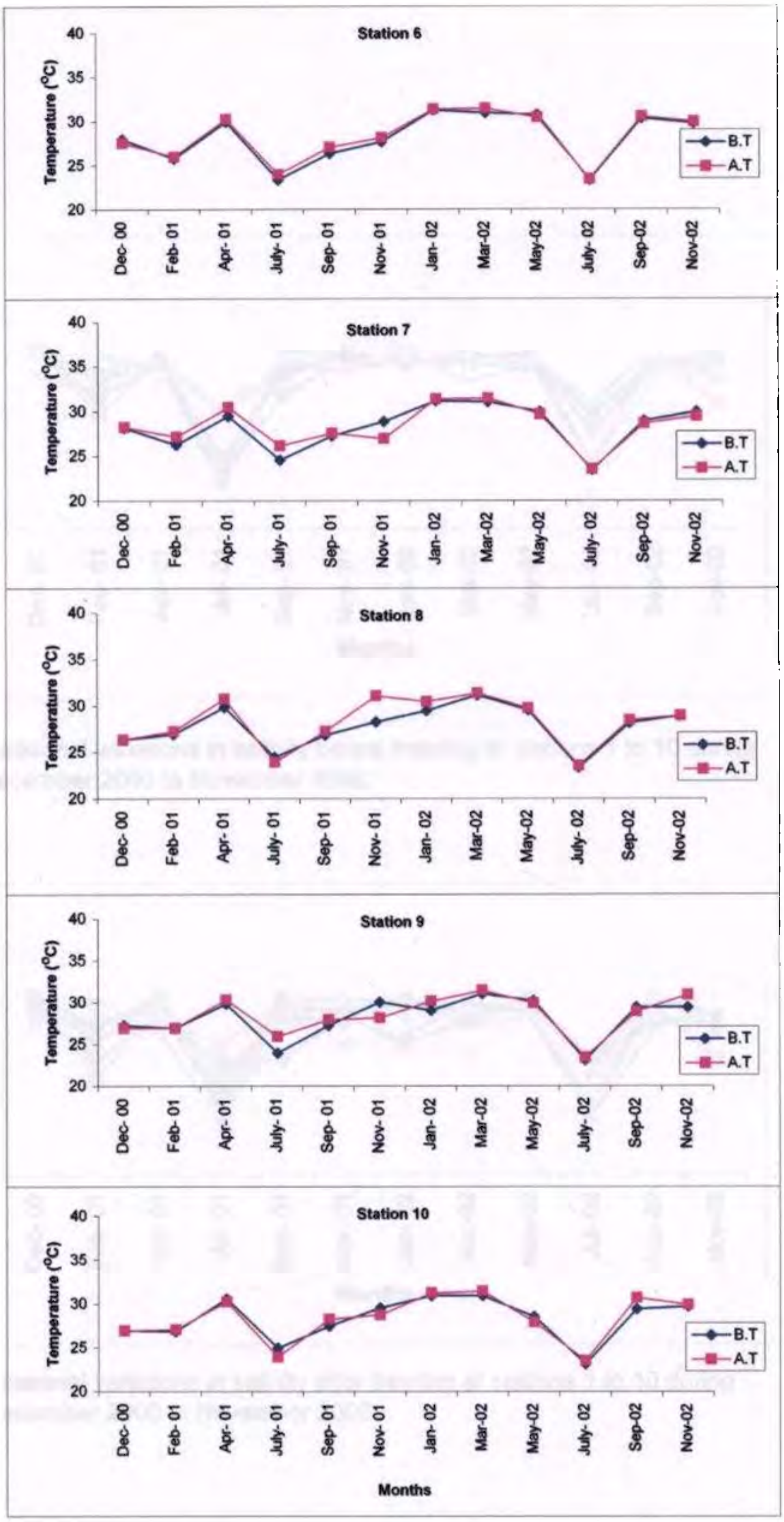


Fig.4.3b Pattern of variations in temperature at bottom before and after trawling during December 2000 to November 2002

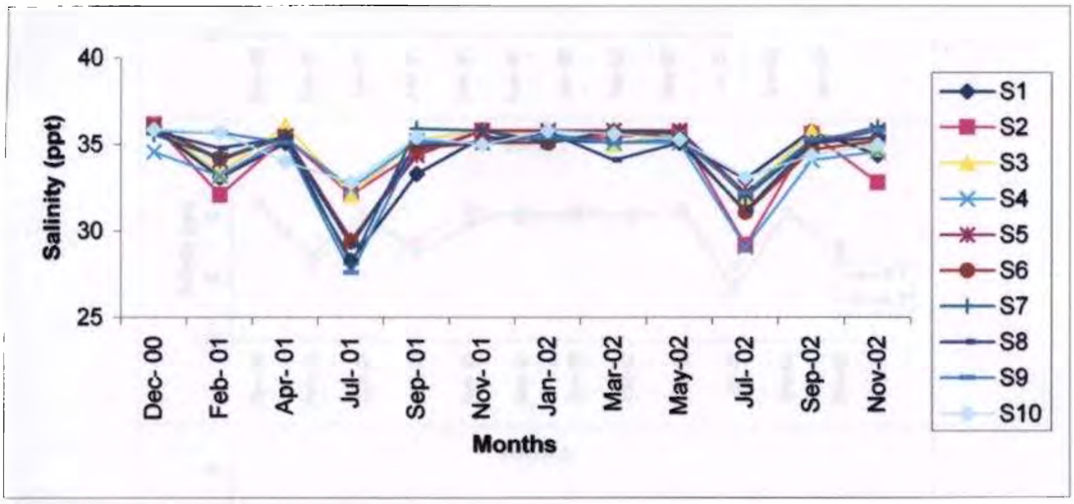


Fig.4.4. Seasonal variations in salinity before trawling at stations 1 to 10 during December 2000 to November 2002.

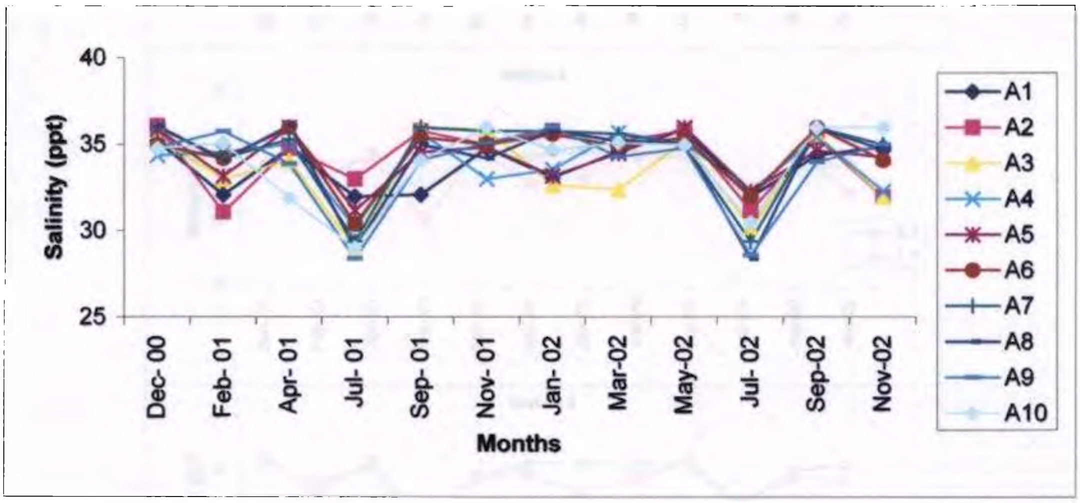


Fig.4.5. Seasonal variations in salinity after trawling at stations 1 to 10 during December 2000 to November 2002.

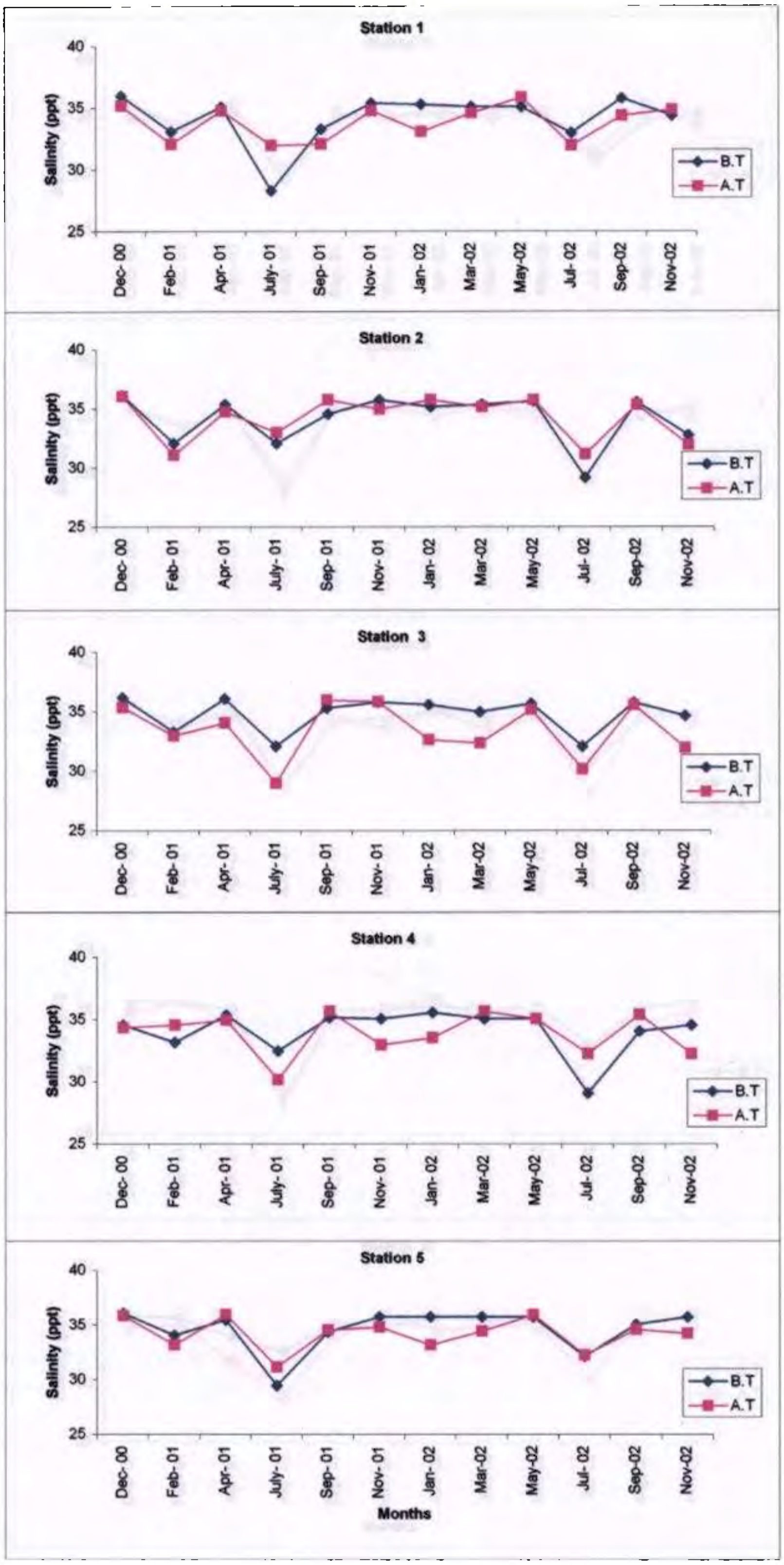


Fig. 4.6a Variations in salinity at bottom before and after trawling during December 2000 to November 2002

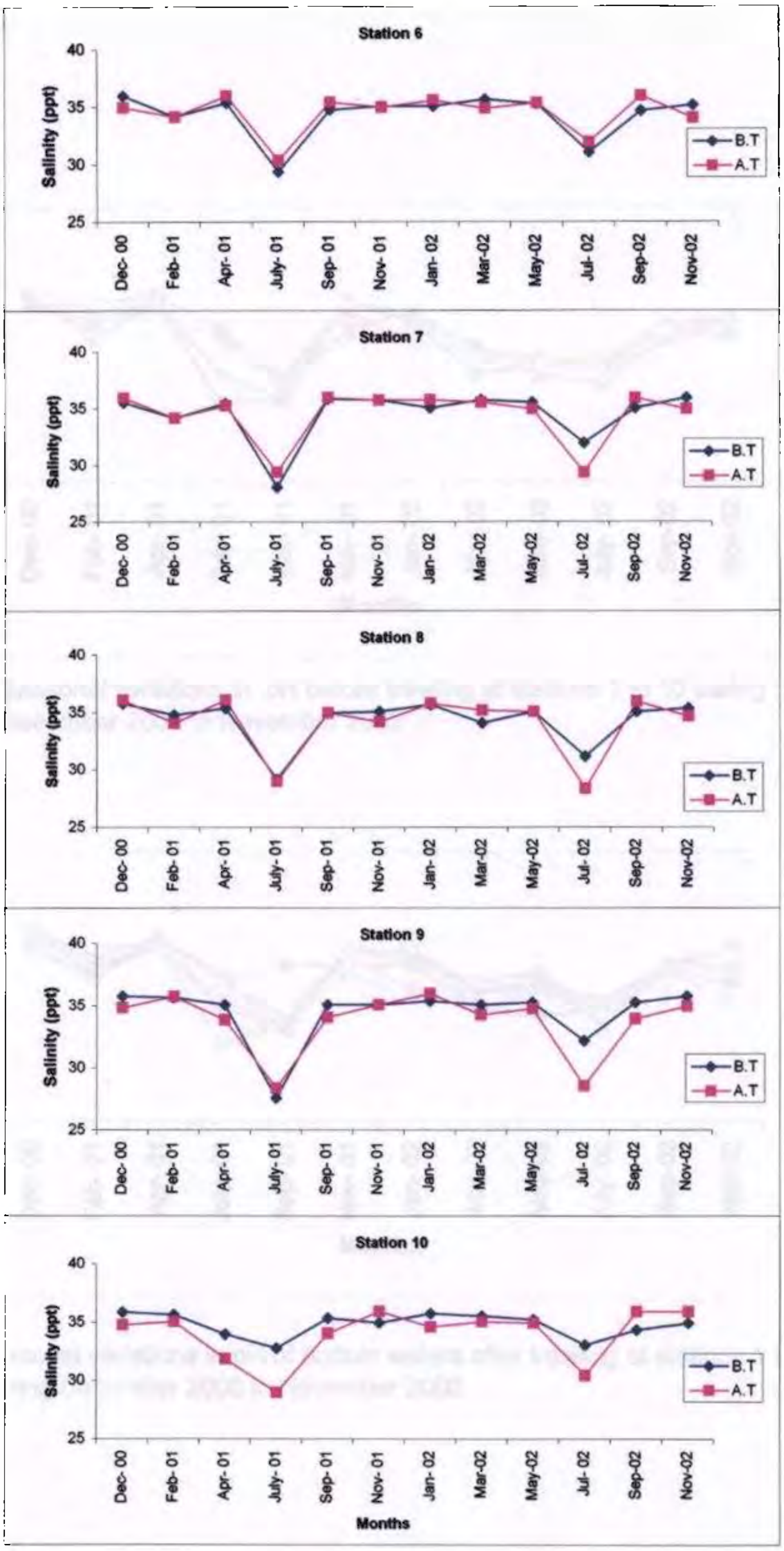


Fig 4.6 b - Variations in salinity at bottom before and after trawling during December 2000 to November 2002

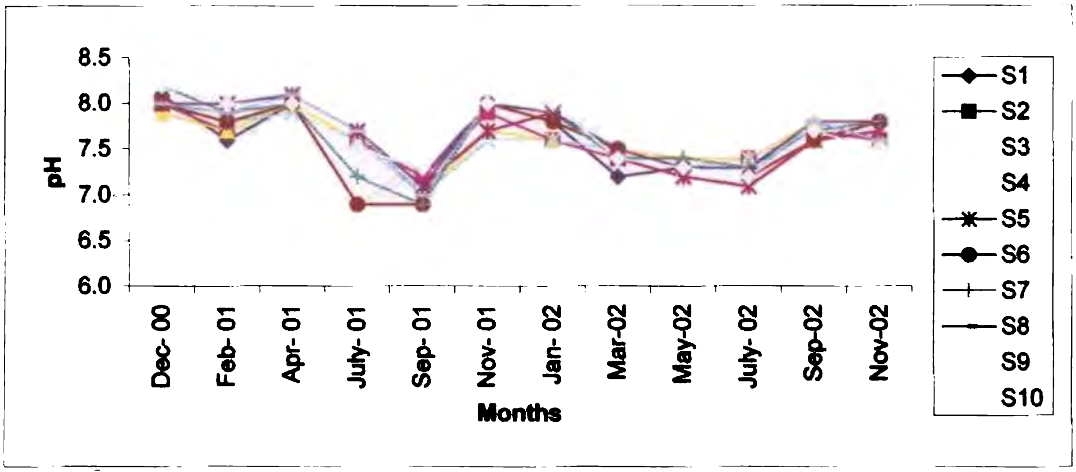


Fig.4.7. Seasonal variations in pH before trawling at stations 1 to 10 during December 2000 to November 2002

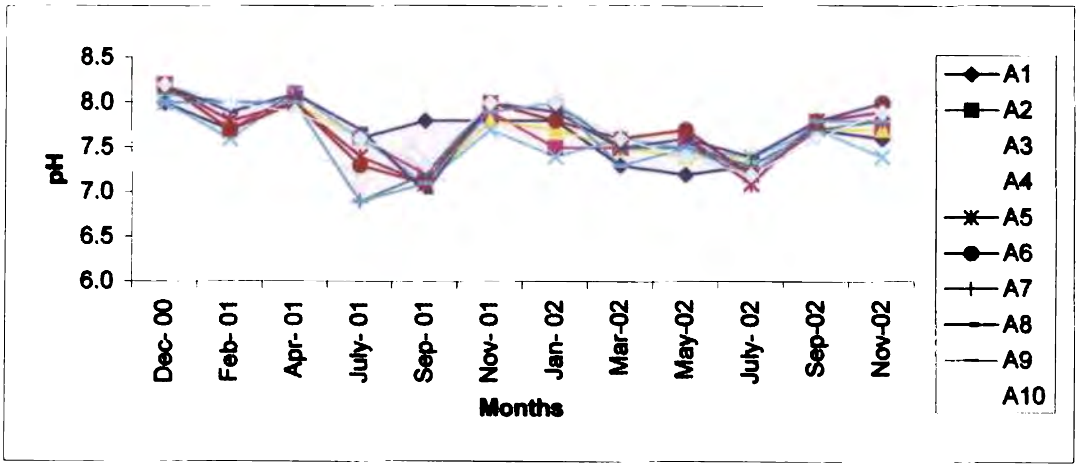


Fig.4.8.Seasonal variations in pH of bottom waters after trawling at stations 1 to 10 during December 2000 to November 2002

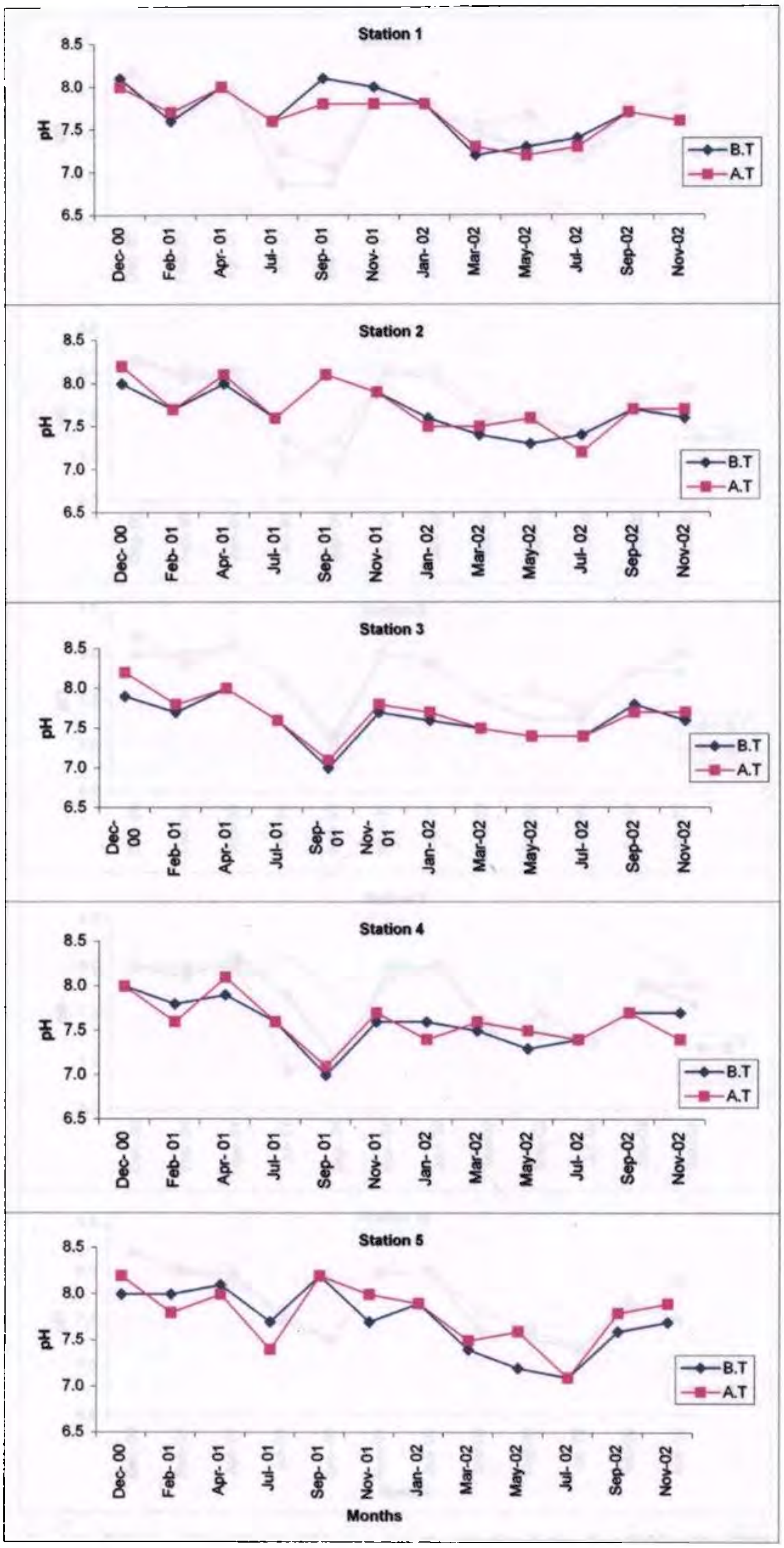


Fig.4.9a. Patterns of variation in pH before and after trawling during Dec.2000 to Nov.2002 at stations 1 to 5

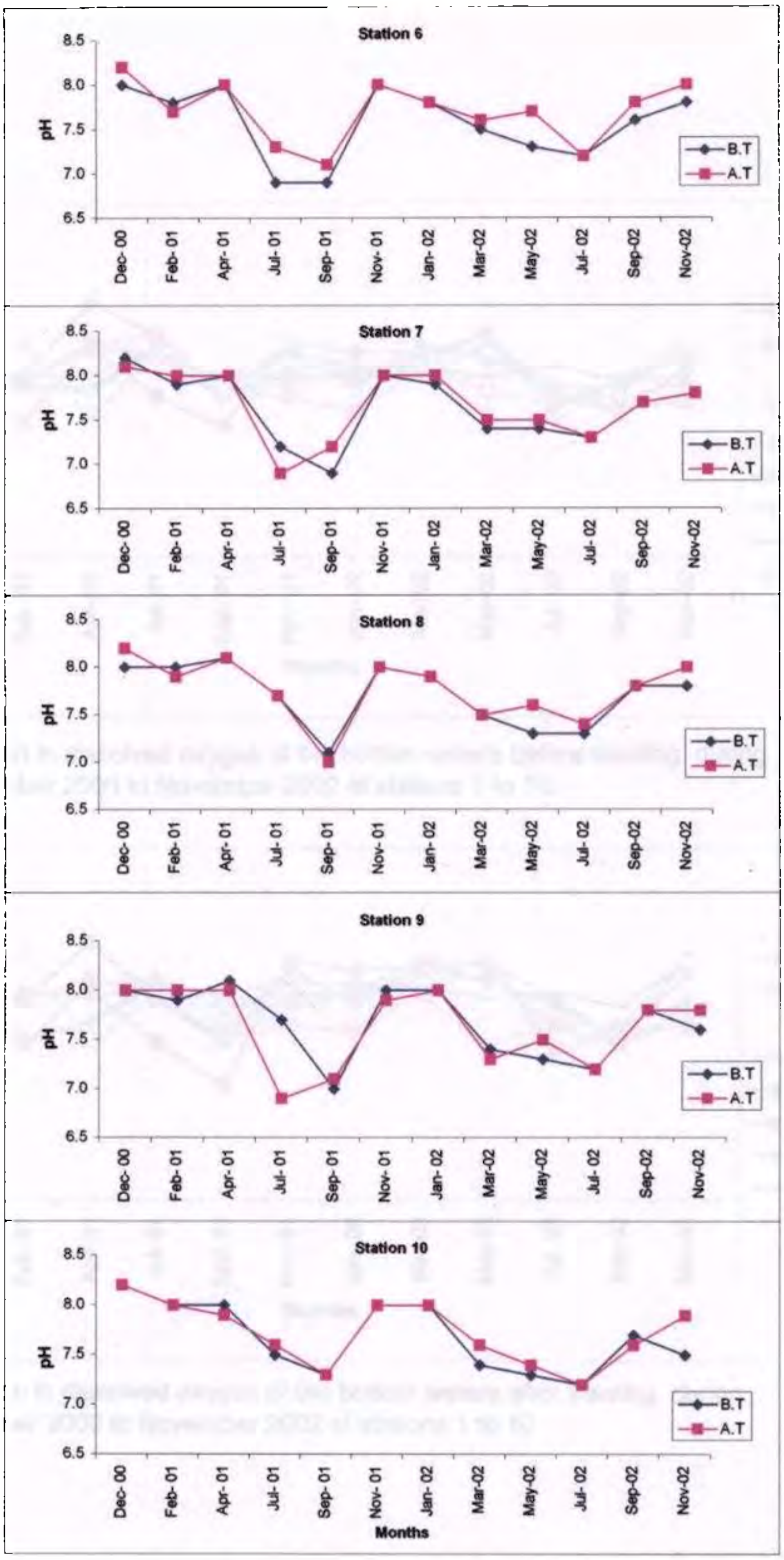


Fig.4.9b. Patterns of variation in pH before and after trawling during Dec.2000 to Nov.2002 at stations 6 to10

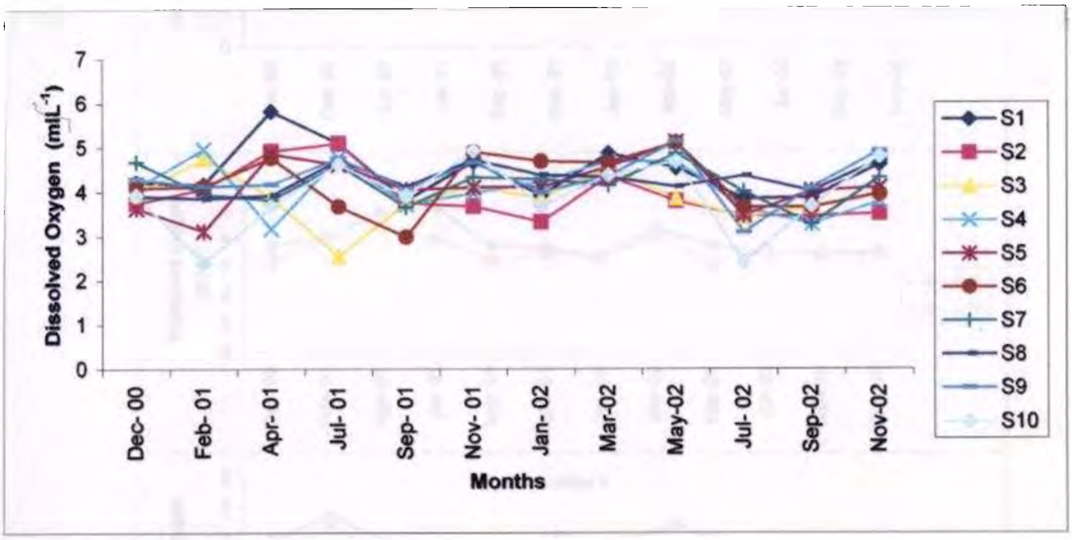


Fig.4.10. Variation in dissolved oxygen of the bottom waters before trawling during December 2000 to November 2002 at stations 1 to 10.

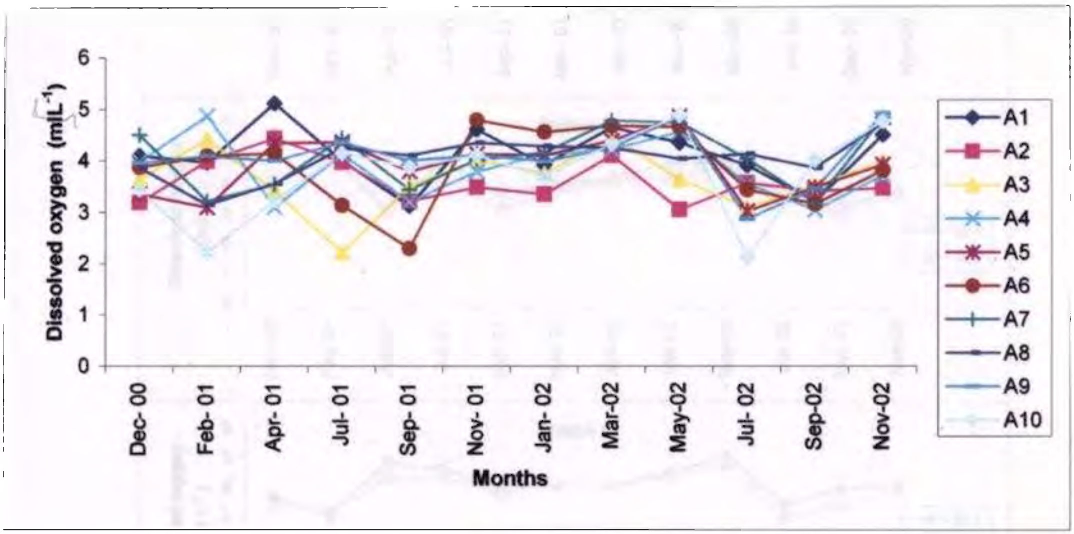


Fig.4.11.Variation in dissolved oxygen of the bottom waters after trawling during December 2000 to November 2002 at stations 1 to 10

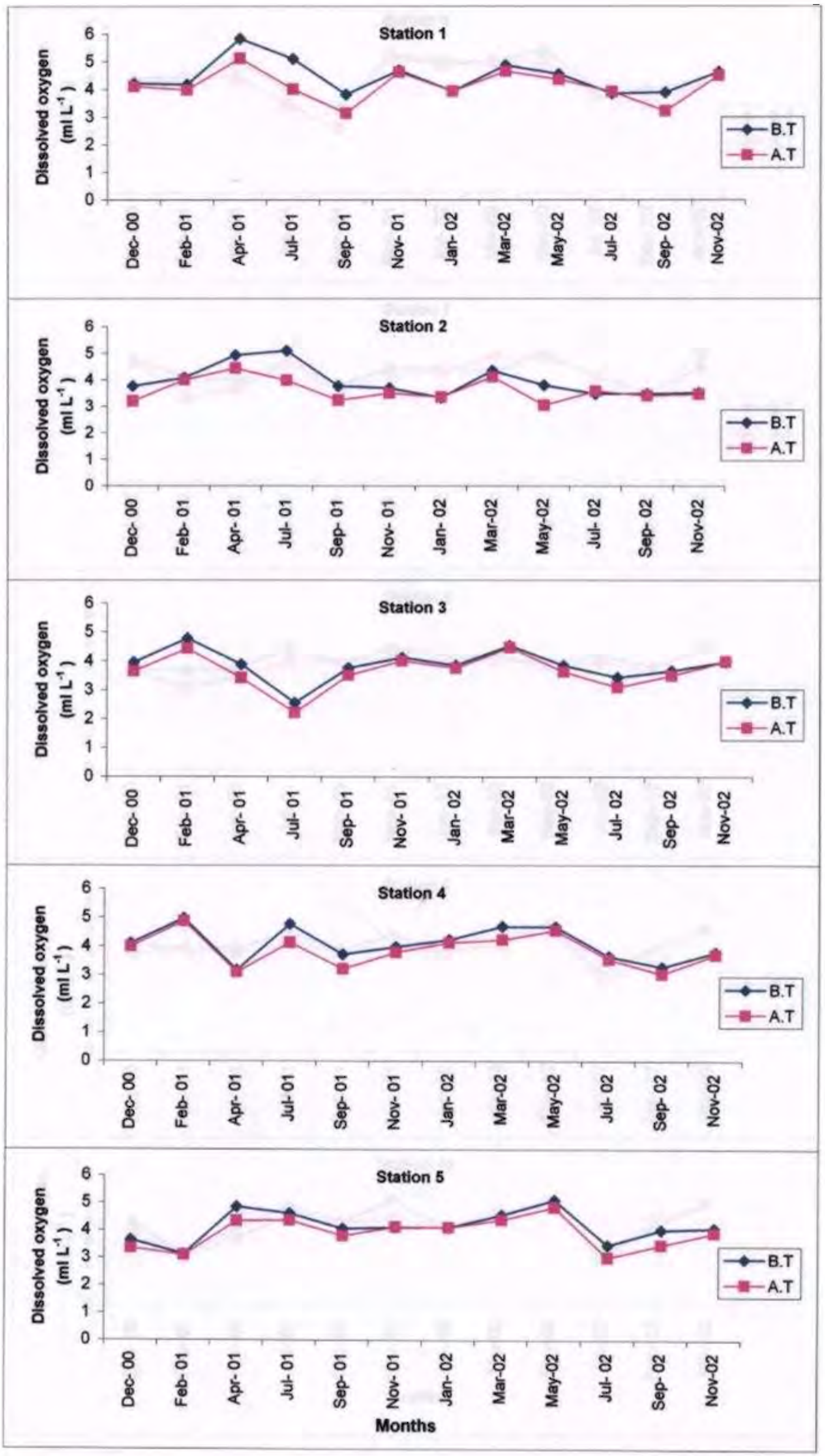


Fig. 4.12a. Comparison of dissolved oxygen before and after trawling from December 2000 to November 2002 at stations 1 to 5

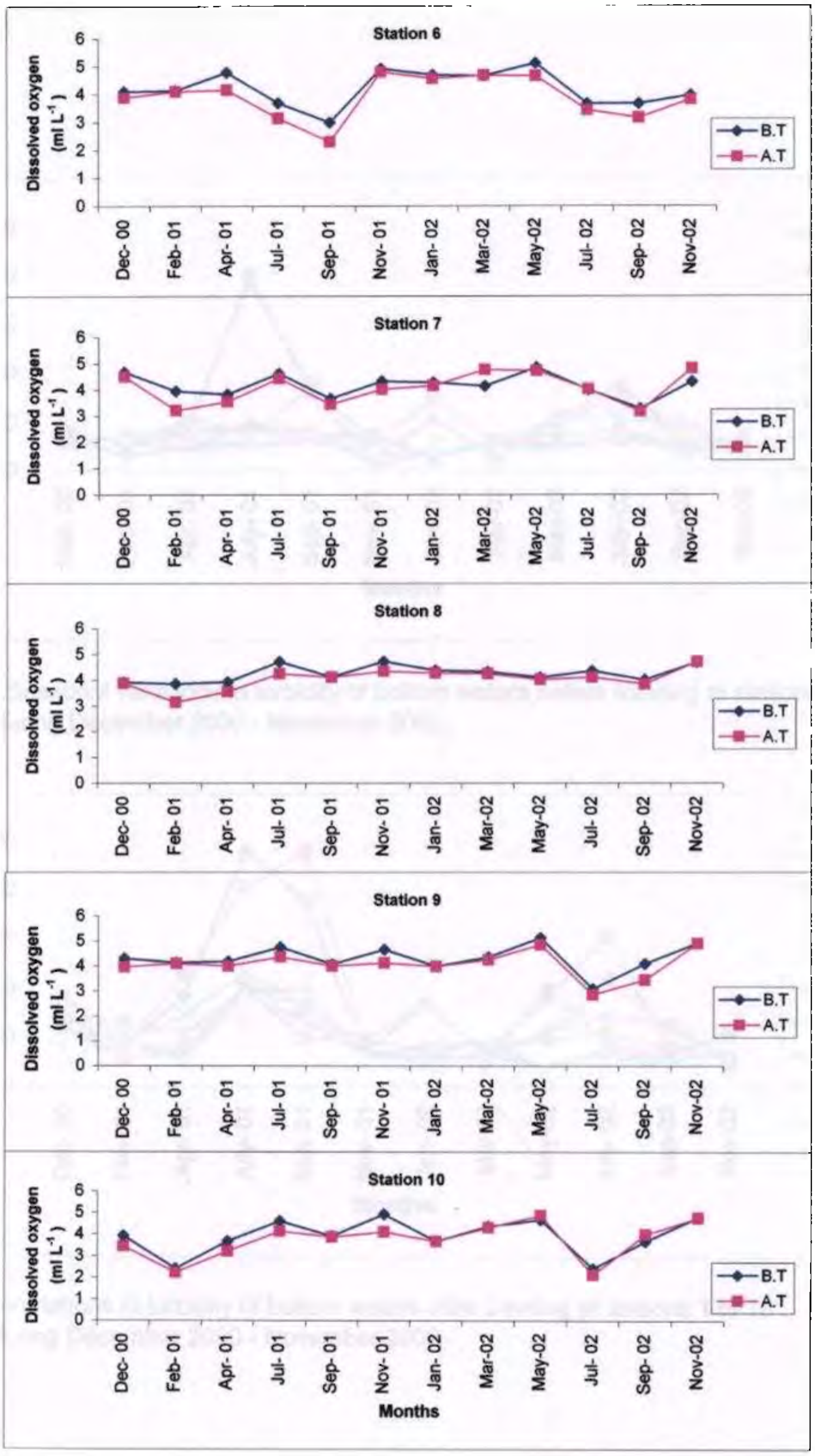


Fig.4.12b.Comparison of dissolved oxygen before and after trawling from December 2000 to November 2002 at stations 6 to 10

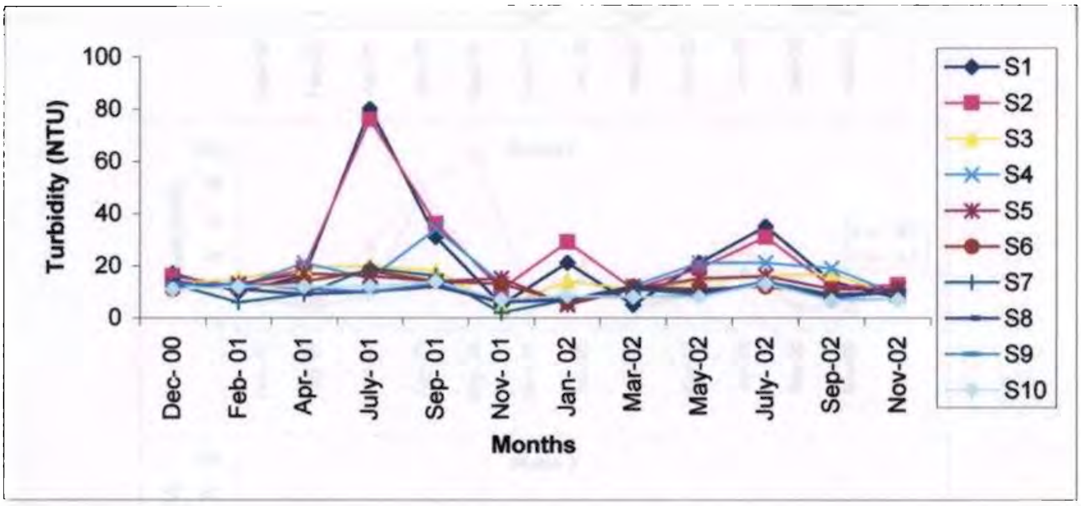


Fig.4.13.Seasonal variations in turbidity of bottom waters before trawling at stations 1 to 10 during December 2000 - November 2002.

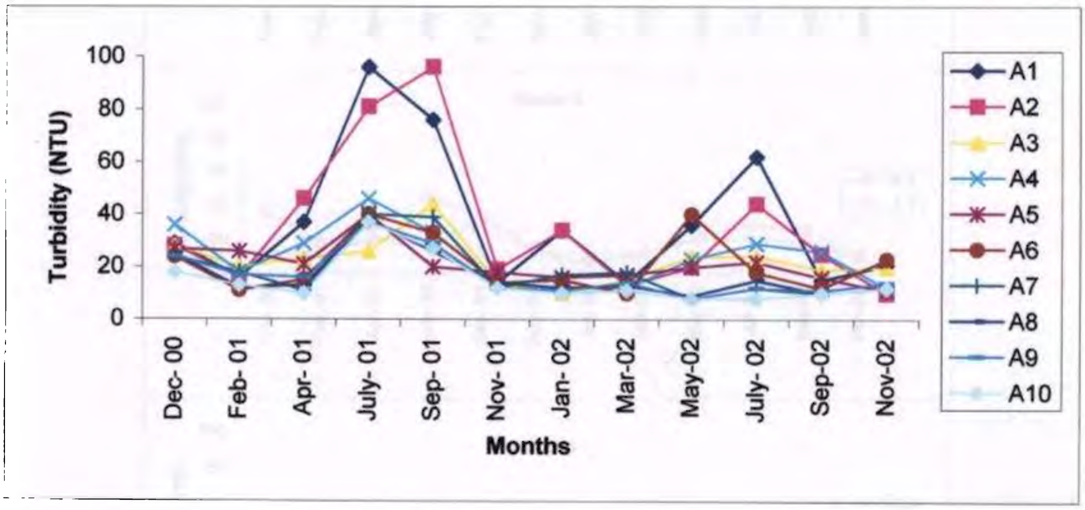


Fig.4.14.Variations in turbidity of bottom waters after trawling at stations 1 to 10 during December 2000 - November 2002.

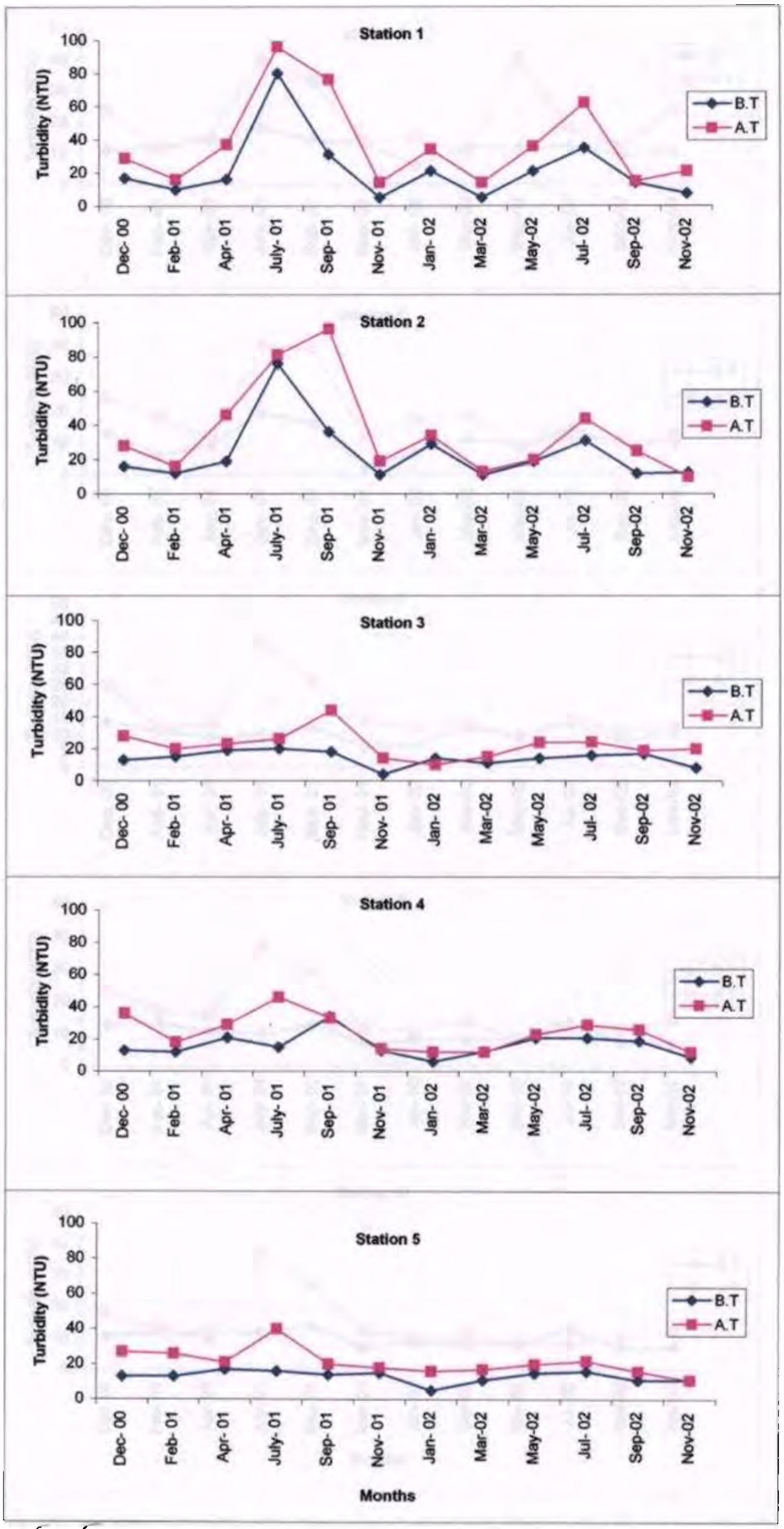


Fig.4.15a Variation in turbidity of bottom waters before and after trawling at stations 1 to 5 during December 2000 to November 2002

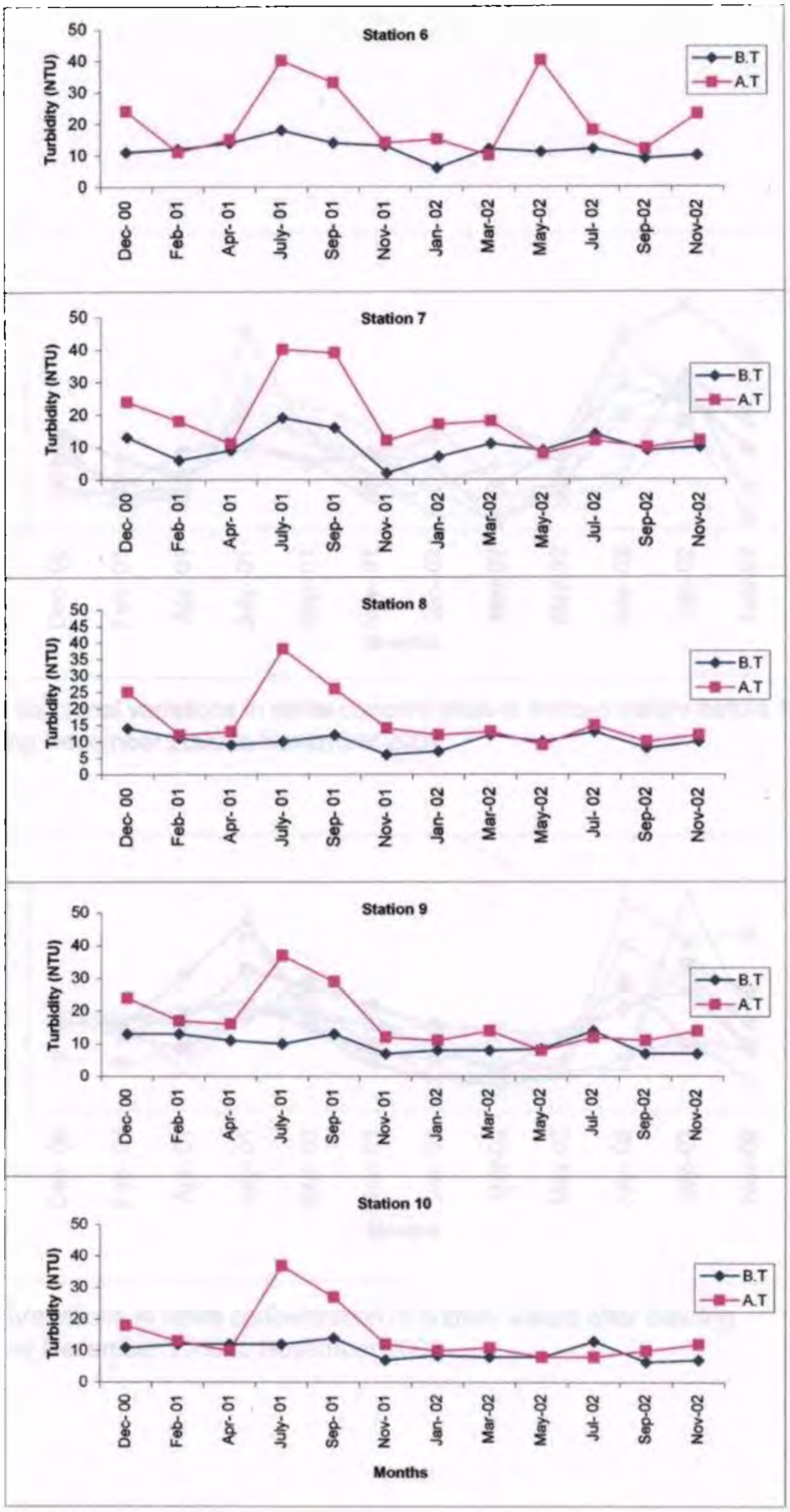


Fig.4.15b. Variation in turbidity of bottom waters before and after trawling at stations 6 to 10 during December 2000 to November 2002

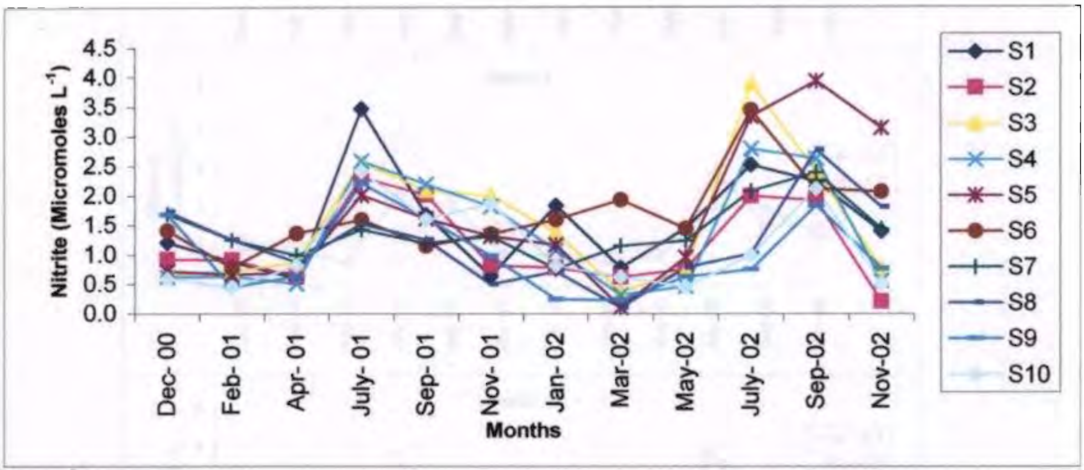


Fig.4.16.Seasonal variations in nitrite concentration of bottom waters before trawling during December 2000 to November 2002

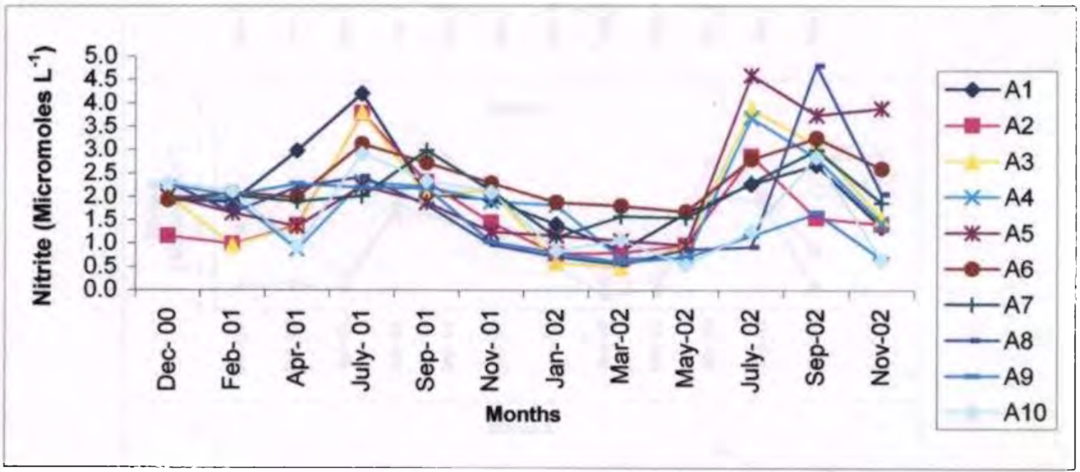


Fig.4.17.Variations in nitrite concentration of bottom waters after trawling during December 2000 to November 2002

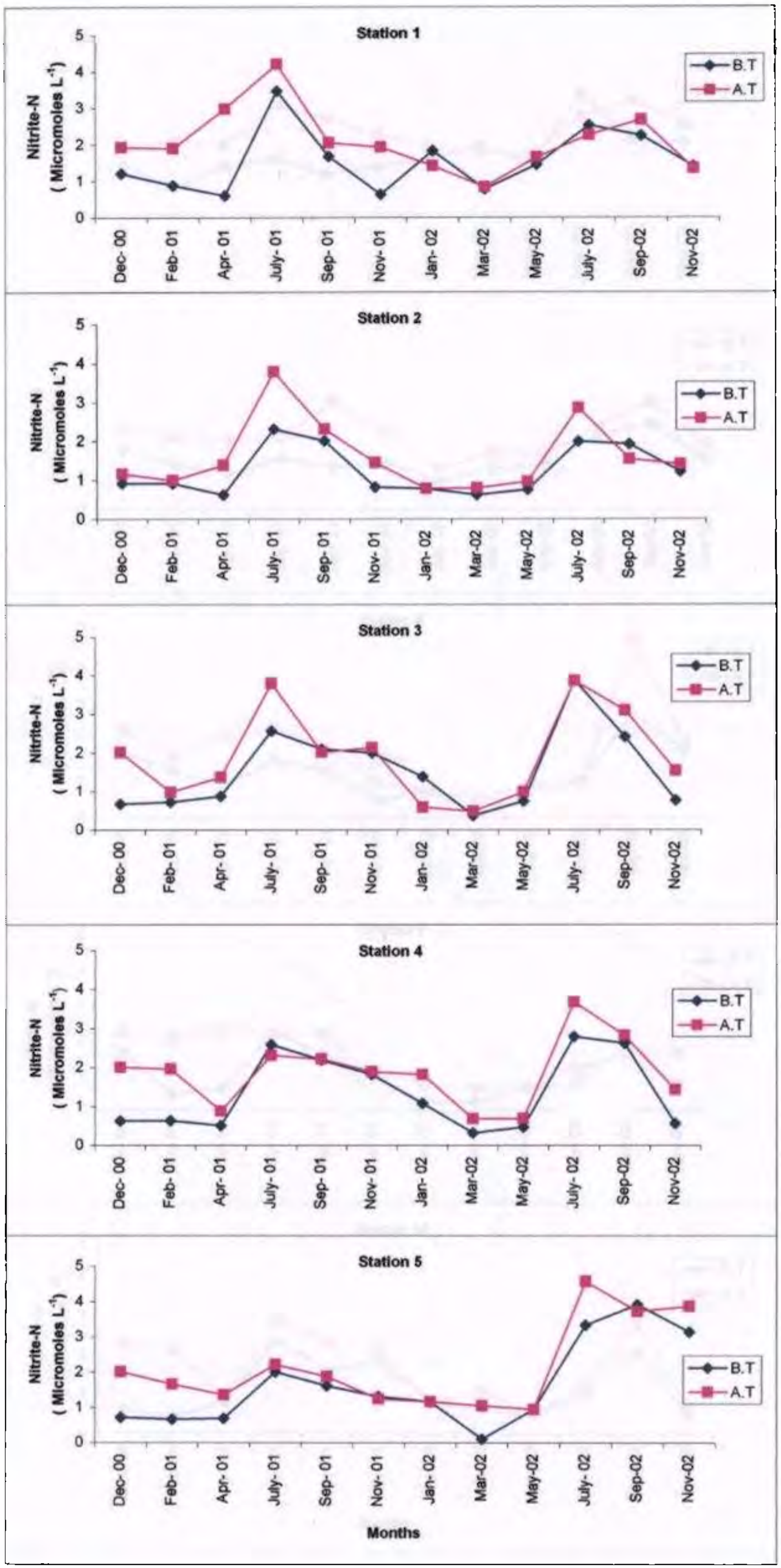


Fig.4.18a. Comparison of nitrite-nitrogen at bottom waters before and after trawling during December 2000 to November 2002 at stations 1 to 5

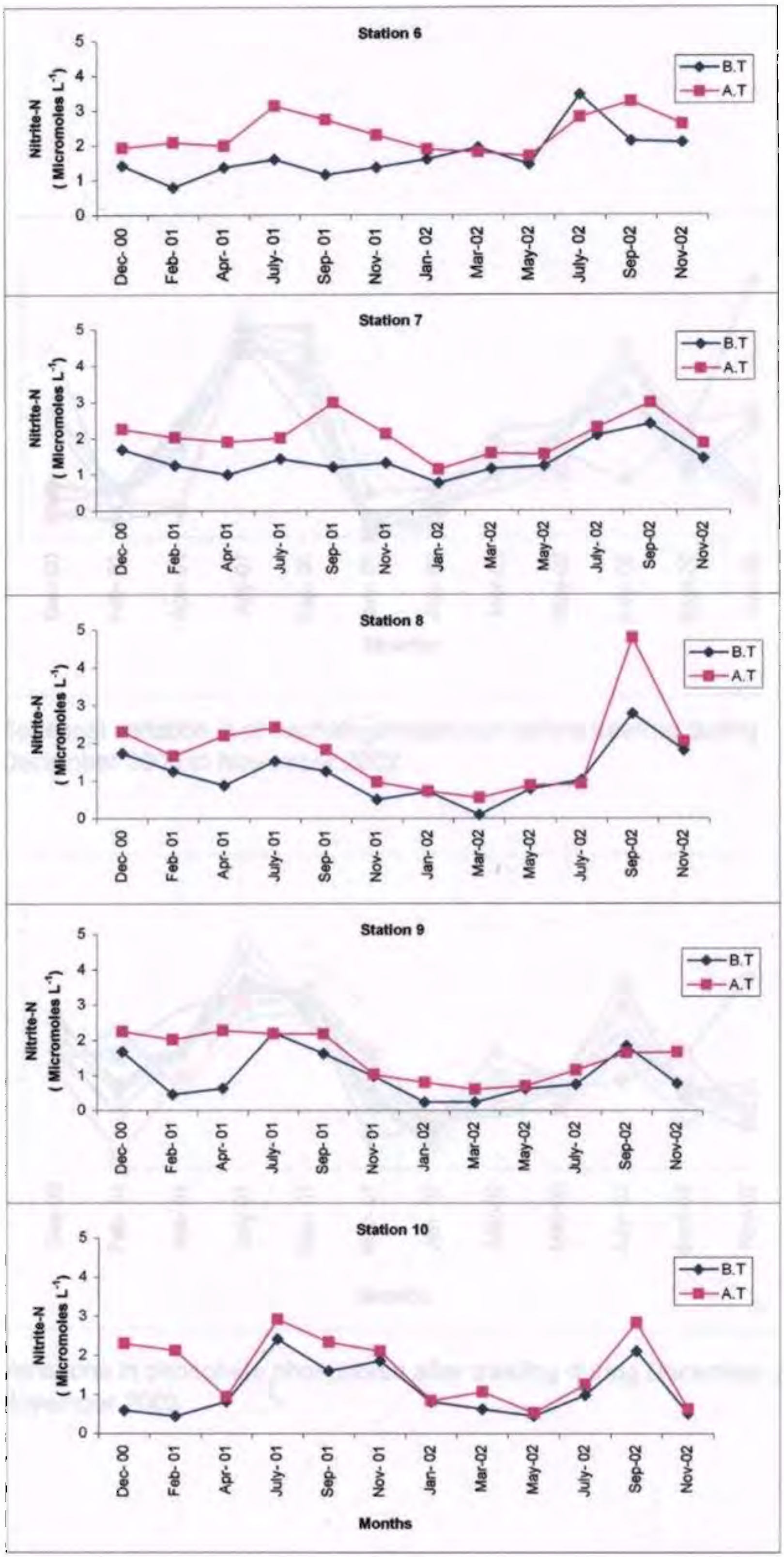


Fig. 4.18b. Comparison of nitrite-nitrogen at bottom waters before and after trawling during December 2000 to November 2002 at stations 6 to 10

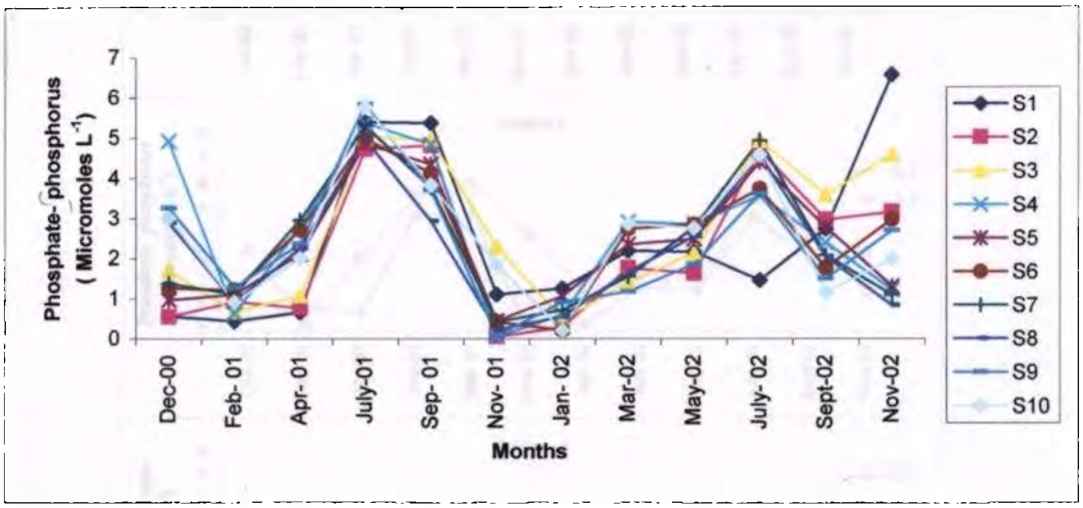


Fig.4.19.Seasonal variation in phosphate-phosphorus before trawling during December 2000 to November 2002

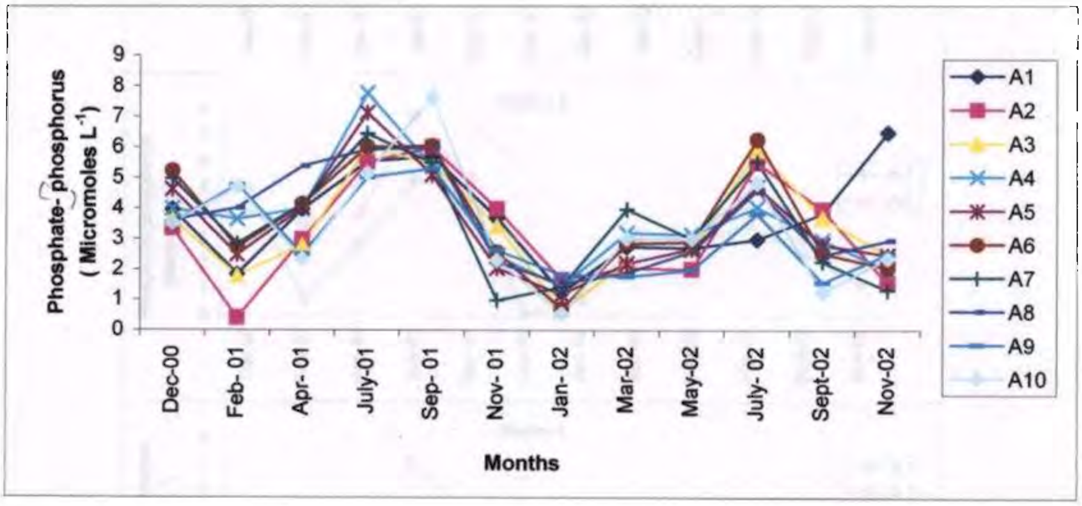


Fig.4.20.Variations in phosphate phosphorus after trawling during December 2000 to November 2002

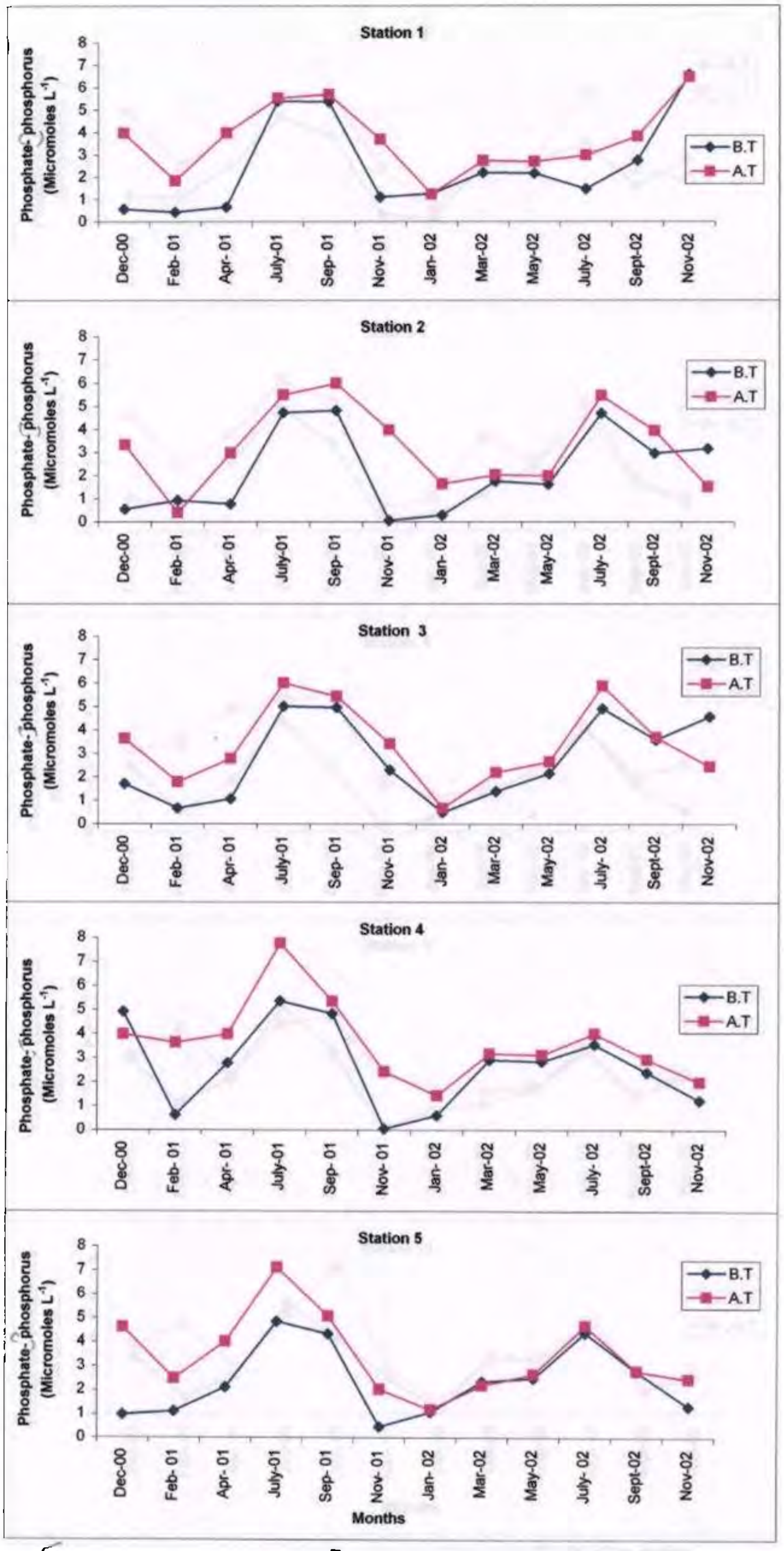


Fig 4.21a. Comparison of phosphate phosphorus before and after trawling during December 2000 to November 2002 in stations 1 to 5

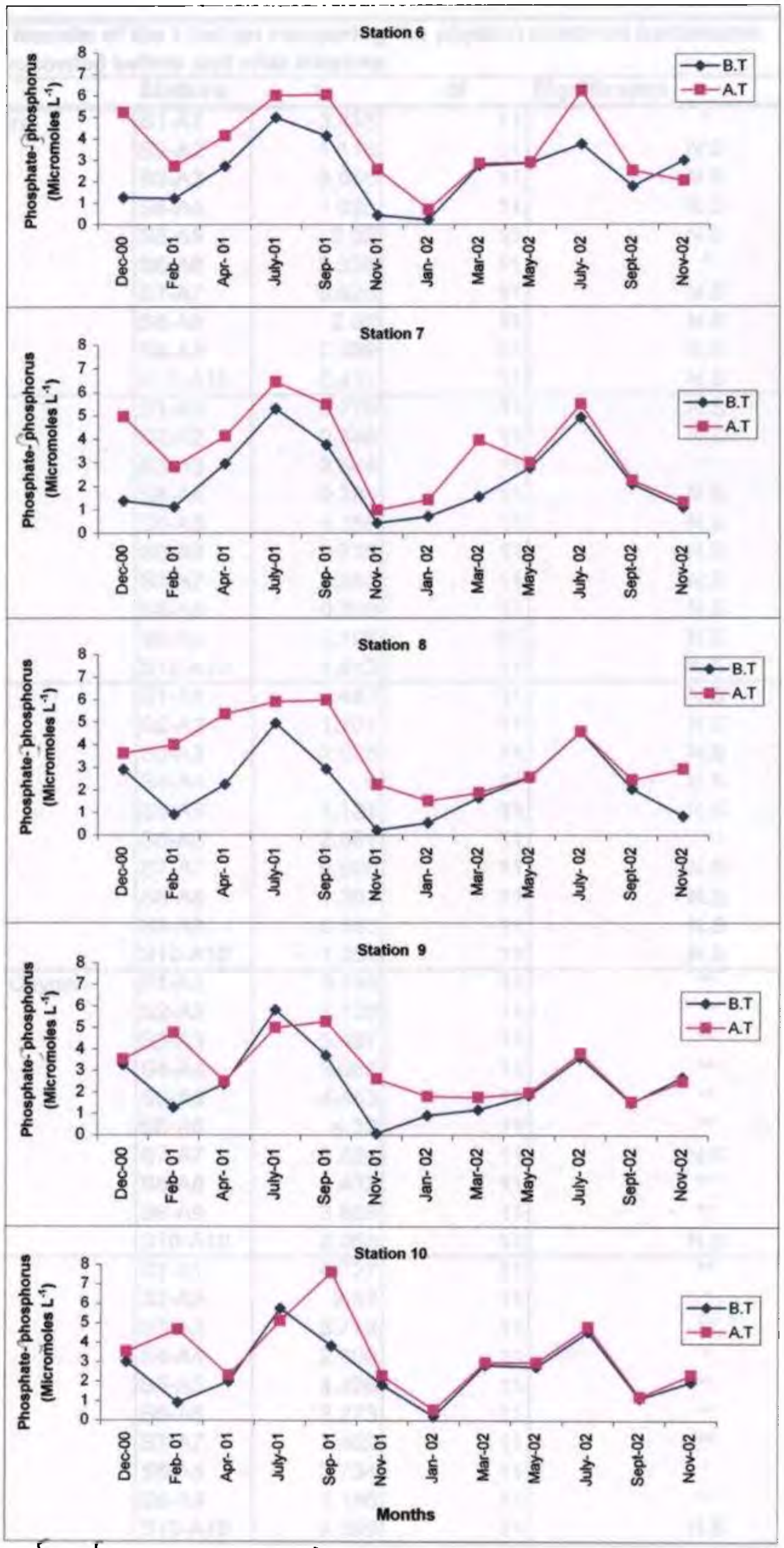


Fig. 4.21b. Comparison of phosphate phosphorus before and after trawling during December 2000 to November 2002 in stations 6 to 10

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Table 4.1c. Results of the t test on comparing the physico chemical parameters recorded before and after trawling

Item	Stations	t	df	Significance
Temperature	S1-A1	3.438	11	*
	S2-A2	1.116	11	N.S
	S3-A3	0.055	11	N.S
	S4-A4	1.025	11	N.S
	S5-A5	2.02	11	N.S
	S6-A6	2.338	11	*
	S7-A7	0.525	11	N.S
	S8-A8	2.02	11	N.S
	S9-A9	0.989	11	N.S
	S10-A10	0.432	11	N.S
Salinity	S1-A1	0.778	11	N.S
	S2-A2	0.346	11	N.S
	S3-A3	3.544	11	**
	S4-A4	0.384	11	N.S
	S5-A5	1.359	11	N.S
	S6-A6	0.739	11	N.S
	S7-A7	0.348	11	N.S
	S8-A8	0.608	11	N.S
	S9-A9	2.196	11	N.S
	S10-A10	1.813	11	N.S
pH	S1-A1	1.483	11	N.S
	S2-A2	1.101	11	N.S
	S3-A3	2.028	11	N.S
	S4-A4	0	11	N.S
	S5-A5	1.121	11	N.S
	S6-A6	2.861	11	*
	S7-A7	0.609	11	N.S
	S8-A8	1.393	11	N.S
	S9-A9	0.553	11	N.S
	S10-A10	1.254	11	N.S
Dissolved Oxygen	S1-A1	3.199	11	**
	S2-A2	3.139	11	**
	S3-A3	5.487	11	**
	S4-A4	3.985	11	**
	S5-A5	4.483	11	**
	S6-A6	4.32	11	**
	S7-A7	0.884	11	N.S
	S8-A8	3.432	11	**
	S9-A9	3.868	11	**
	S10-A10	2.053	11	N.S
Turbidity	S1-A1	4.727	11	**
	S2-A2	2.52	11	*
	S3-A3	3.772	11	**
	S4-A4	2.806	11	*
	S5-A5	4.326	11	**
	S6-A6	3.273	11	**
	S7-A7	3.402	11	**
	S8-A8	2.734	11	*
	S9-A9	3.146	11	**
	S10-A10	2.099	11	N.S

** $P< 0.01$ N.S - Not significant

* $P< 0.05$

✓ **Table 4.2 ,Results of the t test on comparing the Nitrite and Phosphate recorded before and after trawling**

Item	Stations	t	df	Significance
Nitrite	S1-A1	2.423	11	*
	S2-A2	2.707	11	*
	S3-A3	2.139	11	*
	S4-A4	3.404	11	**
	S5-A5	3.301	11	**
	S6-A6	3.378	11	**
	S7-A7	5.405	11	**
	S8-A8	3.348	11	**
	S9-A9	3.201	11	**
	S10-A10	3.293	11	**
Phosphate	S1-A1	3.368	11	**
	S2-A2	2.445	11	*
	S3-A3	2.16	11	*
	S4-A4	3.037	11	*
	S5-A5	3.315	11	**
	S6-A6	3.281	11	**
	S7-A7	3.943	11	**
	S8-A8	3.936	11	**
	S9-A9	2.048	11	N.S
	S10-A10	1.936	11	N.S

** $P< 0.01$ N.S - Not significant

* $P< 0.05$

Chapter 5

IMPACT OF BOTTOM TRAWLING ON SEDIMENT AND ORGANIC MATTER

5.1 Introduction

The sea floor, being the place of accumulation of solid detrital material of inorganic and organic origin is virtually covered with unconsolidated sediments. The sedimentary environment plays an important role in determining the benthic assemblage structure (Rhoads and Young, 1970; Gray, 1981; Rhoads and Boyer, 1983). The ability of the species to establish itself in the system is influenced by the physico chemical nature of the system, specifically the sediment type and quality, the depth, the flux of nutrients/ organic matter into the system and the hydrographic regime. Dependent on the dynamic forces such as waves, currents and biological activity, the uppermost part of the sediment will migrate (Leth and Kuijpers, 1996). Otter trawls , used to catch species that live on or near the bottom are designed to maximize contact with the sea bed and scrape, scour and plough the seabed(de Groot, 1984; ICES, 1988; Krost *et al.*, 1990; Bergman and Hup, 1992; Jones, 1992). Impacts result from the heavy trawl doors digging into the bottom sediments and crashing into hard structures on the sea floor. Additionally, substantial abrasion of the bottom may be generated by the ground rope fitted with weighty bobbins and rubber discs and the belly and cod end of the trawl, especially when the latter becomes heavy with fish and even rocks and boulders (Watling and Norse, 1998). The intensity of disturbance is very much dependent on the details of the gear and sediment type (Hall, 1999). The seabed in many fishing areas is characterized by depressions and rocky mounts, boulders and is teeming with life. The following were the major groups of organisms found associated with a scallop bed - Porifera, Coelentrata, Bryozoa, Brachiopoda, Polychaeta, Mollusca, Cephalopoda, Crustacea, Echinodermata and Chordata (Kenchington, 1999). The sedentary benthic organisms help create diverse communities by providing structural habitat (McConnaughey *et al.*, 2000). Studies in other areas have demonstrated the role of epifauna in providing biogenic habitat structure and shelter to other benthic species (Witman and Sebens, 1990; Auster *et al.*, 1996). It is important to consider substrate when discussing community structure and alteration of substrate has a marked effect on the community composition (Caddy, 1973; Schneider *et al.*, 1987; Thouzeau *et al.*, 1991; Auster *et al.*, 1996; Collie *et al.*, 1997). The process of dragging often covers a large area of benthic habitat and tends to reduce topographical complexity and niche diversity (Auster *et al.*, 1995). Seabed disturbance by mobile fishing gear has emerged as a major concern related to the conservation of essential fish habitat. The biological communities residing in a particular environment have been adapted to live there and therefore, the magnitude and frequency of seabed disturbance should be scaled against the impact of mobile gear (De Alteris *et al.*, 1999). The mobile gears impact rock, sand and mud substrates and also disturb the demersal finfish, lobsters squid and mussels. Recent research implies that these gear types are directly destructive to critical fish habitat because they alter the physical and biological character of the sea bed (Watling and Norse, 1998; Hall, 1999) or are indirectly destructive because they can add large volumes of sediment to the water column and thereby alter the natural pattern of sediment deposition and resuspension (Schubel *et al.*, 1979). The magnitude of the impact is determined by the speed of the towing, physical dimension of gear, weight of the gear, depth of penetration into the sediments, the frequency with which the area is fished, type of substratum and strength of currents or tides in the area fished (DeGroot, 1984; Redant, 1987; Jennings and Kaiser, 1998).

In the early 1950's mechanized fishing vessels were introduced into the capture trawl fishery of Kerala coast and their operations were generally in the region of 25-30 m depth (Mohammed, 1973). Off Cochin coast, the dominant species caught during bottom trawling were prawns, crabs, sharks, rays and catfish (Tholasilingam *et al.*, 1973). Penaeid prawns of commercial importance, such as *Penaeus indicus, Metapenaeus affinis, Metapenaeus dobsoni, Metapenaeus monoceros* and *Parapenaeopsis stylifera* were the major shrimp species exploited from the Cochin region and the major portion of the catches of these species were from shallower depth zones, upto 24 metres (Rao and Dorairaj, 1973). Mohammed (1973) reported that a considerable change in the depth of operation took place after a few years when the operations were carried out further inshore, at about 16-17 m depth. The end of 70's saw otter trawling as the most popular fishing method (John, 1996) and the Kerala waters witnessed a spurt in the number of otter trawls aiming at the exploitation of the rich prawn resources in the inshore waters. Thus the sediments in the fishing grounds have been disturbed constantly with the commencement of intense trawling along the coastal belt.

Animal – sediment relationships have been worked upon by many authors (Reise, 1981; Olafsson and Moore, 1990; Basford *et al.*, 1993;

Chamberlain *et al.*, 2001; Newell *et al.*, 2001). A number of studies have also been carried out to bring to light the effect of trawling on benthic habitat with respect to the physical and biological aspects. Detailed systematic research on the physical impacts of trawling on the sea bed has been conducted in various locations around the world since the 1970's. The ICES study group on the Effects of Bottom Trawling reported in 1998 on the state of the art (Anon,1988). The effects of bottom trawling were classified as scraping, penetration, sediment resuspension, habitat destruction, burying, and mortality in benthos. Demersal trawling has also been postulated to remove large quantities of organic matter from the sea floor to the surface (Linnane *et al.*, 2000).The biological impact of trawling has been investigated by a number of scientists. Reduction in habitat complexity (Auster *et al.*,1996) leads to increased predation on juveniles of marine species, including commercial fish species; as the more complex the habitat the harder it is for predators to find food(Schwinghamer *et al.*, 1996).Repetitive passage of trawl gear will cause mortality and damage of invertebrate species of gastropods, starfish, crustaceans and annelids.

Studies concerning otter trawl and its impact on the sea floor have not been carried out in the Indian context, though the effect of dredging has been investigated upon by few scientists in the Cochin harbour (Nair and Balchand, 1992). This study, off the coast of Cochin, is a pioneer attempt in this regard, aimed at evaluating the impact of otter trawl on the sea floor, using the before / after comparison method of experimental design.

The materials and methods have been explained in Chapter 3.

5.2 Results

The sediment pattern of the study area during the period December 2000 to November 2002 has been depicted in Fig. 5.1 a & b. The inner shelf region off Cochin was constituted predominantly by silty clay sediment upto a depth of 35 m while beyond it the region was composed of sand particles of phi size greater than 2. The color of clayey silt was that of shades of olive gray, indicating high values of organic matter. At less than 10 m depth, the predominant type of sediment is clayey silt, followed by silty clay. Particle size classification of bottom sediments from the area of study indicated that during the first year, sand content ranged from 0.16 to 94.05%, silt content from 1.03 to 62.5 % and clay from 6.12 to 59.58 %. During the second year the ranges of sand, silt and clay were 0.04 to 97.25%, 1.6 to 53.6% and 1.07 to 66.74 % respectively. The clay sediments predominated in the inshore areas, from station 1 to station 5 while at station 5 to 10 the sediments were dominated by sand.

In the samples collected after trawling, the sand proportion ranged from 0.4-96% during the first year while it ranged from 0.15 – 97.4 % in the second. The proportions for silt during the first and second years were 1- 86.2% and 1.3 – 53.15 % respectively. The clay content ranged from 1.05 – 55.3 % and 1.03 – 66.72 % during the first and second years respectively (Fig.5.2 a & b). A drastic decline was noticed in the clay fractions, transforming the grounds to more sandy and silty texture. Stations 1-6 showed a distribution of clayey silt sediment with higher percentage of silt while stations 7 and 8 were turned into a silty sand texture with a dearth of clay fractions after trawling. Ostensible variations were noticed at stations 9 where the sediments, which were clayey sand, were modified to sandy after trawling. Station 10 showed higher percentage of sand, with the loss of clay content from the sediments after trawling. Similarly, sediments at stations 4, 5 and 6 were dominated by clayey silt after trawling, which was previously silty clay in the samples collected before trawling.

5.2.1 Variations in Statistical Parameters

A. Graphic mean : Before trawling, the graphic mean varied from 1.01 to 18.94 phi, with particle size ranging from coarse and medium sand to clay particles. Silt and clay of varying proportions cover the sea floor upto 30 m depth. From 30 m onwards, the texture changed from fine sand to very fine sand. The depth zone of 40- 50 m is dominated by fine sand with phi size ranging from 2- 3 phi, interspersed with patches of very fine sand (3-4 phi). After trawling, the mean values ranged between 0.77 and 8.71 phi, corresponding to coarse sand and clay respectively. Upto 30 m depth, the phi values ranged from 4.90 to 8.71 corresponding to silt and clay particles respectively. The silt particles were found to dominate the shelf in this depth zone, after which the shelf was found to be covered by particles of mean size range 0.77 to 3.58 phi. Highly significant variations were observed when the mean values of sediment, before and after trawling was compared ($P<0.01$, Table 5.1).

B. Standard deviation: The sediments ranged from 0.87 to 2 phi (poorly sorted) and 2-3.26 phi (very poorly sorted). Very poorly sorted sediments were invariably found in the stations closer to the shore, upto a depth of 20 m while stations beyond it were poorly sorted. The sediments after trawling showed very poor sorting to poor sorting, indicating that the transportation agencies were incapable of separating the sediments into different size classes. Statistically significant differences were not noticed when the standard deviation of the before and after trawling values were compared ($P>0.05$, Table 5.2).

C. Skewness which is a measure of the symmetry of grain size distribution, varied widely from –0.83 to +0.63. Positively skewed sediments were found in station 1 and 2 with phi values in the range 0.3 to 1 phi. Sediments were very coarse skewed at station 3, 4 and 5 and the phi values were in the range – 0.3 to –1. At stations 6 -10, the sediments were very fine skewed with the range 1 to 0.3. After trawling, the skewness values ranged from -0.51 to 0.67, with both positively and negatively skewed sediments. The skewness values showed significant variation when the before and after trawling values were compared ($P<0.01$, Table 5.3).

D. Kurtosis: Kurtosis values of the sediments of the study area showed variations from 0.48 to 4.04 phi . The region displaying platykurtic sediments were confined to the near shore stations with clayey silt and silty clay sediments. As the sediments turned sandy in nature, kurtosis rose from very platykurtic to extremely leptokurtic nature as observed at stations 6 to 10. After trawling, the sediments in the study area showed variations from 0.48 to 3.52

ie., very platykurtic to extremely leptokurtic. No significant variations were noticed when the kurtosis of sediments collected both before and after trawling were compared (P>0.05, Table 5.4).

5.2.2 Variations in Textural Parameters

A. Variations in sand: Particle size classification has shown that sand particles were dominant in the 40 –50 m depth zone, where the highest of 94.08 % at station 9 and 97.25 % at station 10 were recorded in the first and second years respectively (Fig.5.3 a & b). The lowest proportion of sand in the first year was 0.16 % at station 2 while that in the second year was 0.04 % at station 1, with silt and clay in higher proportions. Proportion of sand was higher in the 35-40 m zone, when compared to lower depths (0-30 m). Before trawling the sand particles showed significant variation with a reduction in sand content during monsoon (P<0.05, Appendix II, Table 1). After trawling, the range in particle size of sand was from 0.44 to 95.10 % during the first year and 0.15 to 97.44 % during the second (Fig.5.4 a & b). After trawling, almost similar trend of variations in sand particles were observed as noticed before trawling, but with comparatively higher proportions at stations far from the shore (40 – 50 m depth) (P<0.05, Appendix II, Table 2). The sand particles were found to increase significantly at all stations after trawling when compared to before trawling samples, with a perceptible increase at the sandy stations (P<0.05, Table 5.5, Fig.5.5 a & b).

B. Variations in silt content: Percentage distribution of silt fraction of sediment collected before trawling is given in Fig. 5.6 a & b. During the first year, silt fraction ranged between 3.02 - 63.25 % in the samples collected before trawling where the highest (63.25 %) was observed at station 6 in September 2001 while the lowest (3.02 %) at station 9 in November 2001. During the second year, the silt fraction ranged between 1.5 - 53.65 % before trawling with the highest at station 3 in September 2002 while the lowest (1.5 %) was observed at station 8 in January 2002. Spatially, the highest fraction of silt was obtained at 25-30 m depth while the lowest was at the 40 to 50 m zone. Silt fractions of all months and stations showed significant variations (P<0.01, Appendix II, Table 3). Temporally the highest silt proportions were noticed during monsoon and post monsoon periods while premonsoon showed the lowest. Stations located near shore, below 30 m depth zone showed high proportions of silt when compared to those above 30 m depth (stations 7-10). In the samples collected after trawling, silt fractions increased remarkably; however the extent of variation was lesser when compared to that observed for sand fractions of the sediments. Significant variation was also noticed in the samples collected after trawling in all months and stations studied (P<0.01, Appendix II, Table 4). Distribution of silt ranged between 1.0 and 86.12 % and 1.3 - 53.15 % in the samples collected after trawling during first and second years respectively (Fig. 5.7 a& b). During the first year the highest value (86.12 %) was registered at station 2 in February 2001 while it was lowest (1 %) at station 8 in September 2001 whereas during the second year, the highest value (53.15 %) was observed at station 2 in January 2002 and the lowest (1.3 %) at station 8 in March 2002. When the percentage of silt recorded before and after trawling were compared, the highest variation was observed at station 9 in July 2002 where eight-fold increase in silt was noticed in the samples collected after trawling with 18.95 % silt was recorded against 2.32 % before trawling(Fig. 5.8 a& b). Station 8 also showed the wide variation in silt as it increases to 13.85 % after trawling from 3.85 % recorded before trawling. On an average, around 2-fold increase was noticed in the silt fraction recorded after trawling. However *t* test could not reveal any significant variation when the values of before and after trawling were compared ($p > 0.01$, Table 5.5).

C. Variations in clay: The proportion of clay particles in the sediments of the study area are depicted in Fig.5.9 a & b. Clay particles were of maximum abundance in the 0-30 m depth zone, where the highest (59.58 %) was observed at station 3 during November 2001 and the lowest (6.17 %) at station 10 in April 2001 during first year. During the second year, the proportion of clay recorded from samples collected before trawling varied between 1.41 - 66.74 % where the highest (66.74 %) was observed at station 4 in September 2002 and the lowest (1.42 %) at station 9 and 10 in the same period. ANOVA showed significant variation in the clay fractions recorded at different depths studied ($P < 0.01$, Appendix II, Table 5). Monsoon and post monsoon months showed highest clay content in the samples while it was least during premonsoon. In the samples collected after trawling, the clay fraction was found to decrease drastically specifically at the near shore stations which are located below 30 m depth. Percentage of clay obtained in the samples collected after trawling ranged between 1.05 at station 9 in December 2000 - 55.3 % at station 7 during July 2001 and 1.03 at stations 9 and 10 in September 2002 – 66.72 % at station 6 in May 2002 in the first and second years respectively (Fig. 5.10 a& b). ANOVA showed significant variations in the clay fractions collected from at different stations (P< 0.01, Appendix II, Table 6). While comparing to the values recorded before trawling, the clay fraction of the samples collected after trawling showed an apparent reduction (Fig. 5.11 a & b). Highest variation was noticed at station 4 in February where the proportion of clay fraction decreased sharply from 51.31 % before trawling to 0.53 % after trawling, thus registering a 100 times decline due to bottom trawling. Similarly, station 2 also showed about 40 times decrease in clay fraction after trawling where 40.79 % of clay was reduced to meager 0.92 % after trawling. Significant variation (P<0.05, Table 5.5) was observed while comparing both before and after trawling samples collected at six stations 1, 2, 4, 5, and 9 and 10.

5.2.3. Variation in organic matter content of surficial sediment:

Organic matter in sediments of the study area indicated the presence of rich biological activity in the inshore areas especially the muddy bottoms. The highest percentage of organic matter was observed at station 3 with 7.76 % in November 2001 during the first year while during the second, it was 6.93% at station 6 in November 2002. Sandy stations invariably recorded the lowest value of organic matter, with 0.26 and 0.22 % at station 9 during the first and second years respectively (Fig. 5.12). When all the before trawling values were compared using ANOVA, significant variation could be noticed (P<0.05, Appendix II, Table 7). Organic matter analysis showed that premonsoon had the lowest values, a sudden spurt occurred in the post monsoon, while the monsoon season showed moderate values. In the after trawling samples, the range of organic matter was 0.13 to 5.62% during the first year and 0.87 to 6.87 % in the second (Fig. 5.13). Significant differences were also observed in these samples also, with respect to both temporal and spatial variations ($P<0.05$, Appendix II, Table 8). A set of low premonsoon values were followed by an increase during post monsoon, while during the monsoon, percentages of organic matter attained normal lower values once again; the cycle showed a similar pattern as seen before trawling. The comparison of before and after trawling values showed significant variations ($P<0.05$, Table 5.5). There was a significant decrease in the organic matter content of surface sediments after trawling and it was most pronounced in the muddy stations. An example of drastic reduction of organic matter was observed at station 4, when 4.49% of organic matter observed before trawling reduced to 0.77% after the trawl had passed. Also, station 3, with a high organic content of 5.90% was nearly deprived after trawling with an organic content of 2.42% (Fig. 5.14 a & b).

5.3 Discussion

The nature of bottom and general distribution of surfacial sediments in the area of study corroborate to that observed in earlier studies on the western shelf of India (Damodaran, 1973; Hashimi *et al.*, 1978; Nair *et al.*, 1978). The authors observed that the shelf up to 50m is covered dominantly by fine sediments with clayey silt grading to silty clay, while sandy sediments were found to occur between 50 and 100m off the coast of Cochin; the present study revealed that the region from 35m upto a depth of 50m was covered by sand of predominantly medium and fine nature. In a study conducted by Veerayya and Murty (1974) on the sediments of Vembanad Lake, the authors came across silty clays and clayey silts in the channel connecting the lake to sea.

Studies on the organic matter have been postulated to be of much importance in the assessment of the extent of nutrient regeneration in the estuary (Alagarsamy, 1991). Seasonal variation in the organic matter also agrees with that of other studies (Nair and Balchand, 1992). The high organic matter has been ascribed to high productivity of overlaying waters, sewage discharge and clayey sediments. The high percentage of organic matter especially those obtained in the near shore regions characterized by clayey sediments in the present study is in agreement to the above findings. Organic matter is trapped predominantly by clays and to a lesser degree by fine silts, coarse silt and sands and the maximum percentage of organic matter is to be expected in sediments with maximum clay (Sanders, 1968). The rich organic matter obtained in the clayey region also corroborates with earlier studies in the region (Damodaran, 1973). Particle size and organic matter of sediments is important in the distribution and growth of benthic invertebrates. Sediments with large amounts of organic matter are associated with high rates of littoral production (Wetzel, 1983).

In the present study, trawling was found to be responsible for a great number of changes in the grain size parameters and organic matter. Significant differences in the grain size parameters, mean and skewness have been elucidated, which is indicative of profound physical impact of trawl gear on sediment. Poor to very poor sorting implies that the transportation agencies are incapable of separating the sediments into different size classes (Hashimi *et al.*, 1978). Silty clay and sandy clay sediments were very poorly sorted (2-4phi) because the supply of sediments from the river is deposited at a faster rate than they can be reworked (Rao and Rao, 1974). Upto 35 m depth, the sediment was found to be of clayey silt or silty clay nature with minimal proportion of sand. But in 40-50m contour, the sediment becomes predominantly sandy. The sediment phi size varied from 1.01 to 18.94, pertaining to sediment nature varying from medium sand to clay. After trawling, the samples showed a discernible decrease in the phi size, concomitant with increase in the sediment particle size. At station 2, at around 10 m depth, where about 34% of sediment was clay, (>8 phi) concentration reduced after five minutes to about 27% and the grain size decreased to a predominantly silty sediment with mean grain size of 5-7 phi. Most of the stations in the 0-30 m depth zone which was previously clayey showed a predominance in silt immediately after trawling. Statistically significant differences in mean indicated an overall reduction in the phi size of sediments pointing to an increase in grain size immediately after trawling. Black and Parry (1999) studied sediments plumes from scallop dredges and observed a similar increase in the phi size of sediments 30 minutes after dredging. After trawling, the heavier component of sediment obviously settles faster than the lighter ones, reworking the sediment to a significant extent. Thus the stations with silty clay sea floor was metamorphosed into clayey silt in the 0-35 m depth while in the sandy stations, the sand fractions was found to increase in proportion to other component. The increase in the proportion of sand after trawling has also been observed by Schwinghamer *et al.* (1998) in his study on the effects of beam trawling on sandy substrate off Grand Banks. The finer grained bottom material was found to take at least few hours to settle after trawl generated clouds were formed in studies on sediment resuspension (Churchill, 1989). Black and Parry (1999) found that scallop dredge suspends a thin layer of sediment (~0.5 cm thick) inducing initial near bed concentration of 2-15 kg/ cm^3 in a billowing turbid plume. Results from sediment profile imaging photographs showed that a layer of light resuspended material covered the sediment surface, often to a depth of about 2 cm (Lindeboom and de Groot, 1998). Due to relatively lesser content of light particles in the 40-50 m depth, the change in sediment characteristics was less pronounced than in the 0-30 m area. Sand clouds are generated by a trawl door as it is towed over a flat sand-seabed while on hard seabed, the sand clouds are absent. Coarse grained sediments are briefly resuspended but rapidly settle (Main and Sangster, 1981).

Due to the presence of otter trawl on the seabed, parts of the gear penetrate to some extent into sea bottom. The gear penetration depth depends on gear type and number and weight of components, towing speed, and warp length paid out, nature of substratum and the tidal conditions. The magnitude of effects of any given gear differs among the substrates and the vulnerability of substrate increases from coarse sand to fine sand to mud to mixed grounds (Collie *et al.*, 2000; Moore and Jennings, 2000). The tickler chain was seen to affect only a thin layer of top sand (Bridger, 1970) but Caddy (1973) found trawl tracks caused by otter boards of a few centimeters in depth on sandy sediments. Estimates of bottom trawling gear penetration caused by gear components range from a few centimeters to 300 mm in studies conducted on varied sea floor types. Margetts and Bridger (1971) concluded that on sand or muddy sand, the trawl did not appear to penetrate deeply into the seabed, but that on muddy grounds marks lasted for several hours. In coarse sandy areas, the tracks will be of short duration due to the low penetration by the otter boards and the restoring action of waves and currents (Krost *et al.*, 1990).

Fishing gear that disturbs the sediment surface can change sediment grain size distribution or characteristics, suspended load and the magnitude of sediment transport processes (Churchill, 1989; Reimann and Hoffmann, 1991; Dyekjaer *et al.*, 1995; Pilskaln *et al.*, 1998). Alteration of the chemistry and texture of sediments may render the sea bed habitat less suitable for some species, sediment resuspension affects the filter feeders and gills of marine organisms as well as eggs and larvae and also cause the outspread of toxic components and increased rates of nutrient flux. The significant reduction in organic matter after trawling during the present study is an evidence for the disturbance of sea bottom due to trawl gear. Mayer *et al.* (1991) found that bottom trawling can both resuspend and bury biologically recyclable organic material, changing the flow of nutrients through the food web. Alteration in the rate of decomposition of organic matter is also an established indirect effect of trawling.

Direct contact with the seabed and resuspension of the sediments by the gears results in habitat disturbances, a reduction in habitat complexity and subsequently, a reduction in species diversity. Mortality of invertebrate animals remaining in the trawl tracks and of animals caught in the net is also a direct effect of trawl gear scraping the seabed. Apart from physical disruption, the bottom disturbances render disturbed and damaged invertebrates, especially juveniles of marine species susceptible to predation (Messieh *et al.*, 1991). Colonies rooted in sand are dislodged. The magnitude of these effects is dependent on the force induced by the gear on seabed, towing speed, nature of bottom sediments and the frequency of impact. Significant disturbances in mean and skewness of sediment samples after trawling indicate a reworking of sediments after the trawl gear has passed. Schwinghamer *et al.* (1998) demonstrated using acoustic data that the structure of the upper layer of sea bed was significantly altered by trawling. Auster *et al.* (1996) and Tuck *et al.* (1998) reported the removal of biogenic taxa with a subsequent decline in the abundance of species and communities associated with them. Epibenthic animals anchored in the sand were removed by mobile fishing gear. Trawl gear can crush, bury or expose marine flora and fauna, and reduce structural diversity (Auster and Langton, 1999). Benthic organisms and sediment forms add structure to the sea floor and increase habitat complexity. Sea floor structures serve as nurseries for juvenile fish, and provide refuge and food for adults. By way of trawling, these structures are smoothened or dislodged and are not likely to support the variety of fish populations observed in more complex regions (Collie *et al.*, 1997; Kaiser *et al.*, 1999).

Bottom fishing using towed nets and dredges is one of the most widespread sources of physical disturbance to the continental shelf seas throughout the world (Kaiser *et al.*, 2000). The shelf region off southwest coast of India with a commercial fishing fleet of more than 5000 trawlers is being fished intensively for demersal prawn and fish resources throughout the year, except during the period of ban on trawling during monsoon. The fishing effort is not homogenized, but occurs in areas which have been identified as productive fishing grounds by the fishermen where intensive trawling takes place (Lindeboom and De Groot, 1998; Hall, 1999). High demersal fishing intensity causes changes at the ecosystem level in the long term, which cannot be reversed even when the disturbance is removed. Thus impact of bottom trawling on the sediment is of extreme importance due to the role it plays in the benthic ecosystem, in terms of nutrient recycling and habitat complexity and indirectly to the productivity of the overlying waters.

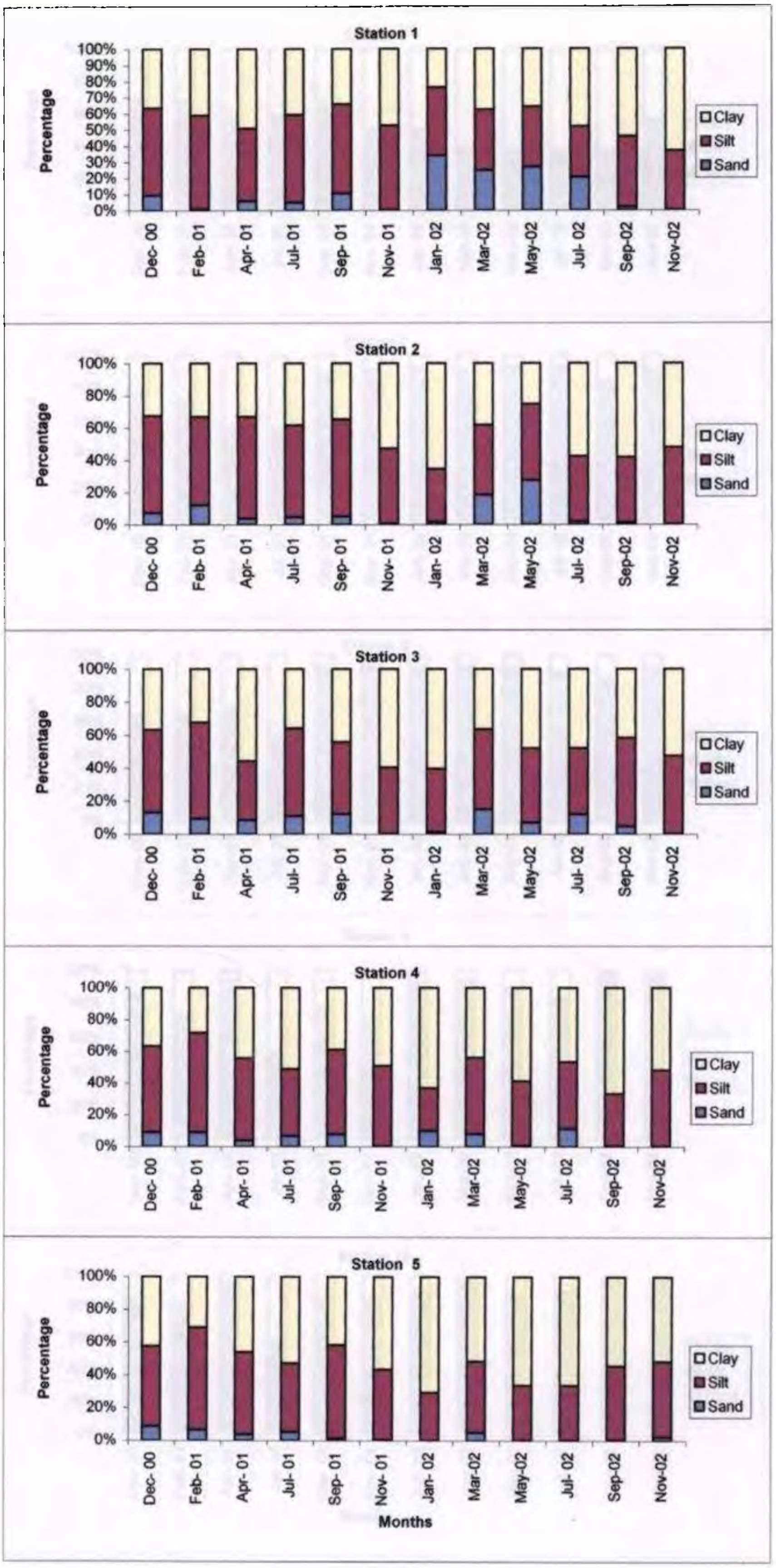


Fig.5.1a Sediment pattern of the Cochin-Munambam area during the period December 2000 to November 2002 at stations 1 to 5

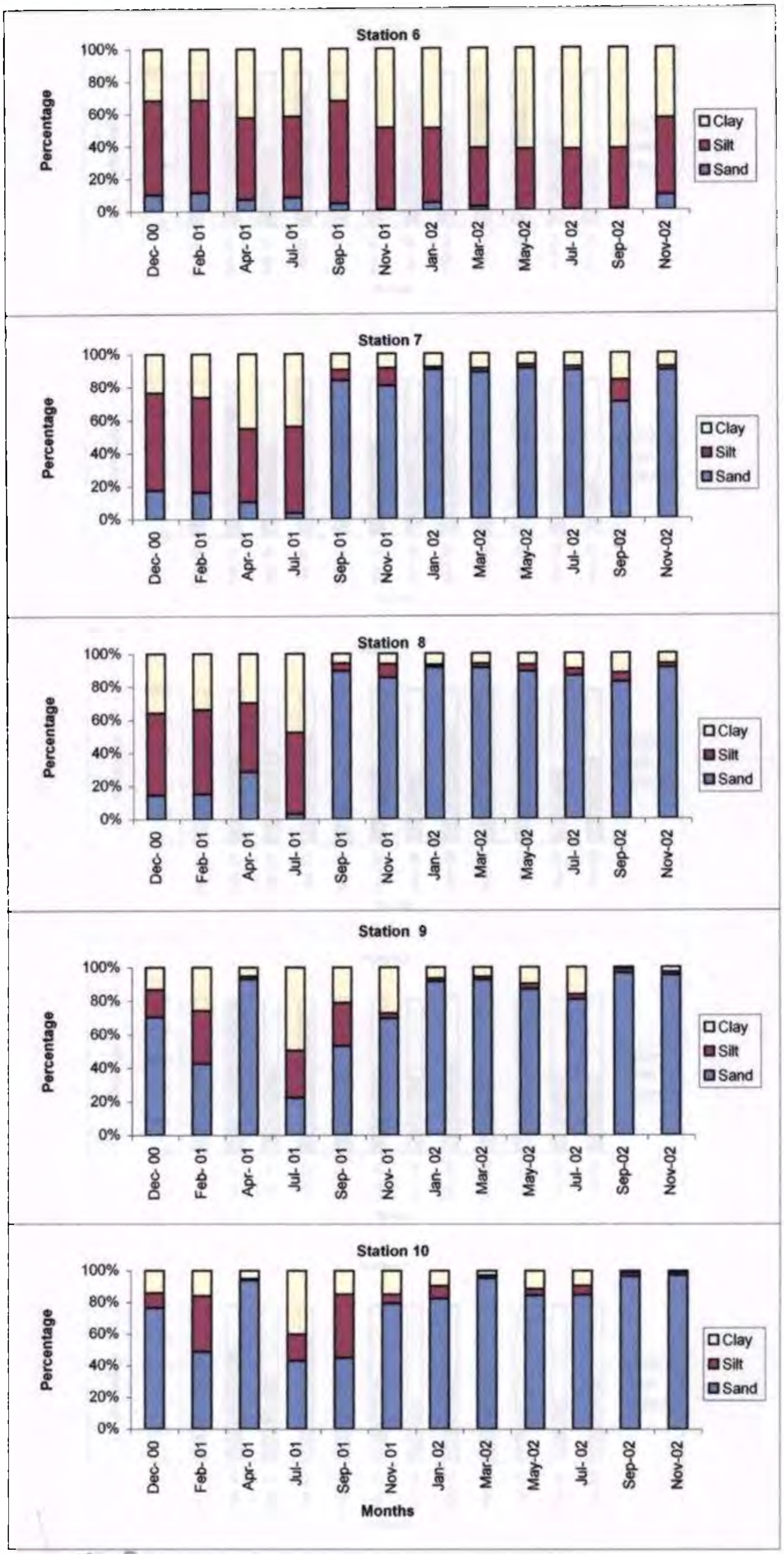


Fig.5.1b.Sediment pattern of the Cochin-Munambam area during the period December 2000 to November 2002 at stations 6 to 10

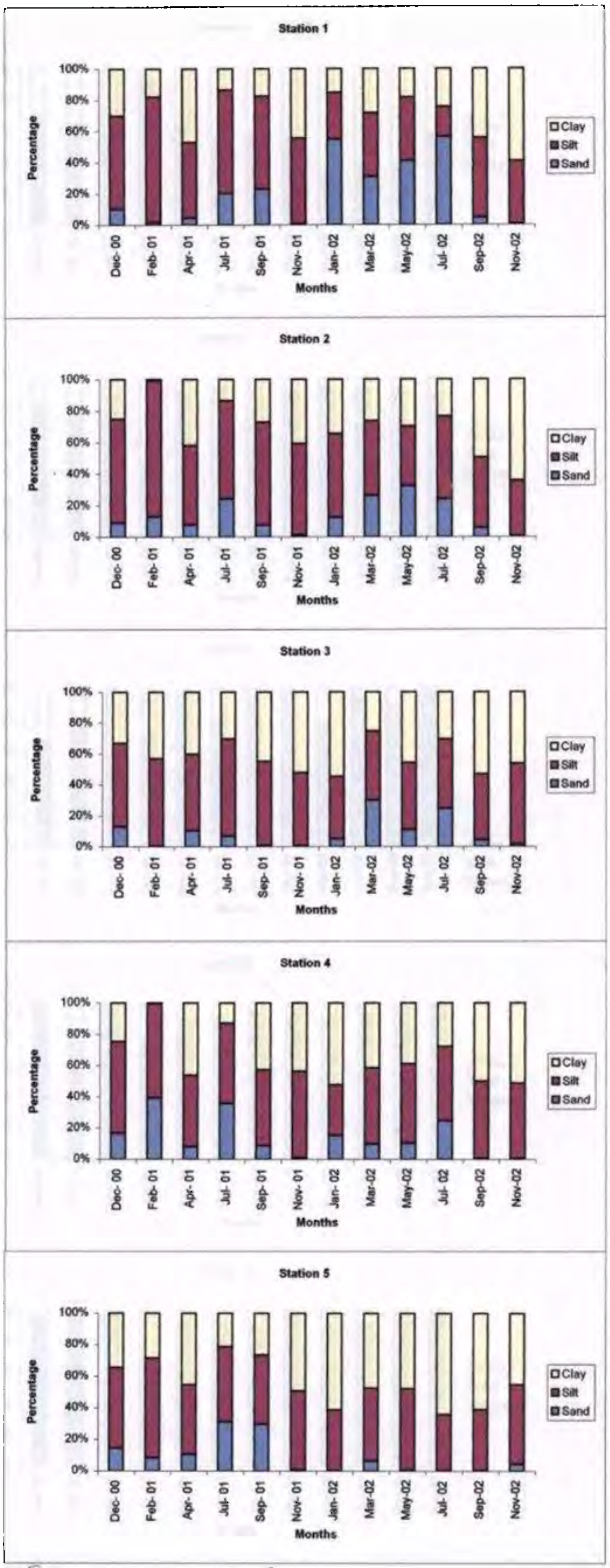


Fig 5.2a. Sediment pattern of the Cochin -Munambam area after trawling during the period December 2000 to November 2002 at stations 1 to 5

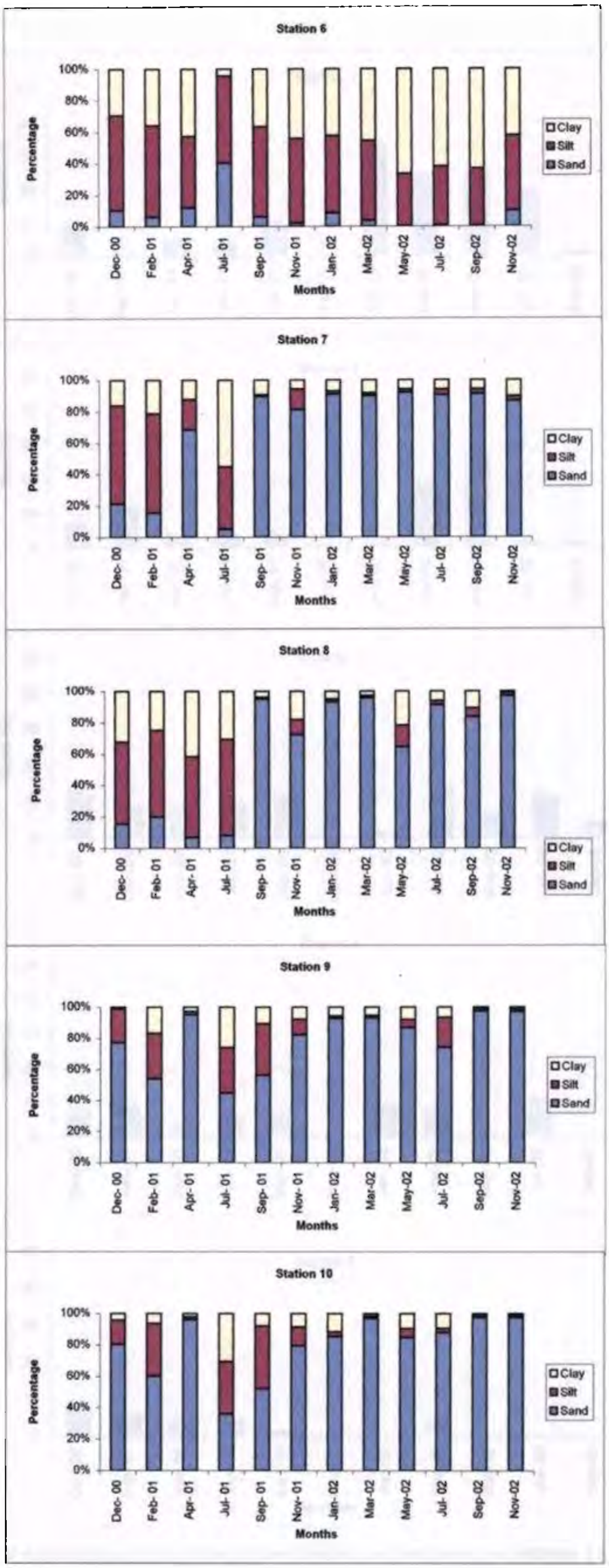
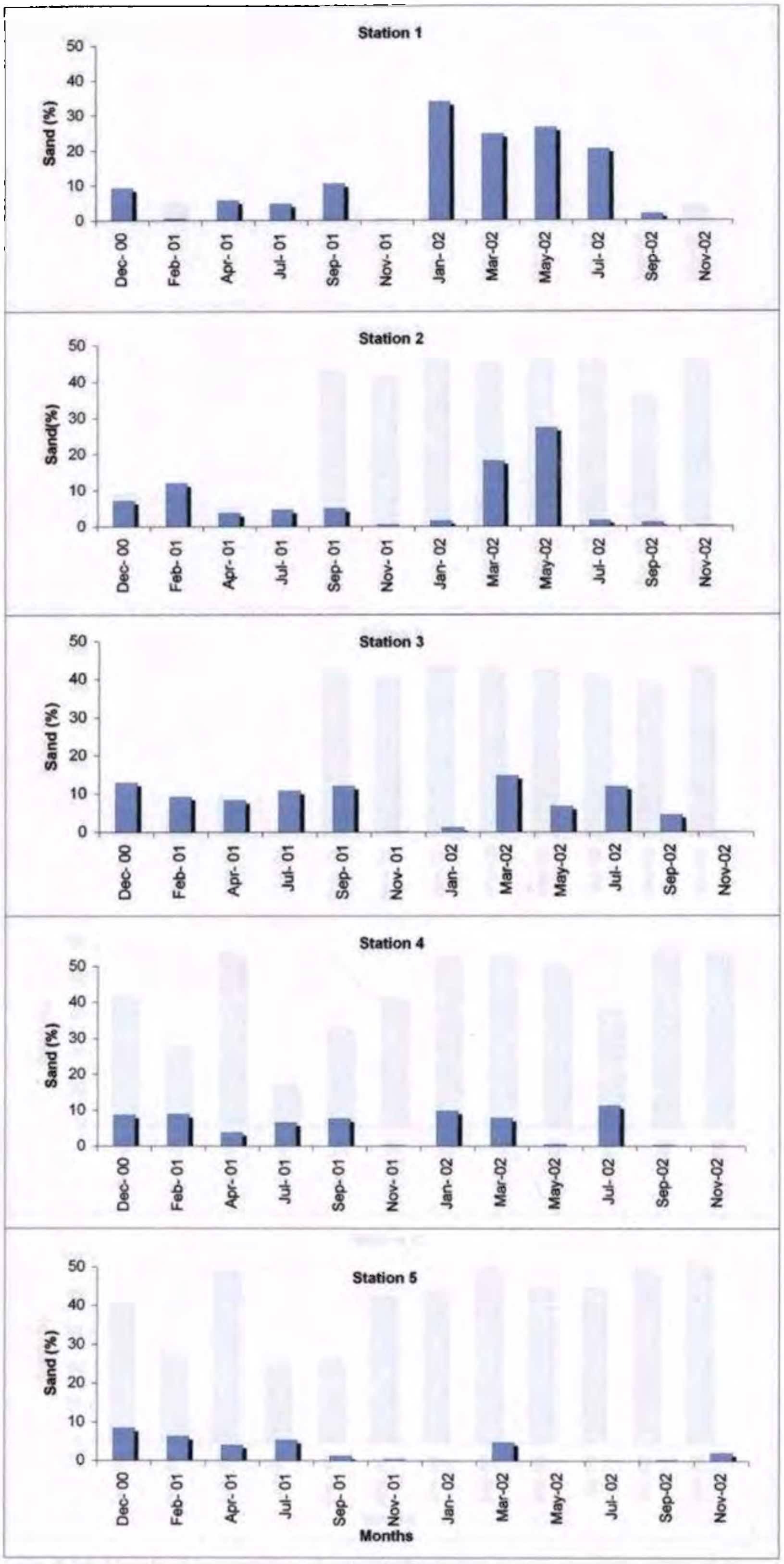
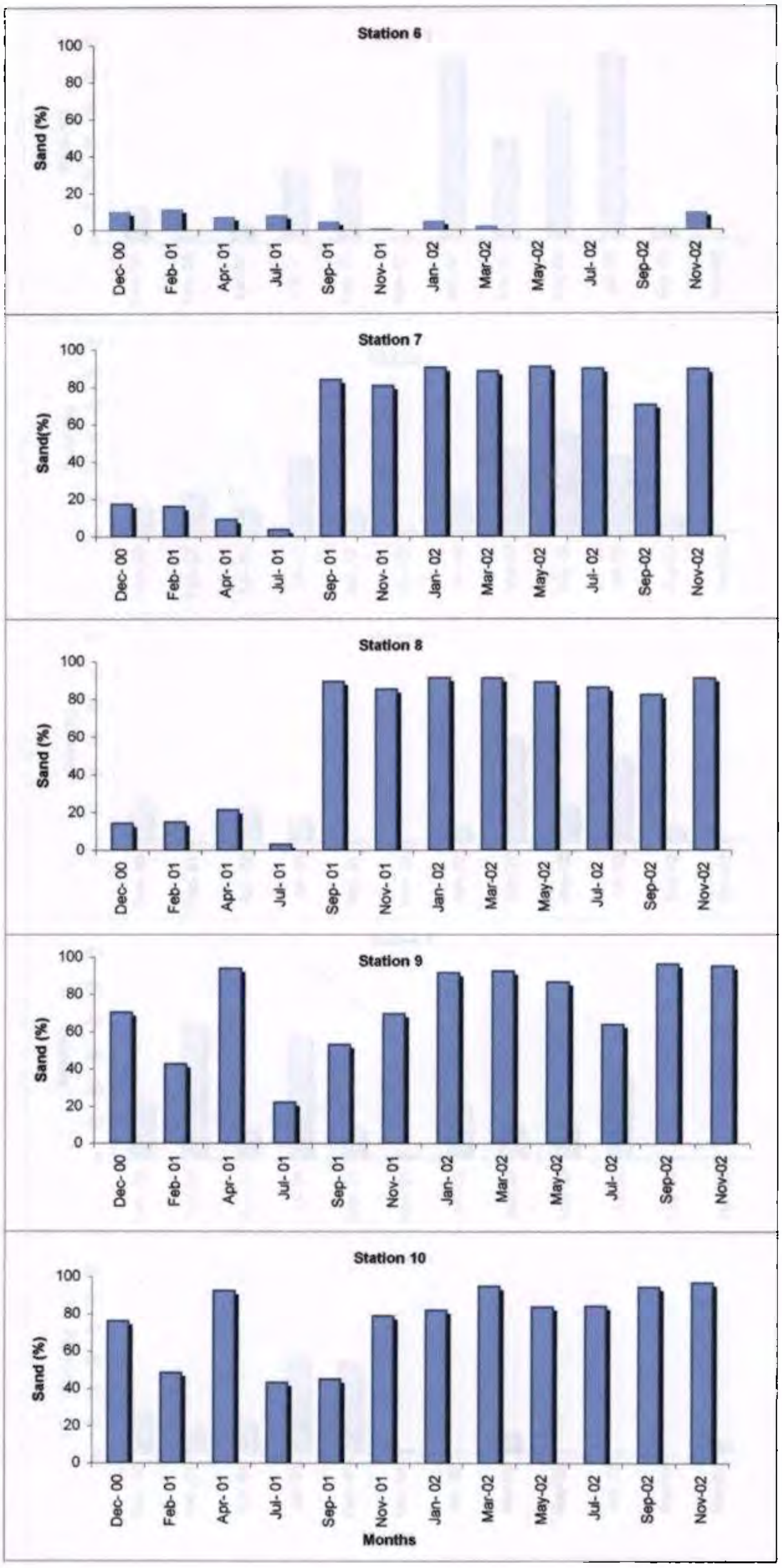


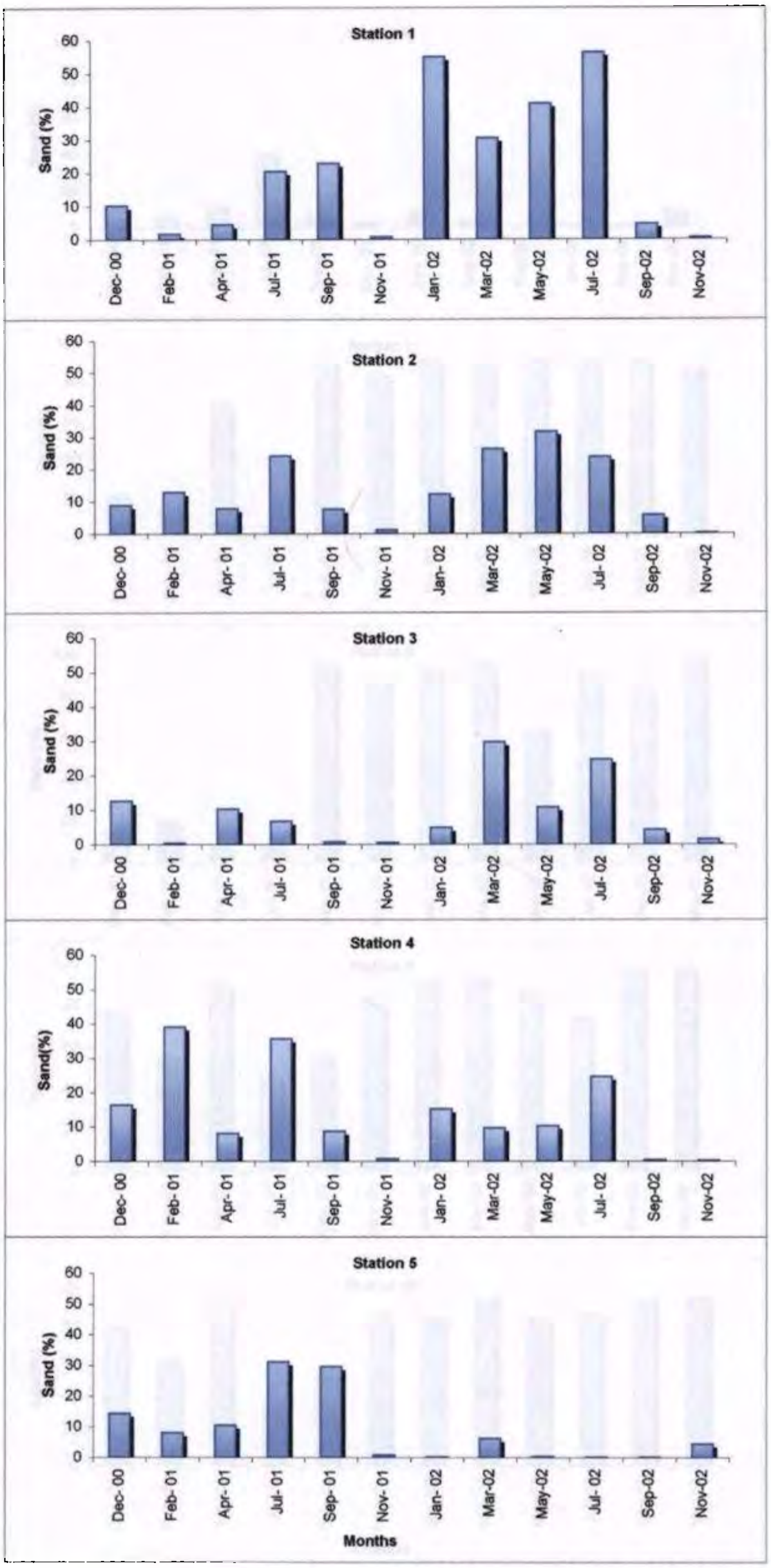
Fig.5.2b. Sediment pattern of the Cochin-Munambam area after trawling during the period December 2000 to November 2002 at stations 6 to 10



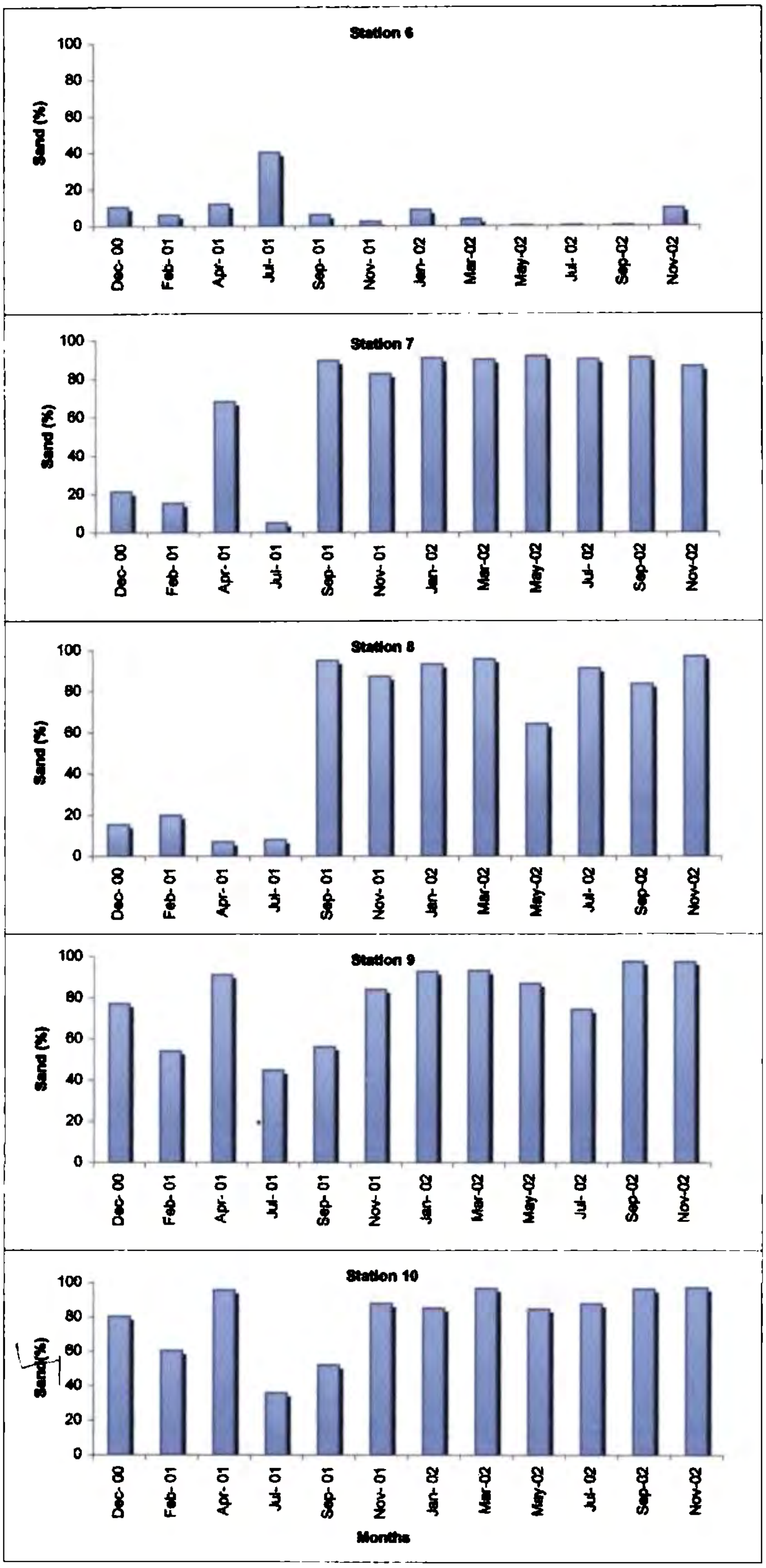
✓ Fig. 5.3 a. Variations in proportion of sand fraction before trawling at stations 1 to 5 from December 2000 to November 2002



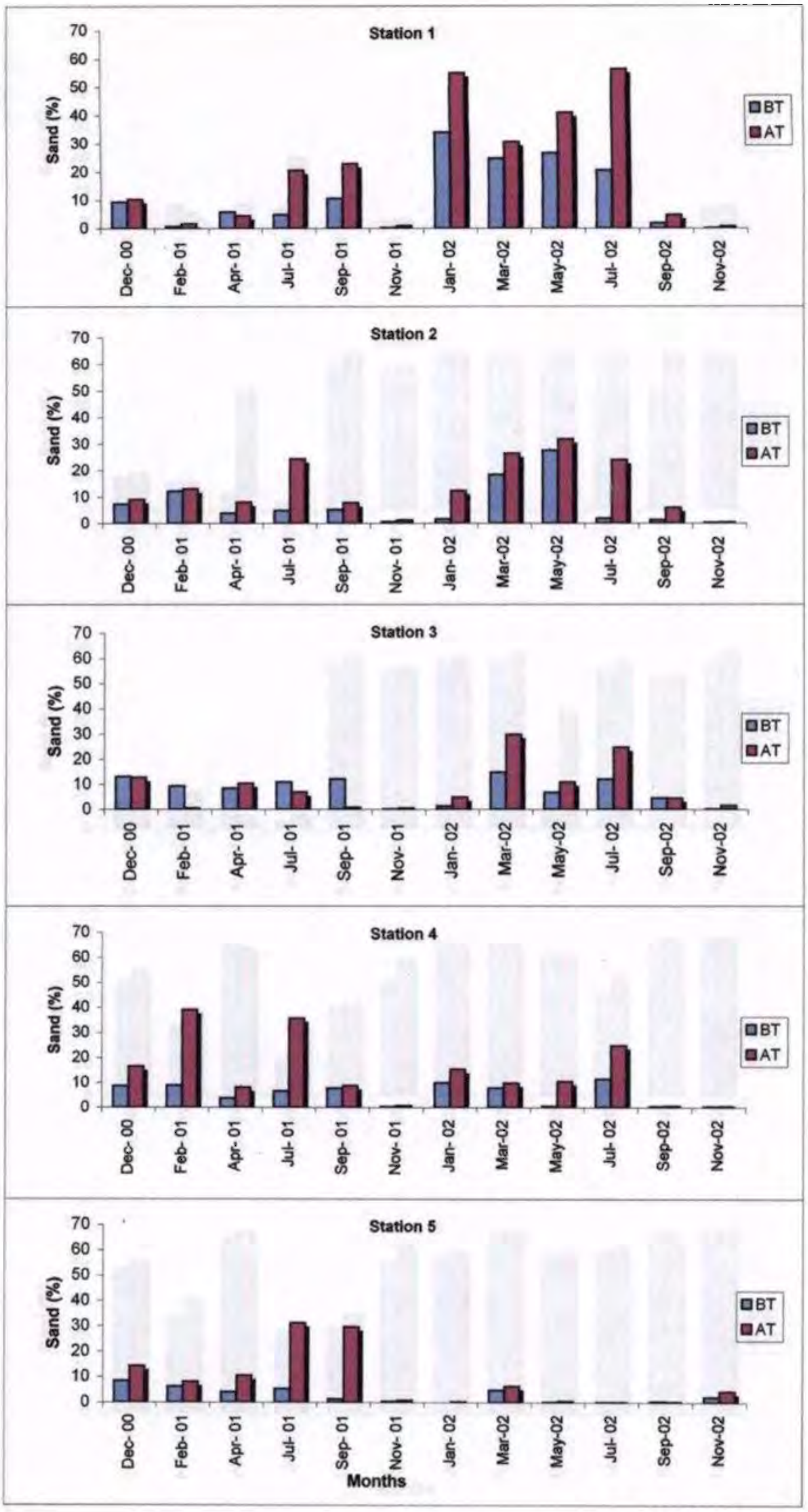
✓ Fig. 5.3 b. Variations in proportion of sand fraction before trawling at stations 6 to 10 from December 2000 to November 2002



✓ Fig. 5.4 a. Variations in proportion of sand fraction after trawling at stations 1 to 5 from December 2000 to November 2002



✓ Fig. 5.4 b. Variations in proportion of sand fraction after trawling at stations 6 to 10 from December 2000 to November 2002



Station 1

Station 2

Station 3

Station 4

Station 5

Fig 5.5a. Comparison of sand content before and after trawling in Cochin-Munambam area from December 2000 to November 2002 at stations 1 to 5

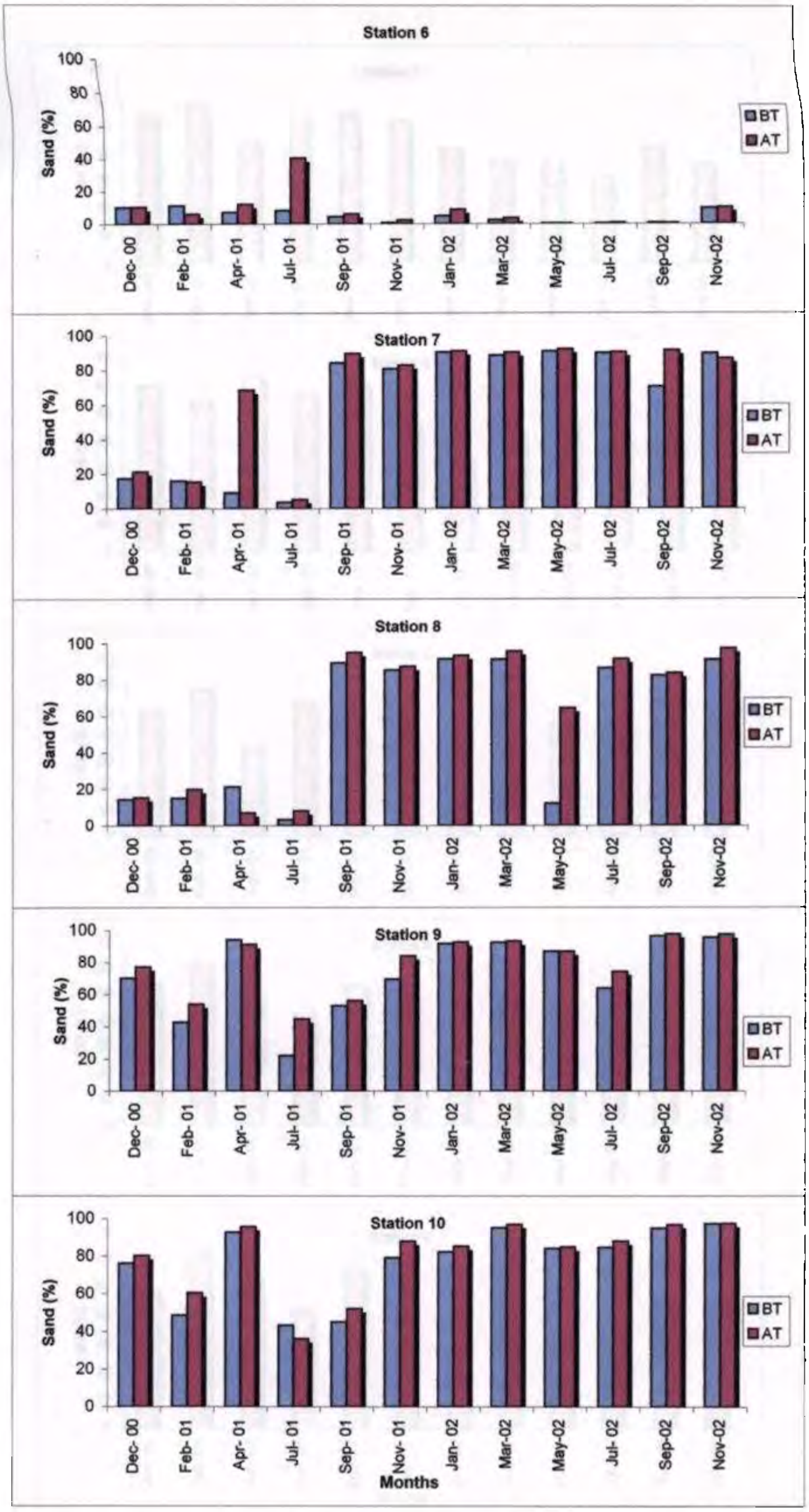


Fig.5.5 b.Comparison of sand content before and after trawling in Cochin-Munambam area from December 2000 to November 2002 at stations 6 to 10

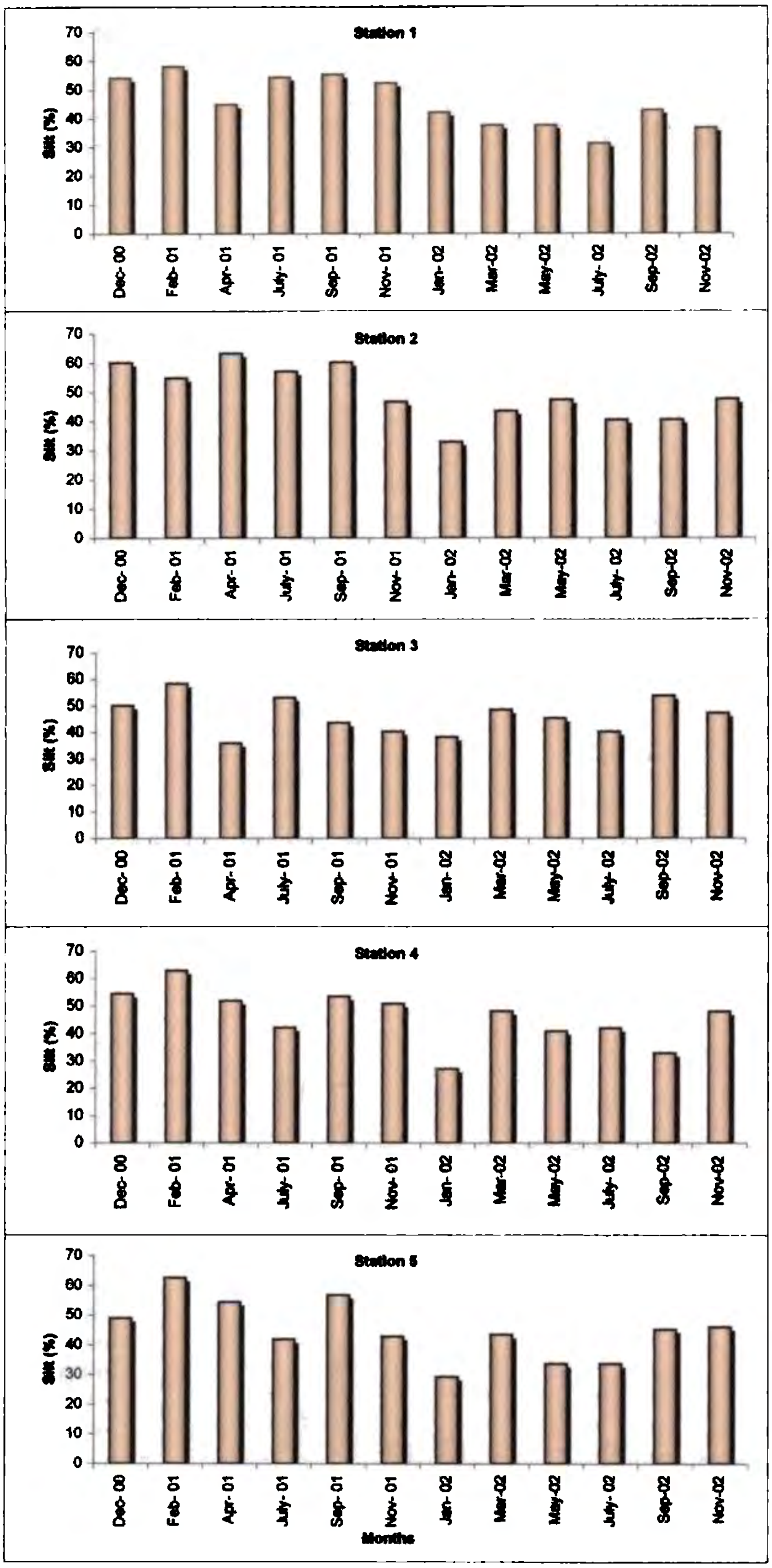


Fig 5.6 a. Patterns of variations in silt fraction at stations 1 to 5 recorded before trawling from December 2000 to November 2002

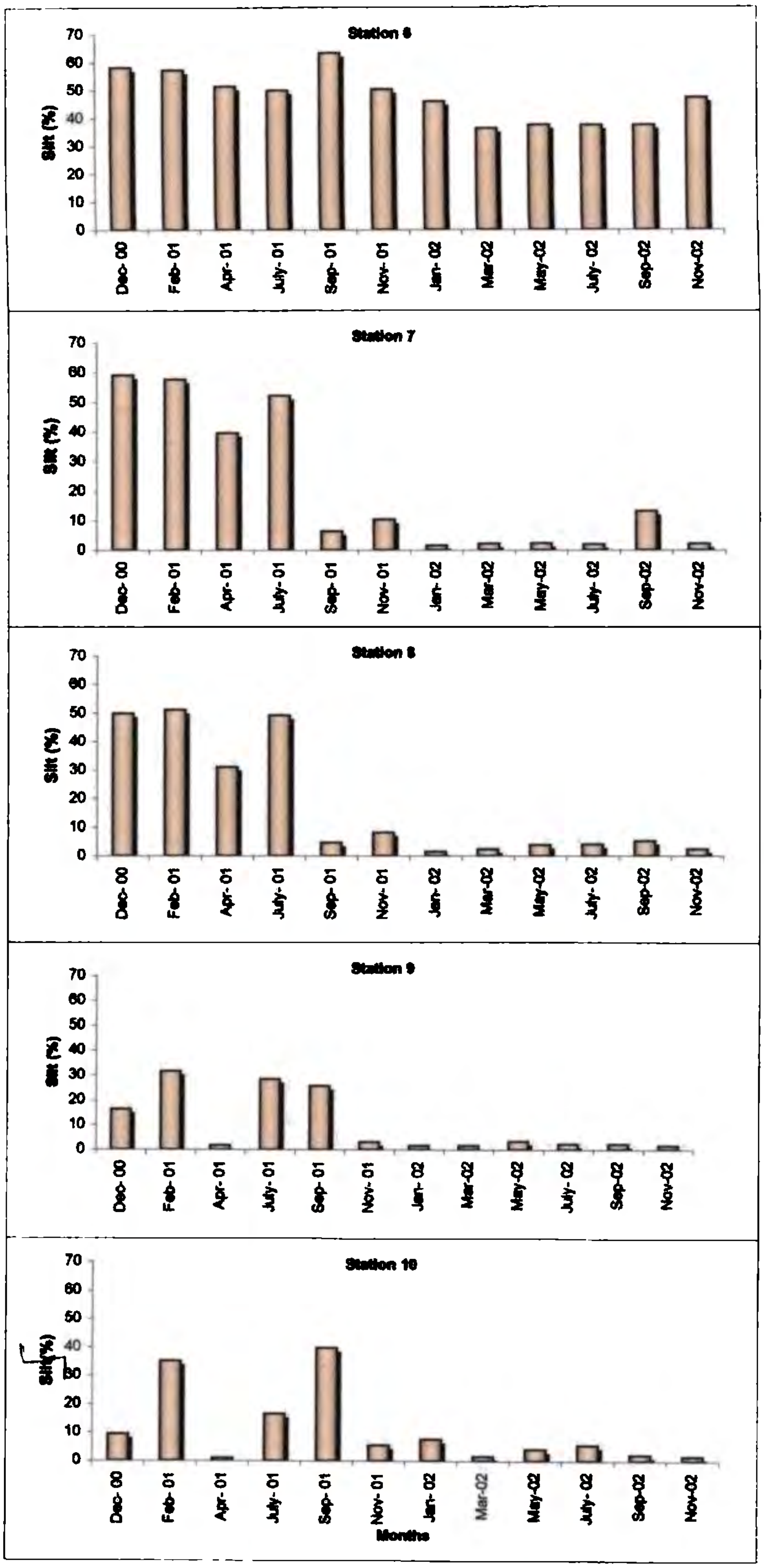


Fig.5.6 b. Patterns of variations in silt fraction at stations 6 to 10 recorded before trawling from December 2000 to November 2002

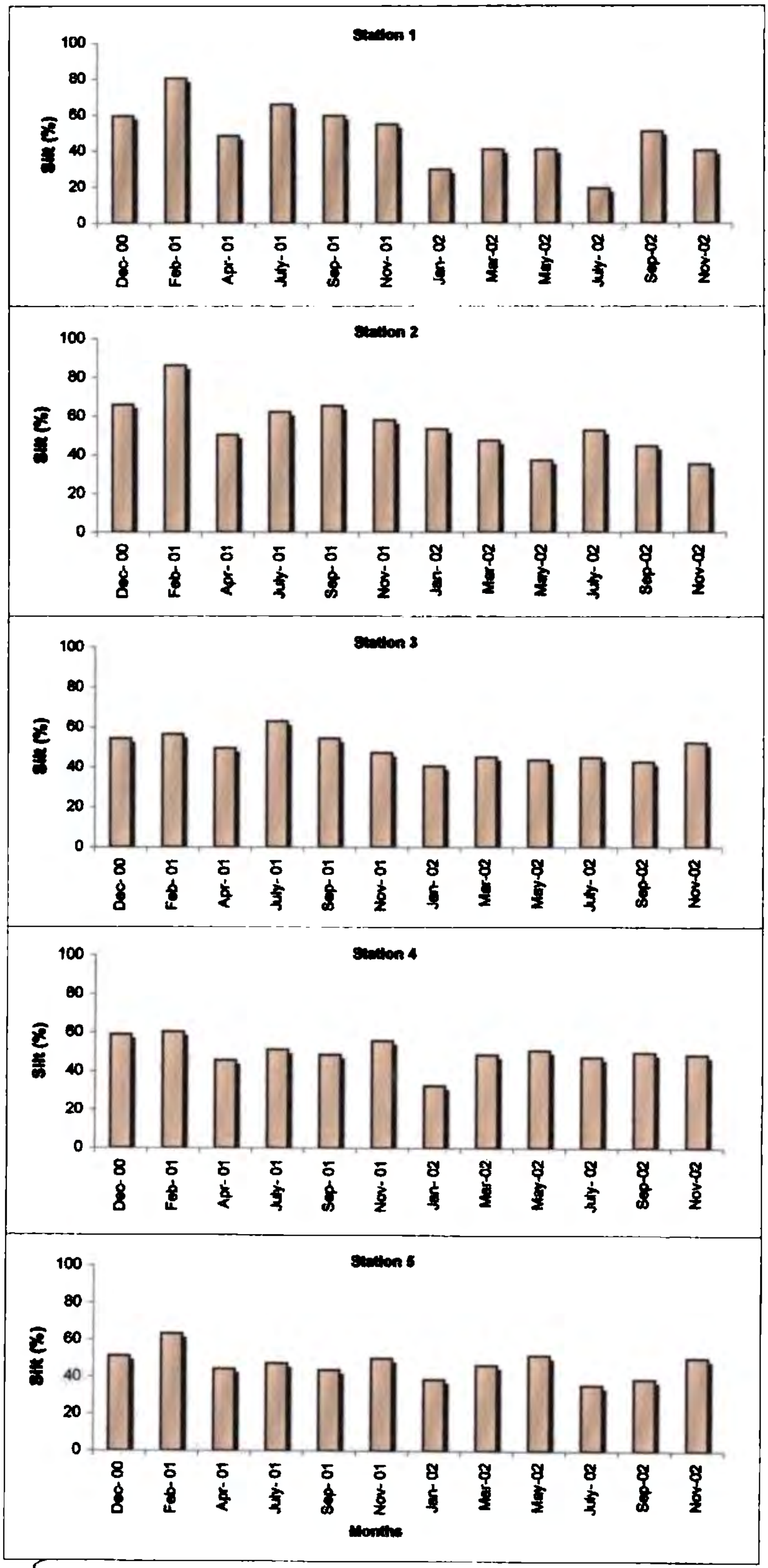


Fig 5.7 a. Patterns of variations in silt fraction at stations 1 to 5 recorded after trawling from December 2000 to November 2002

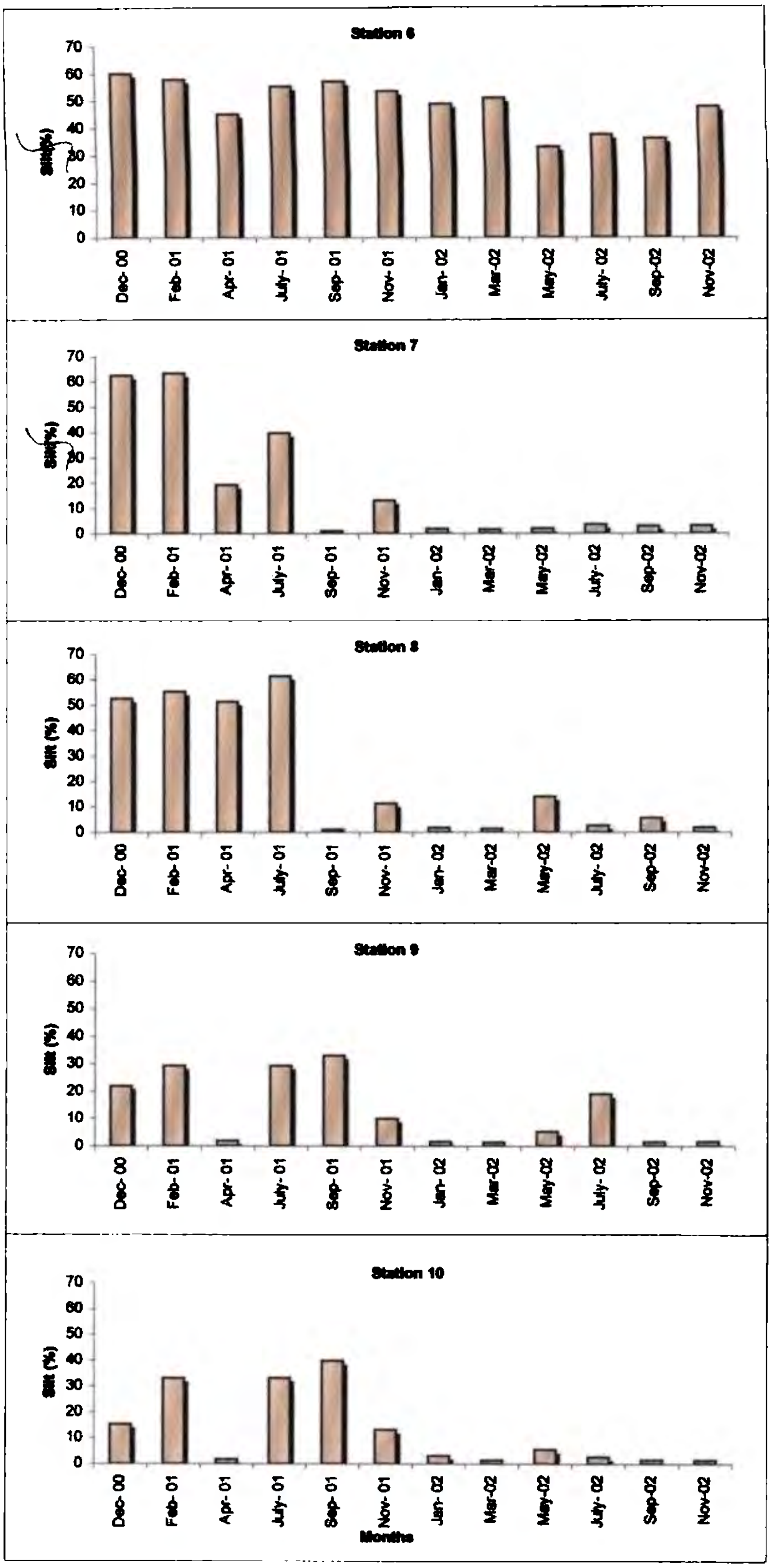


Fig 5.7 b. Patterns of variations in silt fraction at stations 6 to 10 recorded after trawling from December 2000 to November 2002

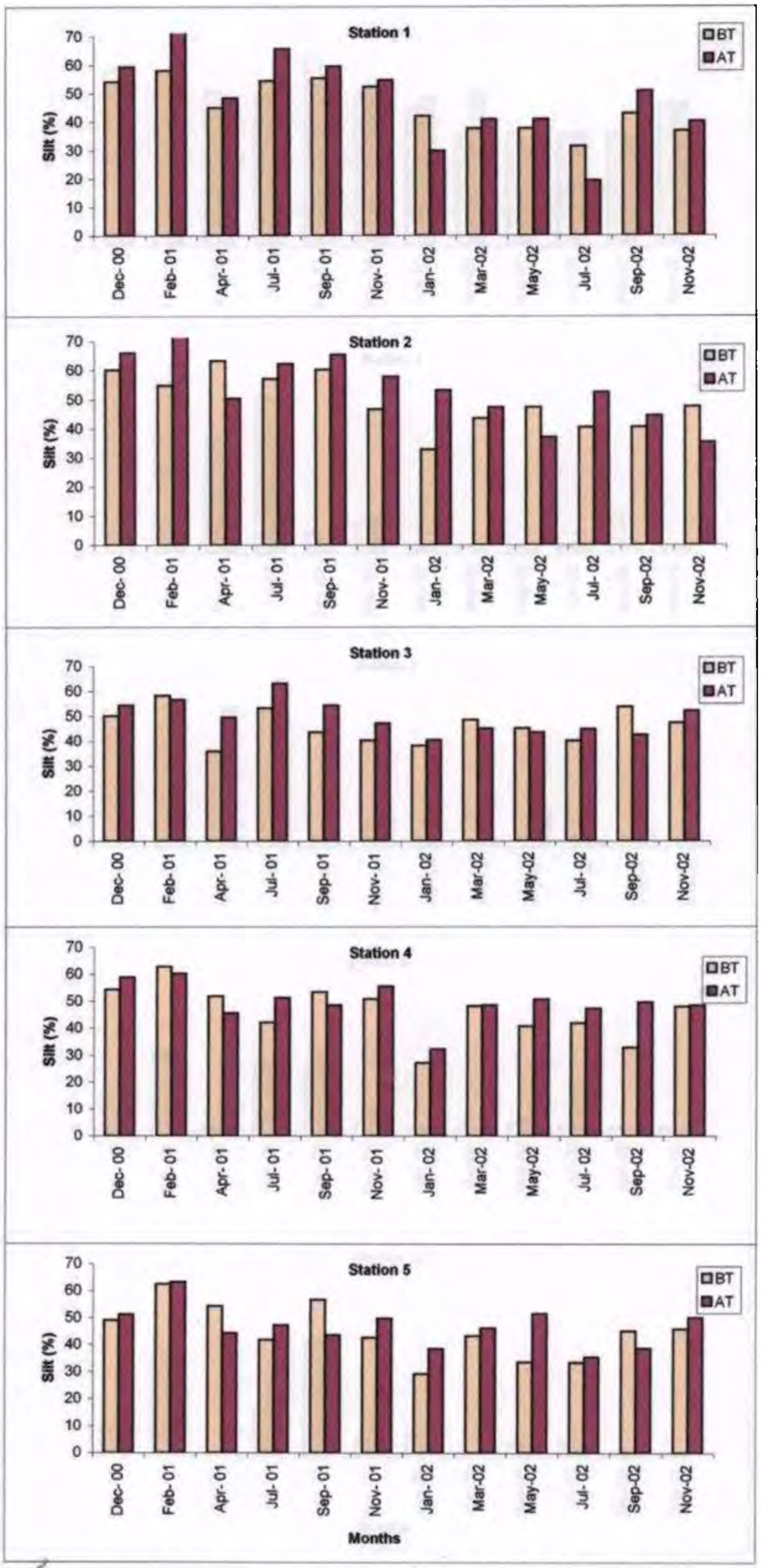


Fig.5.8 a. Comparison of silt content before and after trawling in Cochin-Munambam area from December 2000 to November 2002 at stations 1 to 5

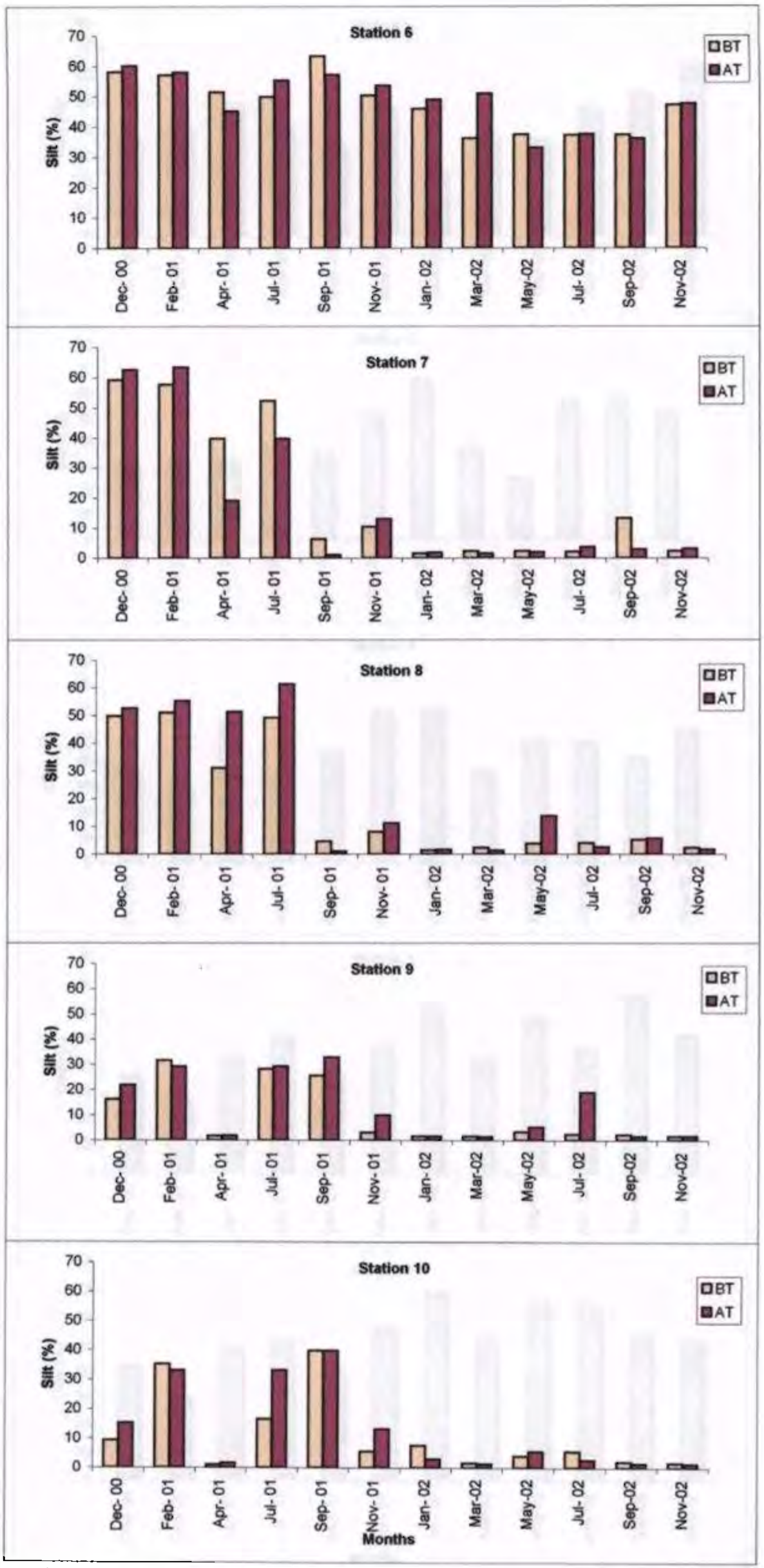


Fig.5.8 b.Comparison of silt content before and after trawling in Cochin-Munambam area from December 2000 to November 2002 at stations 6 to 10

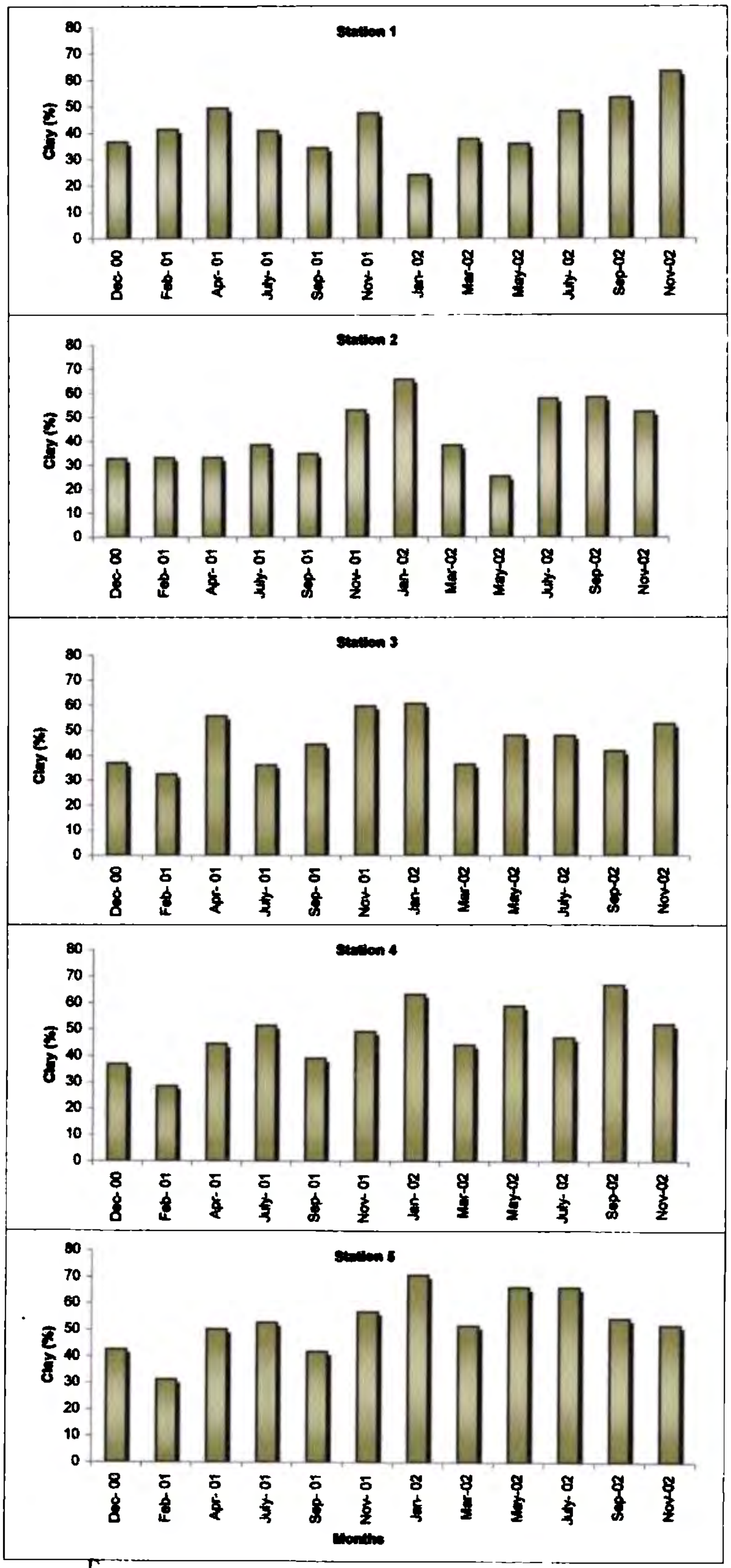


Fig. 5.9 a Patterns of variation in clay fraction before trawling at stations 1 to 5 from December 2000- November 2002

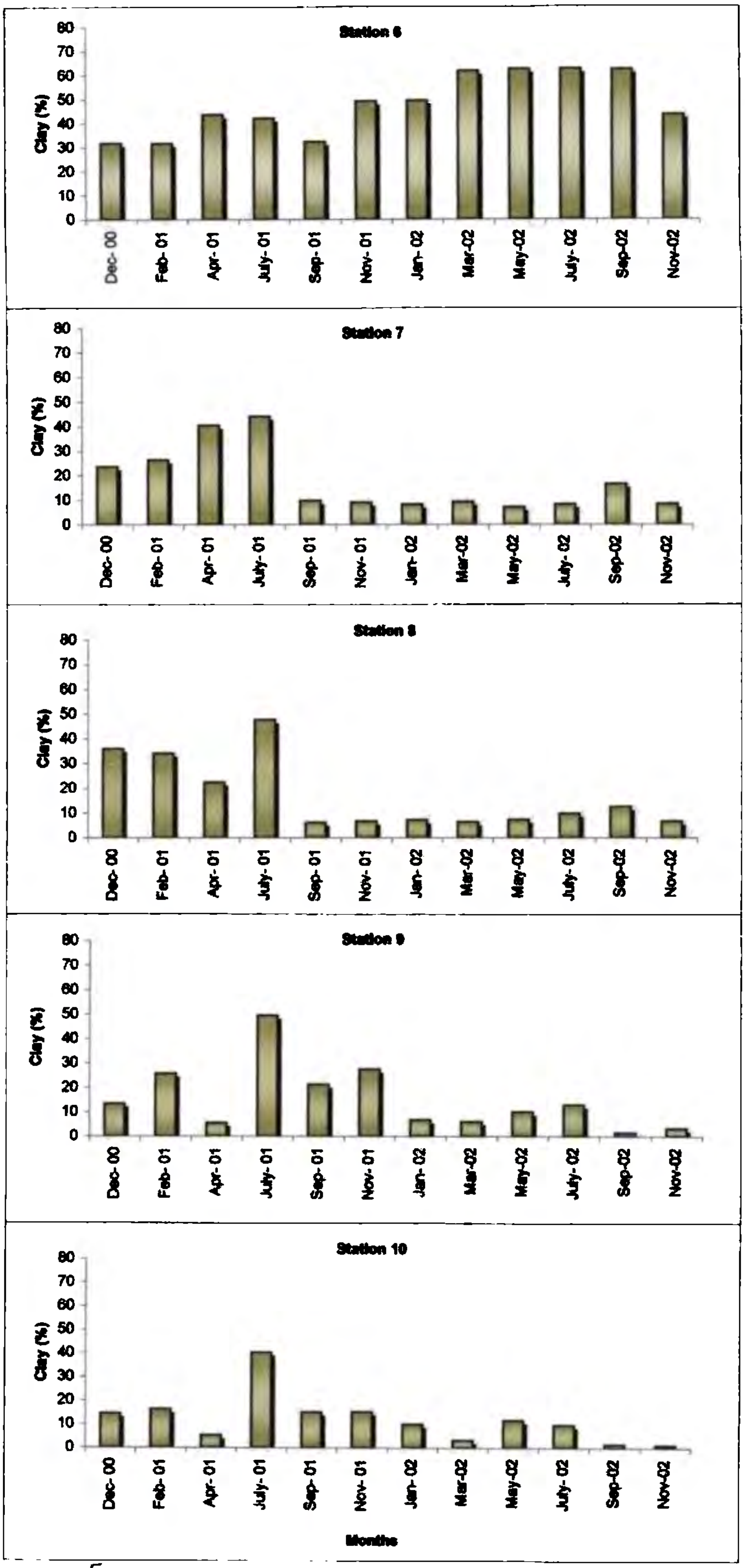


Fig. 5.9 b. Patterns of variation in clay fraction before trawling at stations 6 to 10 from December 2000- November 2002

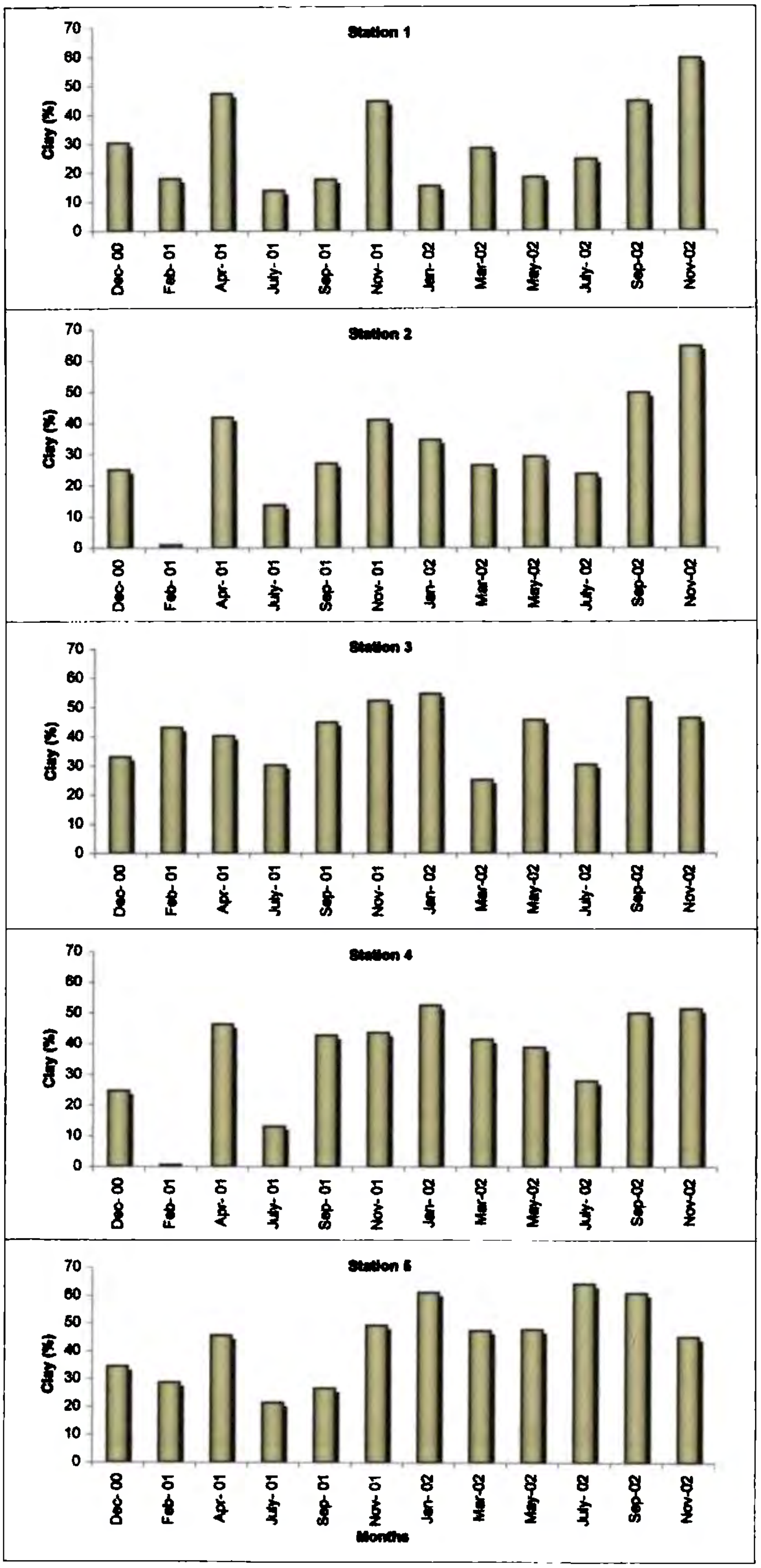


Fig. 5.10 a Patterns of variation in clay fraction after trawling at stations 1 to 5 from December 2000- November 2002

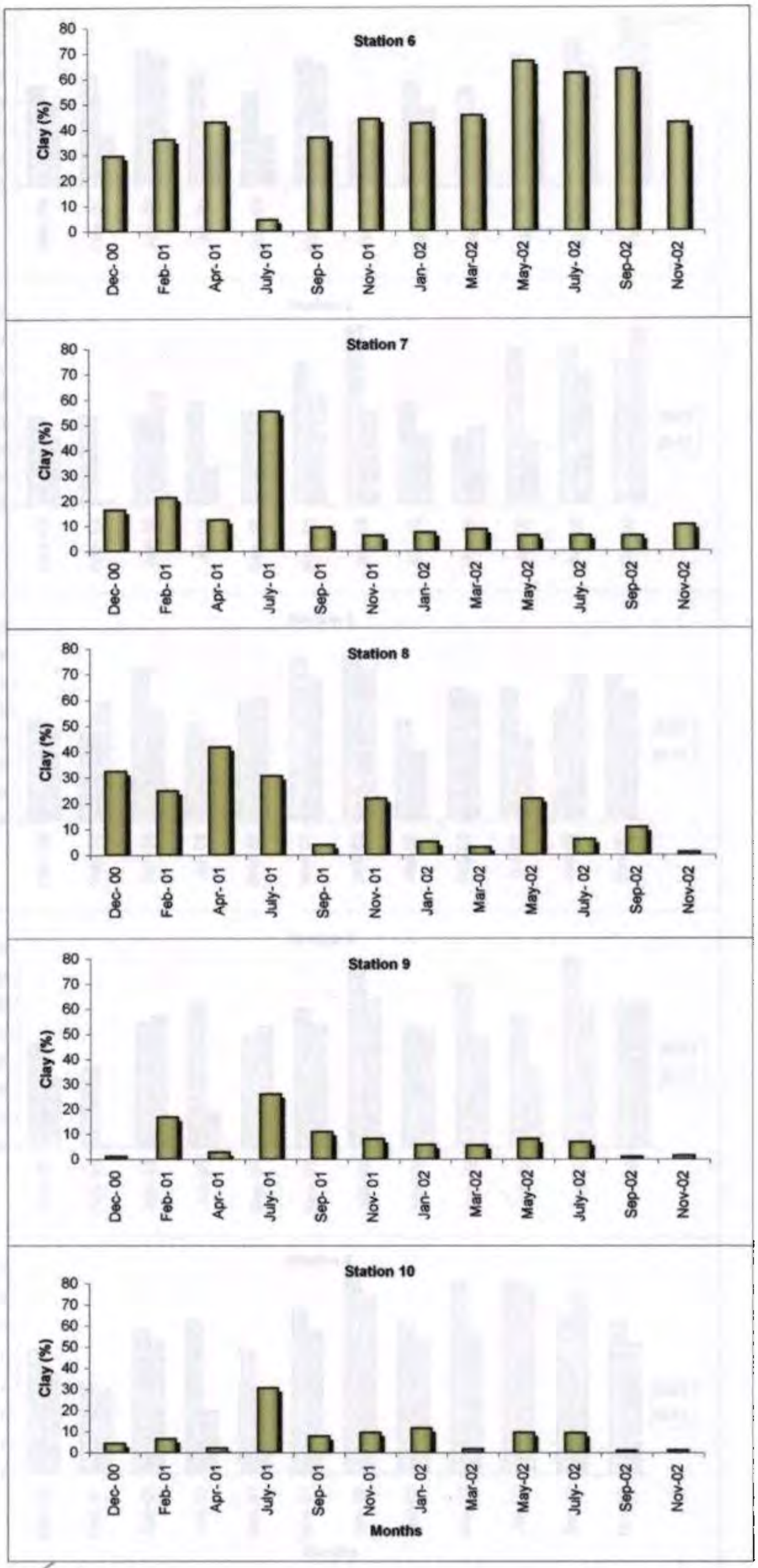


Fig.5.10b. Patterns of variation in clay fraction recorded after trawling at stations 6 to 10 from December 2000 to November 2002

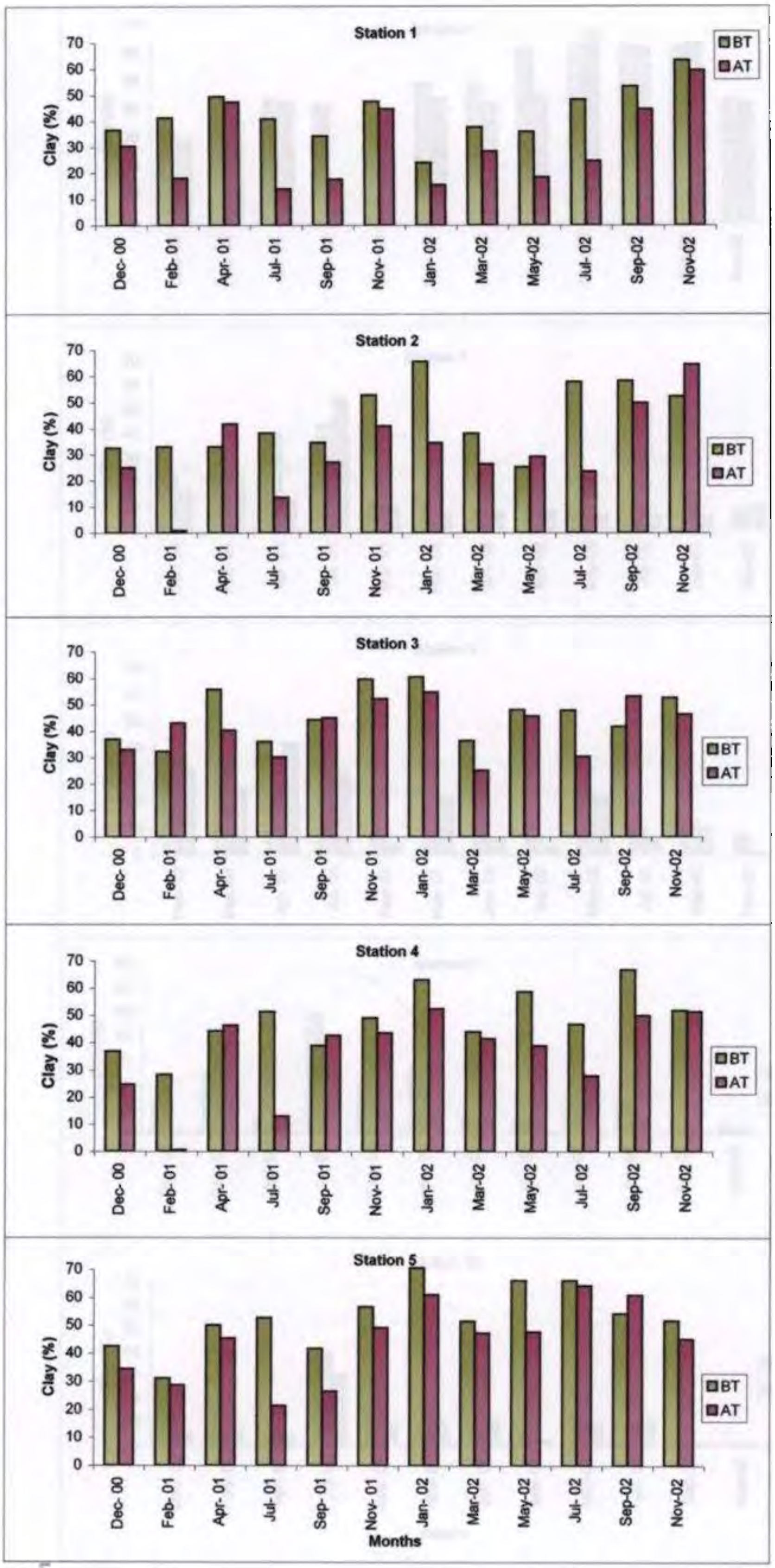
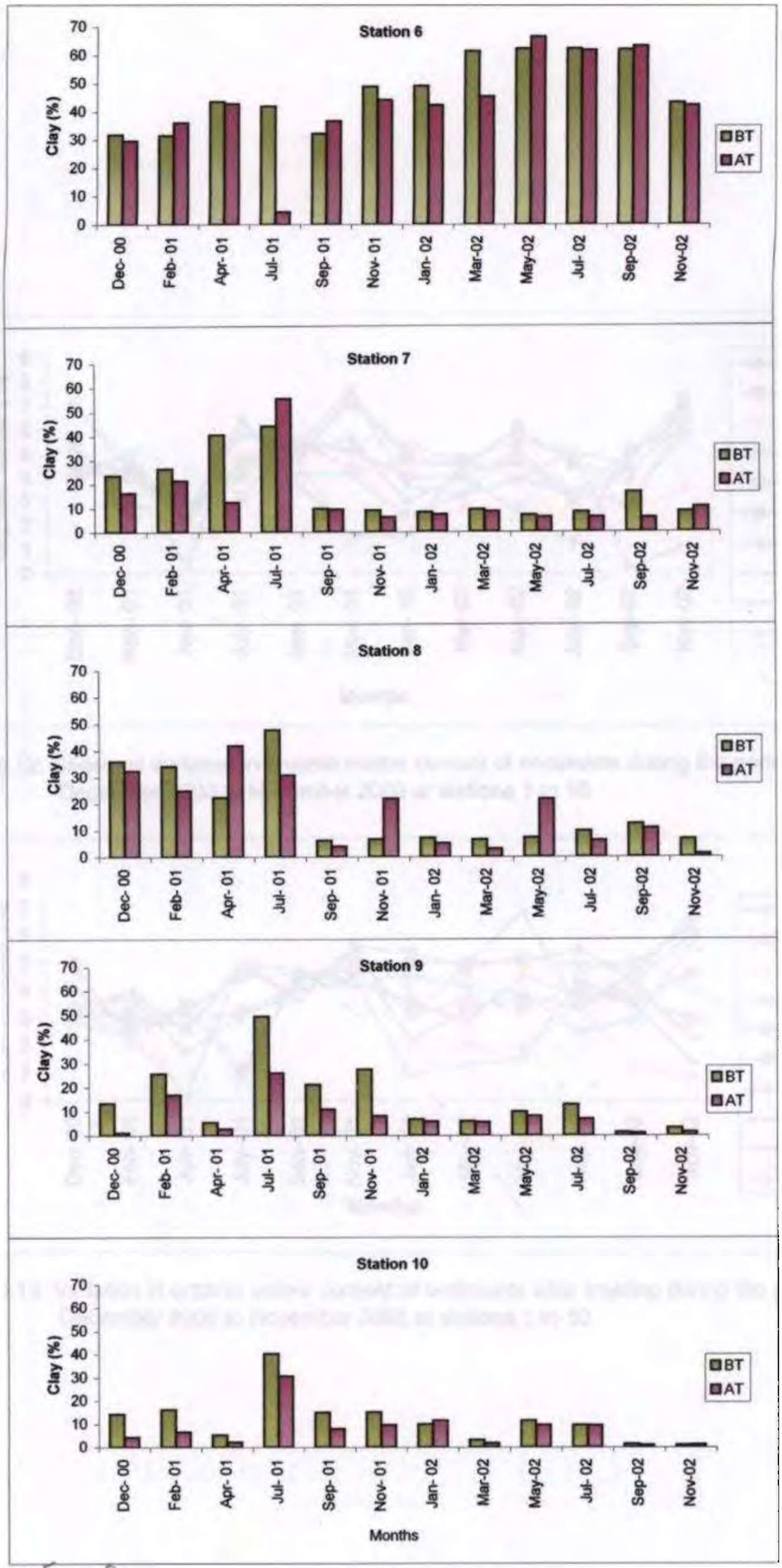


Fig.5.11 a. Comparison of clay content before and after trawling in the study area from December 2000 to November 2002



✓ Fig.5.11 b.Comparison of clay content before and after trawling in the study area from December 2000 to November 2002

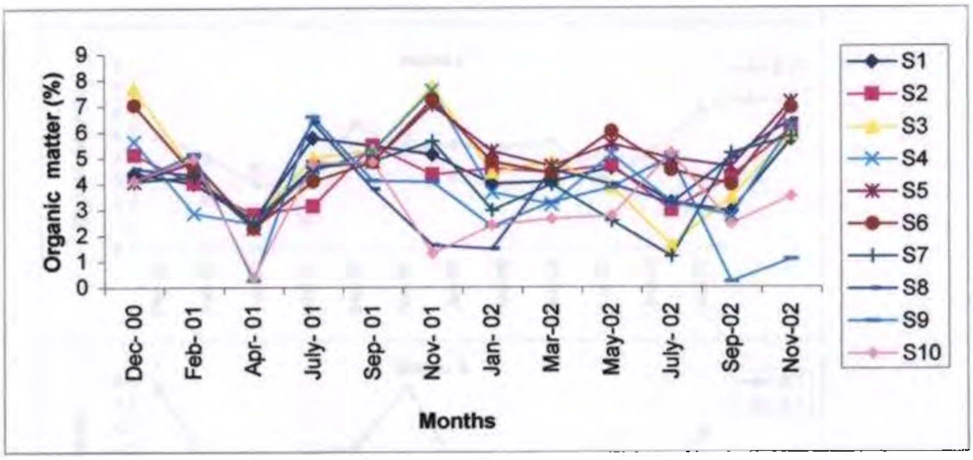


Fig.5.12. Seasonal variation in organic matter content of sediments during the period December 2000 to November 2002 at stations 1 to 10

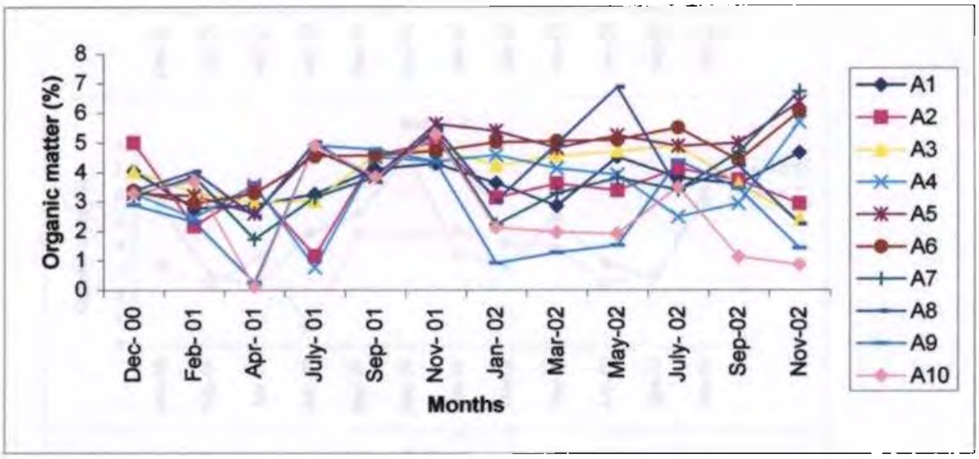


Fig.5.13. Variation in organic matter content of sediments after trawling during the period December 2000 to November 2002 at stations 1 to 10

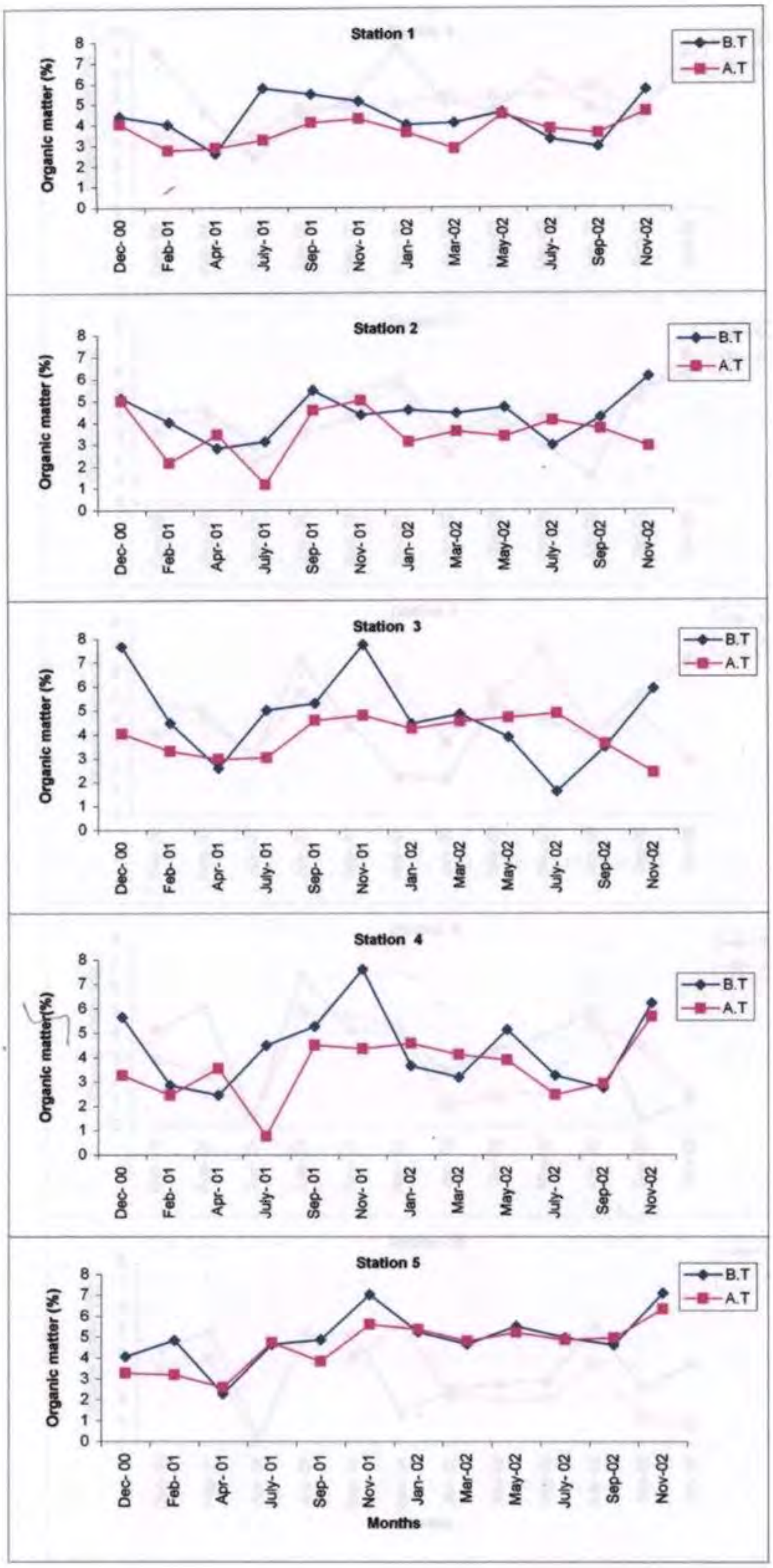


Fig.5.14 a. Comparison of sediment organic matter before and after trawling at stations 1 to 5 during December 2000 to November 2002

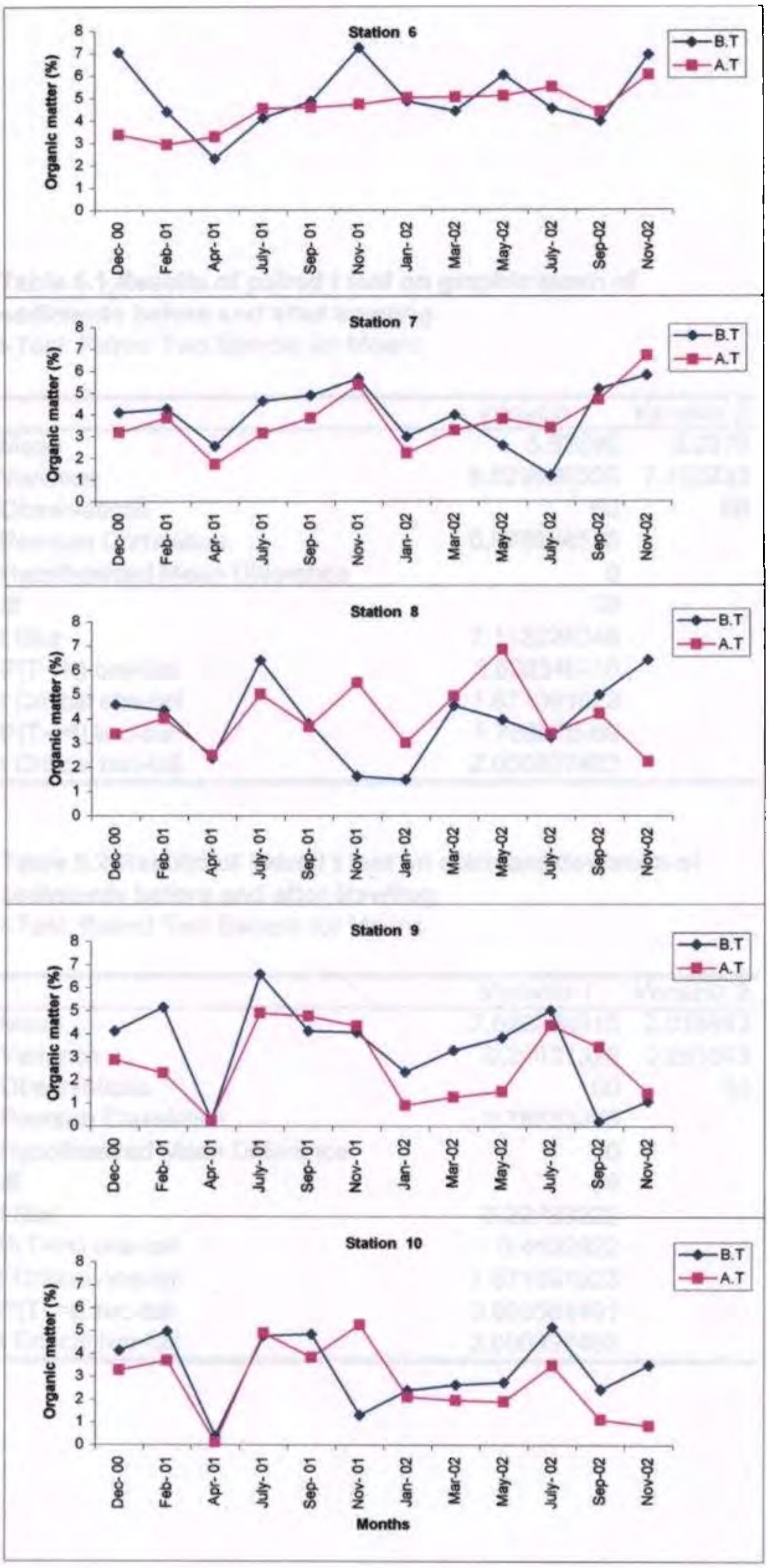


Fig. 5.14 b. Comparison of sediment organic matter before and after trawling at stations 6 to 10 during December 2000 to November 2002

Table 5.1 Results of paired t test on graphic mean of sediments before and after trawling

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	5.82695	5.2975
Variance	6.829460523	7.260233
Observations	60	60
Pearson Correlation	0.976864578	
Hypothesized Mean Difference	0	
df	59	
t Stat	7.113226348	
P(T<=t) one-tail	8.69934E-10	
t Critical one-tail	1.671091923	
P(T<=t) two-tail	1.73987E-09	
t Critical two-tail	2.000997483	

Table 5.2 Results of paired t test on standard deviation of sediments before and after trawling

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.026264015	2.035912
Variance	0.24431326	0.261043
Observations	60	60
Pearson Correlation	0.78753276	
Hypothesized Mean Difference	0	
df	59	
t Stat	-0.22783222	
P(T<=t) one-tail	0.4102822	
t Critical one-tail	1.671091923	
P(T<=t) two-tail	0.820564401	
t Critical two-tail	2.000997483	

Table 5.3 Results of paired t test on skewness of sediments before and after trawling

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	-0.016404399	0.129365
Variance	0.173425769	0.141396
Observations	60	60
Pearson Correlation	0.717060959	
Hypothesized Mean Difference	0	
df	59	
t Stat	-3.758602348	
P(T<=t) one-tail	0.000197038	
t Critical one-tail	1.671091923	
P(T<=t) two-tail	0.000394076	
t Critical two-tail	2.000997483	

Table 5.4 Results of paired t test on kurtosis of sediments before and after trawling

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	1.418160043	1.359273
Variance	1.255957162	1.161597
Observations	60	60
Pearson Correlation	0.802626393	
Hypothesized Mean Difference	0	
df	59	
t Stat	0.659311935	
P(T<=t) one-tail	0.256130379	
t Critical one-tail	1.671091923	
P(T<=t) two-tail	0.512260758	
t Critical two-tail	2.000997483	

Table 5.5 Results of the t test on comparing the sediment fractions and Organic matter recorded before and after trawling

Item	Stations	t	df	Significance
Sand	S1-A1	2.836	11	*
	S2-A2	3.119	11	*
	S3-A3	0.542	11	N.S
	S4-A4	2.814	11	*
	S5-A5	2.095	11	N.S
	S6-A6	1.272	11	N.S
	S7-A7	1.562	11	N.S
	S8-A8	0.092	11	N.S
	S9-A9	2.722	11	*
	S10-A10	2.296	11	*
Silt	S1-A1	1.307	11	N.S
	S2-A2	1.397	11	N.S
	S3-A3	1.627	11	N.S
	S4-A4	1.876	11	N.S
	S5-A5	0.739	11	N.S
	S6-A6	0.608	11	N.S
	S7-A7	1.31	11	N.S
	S8-A8	1.928	11	N.S
	S9-A9	1.955	11	N.S
	S10-A10	1.081	11	N.S
Clay	S1-A1	4.931	11	**
	S2-A2	2.637	11	*
	S3-A3	1.729	11	N.S
	S4-A4	3.341	11	**
	S5-A5	3.109	11	*
	S6-A6	1.339	11	N.S
	S7-A7	1.417	11	N.S
	S8-A8	0.029	11	N.S
	S9-A9	3.283	11	**
	S10-A10	3.197	11	**
Organic matter	S1-A1	2.411	11	*
	S2-A2	2.246	11	*
	S3-A3	1.43	11	*
	S4-A4	1.806	11	*
	S5-A5	2.121	11	N.S
	S6-A6	1.221	11	N.S
	S7-A7	0.687	11	N.S
	S8-A8	0.129	11	N.S
	S9-A9	1.331	11	N.S
	S10-A10	1.216	11	N.S

N.S - Not significant

* - P< 0.05 ** - P< 0.01

Chapter 6

SHORT TERM EFFECTS OF BOTTOM TRAWLING ON NEMATODA AND HARPACTICOIDA

6.1 Introduction

The round worms or the nematodes are one of the most common phyla of animals with over 20,000 described species. They are ubiquitous in fresh-water, marine and terrestrial environments where they often outnumber other animals in both individual and species counts and are found in locations as diverse as regions permanently covered with ice and the deep ocean trenches. Approximately 50% of known nematode species are marine, 25% are free living species found in soil or freshwater, 15% are parasites on animals and 10% of known species are parasites of plants. All nematodes are covered with a cuticle; in parasitic forms it is thin but in free living forms the cuticle is thick and hardened that it enables the animals to survive in environments where none other can exist. Free living marine nematodes are important and one of the most abundant members of the meiobenthos in the majority of marine sediment ecosystems. They are characterized by direct benthic development, with the whole of their life cycle closely coupled to the sediment and no dispersal phase and generation times very much less than one year. Warwick (1988) and Heip *et al.* (1988) hypothesized that aspects of their ecology might make them more sensitive to rapid changes in the environment compared to macrofaunal organisms which live often for more than a year and have planktonic phase in their life cycle. It was further hypothesized that meiofauna was less sensitive to physical disturbance than macrofauna (Warwick *et al.*, 1990). This was further supported by experimental studies which demonstrated interalia, that nematodes are sensitive to the nature, frequency and quantity of disturbance

(Schratzberger and Warwick, 1998,1999). Somerfield *et al.* (1995) examined changes in the nematode and macrofaunal community structure along a transect through a site receiving a continuous input of organically enriched sediments off Northwest England. They concluded that nematodes were more sensitive to ongoing sediment deposited at the site while the macrofauna reacted to events over longer periods of time.

Harpacticoid copepods are benthic crustaceans which appear to be ubiquitous in the marine environment. Harpacticoid copepods are very abundant among algae, detrital debris, on rocks and in muddy sediments. They also occur in low numbers in the plankton. They are considered one of the most important components of the marine environment since they form a significant part of diet of many animals, especially of commercially exploited fishes and they are potentially important indicators of environmental conditions. They are very fecund, and their life cycles short, often taking only a few days to go from adult through eggs to immature forms and then to adult. They are major constituent animals of the detritivore guild, feeding on small particulate debris. Additionally, they eat bacteria and microalgae that they scrape off sand grains (Hicks and Coull, 1983).

Human activities are rapidly reducing the Earth's biological diversity and studies have found that physical destruction of ecosystems is the most pervasive cause of biodiversity loss. In sea, the leading cause of destruction is the use of mobile fishing gear such as bottom trawls and dredges. These are used to catch benthic and demersal fishes, crabs, lobsters, shrimps, bivalves, sea urchins and corals and disturb the sea bed in many ways that overturn rocks, flatten sand waves, and crush bury and expose benthic organisms and biogenic structures (Watling and Norse, 1998; Auster and Langton, 1999). Biological activity is most pronounced at interphases and sea bed is no exception. The species and abundance of life in half metre above and below the sediment – water interphase are usually orders of magnitude higher than in overlying water column (Ausich and Bottjer, 1982).Structural complexity provides smaller species with living space, increased food abundance, and refuge from predation(Sebens, 1991). The diversity of benthic infauna and epibiota provides essential habitat features including structures and food that sustain some of the worlds' commercial fishes. Ecological theory and observations both suggest that severe disturbances that remove such structures from the sea bed will profoundly change species composition, harming many species but favouring some others, thereby decreasing species diversity. In this regard, trawling has a similar effect of organic enrichment, which reduces species diversity and produce communities comprising large numbers of opportunistic species (Pearson and Rosenberg, 1978). Many international studies have been conducted where scientists have looked at the effects of mobile fishing gear, including Northern Europe, Australia, New Zealand, and the Atlantic and Pacific coasts of North America. Thrush *et al.*(1998) found that areas with least disturbance from trawling and scallop dredging had the most long lived surface dwelling invertebrates, and the smallest proportion of opportunistic species. In all the studies it became clear that trawling tended to eliminate competently dominant long lived disturbance sensitive structure forming benthic species, freeing up food and space for shorter lived disturbance insensitive opportunistic species. In the absence of the essential benthic structures or food, groupers and cods disappear and lizardfishes and flat fishes fare better (Norse and Watling, 1999).

Studies on the distribution, habitat and food ecology of the meiobenthos have been undertaken on a large scale in many parts of this country, from bays, estuaries, salt marshes, beaches and seldom in the coastal marine environment. In view of the declining fisheries in the state of Kerala and to obtain a detailed information on the effects of otter trawling on the benthic habitats and communities of the inshore fishing grounds, a two year study was conducted along the Cochin - Munambam fishing belt, in which meiofaunal groups were studied for possible indicators of the impact of bottom trawling. The experimental design was of the before/after type, which yielded information on the immediate effects of trawling on sea bottom and its communities. The materials and methods are described in Chapter 3, "Materials and Methods".

6.2 Results

6.2.1 Nematoda :

Seasonal variations in the abundance of nematodes in the Cochin - Munambam area is shown in Fig.6.1. Nematode density was highest at station 4 with 2677 individuals per 10 cm^2 during the first year. A few stations in the 45 m depth zone showed nil density of nematodes. During the second year, nematode density was highest at station 10 with 2463 ind./10 cm^2 in the monsoon month of July 2002. Seasonwise, premonsoon and post monsoon showed moderate abundance, with an average of 900 and 640 ind./10 cm^2 respectively, while the peaks of nematode abundance was noticed in monsoon season during both the years. The abundance of nematodes showed highly significant variation ($P<0.05$, Appendix III, Table 1) when the densities were compared month wise pointing to a strong seasonal influence. Significant variations were also observed when the stations were compared depth wise ($P<0.05$), using ANOVA (Appendix III, Table 1). The variations arose presumably due to higher abundances in the inshore areas compared to the offshore stations where there was a decrease in density of nematodes; in short, the nematodes were not evenly distributed in the study area. Interestingly, though the abundance was higher in the 0-35m zone, the peak observed in the second year was at station10 which is the farthest from the shore.

After trawling, the abundance of nematodes was found to increase in almost all the samples (Fig 6.2). The highest density was at station 6 in April 2001 during the first year while a lower peak with 1642 / 10 cm^2 was observed in the succeeding year at station 9 in July 2002 . Results of ANOVA showed a significant temporal variation in nematode density which further points out the strong seasonal influence ($P<0.01$) on these organisms (Appendix III, Table 2). After trawling there was no significant difference in the nematode abundance when the stations were compared depthwise ($P>0.05$, Appendix III, Table 2), presenting a more or less uniform distribution of nematodes between stations. Analysis of the nematode abundance in the samples collected before and after trawling showed that trawling had significant effect on the abundance of nematode assemblages ($P<0.01$, Fig. 6.3 a & b). The significant differences were noticed at stations 1 to 7 ($P<0.05$) while stations 8 to 10 did not show any significance ($P>0.05$, Table 6.1).

6.2.2 Harpacticoida :

Harpacticoid copepods ranked second in abundance in the meiofauna group in the study area, with highest of 1321 ind./10 cm^2 in April 01 at station 10, during the first year(Fig.6.4). The peak abundance during the second year was at station 4 in May 2002 with 3499 ind./10 cm^2. As in the case of nematodes, the harpacticoids also showed nil abundances, in a few stations, especially those in the off shore region (7-10). Seasonwise, the premonsoon showed the highest number of harpacticoids compared to monsoon and post monsoon. Significant differences were noticed ($P<0.05$) when stations were compared temporally showing a strong influence of monsoon on abundance pattern(Appendix III, Table 3). Significant difference was also observed when the stations were compared spatially ie within the depth zones ($P<0.01$, Appendix III, Table 3) with the bulk of organisms concentrated towards the inshore regions compared to stations located far off from the shore at 40 – 50 m depth.

In after trawling samples, the harpacticoid abundance showed a drastic increase in samples collected after trawling, at most of the stations (Fig.6.5). During the first year, peak abundance was observed at station 4 with 1160 ind./10 cm^2 in November 01, while 2392 ind./10 cm^2 were registered from the same station in May 2002 during ~~the second~~ year. ANOVA showed significant differences both station wise and month wise after trawling which corroborate that the meiofauna underwent both spatial and temporal variations after trawling ($P<0.01$, Appendix III, Table 4; Fig. 6.6 a & b). Comparison of abundances of harpacticoids before and after trawling (t test) revealed a significant difference in abundance at stations 1, 2, 5, 8, 9 and 10 ($P<0.05$, Table 6.1).

6.3 Discussion

Nematodes were the most prominent of all meiofaunal groups and averaged a density of 770 and 1000 ind./10 cm^2 during the first and second years of observation in the study area. Many benthic studies have been conducted along the Indian coast, and almost all of them have identified nematodes to be the most abundant meiofaunal taxa (Ansari *et al.*, 1982, Damodaran, 1973; Harkantra and Parulekar, 1989; Ingole *et al.*, 1987; Kondalarao and Murty, 1988; Goldin *et al.*, 1996; Rao and Sarma, 1990; Varshney *et al.*, 1984). Harpacticoids were not as abundant as nematodes in the present study, nevertheless, occupied an important position in the meiobenthic group. The same was also the case in a few studies on meiobenthos in the coastal areas and estuarine habitat (Harkantra and Parulekar, 1989; Rao and Sarma, 1990). In the present study, nematodes were at peak density during the monsoon season while the post monsoon witnessed a slight decline in the samples collected before trawling, during both the years of observation. These results are in contrast to the observations made elsewhere by many authors who witnessed a rejuvenation of meiofauna in the post monsoon season (Varshney *et al.*, 1984; Ingole *et al.,* 1987; Harkantra and Parulekar, 1989). It is of interest to note that the period of monsoon and the increase in nematode fauna coincide~~s~~ with the imposition of ban on monsoon trawling along Kerala coast, during when there are no anthropogenic disturbances to the sea floor, but only the natural forces acting upon it. It may be presumed that in the scale of variant types of disturbances, man made disturbances would outweigh that of natural ones, causing the nematode fauna to decrease after the monsoon when the ban is lifted. Within intensively fished grounds, the background levels of natural disturbance may have been exceeded, leading to long-term changes in the benthic community (Jennings and Kaiser, 1998). It has been reported by many authors that the communities observed at the present time may be the product of decades of continuous fishing disturbance (Bergman and Hup, 1992; de Groot and Lindeboom, 1994; Dayton *et al.*, 1995). The harpacticoid copepods, on the other hand, followed the normal cycle of reproduction and abundance, and unlike the nematodes, they decreased in density during the southwest monsoon with a subsequent increase in the post monsoon season (Goldin *et al.*, 1996; Rao and Sarma, 1990; Varshney *et al.*, 1984).

Sedimentary environment plays an important role in the abundance of meiofauna (Hulings and Gray, 1976).In the present study, the sediments upto 35 m water depth fell into the classification of poorly sorted and very poorly sorted. This zone is characterized by fine clay and high percentage of organic matter. Sorting has been suggested by Jansson (1967) as being a more relevant factor than median grain size to the meiofauna in that it more closely relates to space. Poorly sorted sediments have small pore spaces whereas well-sorted sediments are characterized by larger pore spaces for equivalent size range. The pattern of distribution shown by the nematodes in the present study revealed that a distinct zonation exist, wherein they were more abundant in the 0-35 m zone when compared to the depth zones beyond 35 m. In the 35-50 m zone, the sediment sorting changed to moderately sorted and became coarser with more free space for movement, which appears to be favourable for the nematodes. In the present study, nematodes were found in higher abundance in 0-35 m zone. Nematodes were dominant in the sediment with fine grain size and the relative abundance of harpacticoids increased as the sediment became coarser (Heip *et al.*, 1985). Space alone probably cannot limit meiofaunal abundance since the fauna never occupy the total volume of pores (Hulings and Gray, 1976). For animal populations, space is rarely a limiting factor, except for sessile species (Andrewartha, 1961).

It is well known that detritus is of vital importance for the nutrition of meiofaunal organisms in sediment (Giere, 1993). Experimental work in marine systems has demonstrated that detritivorous meiofauna may utilize bacterial biofilms and not the detrital substrata itself (Fenchel and Riedl, 1970; Hargrave, 1973; Meyer-Reill and Faubel, 1980). The nematode fauna in the present study was positively correlated with stations showing high organic matter, in the depths upto 35 m and thenceforth the sandy substrata predominantly characterized by a low percentage of organic matter, harboured a lower density of nematodes. Further more, in some members of meiofauna such as marine nematodes, the functional relations between the structure of meiofauna mouthparts and the shape of bacteria have been demonstrated in detail (Jensen, 1987). The results of the present study showed that the marine harpacticoids did not show significant correlation with organic matter but they have been found to discriminate between various groups of bacteria and microfungi (Carman and Thistle, 1985) and found possessing mouthparts suited to the shape of bacteria (Marcotte, 1984). Studies have shown that invertebrates not only take up particulate/fine organic matter but also dissolved organic substances adsorbed to organic particles (Meyer-Reill and Faubel, 1980).The results of the present study revealed that the presence of organic matter content influenced the nematodes to a great extent. Both nematodes and harpacticoids exhibit patchiness in their distribution , with some stations apparently devoid of these fauna during both the years of observation. Meiofauna are believed to be highly selelctive feeders with distinct and often highly specialized food niches (Kennedy, 1994). Meyer *et al.* (1970) observed that marine nematodes aggregate in areas where organic material is in plenty and utilize the organics absorbed to sediment or detrital particles. Micro differences in physical and biological features of the sediment affect the concentration and movement of the nematode fauna (Gerlach, 1971; Weiser, 1960). Harpacticoid copepods are reported to live freely in the interstices of sands or as burrowers in non-capillary sediment (Hicks and Coull, 1983). A species of marine meiobenthic harpacticoid has also been observed to build tubes within 30 minutes of entering the experimental sediment chamber. All tubes are constructed from a matrix of fine sand particles and detritus bound together with an acid mucopolysaccharide, with lateral extensions to form a continuous infaunal network that rapidly transforms the free surface sediments to a cohesive mucous mat. The tubes are elongate and extend as deep as 3.9mm (Chandler and Fleeger , 1984).

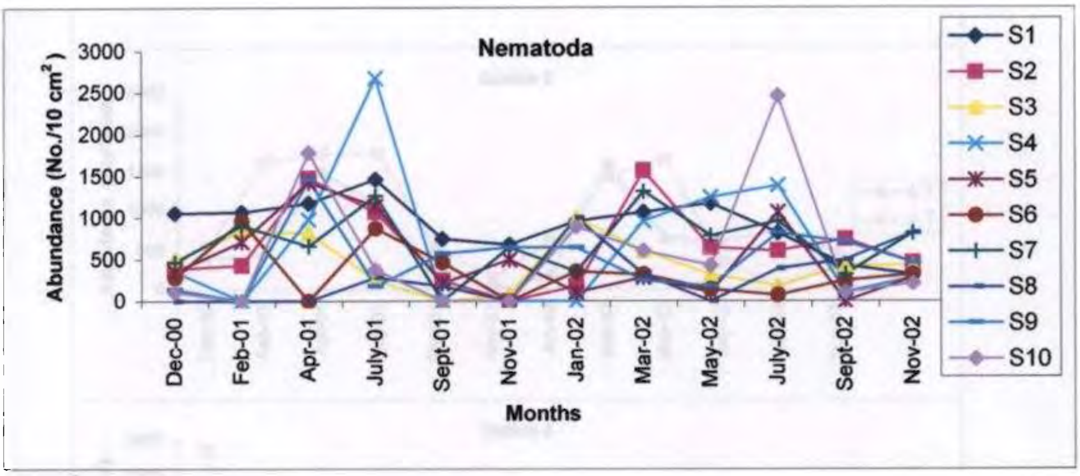
Post trawling increase in abundance of nematodes was significant when compared to the pretrawling densities. Greater abundances of nematodes were also found in highly trawled areas during a study on the effects of otter trawling in Monterey Bay (Engel and Kvitek, 1998). Chicharo *et al.* (2002 b) also observed higher values of abundance of meiofauna at a fished area compared to a non fished area and was dominated by Nematoda, which represented 90% of the total meiofauna. Majority of the demersal fishing activity occurs in the shallow seas on the continental shelf at depths ranging from 25-100 m (Jennings and Kaiser, 1998). Benthic communities in those environments experience continual disturbances at various scales (Hall, 1994). Large-scale natural disturbances occur in the form of seasonal storms and strong tidal currents, whereas smaller disturbances occur in the form of predator feeding activities (Hall, 1994), which may have considerable effects on benthic communities. Studies have shown that in fishing grounds, the disturbance caused by the fishing gear has much more impact than the natural ones. Fishing gears that are towed across the seabed lead to perturbation of the benthic fauna and habitats (de Groot, 1984; Messieh *et al.*, 1991; Jones, 1992;

Dayton *et al.*, 1995; Jennings and Kaiser, 1998, Auster and Langton, 1999). Otter trawls have been observed to overturn rocks and scrape off the upper sediment layer , which is resuspended to expose the subsequent layers. The burrowing benthic fauna including the nematodes and harpacticoids are brought to the surface, which may account for the increase in their abundance observed in the post trawling samples in the present study. High intensity trawling favours opportunistic species and many nematodes have been considered as pioneer species known to be early colonizers on frequently disturbed areas and scavenging on organic matter (Brusca and Brusca, 2003).

Most studies have shown that it is possible to detect short term changes in community structure in response to fishing disturbance (de Groot, 1984; Currie and Parry, 1996; Kaiser and Spencer, 1996). When an area has been continuously fished for several decades, it can be difficult to distinguish between changes in the community caused by fisheries disturbance and those by natural phenomena (Currie and Parry, 1996). Analysis of meiofauna as a potential indicator of anthropogenic perturbation in aquatic ecosystems has often been limited to monitoring surveys for pollution (Pranovi *et al.*, 2000). However, meiofauna analysis, especially that of the numerically dominant nematodes may be used to reveal the existence of bottom trawling disturbance which took place in this study. The magnitude of increase in abundance of nematodes and copepods immediately after trawling is an indication of trawling disturbance although of a short-term duration.

The majority of meiofauna live in the upper few centimeters of sediment (Mare,1942; McIntyre,1969; Christian *et al.*,1975; Yingst ,1978). Trawl penetration has been estimated at 2-3 cm in coarse sands while in muddy sediments the depth is at 10 cm or more (de Groot and Lindeboom, 1994). The benthic nematodes are either resuspended and /or exposed after the passage of trawl which justifies the increase in abundance immediately after trawling.

The short generation times of meiobenthic nematodes and harpacticoids, their ability to withstand disturbance by rapidly recolonising the affected areas and their opportunistic behaviour have suited them to colonise harsh environments created by otter trawls along the water sediment interphase. Though direct mortality of infauna, especially meiobenthos has not been recorded, these fauna can succumb to a decrease in density as trawling progresses in the long term. Meiofauna, especially harpacticoids are preyed upon by juveniles of a large number of fish species (Evans, 1983) and shrimp (Gerlach, 1971), and playing an important role in benthic remineralisation, may no longer be able to support these functions which would undoubtedly have far reaching consequences in the benthic and pelagic realm.



✓ Fig.6.1. Seasonal variation in abundance of nematodes recorded before trawling during the period December 2000 to November 2002 at stations 1 to 10

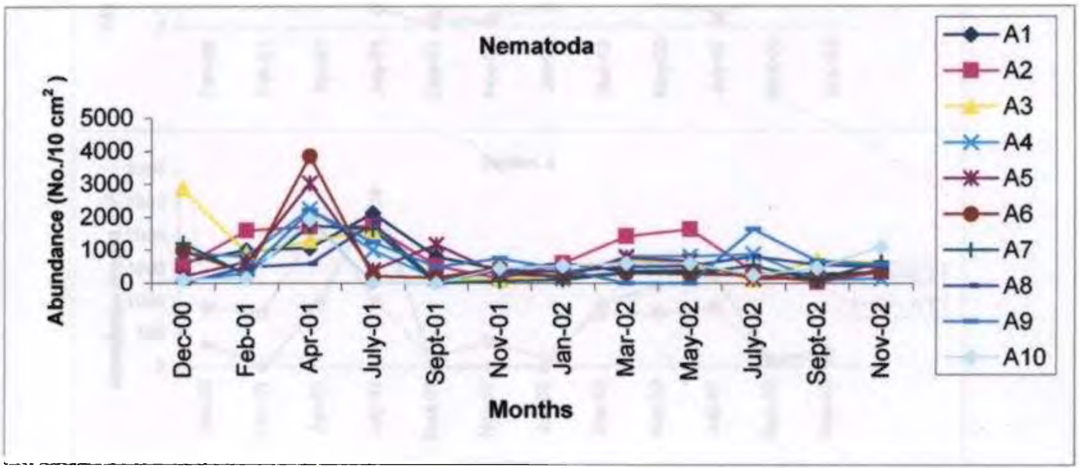


Fig.6.2. Variation in abundance of nematodes recorded after trawling during the period December 2000 to November 2002 at stations 1 to 10

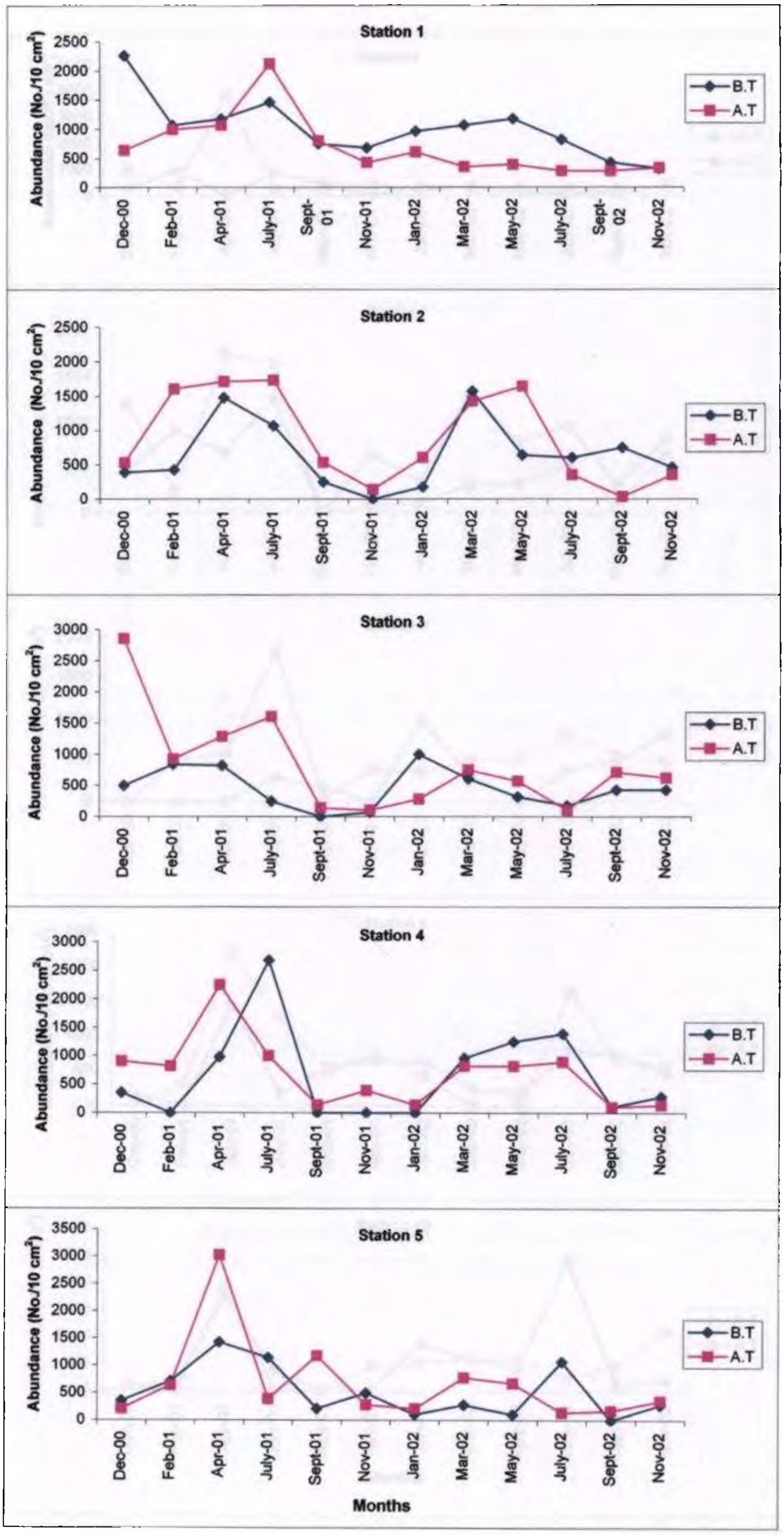


Fig.6.3 a. Comparison of abundance of nematodes before and after trawling at stations 1 to 5 during the period December 2000 - November 2002

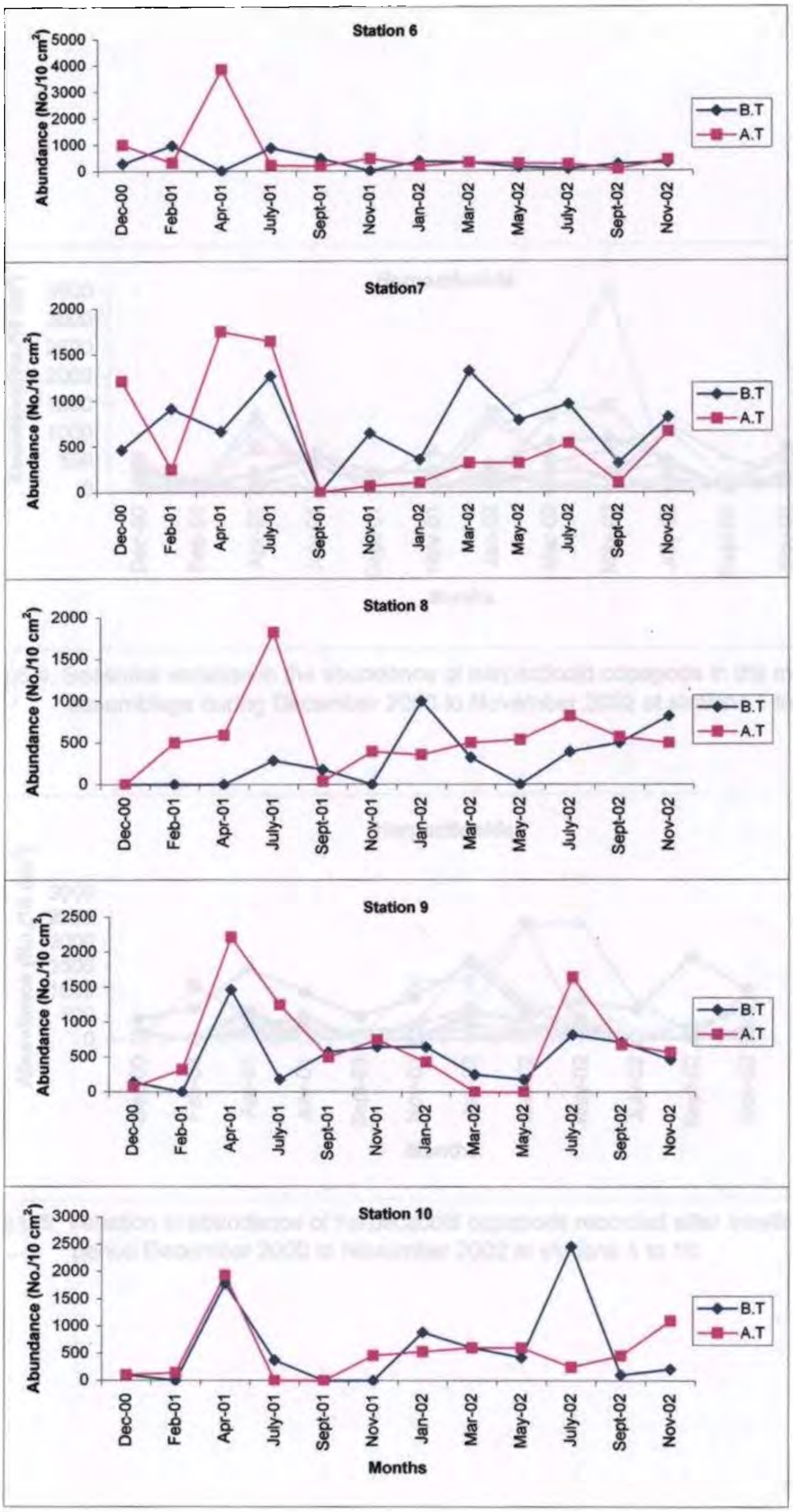


Fig.6.3. b. Comparison of abundance of nematodes before and after trawling at stations 6 to 10 during the period December 2000 - November 2002

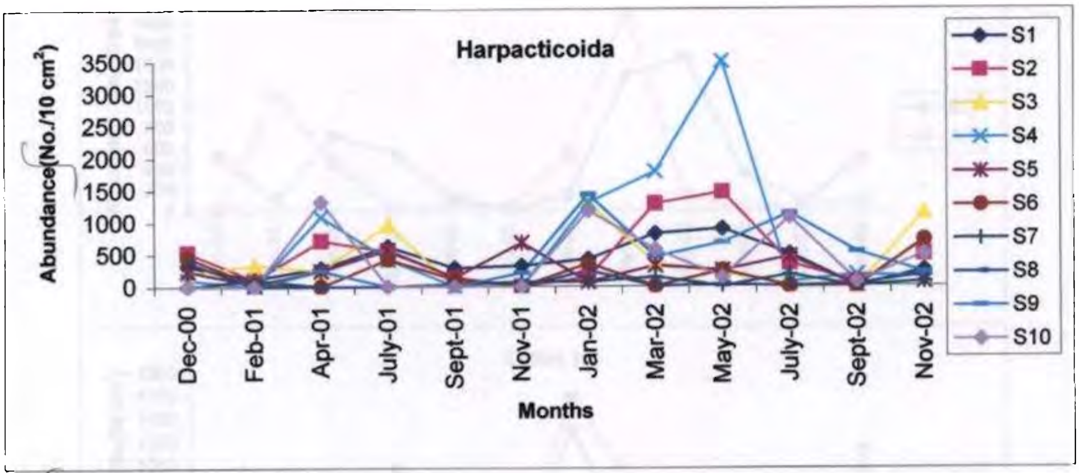


Fig.6.4. Seasonal variation in the abundance of harpacticoid copepods in the meiofaunal assemblage during December 2000 to November 2002 at stations 1 to 10

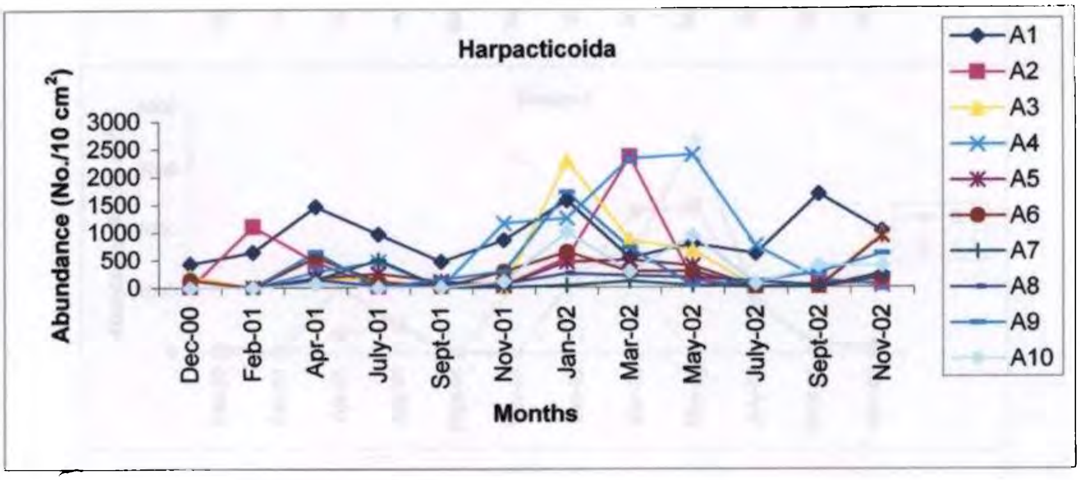


Fig.6.5. Variation in abundance of harpacticoid copepods recorded after trawling during the period December 2000 to November 2002 at stations 1 to 10

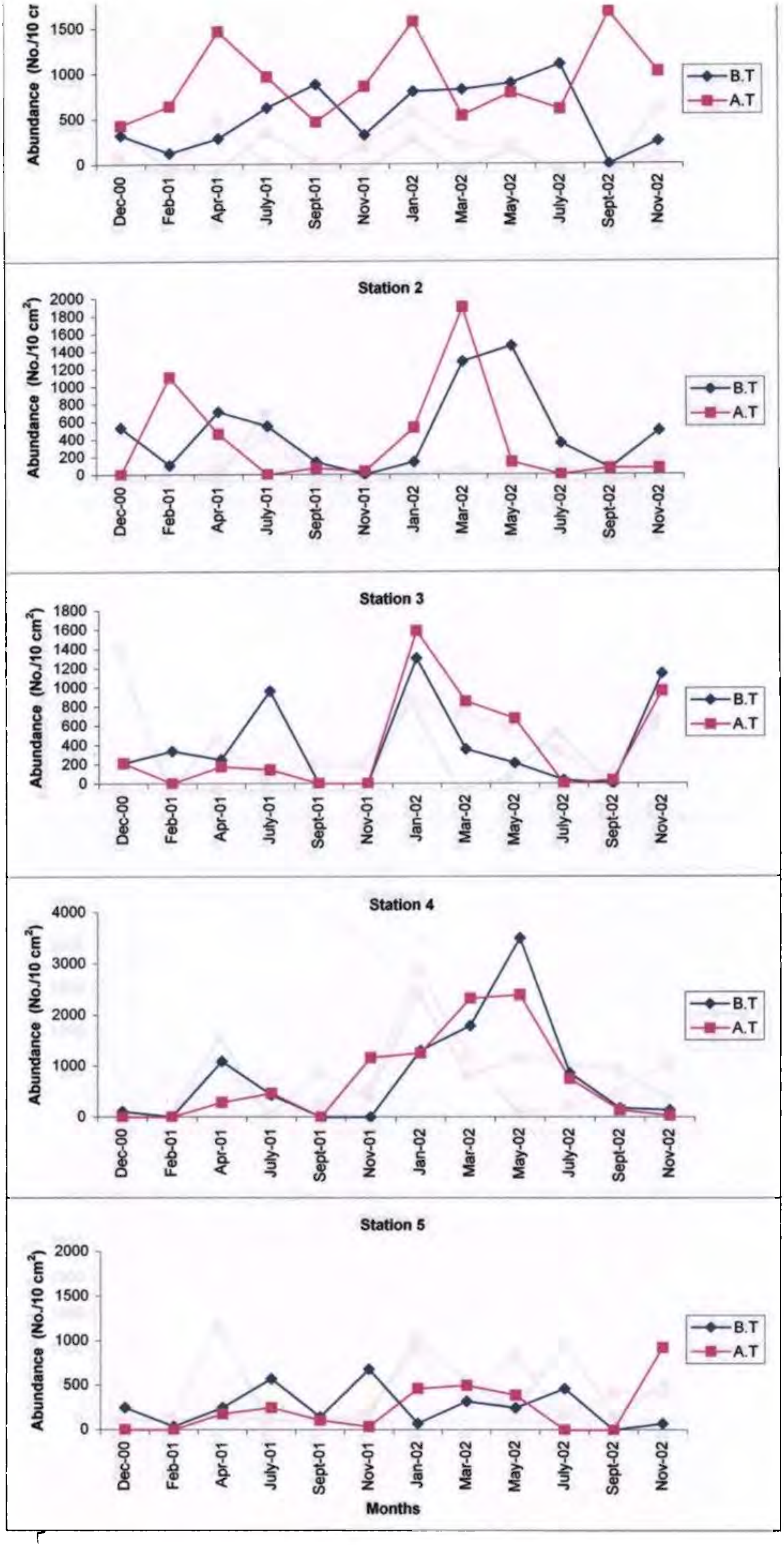


Fig.6.6.a. Comparison of copepod abundance before and after trawling during December 2000 to November 2002 at stations 1 to 5

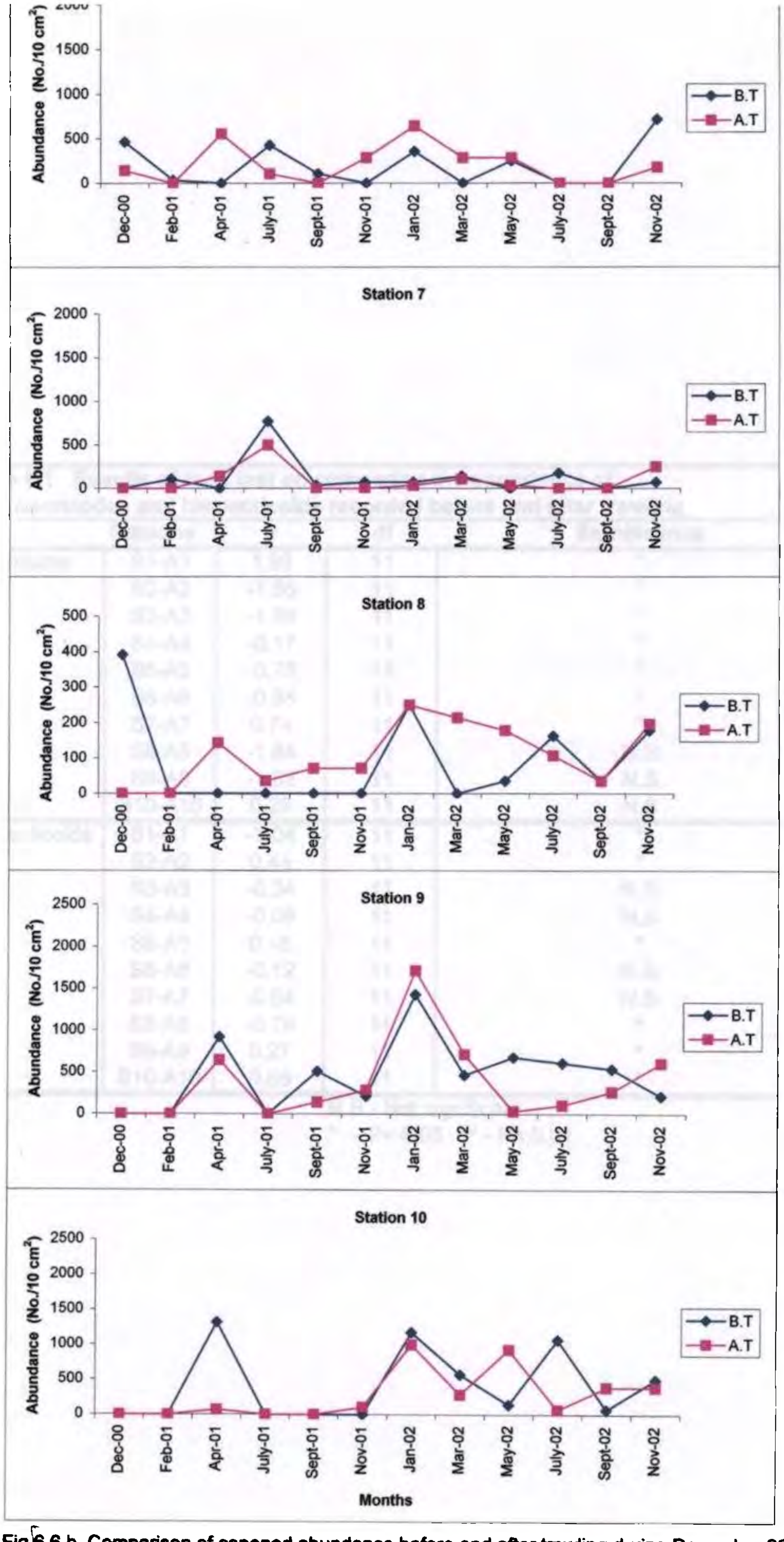


Fig.6.6.b. Comparison of copepod abundance before and after trawling during December 2000 to November 2002 at stations 6 to 10

✓

Table 6.1 Results of the t test on comparing the abundance of nematodes and harpacticoids recorded before and after trawling

Item	Stations	t	df	Significance
Nematodes	S1-A1	1.98	11	*
	S2-A2	-1.55	11	*
	S3-A3	-1.68	11	*
	S4-A4	-0.17	11	*
	S5-A5	-0.78	11	*
	S6-A6	-0.85	11	*
	S7-A7	0.74	11	*
	S8-A8	-1.64	11	N.S
	S9-A9	-1.52	11	N.S
	S10-A10	0.29	11	N.S
Harpacticoids	S1-A1	-3.04	11	*
	S2-A2	0.44	11	*
	S3-A3	-0.34	11	N.S
	S4-A4	-0.09	11	N.S
	S5-A5	0.18	11	*
	S6-A6	-0.12	11	N.S
	S7-A7	-0.64	11	N.S
	S8-A8	-0.79	11	*
	S9-A9	0.27	11	*
	S10-A10	0.86	11	*

N.S - Not significant

* - $P< 0.05$ ** - $P< 0.01$

Chapter 7

SHORT TERM EFFECTS OF BOTTOM TRAWLING ON POLYCHAETA AND FORAMINIFERA

7.1 Introduction

The seafloor communities, irrespective of the sediment characteristics, are populated by marine worms, which reside in elaborate burrows inside the sediment. These are polychaetes, commonly called "bristle worms" and are multi-segmented annelids with parapodia classified under the Phylum Arthropoda. Polychaetes are dominant benthic fauna in the marine environment and number more than 10,000 known species in the world so far (Brusca and Brusca, 2003). Marine benthic polychaetes have been subject of study in most of the macrobenthic investigations, since they have often been found to dominate the macrofaunal content of a given area (Bergman and Hup, 1992; Smith *et al.*, 2000; McConnaughey *et al.*, 2000). But in a few instances polychaetes have also been included under the meiofaunal category due to the presence of juveniles and are treated as meiofauna by some scientists (Bell, 1980) and as macrofauna by others (Gee *et al.*, 1985).

Polychaetes exhibit a wide variety of feeding habits, such as surface and subsurface deposit feeding, suspension feeding and filter feeding. They are non selective deposit feeders which ingest and or mud grains, showing little discrimination for the size and nutritional value of the particles, assimilating any organic material in the ingested sediment. Selective deposit feeders however utilize structures such as palps, tentacles or buccal organs to select particles with high nutritional value. An interesting ability of the polychaetes is their capacity to regenerate lost appendages such as palps tentacles cirri and parapodia including that of posterior ends. In terms of its significance to humans, the polychaetes play an important role in the marine benthic food chain, not only serving as food for other organisms such as fishes including the commercially important ones and birds but also recycling organic mater within the sediment and breaking down plant material. In previous studies based on polychaetes, they have been used to infer the condition and health of the benthic environment, as they are important members of meiofauna in sediments. Rygg (1985) suggested that the absence of sensitive species such as *Harmothoe imbriata* and *Maldane sarsa* would be an indicator of detrimental environmental conditions. In countries such as USA, UK, Canada and Germany, polychaetes play an important role in biomonitoring the marine environmental quality by acting as monitors for toxic material and as pollution indicators. This ability is due to their direct contact with the water column and sediments thus showing sensitivity to anthropogenic compounds, which are expressed through changes in their reproduction, growth and mortality.

The foraminifera are single celled organisms with shells or tests (internal shells) made of organic compounds, sand grains or other particles cemented together. About 4,000 species have been estimated to live in the world's oceans, a mere 40 species are planktonic, and the remainder are benthic. The benthic species burrow actively though slowly, through the sediment at speeds upto 1 cm/hr. Foraminifera are abundant members of the meiobenthic group and forms an important part of the marine food chain. Their predators include marine snails, sand dollars and small fish. Foraminifera, especially the fossilized ones, have been put to use in studies concerning biostratigraphy, paleoecology and oil exploration based on their shell type and shell chemistry. The use of these fauna in impact assessment of bottom trawling is a relatively new venture dating back to less than 40 years.

Disturbance, defined as any stochastic event that initiates species populational change either from density – independent mortality and/ or a change in the resource base of the community, has been shown to be an important factor influencing the community structure in many environments (Sherman and Coull, 1980). Anthropogenic disturbance in the form of bottom trawling is a fishing practice that came into existence in the fourteenth century, and is still continued in fishing areas all over the world albeit with technological improvisations. Bottom trawling is an indiscriminate method of fishing that is used to capture a wide array of age classes of fish and other bottom dwelling species and is thought to be the most disruptive and widespread anthropogenic physical disturbance to coastal bottom communities (Krost, 1990). This intuition has been confirmed by scientists who in the past 2 decades have focused great deal of research in determining the effects of bottom trawling on the sea floor habitat. Marine ecosystems are influenced by fishing activities in a variety of ways, both directly and indirectly (Gislason, 1994; Dayton *et al.*, 1995; Gislason *et al.*, 2000). Inspite of all the efforts, a measurable quantity of the impact of bottom trawling on the whole ecosystem is yet to be worked out. The present investigation aims at determining the effect of bottom trawling on the microscopic polychaetes and foraminiferans and thus testing the hypothesis that bottom trawling poses an undeniable threat to the benthic ecosystem. Refer Chapter 3 for materials and methods.

7.2 Results

7.2.1 Polychaeta

Before trawling: The polychaete population in the study area showed very high variability, with densities ranging from 0- 350 ind./10 cm^2 and 0-1000 ind./10 cm^2 during the first and second year, respectively(Fig.7.1). The core samples of meiofauna showed nil density of polychaetes at many stations in the outer zone (41-50 m water depth) and particularly at station 10 which apparently harboured fauna other than polychaetes during the entire investigation carried out through the first year. The second year, however, showed a slight increase in density at station 10 and at both temporal and spatial scales, the highest was observed at station 1 in May 2002 with 1000 ind. /10cm^2. ANOVA of all the before trawling stations showed variation which was not significant both month wise and station wise (P>0.05, Appendix IV, Table 1). Spatially, the inshore stations showed a slightly higher density compared to the stations located outside the 41 m depth. The post monsoon showed a hike in density during both the years of observation, though statistical significance could not be observed (P>0.05). The premonsoon showed a lesser density of polychaetes, while the least was found during monsoon. Apparently the monsoon season did not bring about measurable changes in density as evident from the statistical insignificance.

After trawling: The polychaetes observed after trawling showed a distribution comparable to that obtained before trawling in that both temporal and spatial variation patterns were almost similar. The population density varied from 0-178 ind./10 cm^2 during the first year and from 0-606 ind./10 cm^2 in the second (Fig.7.2). Analogous to the before trawling values, higher densities were observed during the second year compared to the first. Highly significant variation ($P>0.01$) was observed when the densities were compared stationwise after trawling (Appendix IV, Table 2), indicating a definite rearrangement of fauna between stations after trawling. But no such variations were noticed month wise indicating that seasonal changes in polychaete population were not pronounced or could not be detected. The before and after trawling values at each station were compared using t test which yielded significant differences ($P<0.05$) in the density of the fauna at station 1, 3,5,7 and 8 while the comparison between the other stations were not statistically significant ($P>0.05$,Fig.7.3 a & b, Table 7.1).

7.2.2 Foraminifera

Before trawling: The foraminiferan population outnumbered that of polychaetes in the majority of the stations throughout the period of investigation. The density of foraminiferans ranged between 0 and 1999 ind./10cm^2 during the first year and 0-2320 ind./10 cm^2 during the second year (Fig. 7.4). An almost uniform pattern of distribution was observed stationwise and comparison of densities did not yield significant results ($P>0.05$, Appendix IV, Table 3). Depth did not play a significant role in their distribution ($P>0.05$) and no clear-cut pattern was observed when foraminiferan distribution was compared depth-wise. Temporal variation in foraminiferan abundance also did not show significance ($P>0.05$, Appendix IV, Table 3) pointing to the fact that monsoon made no apparent contribution to the total density of foraminifera.

After trawling: The density and pattern of abundance of foraminiferans was very similar to that observed before trawling which is depicted in Fig. 7.5. The density ranged from 0-3141 ind./10 cm^2 in the first year while during the second, it ranged between 0 and 4105 ind./10 cm^2. While stations 6 and 8 harboured the highest number of individuals during the study before trawling, the highest values after trawling were observed from stations 1 and 6 in the first and second years respectively (Fig. 7.6 a & b). Using t test, the individual stations were compared by taking values of before and after trawling and the results revealed that stations 5,6,8,9 and 10 showed significant difference ($P\leq0.05$, Appendix IV, Table 4). The other stations, which are closer to the shore failed to show any significance between treatments ($P>0.05$, Table 7.1).

7.3 Discussion: Meiobenthic organisms are responsible for rapid turnover of elements and nutrients, besides acting as potential food resources of macrofauna (Olaffson and Moore, 1990). Their importance in the marine ecosystem has long been recognized (Coull, 1990). The standing crop of marine and estuarine benthic food resources is important not only to demersal fishes but also to pelagic fishes at some point of their life cycle (Coull, 1999). Meiobenthic ecology studies in India have been undertaken predominantly in the estuarine and tidal marshes of the west coast (Goldin *et al.*, 1996;

Harkantra and Parulekar, 1989; Varshney *et al.*, 1984) and the east coast (Chatterji *et al.*, 1995; Ansari *et al.*, 1982; Vijayakumar *et al.*, 1991; Kondalarao and Murty, 1988; Rodrigues *et al.*, 1982) and have identified polychaetes as an important group among meiofauna. Studies have also been conducted on the ecology and distribution of recent benthic foraminifera from the east coast (Kaladar *et al.*, 1990; Rao *et al.*, 1990; Manivannan *et al.*, 1996) and from the west coast (Rao and Rao, 1979; Nigam, 1987; Nigam and Theide, 1983; Khare *et al.*, 1995) of India.

Marine polychaetes have been subject of study in most of the benthic studies undertaken as they form a significant component of benthic fauna in a variety of sea bottom sediments. Polychaetes, by virtue of their larger sizes have been most frequently assigned to the macrofauna group but occasionally form part of the meiofaunal group due to the presence of juvenile members in the sediment cores.

Polychaetes in the present study had a trivial representation in the meiobenthos compared to that of copepods and nematodes, but their presence could not be ignored due to the fact that they represented more than 10 % of the total meiofauna. Many studies conducted in the west and east coast of India in the shelf waters reported the dominance of polychaetes in the macrobenthic assemblage (Damodaran, 1973; Parulekar and Wagh, 1975; Hridayanathan, 1981; Harkantra *et al.*, 1982). Polychaetes also constituted the major bulk of macrobenthos along the Cochin backwaters (Pillai, 1977; Sunilkumar, 1995). Polychaetes have been considered part of the meiofauna in many studies along the west coast of India and abundances of 13-342 ind./10 cm^2 have been reported in Saphala salt marsh (Ingole *et al.*, 1987) and 56-672 ind./10 cm^2 in Versova (Varshney *et al.*, 1984) off Bombay coast. In the present study, a range of 0-350 ind./10 cm^2 was observed during the first year while it ranged from 0-1000 during the second year. Comparatively, this region was denser in juvenile polychaetes than the above mentioned regions on the west coast. Oxygen concentration, sediment grain size and total organic carbon are three factors which characterize the meiobenthic population size and community structure (Montagna, 1991). The polychaetes in the present study were found predominantly in the inshore region (0-35m), a substratum characterized by rich organic matter in sediments. A positive correlation between organic matter and meiofauna population was observed by Ingole *et al.* (1987). Detritus is of vital importance for the nutrition of meiofauna in sediments (Giere, 1975; Tenore, 1977; Gerlach, 1978; Briggs *et al.*, 1979). Detritus itself plays a minor role while bacteria attached to the detritus are the major food source for detritus feeders. Sediment characteristics such as grain size, interstitial space and porosity of sediment are considered important in the distribution and abundance of polychaetes. In the present study, the inshore region of 0-35m, with its silty clay and clayey silt texture form an ideal substrate for the juvenile polychaetes to thrive on. Since the oxygen values of the bottom waters were almost at the saturation level, this factor could not be considered a limiting factor in the study area. In the present study, the highest abundance was recorded during the post monsoon followed by premonsoon and monsoon.

Ingole and Goltekar (2004) found that monsoon acted as a trigger for the reproduction for meiobenthic organisms with the post monsoon season showing a vigorous increase in the density of the fauna. Harkantra and Parulekar (1984) also reported replenishment of benthic fauna with high species diversity after the southwest monsoon.

Foraminiferan abundance has been studied extensively along the east and west coasts of India (Rao, 1974; Setty and Nigam, 1982; Nigam and Khare, 1999). In the present study the foraminifera ranged from 0 to 1999 ind. /10cm^2 and 0-2320 ind. /10cm^2 during the first and second years, a finding which is corroborating with previous reports from the west coast of India (Nigam and Theide, 1983; Khare *et al.*, 1995). Setty and Nigam (1982) observed that clayey sediments was poor in foraminifera whereas sandy areas included large sized foraminifera in abundance. Organic matter was correlated negatively with foraminiferan abundance. In the present study, foraminiferan population was found significantly higher in the offshore areas (35 –50 m water depth) when compared to inshore areas (stations 5-10). The results of the present study also revealed that foraminifera were found to flourish in silty sand mixed with low quantities of mud, an observation which fully conforms to that of Khare *et al.* (1995). The region comprising 35-50m was predominantly sandy which is in agreement with that of Setty and Nigam (1982).

Antony (1979), from his studies in Cochin estuary, postulated that dissolved oxygen was an important ecological factor in controlling the foraminiferan population. pH was also determined to be an important factor having profound effect on the foraminiferal population since the lowering of pH below 7.5 caused disintegration of the tests by dissolution of $CaCO_3$. In the study area, only a slight variation in pH values were observed between stations in the bottom waters which varied between 7.8 and 8.3 and thus was found adequate for the maintenance of tests. Abundance of foraminifera was highest during post monsoon while it was lowest during premonsoon, an observation that is in full agreement with the repeated views on the general pattern of meiofaunal reproduction (Gerlach, 1978; Briggs *et al.*, 1979; Ingole *et al.*, 1987; Varshney *et al.*, 1984).

During the study, the number of polychaetes was found to increase in the samples collected after trawling. Increase in polychaete abundance was a phenomenon reported by many scientists in the after trawling samples (Bergman and Hup, 1992; Ball *et al.*, 2000; Tuck *et al.*, 1998). Physical disturbance of the bottom may expose the benthos to predators (McCall, 1997). The number of species and individuals increased following the trawling disturbance in a study conducted in the muddy sediments of Gareloch Bay by Ball *et al.* (1999) and the present findings are in conformity with this observation.

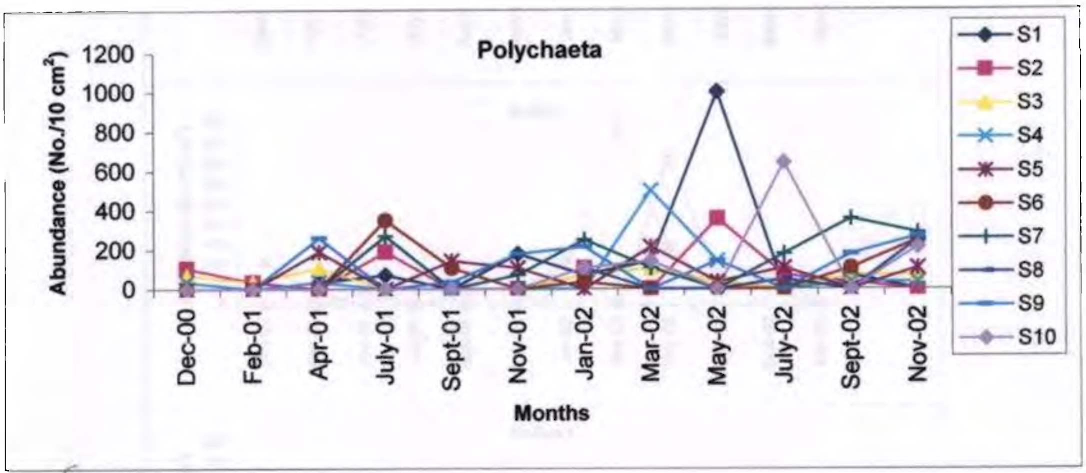
The sediments in the study area, upto a water depth of 35 m are fine and soft, fluctuating between silty clay and clayey silt. The soft nature of the muddy sediments makes them more susceptible to the physical impacts of the trawl gear compared to harder and coarser sediments. The trawl doors penetrate deeply into mud and this results in a potentially greater effect on infaunal communities (Ball *et al.*, 1999). Churchill (1989) estimated that fine and muddy sand were typically penetrated to a depth of 2 cm and 4 cm respectively whereas the penetration depth for coarse sand was 1cm. Bottom trawls can alter the physical structures of the sea floor by scraping plowing, smoothing sand ripples removing stones and turning over boulders. The mechanical perturbation of the sea bed interferes with the physical and chemical properties of the habitat and lead to direct mortality of the benthic fauna (Krost, 1990). The shallow grounds of the study area are subjected to intense trawling activities which alter the sea floor habitats and reduce habitat complexity , making the fragile invertebrate species vulnerable to trawling as reported by Bergman and Hup (1992) and Houghton *et al.* (1971). Bergman and vanSantbrink (1994) observed that an otter trawl caused direct mortalities in a number of invertebrate species. But direct mortalities in polychaete species has not been observed by the workers. On the other hand, some polychaete species apparently increased in density immediately after trawling denoting that a larger fraction of the population came into the reach of the grab possibly because of the resuspension of the top layers of the sediment (Kaiser and Spencer, 1996; Kaiser *et al.*, 2000). In the present study also similar interesting observation was made wherein the van Veen grab exposed more juvenile polychaetes after trawling than that collected before the trawling operations.

Small sized species tend to show lower direct mortalities when compared to larger sized species. Trawling affects small sized benthos mainly by disturbing the sediment; whereupon the animals are resuspended and possibly translocated by currents (Bergman and vanSantbrink, 2000a). Chesney and Tenore (1985), while studying the effects of predation and disturbance on the population growth of the polychaete *Capitella capitata*, found that natural disturbances in the benthic environment, of individual activities essential for population growth such as settlement of larvae, affected the population structure. During a trawling disturbance, early benthic phase juveniles were found to suffer the highest rates of habitat mediated mortality (Barnette, 2001; Collie *et al.*, 2000). Moreover, during a natural disturbance, finer particles of organic matter would be resuspended and displaced by the current flow. During the present study, organic matter was found to be washed out in significant proportions from the area of experiment by resuspension of upper sediment layers. Chronic trawling practices are capable of affecting the organic matter content of a given area significantly and the opportunistic polychaetes which inhabit the disturbed area has to adapt to a lesser food content, compared to the areas which are lightly trawled or devoid of trawling. Scientists examining the effects of dredging in the Gulf of Maine noticed a change in substratum from more organic silty sand to a sandy gravelly appearance (Langton and Robinson, 1990). A similar observation was made in the present investigation also when the clay content was washed off to a significant extent and the sediment became coarser in due course. Growth, reproduction as well as somatic growth of animals is often limited by the food availability (Sebens, 1982) and communities become dominated by juvenile stages when extensive and repeated trawling disturbances are prevalent (Sainsbury, 1988; Eleftheriou and Robertson, 1992). The limited food availability can be considered one of the reasons of the presence of small sized individuals in the study area.

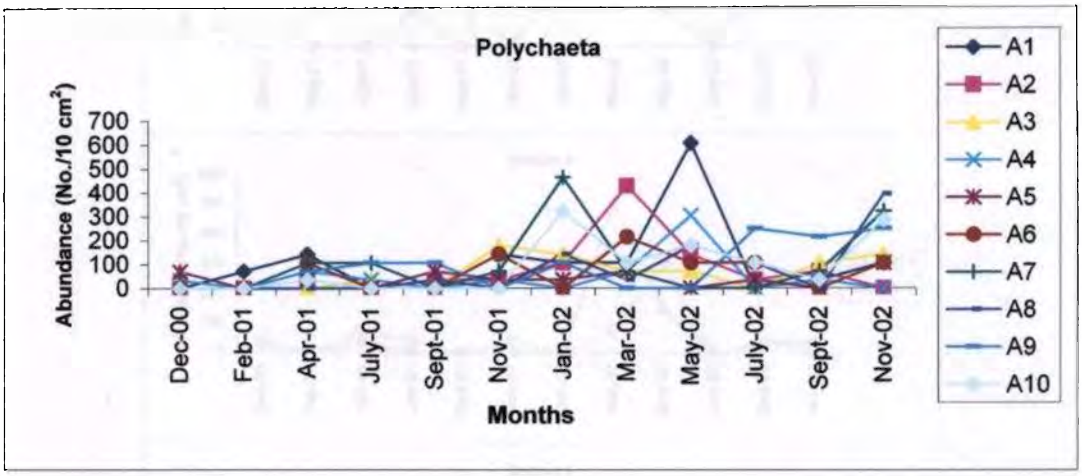
Foraminiferans have been observed by many workers to be the least mobile members of the meiobenthic group (Sherman and Coull, 1980; Wefer and Richter, 1976; Scheibel, 1974). In the present study, foraminiferans have shown a steep increase in number immediately after trawling. The meiobenthic studies concerning this particular taxa are scarce and so far the impact of trawling on this group has not been elucidated, though a general increase in meiofaunal population has been observed immediately after trawling. Shallow coastal areas especially those subjected to upwelling has been found to harbour burrowing foraminifera at sediment depths of about 2-3 cms (Drinia *et al.*, 2004). The study area, which also is characterized by upwelling waters during the southwest monsoon also accommodated a populous density of foraminifera. It can be thus presumed that the trawl gear, during the process of scraping away the upper layer of sediment with its otter boards, expose the fauna beneath, thus the grab comes into contact with those foraminiferans which had been ploughed up by the bottom trawl.

In effect, the polychaetes and foraminiferans are likely to be affected through habitat modifications, exposure to predators, resuspension and subsequent transport in the water column. Only small proportions are expected to be directly crushed and none removed as bycatch. The clouds of suspended sediment causing high levels of turbidity and sedimentation have been reported to prevent settlement of benthic larvae (Galstoff, 1964; Stevens 1987), thus affecting recolonisation after disturbance. The experiment presented here described the immediate effects of commercial bottom trawling on the density of polychaetes and foraminiferans. As pronounced changes could be identified for a two year period , where disturbance events associated with both commercial trawling and experimental trawling have occurred at a relatively regional scale, there is a potential for much longer lasting changes to the ecosystem structure as a result of commercial fishing practices using bottom trawlers. However, assessing possible large scale changes is difficult and predicting their effect on the ecosystem is even more problematic (Thrush *et al.*, 1995). Evaluating the long term effects of bottom trawling on benthic ecosystem is difficult due to the fact that consistent long term series on the long term abundance of non commercial species are scarce(Rumohr and Kujawski, 2000).

Environmental recovery after a disturbance depends on the life histories of the organisms that live in or create a habitat (Emeis *et al.*, 2001), the size of the area disturbed (Thrush *et al.*, 1998) and on the spatial pattern of disturbance (Auster and Langton, 1999). Each trawl track is a small disturbance, but over a long enough period and with widespread coverage, the small changes can result in a large effect.



✓ Fig.7.1. Seasonal variation in the abundance of polychaetes in the meiofauna during December 2000 to November 2002 at stations 1 to 10



✓ Fig.7.2. Variation in abundance of Polychaetes in the meiofaunal assemblage after trawling during December 2000 to November 2002 at stations 1 to 10

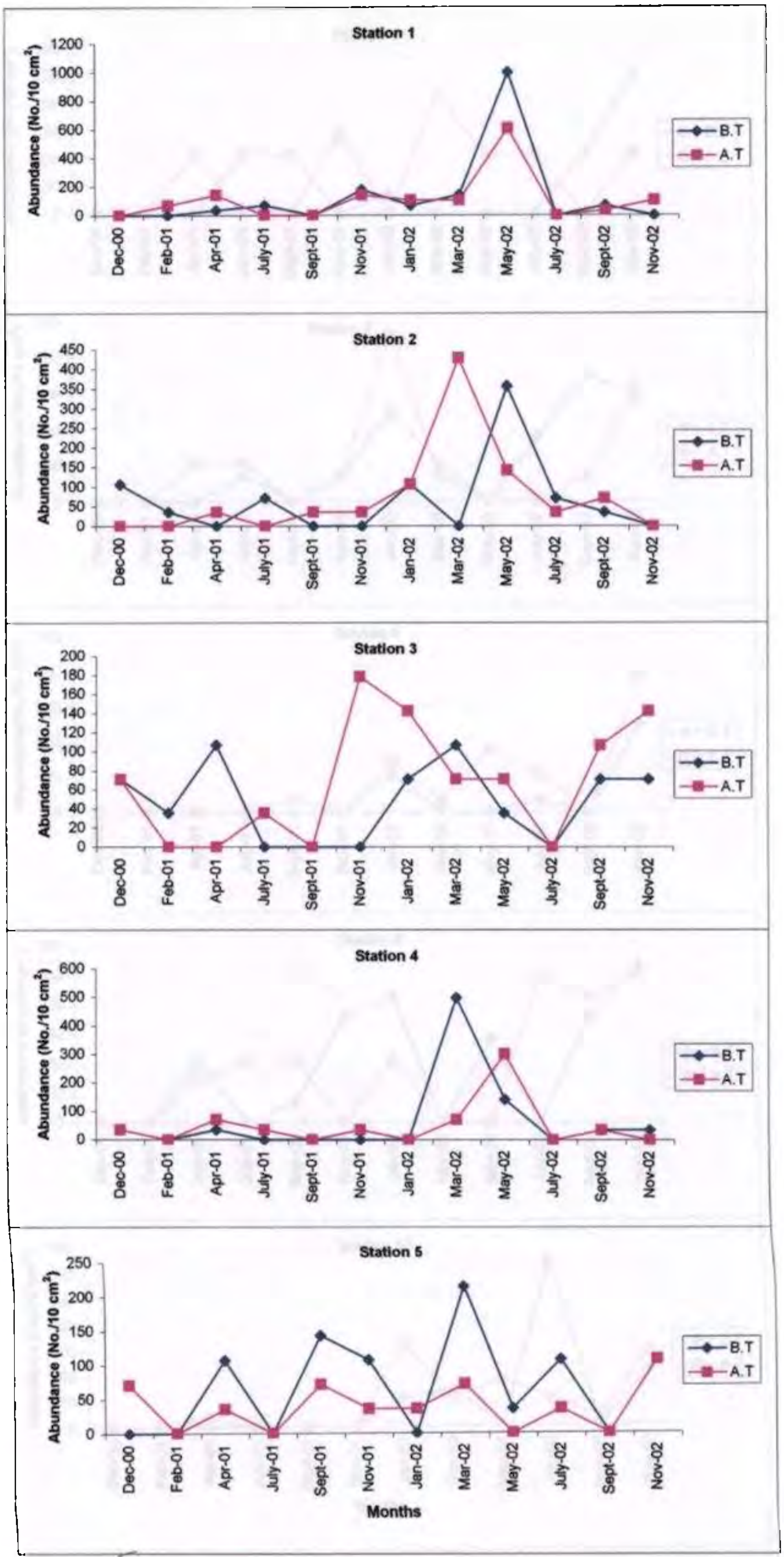


Fig. 7.3 a Comparison of abundance of polychaetes before and after trawling during December 2000 to November 2002 at stations 1 to 5.

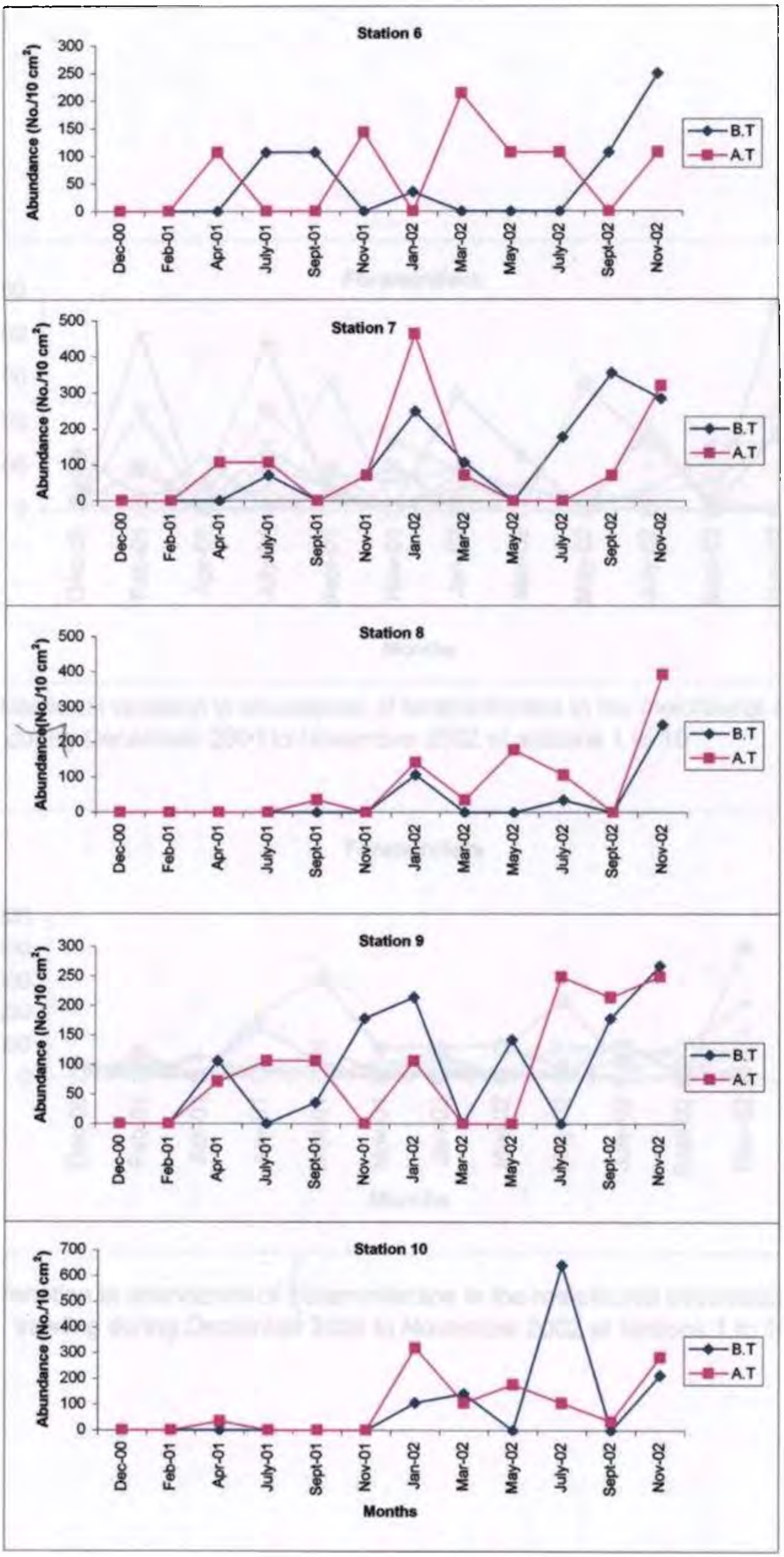


Fig.7.3 b. Comparison of abundance of polychaetes before and after trawling during December 2000 to November 2002 at stations 6 to 10.

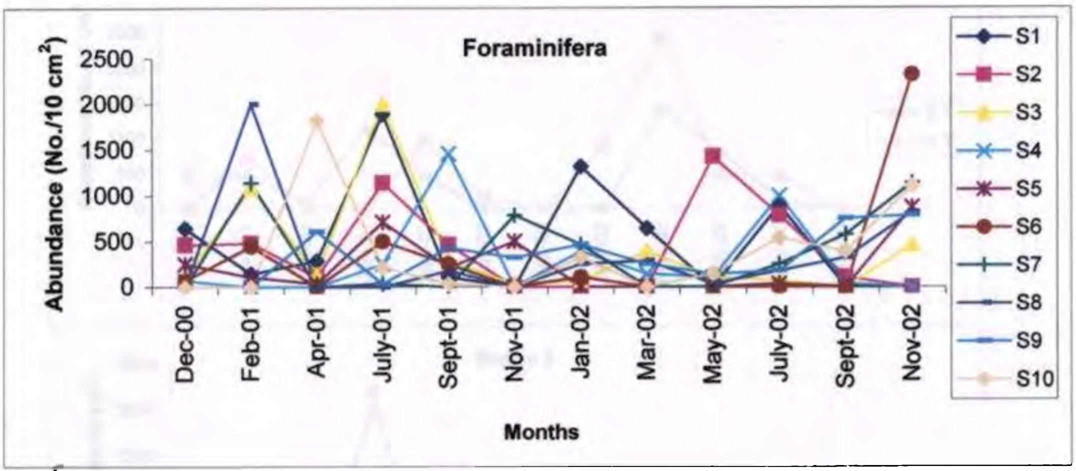


Fig.7.4. Seasonal variation in abundance of foraminiferans in the meiofaunal assemblage during December 2000 to November 2002 at stations 1 to 10

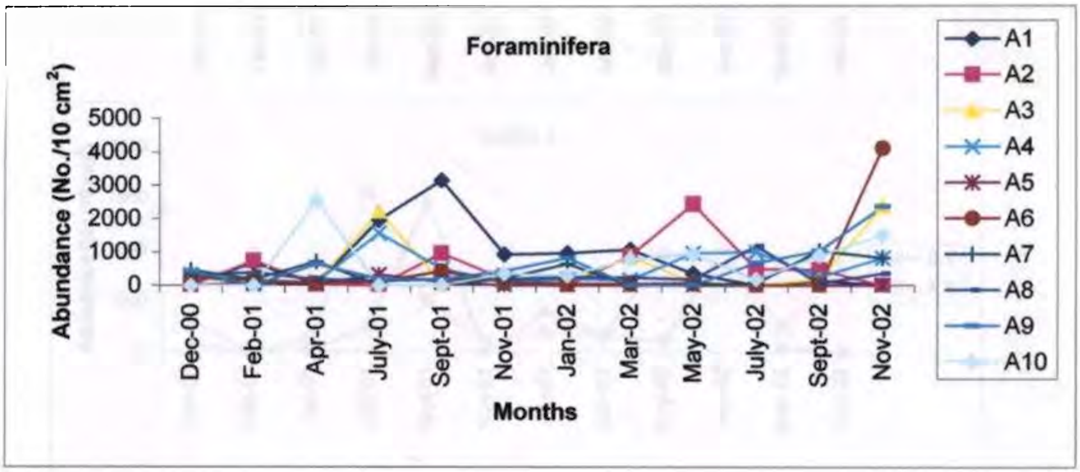


Fig.7.5. Variation in abundance of foraminiferans in the meiofaunal assemblage after trawling during December 2000 to November 2002 at stations 1 to 10

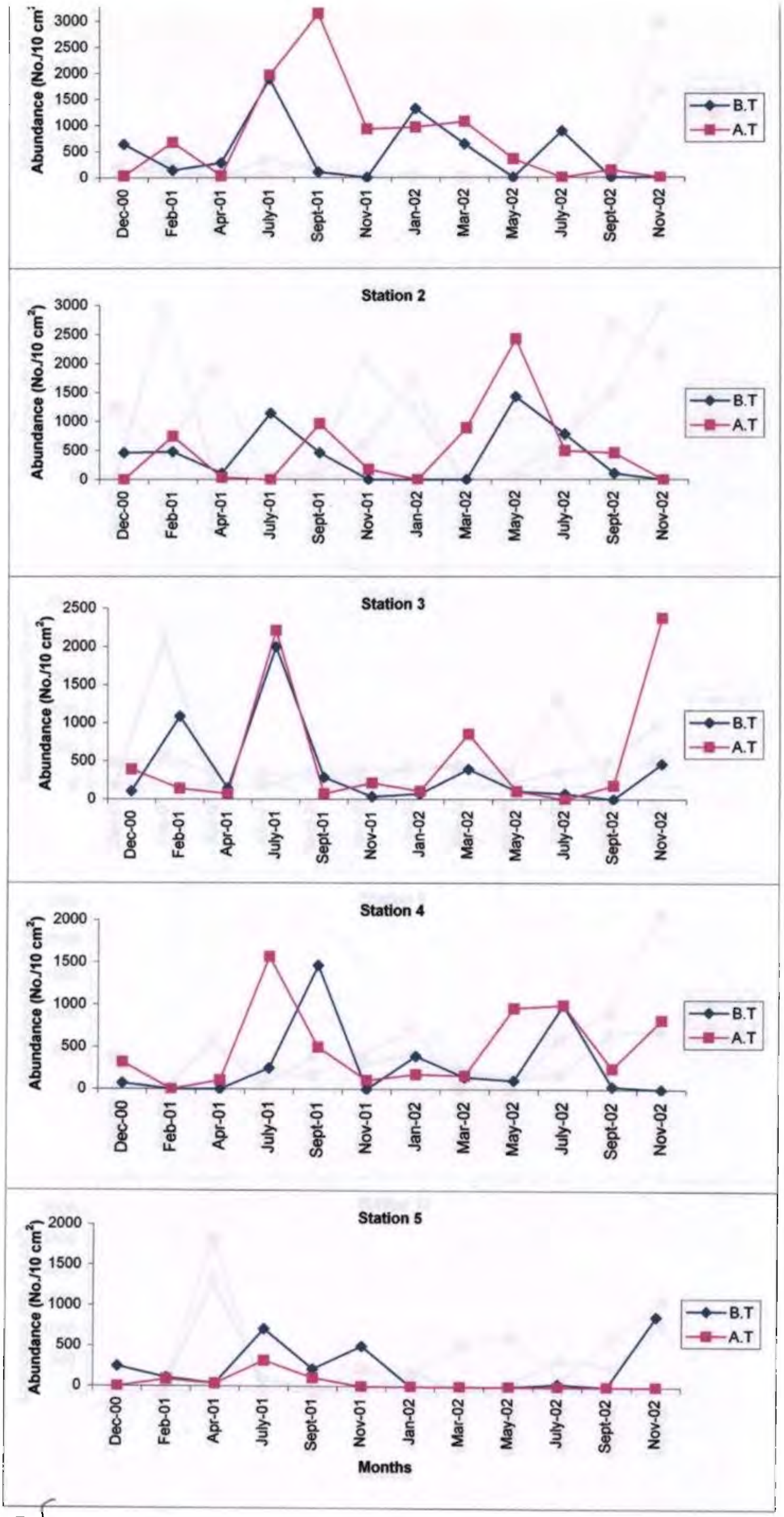


Fig.7.6 a. Comparison of foraminiferan abundance before and after trawling during December 2000 to November 2002 at stations 1 to 5

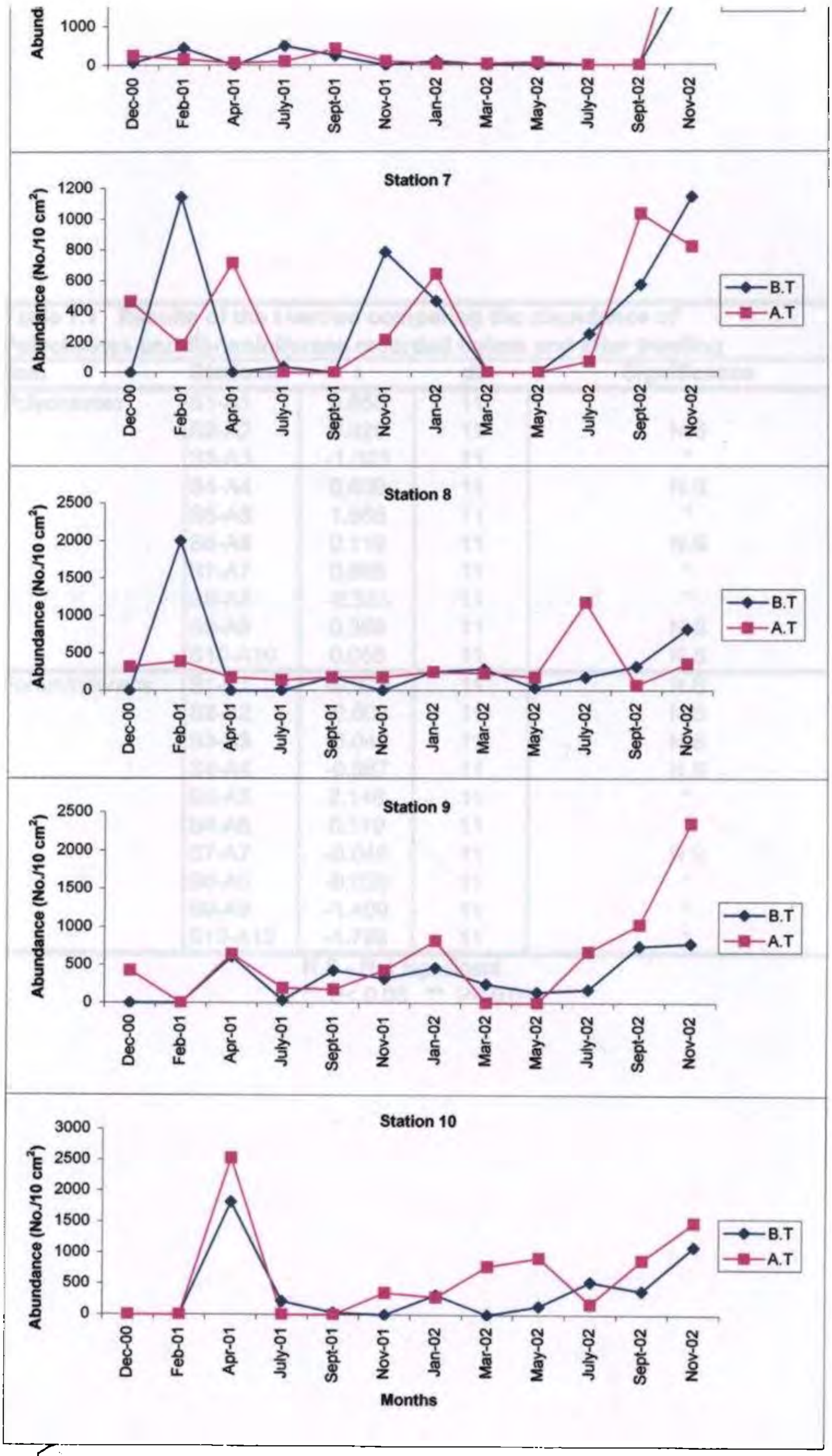


Fig.7.6.b. Comparison of foraminiferan abundance before and after trawling during December 2000 to November 2002 at stations 6 to 10

Table 7.1 Results of the t test on comparing the abundance of Polychaetes and Foraminiferans recorded before and after trawling

Item	Stations	t	df	Significance
Polychaetes	S1-A1	0.553	11	*
	S2-A2	0.020	11	N.S
	S3-A3	-1.023	11	*
	S4-A4	0.409	11	N.S
	S5-A5	1.868	11	*
	S6-A6	0.119	11	N.S
	S7-A7	0.668	11	*
	S8-A8	-2.333	11	*
	S9-A9	0.388	11	N.S
	S10-A10	0.056	11	N.S
Foraminiferans	S1-A1	-0.975	11	N.S
	S2-A2	-0.608	11	N.S
	S3-A3	-0.044	11	N.S
	S4-A4	-0.887	11	N.S
	S5-A5	2.146	11	*
	S6-A6	0.179	11	*
	S7-A7	-0.045	11	N.S
	S8-A8	-0.026	11	*
	S9-A9	-1.409	11	*
	S10-A10	-1.795	11	*

N.S - Not significant

* $P< 0.05$ ** $P< 0.01$

Chapter 8

SHORT TERM EFFECTS OF BOTTOM TRAWLING ON KINORHYNCHA AND OSTRACODA

8.1 Introduction

The Kinorhyncha are a group of microscopic marine animals that comprise 130 species (Pardos *et al.*, 1998). They live in interstitial cavities and crevices of coarse or fine sandy substrate or of muddy sediments (Gerlach, 1956; Higgins 1990; Vanhove *et al.*, 1995). Kinorhyncha are relatively abundant representatives of the permanent meiofauna, occasionally ranking third or fourth in number within a meiobenthic sample. Only the upper 1-10 cm of oxygen rich substratum contain Kinorhyncha both in eulitoral and sublittoral habitats (Thistle *et al.*, 1985). Kinorhyncha feed on diatoms or bacteria (Higgins, 1990), are herbivorous or detritivorous, and occur worldwide, from polar to tropical seas. Kinorhyncha are eurybathic, euryhaline and eurythermal and are endowed with burrowing ability which helps them to lead an endobenthic life in muddy sediments. Epibenthic species are also present which live in the sediment water interphase. In many high energy beaches the Kinorhynchs have been found at depths of 3.3 ft. Being placed into sediment, Kinorhyncha can agglutinate the detrital particles and convert the particles into concretions glued together by mucus. As also noted for nematodes ,these activities result in soft bottom acquiring a particular framework. The significance of Kinorhyncha to humans is unknown till date. Many studies have been conducted to learn more about this group of meiofauna and most studies concentrate on the upper 100 m of the continental shelf and no record of a kinorhynch from below 500 m has been identified upto the species level.

The ostracods are small crustaceans that secrete a bivalved carapace made of magnesium calcite. They occur in most aquatic environments. The carapace is composed of two valves, hinged dorsally. The species occurrence is controlled by a wide range of factors, including habitat type and stability, water depth and energy level, water temperature, salinity and ionic composition, competition and predation. Ostracods are benthic swimmers and live on sandy substrata of coastal waters at depths of 0-50 m. They are active during the night and hide in the sand during the day (Vannier and Abe, 1993). Their poor swimming ability limits the extent to which they can spread. The larvae and juveniles are also benthic and become adults through five stages. Their life span is about 6 months.

Pickett and White(1985) has defined disturbance as any discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment. In this regard it is important to acknowledge that fishing is a form of physical disturbance, especially bottom fishing. As the scale and frequency of disturbance events increase, lasting ecological effects become apparent despite the background of naturally occurring disturbances. The additive effect of an entire fishing fleet trawling the sea bed can cause widespread changes to the composition of sea bed communities (Jennings *et al.*, 2001a). Bottom fishing gears have been designed to remain in close contact with the seabed and inevitably catch a large proportion of non target species. These bycatch species give a clue to the wider impacts that these gears have on the benthic community. Studies of the effects of bottom trawling on benthic fauna have tended to deal with either infauna or epifauna. The majority of studies till date have focused on infauna, the preference due to the fact that infauna are more easily sampled quantitatively with standardized sampling devices such as grabs/corers (Kaiser and Spencer, 1996; Wolf and Mulder, 1985; Brylinski *et al.*,1994; Kaiser *et al.*, 1999; Thrush *et al.*,1995; Tuck *et al.*, 1998).

Studies across the globe have revealed the presence of kinorhynchs and ostracods from the water bodies ranging from stagnant water to coastal seas and deep oceans (Schratzberger *et al.*, 2002). Exclusively meiofaunal groups, these organisms have not been subjected to studies on the impact of trawling but in the regions in which they are abundant these organisms can possibly be used as a method of evaluation of the impact. This study is thus a pioneer in this regard which attempts to adopt the hypothesis of impact of trawling. Refer Chapter 3 for materials and methods.

8.2 Results

8.2.1 Kinorhyncha

Before trawling : The kinorhynchs were ranked 5th in the order of abundance along the study area. These organisms ranged between 0-606 ind./10cm^2 in the first year and from 0-1927ind./10 cm^2 during the second year (Fig.8.1). Statistical analysis of the abundance values before trawling did not reveal any spatial or temporal significance (P>0.05, Appendix V, Table 1), showing that neither the location of stations or seasons had apparently influenced the distribution or reproduction of these fauna. But on the examination of data, it could be seen that spatially the fauna were concentrated more along the inshore clayey silt sediments than in the sandy offshore sediments.

After trawling : The highest values after trawling were observed at station 4 with 642 ind./10 cm^2 area in the first year , while during the second year it was 464 ind./10cm^2 at station 1(Fig.8.2). The temporal variations were not significant signaling the apparent lack of influence of monsoons on the kinorhynchs. On the other hand, there was significance in the spatial variations in the fauna ($P<0.05$, Appendix V, Table 2; Fig.8.3 a & b) indicating the hand of extraneous forces in the distribution of these fauna . A comparison of before and after trawling values did not indicate any significant variation due to trawling ($P>0.05$, Table 8.1).

8.2.2 Ostracoda

Before trawling : The abundance of ostracods is given in Fig.8.4. The abundance during the first year was between 0 and 535 ind./10 cm^2 with the highest at station 9 in July 2001. During the second year the highest was observed at station 2 with 321 ind./10 cm^2. Several stations, throughout the period of sampling were consistently devoid of the fauna, with the inshore stations showed more patchiness than the offshore ones. At station 1, ostracods were encountered only in December 2000, July 2001 and July 2002 , while during all the other months, the presence of ostracods could not be detected. Spatial variation was significant with the highest abundance in the muddy and sandy stations at the 30-50 m depth range, the least in the inshore clayey sediments ($P<0.01$, Appendix V, Table 3). Seasonally no significant differences could be perceived both during the first and second years (P>0.05, Appendix V, Table 3) though the post monsoon values showed a slight increase.

After trawling : The population density of ostracods showed a slight increase immediately after trawling. During the first year it varied between 0 and 285 at station 8 in November 2001 , while during the second year a slightly higher abundance of 642 ind./10 cm^2 at station 2 in May 2002 was observed (Fig.8.5). As in the before trawling samples, the after trawling samples values also showed concentration of fauna in certain areas whereas many stations showed nil values of ostracods. Two way ANOVA did not reveal any statistical significance between the values (P>0.05, Appendix V, Table 4) indicating that temporal variations were not present after trawling. During the monsoons, the major seasonal force acting on any organism also did not exert any apparent significant influence on the ostracods (P>0.05). A comparison of the abundance of ostracods before and after trawling is given in Fig. 8.6 a & b. t test, used to compare the before and after trawling abundances, did not bring out any significant differences in most of the stations except at station 5 (P<0.05, Table 8.1), though the values were on the higher side after trawling in most of the stations.

8.3 Discussion:

Several studies on meiofauna have revealed the presence of kinorhynchs in sediments, both on the east and the west coasts (Damodaran, 1973; Rodrigues *et al.*, 1982; Rao and Sarma, 1990; Ingole *et al.*, 1987).

Kinorhynchs were found to occupy fine silty substrata (Rodrigues *et al.*, 1982; Kondalarao and Murty, 1988) but their numbers were very low when compared to the other meiofaunal groups such as nematodes and copepods. The present study also revealed the presence of kinorhynchs along the south west coast and predictably, with lower percentages compared to nematodes and copepods. On the east coast of India, Kinorhynchs occurred mostly during February to April and again during September to November and comprised 0.3% of the total meiofauna. In this study the kinorhynch population showed a slightly higher percentage of 0.5. High organic content of soil found to be conducive to the growth of kinorhynchs (Kondalarao and Murty, 1988). High abundance of population coincided with high organic carbon in the sediment, especially in stations 1 to 4, supporting the view that availability of food is one of the limiting factors in the distribution and abundance of kinorhynch population a finding which is in agreement with that of other meiofaunal groups (Rao and Sarma, 1990; Ingole *et al.*, 1987) . However, in the present study area, it was also evident that the presence of food was not the lone criterion on which the density was dependent upon since even the moderately rich organic mud did not harbour these organisms as manifested from their absence from some stations during certain months. Seasonal variations observed in the present study were comparable with similar findings reported from the west coast of India (Damodaran, 1973 ; Ingole *et al.*, 1987).

The ostracods also formed an undeniable part of the meiofaunal group along the west coast and though ranked 6th on order of abundance , made its presence felt in the offshore stations with more or less silty sand substrata. Ostracods have been demonstrated by earlier worker to prefer muddy sand (Ansari *et al.*, 1982; Ansari *et al.*, 1980). Seasonality could not be demonstrated statistically in ostracods in the present study presumably due to dearth in ostracod numbers in the samples throughout the experimental trawling operations, though the post monsoon months showed a slight increase in number during both the years . Horizontally, the ostracods showed a patchy distribution and it has been postulated that such variation in spatial distribution of meiofauna are controlled by variations in more localized physical, chemical and biological factors (McIntyre ,1969; Coull and Bell,1979).

A comparison of the spatial distribution of the kinorhynchs before and after trawling revealed significant differences thus exposing the havoc caused due to dragging of the heavy net across seafloor. There was a general decrease of kinorhynchs after trawling, which may be attributed to their dispersal immediately after trawling. Kinorhynchs along with the other groups of meiofauna were found to decrease immediately after trawling /dredging in impact studies across the globe (Thrush *et al.*, 1995; Sainsbury, 1988; Rice *et al.*, 1989; Bergman and Hup, 1992; Eleftheriou and Robertson, 1992). Ostracod samples did not show any significant difference when before and after trawling values were compared (P>0.05). But in a dredged site ostracods were found to decrease immediately after dredging when compared to a reference site (Thrush *et al.*, 1995)

Bottom trawling is well known as the most dangerous and destructive fishing method due to its destructive impacts on the marine ecosystem (Watling and Norse, 1998). During bottom fishing with otter trawls, large quantity of epifaunal and infaunal organisms are injured, removed or killed by the passage of heavy otter boards and nets (Auster *et al.*,1996; McConnaughey *et al.*, 2000).

The results of the present study revealed that small organisms such as kinorhynchs and ostracods are affected by trawling through modifications to their habitat, exposure to predators and resuspension and subsequent transport in the water column. Only a small portion is expected to be directly crushed and removed as bycatch.

In the present context both kinorhynchs and ostracods did not show any apparent signs of being disturbed, the significance of comparison between before and after trawling values being greater than 0.05. Nonetheless, the disturbance to habitat in a chronic manner can ultimately lead to the breakdown of the resilience of the organisms against disturbance. When the resilience is exceeded, the system can flip to an alternative state from where it will not return simply by removing the source of disturbance (Holling *et al.*, 1995). These regime shifts can affect valuable ecosystem services, including fisheries yield (Collie *et al.*, 2000; Knowlton, 1992). Early benthic phase juveniles have the highest rates of habitat mediated mortality (Barnette, 2001). Ostracods are known to moult 4 to 5 times in a year and constitute and important component of the scavenging community, cleaning up dead and decayed on the ocean floor. Kinorhynchs, with almost equal number of generation times also constitute an important fauna on the seafloor, with tasks such as scavenging and nutrient regeneration. Being short lived, this community is better equipped to cope with disturbance than the macro or mega fauna, but even this equilibrium can be disturbed when incessant trawling takes place.

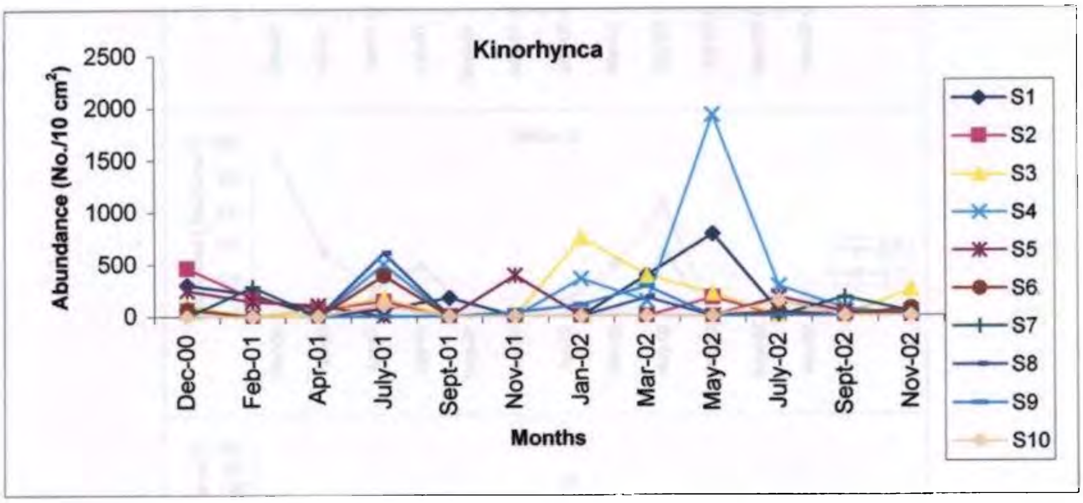
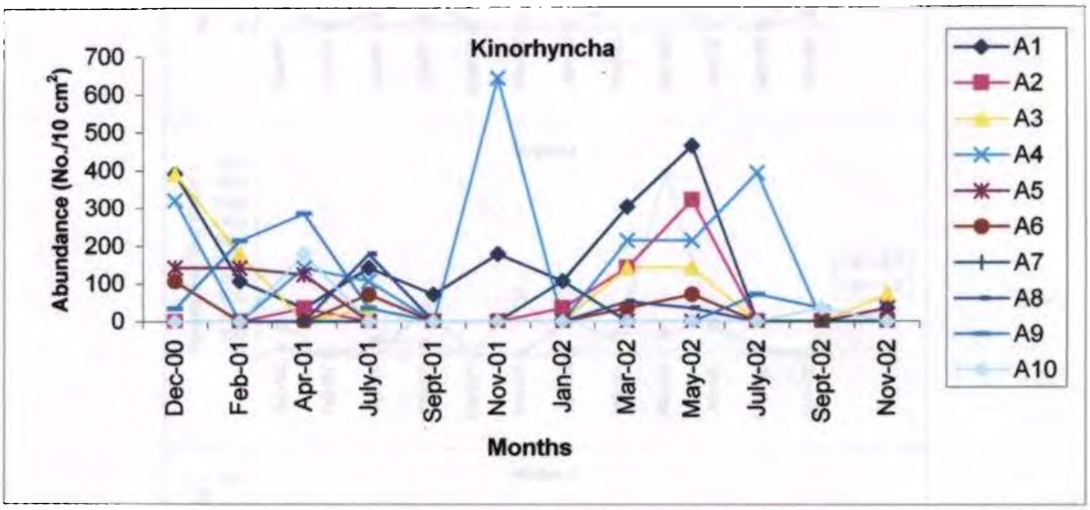


Fig. 8.1 . Seasonal variation in abundance of kinorhynchs in the meiofaunal assemblage during December 2000 to November 2002 at stations 1 to 10



✓ Fig. 8.2. Variation in abundance of kinorhynchs in the meiofaunal assemblage after trawling during December 2000 to November 2002 at stations 1 to 10

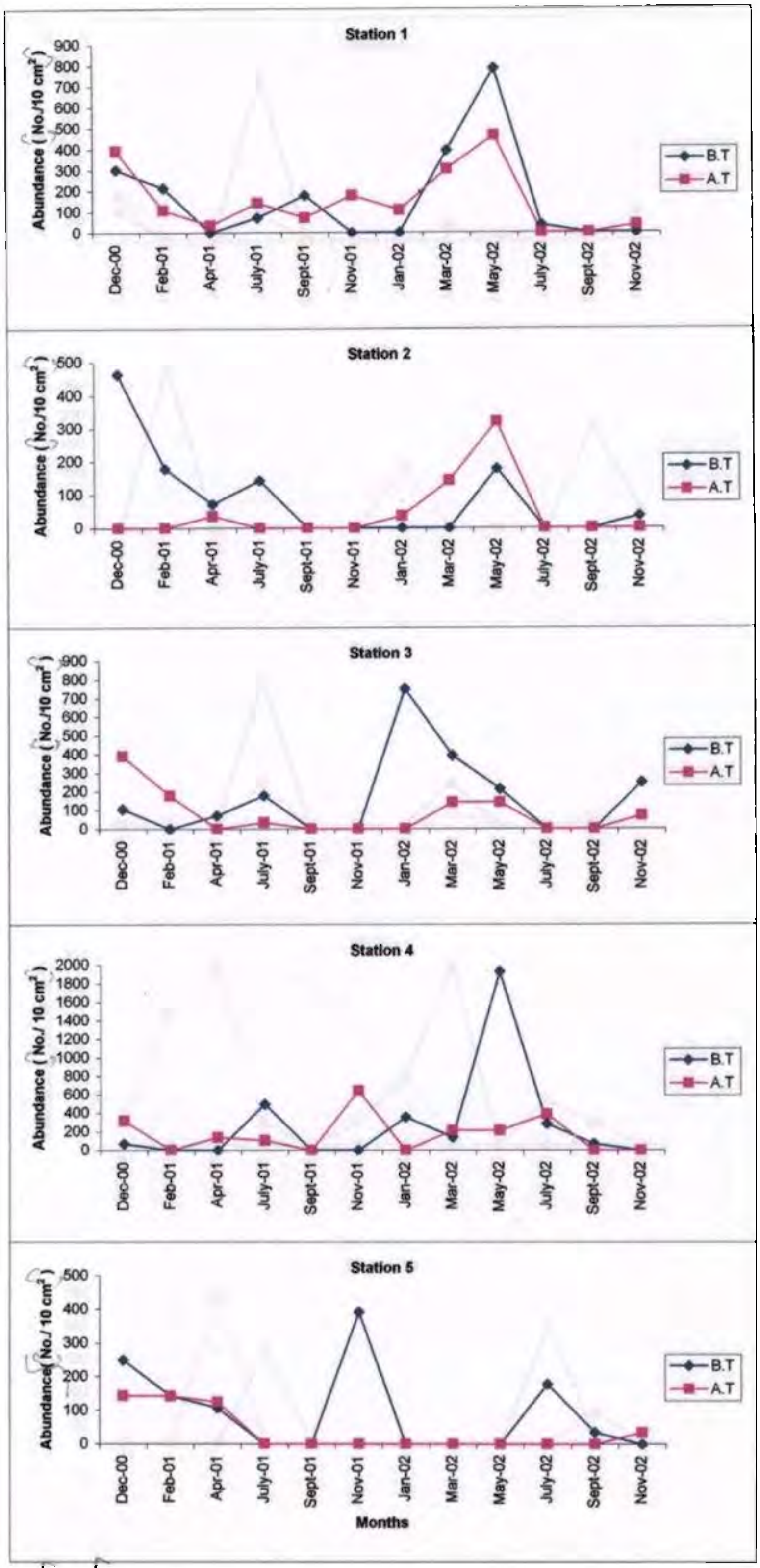
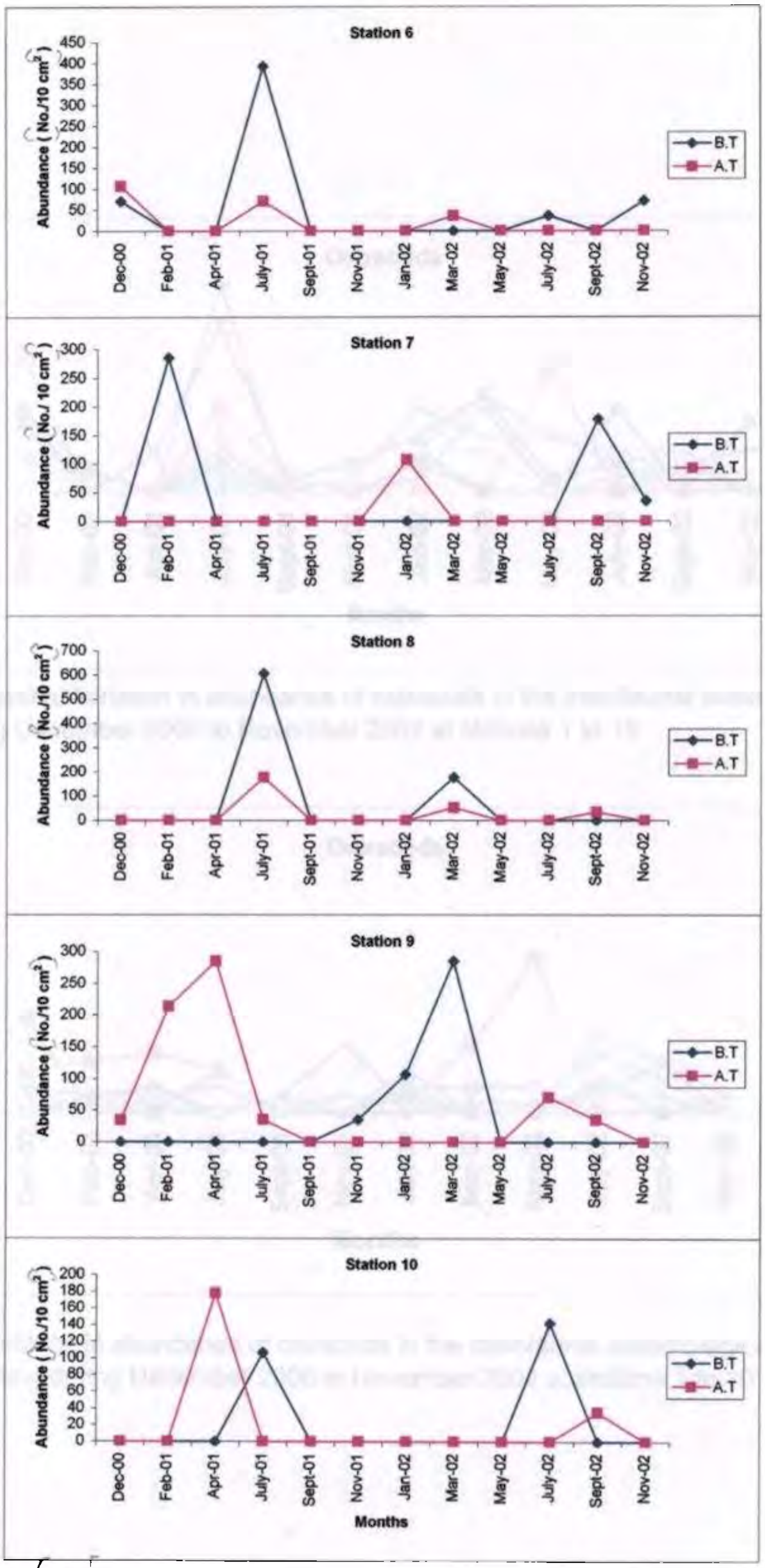


Fig.8.3 a. Comparison of abundance of kinorhynchs before and after trawling during December 2000 to November 2002 at stations 1 to 5



✓ Fig.8.3 b.Comparison of abundance of kinorhynchs before and after trawling during December 2000 to November 2002 at stations 6 to 10.

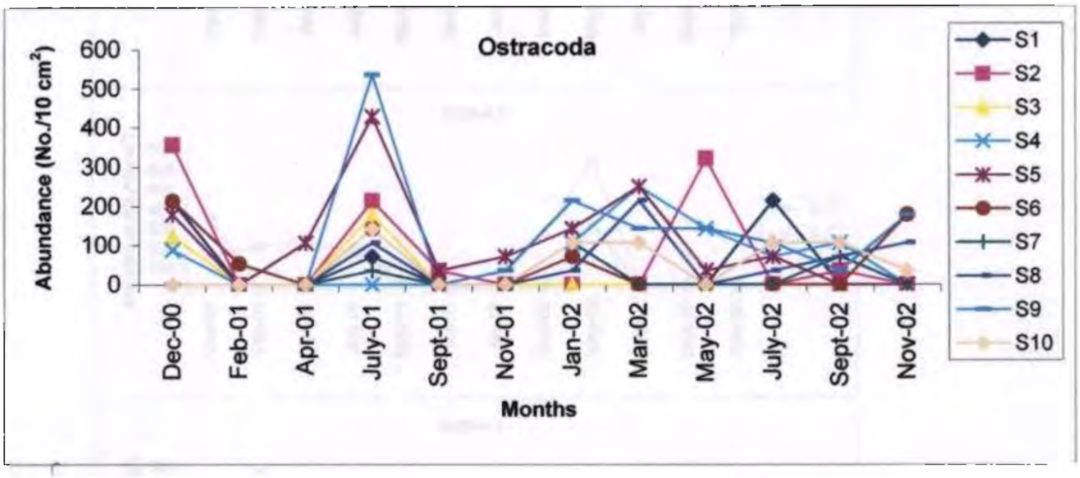


Fig.8.4. Seasonal variation in abundance of ostracods in the meiofaunal assemblage during December 2000 to November 2002 at stations 1 to 10

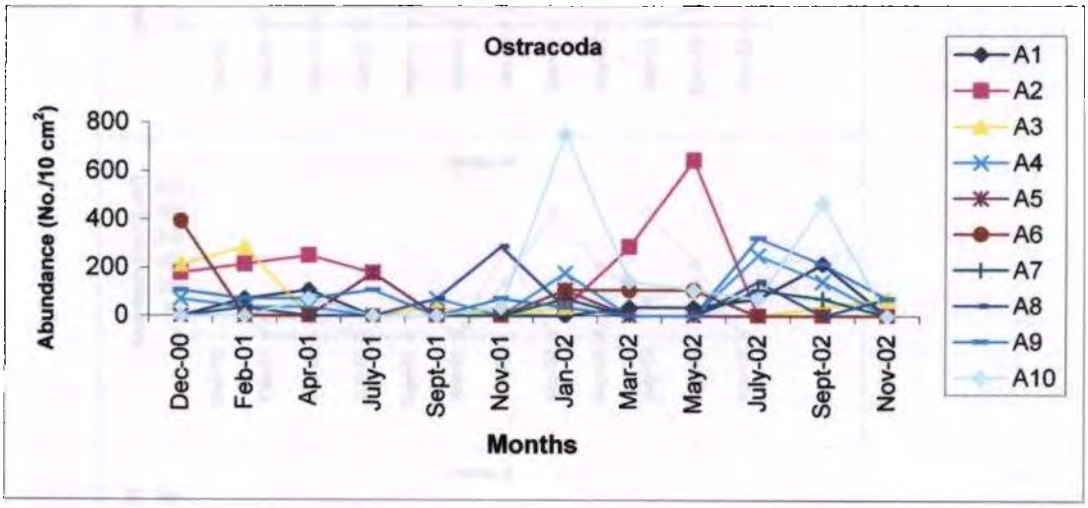


Fig.8.5. Variation in abundance of ostracods in the meiofaunal assemblage after trawling during December 2000 to November 2002 at stations 1 to 10

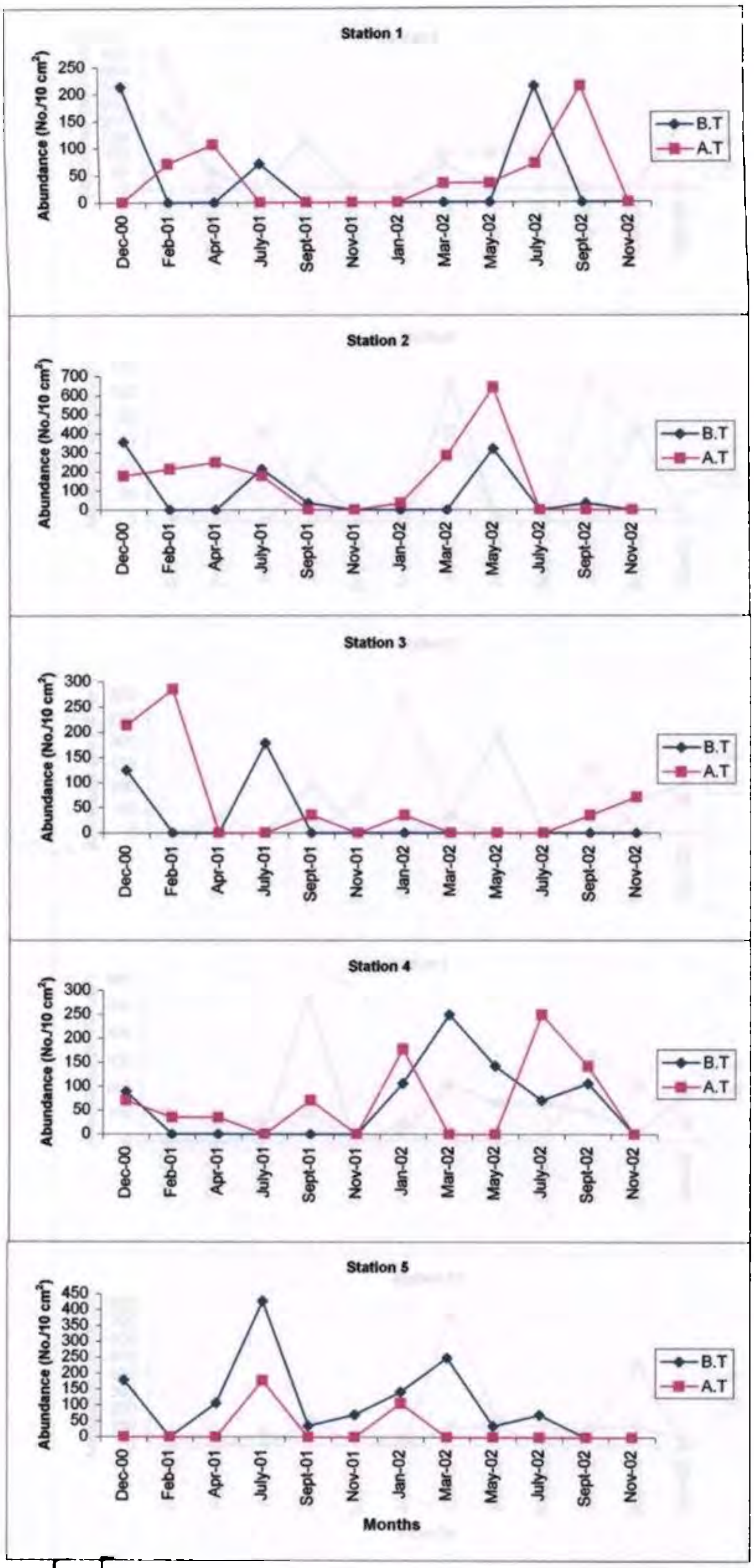


Fig.3.6 a Comparison of abundance of ostracods before and after trawling during December 2000 to November 2002 at stations 1 to 5

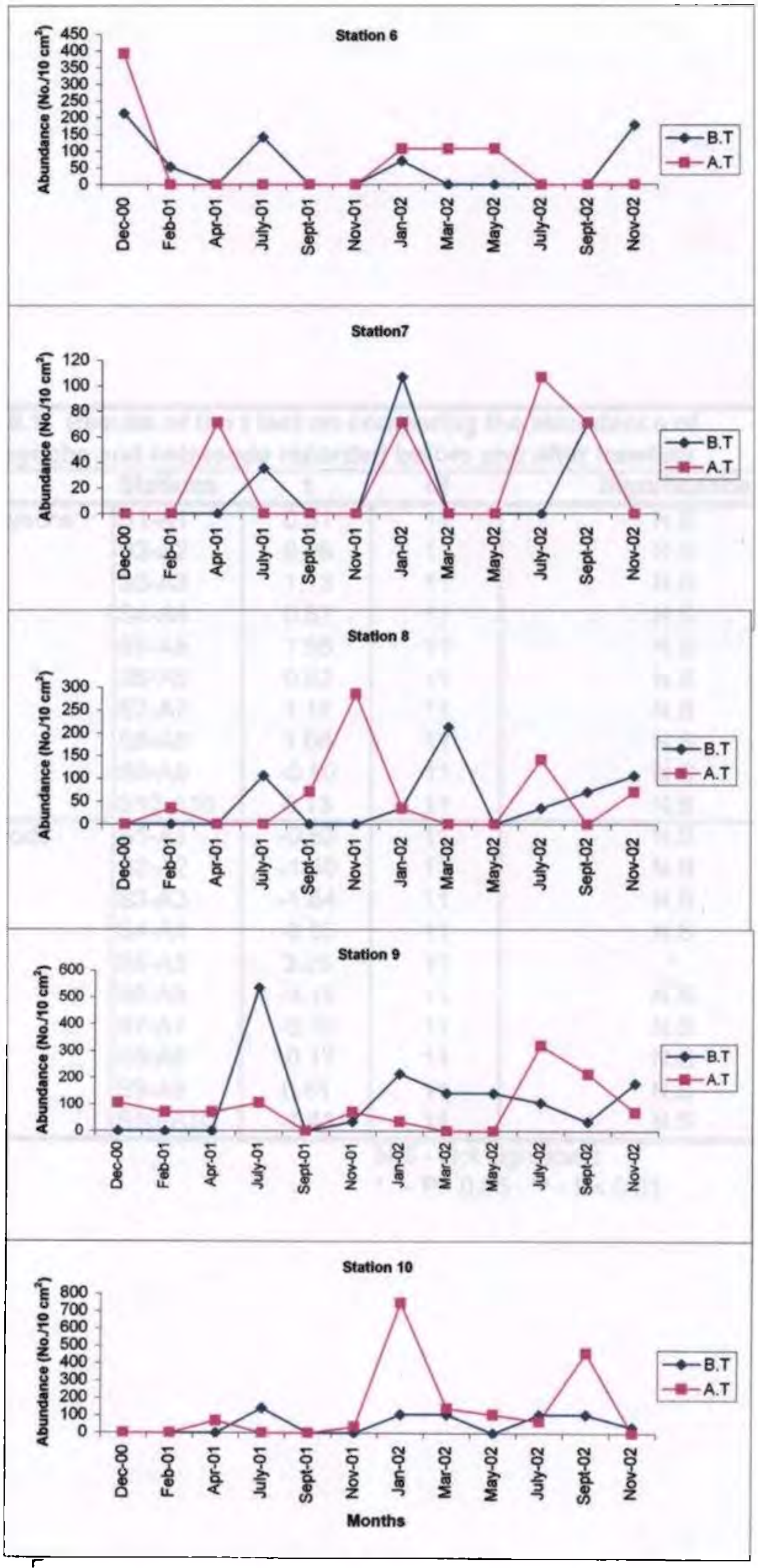


Fig 8.6 b Comparison of abundance of ostracods before and after trawling during December 2000 to November 2002 at stations 6 to 10

Table 8.1. Results of the t test on comparing the abundance of Kinorhynchs and ostracods recorded before and after trawling

Item	Stations	t	df	Significance
Kinorhynchs	S1-A1	0.31	11	N.S
	S2-A2	0.95	11	N.S
	S3-A3	1.13	11	N.S
	S4-A4	0.67	11	N.S
	S5-A5	1.56	11	N.S
	S6-A6	0.82	11	N.S
	S7-A7	1.12	11	N.S
	S8-A8	1.08	11	N.S
	S9-A9	-0.50	11	N.S
	S10-A10	0.13	11	N.S
Ostracods	S1-A1	-0.82	11	N.S
	S2-A2	-1.50	11	N.S
	S3-A3	-1.04	11	N.S
	S4-A4	-0.05	11	N.S
	S5-A5	3.25	11	*
	S6-A6	-0.15	11	N.S
	S7-A7	-0.76	11	N.S
	S8-A8	-0.17	11	N.S
	S9-A9	0.51	11	N.S
	S10-A10	-1.41	11	N.S

N.S - Not significant

* - $P< 0.05$ ** - $P< 0.01$

Chapter 9

IMPACT OF TRAWLING ON THE VERTICAL DISTRIBUTION OF MEIOFAUNA

9.1 Introduction

With rapid rate of urbanization, industrial growth and different types of anthropogenic changes, the use of biological parameters in monitoring the health of the environment is being increasingly appreciated, and when compared to plant, animal communities have been largely used in such monitoring programs. Biological monitoring thus precisely aims at establishing the adverse effect in terms of damage done to the biota as a result of environmental impact. Benthos is a distinct entity among the biological components of the benthic ecosystem directly related to bottom sediment. They are the first causality of a disturbed benthic environment. Benthic organisms have been reported to show great variations in quality and quantity as a consequence of environmental disturbance and hence are ideally suited for the assessment of pollution (Ansari and Parulekar, 2001; Ansari *et al.*,2003). Meiofauna have been used by many scientists to work out the ecotoxicological effects of an oil spill (Ingole *et al.*, 2006) and the destructive effects of polymetallic nodule mining (Ingole *et al.*, 2005). In nature, the coastal marine ecosystems are characterized by frequent disturbances which affect the structure of ecological communities by removing established species and allowing the fugitive species to colonise a disturbed area (White, 1979). Meiofauna, adapted to interstitial existence show a variety of life history attributes, suggesting that these communities are capable of responding to anthropogenic and natural disturbances to establish their recolonisation.

Human activities are affecting the marine benthic communities in a way that has yet to be fully understood or examined in a pre disturbed state (Kenchington, 1999). As fishing activity is intensive and continuous, it is likely to affect an area more than once a season, there is likely very little of the sea floor in existence that is representative of the undisturbed benthic community (Auster *et al.*, 1996). A few authors have likened trawling to forest clear cutting (Levy, 1998 ; McAllister 1998). As on land, biodiversity of sea is profoundly threatened (Norse, 1993; Butman and Carlton, 1995). The bays and continental shelves where most of the trawling occurs, constituting 7.4% of the sea's area (Sharp, 1988), are among the most biologically productive marine ecosystems. The benthic ecosystem serves as a connection between the pelagic and the microbial realms, continuously transferring energy and nutrients through them. The meiobenthic community with their high turn over rate has been demonstrated to be extremely important for maintaining the benthic productivity, which has surpassed that of its larger counterparts- the macrofauna.

Bottom trawling has been a subject for serious concern for the past 3 decades owing to the physical and biological damage it inflicts on the sediment layers of the productive areas of the ocean. Systematic research on the physical effects of trawling on seabed substrata dates from 1970, when the International Council for the Exploration of Sea requested information on the effects of trawls and dredges on the seabed (ICES, 1971). Due to the pressure of the gear on the seabed, certain parts penetrate to varying extent into the substratum. The penetration depth depends largely on the nature of the substratum (Margetts and Bridger, 1971; de Groot, 1972). Tracks made by the beam or the otter trawls have been seen to persist more in the muddy and soft sandy grounds (Bergman and vanSantbrink, 1994). While it has been relatively simple to detect significant changes in the abundance of larger organisms as a result of fishing disturbance, smaller invertebrates show conflicting responses. Bergman and Hup(1992) found both increases and decreases in the abundance of small invertebrates after fishing an area with beam trawl. Vertical distribution of metazoan population has been gauged in many studies to be confined to the upper 2 cms of sediment in water bodies (Ingole *et al.*,2000). The present study aims at understanding the vertical distribution of meiofauna in the sediments of the study region and practical utility of using it to throw light on the impact of bottom trawling.

9.2 Results :

The meiofaunal core samples obtained before and after trawling were sliced into two parts, the upper and the lower, with the upper consisting of 0-5 cms and the lower with 5-10 cm of sediment in the vertical core. Thus the fauna of upto 10 cm depth were observed from each sample. At each station duplicate samples were taken , the average being presented here. The samples were mixed with a solution of RoseBengal and 4% formalin in buffered sea water.

9.2.1 Nematoda : The nematode fauna were analysed in samples from all the depth zones namely 0-10 m, 10-20 m, 20-30 m, 30-40 m, and 40-50 m. At each station the vertical distribution of nematodes was worked out by examining the two slices obtained from core sampling. The abundances observed in the samples have been plotted depthwise and shown in Fig.9.1 to compare their vertical distribution. At the 0-5 cm sediment depth, the maximum number of nematodes encountered was 1071 ind./10 cm^2, in July 01 at 0-10 m depth zone. A minimum of 35.7 ind./10cm^2 was enumerated in November 2001 at 10-20 m depth zone. While examining the second sediment layer, representing the layer below 5cms upto 10 cms, the nematode density was found to be 1000 ind./10 cm^2 in July 01 at the 10-20 m depth zone, while the minima was at nil ind./10 cm^2 at 3 stations in September and November 2001. Paired t test was used to compare the fauna recorded in the two depth layers. It could be seen that at zones 0-10 m, 30 – 40 m, and 40-50 m, there existed significant differences ($P<0.01$,Appendix VI, Table 9.1) in density, with the upper layer containing more number of nematodes than the layer below it.

After trawling, at 0-5 cm layer, the nematodes varied between 1695 ind./10 cm^2 in July 2001 in 0-10 m depth zone and 35.7 in September 01 at 30-40 m zone(Fig.9.2). In this upper sediment layer, the fauna in the 0-10 m, 10-20 m, 20-30 m, and 40-50 m zones showed significant changes ($P<0.05$, Appendix VI, Table 9.2) immediately after trawling. This implies that trawling brought about dispersion of fauna within the depth layers. In the next sediment layer, the layer below 5 cms up to 10 cms, significant differences were also noted ($P<0.05$, Appendix VI, Table 9.3) when before and after trawling values of this layer were compared (Fig.9.3). The differences noted were at stations 0-

10m, 10-20m, and in the 20-30 m zones, but in the final two zones the differences could not be noticed. The sandy nature of sediment might have proven difficult for the otter boards to penetrate more into the bottom during fishing.

9.2.2 Harpacticoida: The distribution of harpacticoids also showed a pattern similar to that of nematodes, with higher density in the upper sediment layer namely the 0- 5 cm layer compared to the layer below it, up to 10 cms (Fig.9.4). At the 0-5 cm layer, the highest value of harpacticoids was 1195 ind./10 cm^2 at 10-20 m depth zone, in January 2002. The lowest value observed was 17 individuals at the 0-10 m zone in September 2002. The next layer (5- 10 cms) harboured a density lesser than that found above, with a maximum of 1588 ind./10 cm^2 in May 2002 at 10-20 m depth zone(Fig.9.4). Many stations in this layer showed nil number of harpacticoids indicating a dearth of these animals below 5 cms. While comparing both the sediment layers statistically, there was significant differences in faunal density in the sediments in 0-10m, 20-30m and 40-50 m (P<0.01, Appendix VI, Table 9.1).

The distribution after trawling showed a more or less similar pattern of density, with higher density still in the upper layer compared to the layer below. A maximum of 1285 ind./10 cm^2 was found in March 2002 and September 2001 in the upper layer while a minimum of 17 was observed in March -02 and September 2001 respectively(Fig.9.5). The subsurface layer showed a highest of 410 ind./10 cm^2 in 0-10 m zone in April 2001 while harpacticoids were apparently absent from many stations in atleast 50% of the samples.

The before trawling values in 0-5 cm layer were compared to that recorded from the same layer after trawling using t test. Both 0-10 m zone and 10-20 m zone showed significant differences ($P<0.05$, Appendix VI, Table 9.2) in harpacticoids abundance when before and after trawling values were compared. There was significant increase in the after trawling values of harpacticoids in this zone(Fig.9.5). In the 5-10 cm slice a single station (30-40 m zone) was seen to be perturbed by the otter trawl to a significant effect ($P<0.05$, VI, Table 9.3, Fig.9.6). In this zone also a maximum of 40% increase was observed in the harpacticoid fauna after trawling.

9.2.3 Polychaeta : Juvenile polychaetes also showed the invariable pattern of higher density in the upper zone, in comparison to the lower layer and the values have been depicted in Fig.9.7. A maximum of 517 ind./10 cm^2 was observed from the upper sediment layer in the 0-10 m depth zone. In the 5-10 cm layer, the highest number of only 250 ind./10 cm^2 were observed in March 2002. t test was used to compare the meiofauna obtained from 0-5 and 5-10 cm sediment layers in each zone. Significant differences ($P<0.05$, Appendix VI, Table 9.1) were noticed in the case of polychaete abundance at 0-10 m, 20-30 m, and 40-50 m zones. The significance thus reveals the variation in abundance shown between the two depth layers.

In after trawling samples, the values in the upper sediment layer were more or less comparable to that before trawling. The distribution pattern remained the same with higher density in the upper layer. In this layer a highest of 357 ind./10 cm^2 was observed in the 0-10 m zone in May 2002. The next sediment layer was populated to a lesser extent and the highest number of individuals recorded was 196 in the 40-50 m zone, in November 2002.

A comparison was made on the population density of polychaetes recorded in the 0-5cm layer before trawling and after trawling using the t test. At depth zone 10-20 m, highly significant differences were observed ($P<0.05$, Appendix VI, Table 9.2; Fig.9.8) and similar results were also recorded at 30-40 m zone in the density immediately after trawling when compared to that before trawling.

In the next lower layer, in the depth of 5-10 cm, the 30-40 m depth zone showed significant changes immediately after trawling ($P<0.05$, Appendix VI, Table 9.3). There was a steep decrease in polychaete fauna after trawling, with many stations registering nil polychaetes after trawling (Fig.9.9).

9.2.4 Foraminifera : In keeping with the trend so far known, in the population of foraminiferans, 0-5 cm sediment layer outnumbered that of 5-10 cm layer (Fig.9.10). In the 0-5 cm layer, the highest number registered was 1088 ind./10 cm^2 in July 2001 and November 2002. In the layer beneath, however, only a maximum of 678 ind./10 cm^2 was observed in September 2001 at 10-20 m depth zone. A comparison of the two layers based on the abundance of foraminiferans was carried out using t test. The test revealed significant differences in the faunal abundance in 20-30 m depth zone ($P<0.05$, Appendix VI, Table 9.1). The other stations did not show significant differences in the faunal abundance.

After trawling, in the 0-5 cm layer, the maximum abundance of foraminifers registered was 1463 ind./10 cm^2 at 10-20 m depth range in the month of July 2001 while many stations registered zero occurrence in the inner zone, especially 0-10 and 20-30 m zones (Fig.9.11). A comparison of abundance of foraminiferans before and after trawling in this layer revealed a significant difference ($P<0.05$, Appendix VI, Table 9.2) at the depth ranges 10-20 and 40-50 m. When compared to the before trawling samples, the abundance was on the higher side after trawling, in both these depth ranges, which is indicative of exposure of fauna. In May 2002, the density of 18 ind./10 cm^2 in the 10-20 m depth zone observed in the before trawling samples showed an escalation to 321 ind./10cm^2 immediately after trawling. Similarly, in the 40-50 m zone, the initial value of 54 ind./10 cm^2 observed before trawling increased to 357 ind./10 cm^2 after trawling.

In the 5 – 10 cm layer, after trawling, the highest abundance observed was 1374 ind. /10 cm^2 in the 0-10 m depth zone in September 2001. This layer also showed nil occurrence in the depth ranges 20-30, 30-40 and 40-50m for a few months (January 2002 to September 2002). A comparison of the before and after trawling values in this layer showed a higher abundance in 0-10 and 40-50 m depth zones but statistical significance ($P>0.05$, Appendix VI, Table 9.3) was not found in any of the stations studied (Fig.9.12).

9.2.5 Kinorhyncha : In the study area, the kinorhynchs showed a clear demarcation of the 0-5 and 5-10 cm layers, with the former harbouring 70% of kinorhynchs (Fig.9.13). The highest number of individuals recorded in the 0-5 cm layer was 963/10 cm^2 in the month of May 2002 in 10-20 m depth zone. The maxima in the layer below it (5-10 cm) was 125 ind./ 10 cm^2 in the 10 -20 m depth zone during July 2001. Comparison of the kinorhynch population in the 0-5 and 5-10 cm layers showed significant differences at 0-10, 10-20 and 20-30 m depth zones (P<0.05, Appendix VI, Table 9.1).

After trawling, in the 0-5 cm layer, the highest abundance of kinorhynchs was registered at 232 ind./10 cm^2 at 10-20 m depth zone in November 2001(Fig.9.14). After trawling many stations registered nil occurrence, especially in the offshore stations in the depth range 30-40 and 40-50 m. The values recorded before and after trawling in this layer were compared using t test and significant difference was observed at depth zone 10-20 m and 20-30 m (P<0.05, Appendix VI, Table 9.2). The after trawling samples registered a decrease with the highest plummeting being registered at the depth zone 20-30 m when 196 ind./10 cm^2 enumerated before trawling decreased to nil in after trawling samples in November 2001.

In the 5-10 cm sediment layer, the highest number of individuals observed after trawling was 89/10 cm^2 at depth ranges 10-20 and 30-40 m in the month of November 2001 and September 2002 respectively. A comparison of the density before and after trawling did not reveal any significant differences(P>0.05, Appendix VI, Table 9.3) between the values, though a slight decrease could be noticed at the depth zones nearer to the shore, such as 0-10 and 10-20m(Fig.9.15).

9.2.6 Ostracoda : These fauna were distributed in a highly patchy manner, with higher numbers in the first 5 cms of sea floor sediment. In the upper 0-5 cm layer, the highest number of individuals observed was 232 in the 20-30 m zone in July 2001(Fig.9.16). In the stations located at higher depths, the population density was found to be gradually increasing and was found to attain a peak in the 40 -50 m depth zone. The 5-10 cm layer showed a lower percentage of ostracods compared to the layer above and this situation prevailed in all the five depth zones investigated. The ostracods in the 0-5 cm and 5-10 cm were compared using t test which revealed a significant difference at depth zones 20-30, 30-40 and 40-50m ($P<0.05$, Appendix VI, Table 9.1).

In the 0-5 cm layer, after trawling, highest density of 339 ind./10 cm^2 was observed in May 2002 at 0-10 m depth zone(Fig.9.17). A number of depth zones showed nil values for ostracods in the after trawling samples during various months . A comparison of the before and after trawling values in this layer (0-5 cm) did not reveal any significant differences except at 20-30 m zone ($P<0.05$, Appendix VI, Table 9.2).

Ostracods in the 5-10 cm layer after trawling were very low in abundance in the samples from depth zones 0-10, 10 -20 and 20-30 m. At the depth zones 30-40 and 40 -50 m higher density of ostracods could be noticed and the highest recorded density was 178 ind./10 cm^2 in September 2002 in the depth range 40-50 m (Fig.9.18). A consistent increase or decrease in the after trawling values compared to the before trawling density could not be observed (P>0.05, Appendix VI, Table 9.3) in the case of ostracods. t test could not reveal any significant differences at any of the depth ranges.

9.3 Discussion : The depth stratification of meiofauna has been subject of study in almost all the meiofaunal investigations (Damodaran, 1973; Parulekar *et al.*, 1976; Ansari *et al.*, 1980). In India, most of the studies have been carried out in backwaters (Vijayakumar *et al.*, 1991) and inshore areas (Parulekar *et al.*, 1976, Ansari *et al.*,1980) but globally, studies have even been conducted in deep sea environment (Corliss,1985; Gooday,1986; Montagna,1991). In the methodology employed to study the vertical distribution of meiofauna, different depth intervals of observation have been adopted by scientists i.e. 1 cm, 2 cm, 4 cm and 5 cm. In the present study, the 5 cm interval was chosen to get a picture of vertical distribution of meiofauna within the sediment.

Vertically the bulk of meiofauna resides in the top 5 cm layer of the substratum (Damodaran, 1973). The results of the present study fully concur with this natural phenomenon, with the upper 5 cm sediment teeming with rich meiofauna, especially the nematodes. Such high aggregations are attributed to the availability of food and oxygen in the top layer (Parulekar *et al.*, 1976; Ansari *et al.*, 1980). In the case of nematodes it could be observed that at depth zones 0-10 m, 30-40 m and 40-50 m, there existed significant differences in the abundance between the 0-5 and 5-10 cm layers ($P<0.05$). Nematodes were more abundant in the fine sedimentary environment 0-10, 10-20 and 20-30m zones, which was characterized by lower penetration of oxygen in the deeper layers, leading to aggregation in the top layers. Differential feeding types of nematodes have also been postulated to contribute to differences in their distribution. Bacterial or diatom feeders may be distributed in the upper layers while omnivores or carnivores in the deeper layers (Coull,1973; Brown and Sibert, 1977; Gerlach ,1978; Tietjen,1971). Harpacticoids showed extreme preference for surface and in the present study they were significantly higher density in the upper sediment (0-5 cm). Montagna (1991) also observed different meiofaunal groups exhibit different vertical distribution patterns and that harpacticoids were found almost exclusively within the top 2 cms. All the other groups including nematodes, polychaetes and foraminiferans exhibited a sharp decrease in abundance with depth. These animals may be less resistant to oxygen deficiency and need the space for comparatively active swimming (Harkantra and Parulekar, 1989). Rees *et al.*(1992) reported that the highest number of individuals and taxa were found at or near to the sediment surface , however it was not unusual to encounter animals at depth of 10 cm or more. In the present study too, the population density of meiofauna was not too low in the 5-10 cm layer due to the presence of nematodes, harpacticoids and a lesser number of polychaetes. The population density of kinorhynchs and ostracods in the 5-10 cm layer was found to be very low when compared with that of the former taxa. Fenchel and Reidl (1970) observed the redox potential discontinuity layer , which was about 2-3 cms deep, which acted as a barrier to the high abundance of meiobenthos. Similarly, Vijayakumar *et al.* (1991) recorded significant decrease in meiofauna with increasing depth of sediment , and that the reduction was more pronounced in the backwaters where a black sulphide layer was present in the upper 5 cms sediment of the backwaters. This layer was not found in the top 10 cms of the near shore area, where a gradual reduction in the fauna took place, in contrast to the steep decrease in the backwaters. In the present study too, a steep decrease was not found, which may be due to the absence of this anoxic layer. Moreover the coarse sedimentary environment in 30-40 and 40-50 m depth range in the study area characterized by easy penetration of oxygen (Jayaraman *et al.*,1959) could also be helpful in maintaining favourable conditions for the survival of meiofauna. While comparing the abundance of foraminiferans in the study area,the 0-5 and 5-10 cm layers showed almost uniform distribution within the sediment with significant differences only in the 20-30 m zone. Studies have shown that in soft sediments most living benthic foraminiferans are encountered below the sediment surface and can thrive at 6-15 cms within the sediment (Coull *et al.*, 1977; Collison, 1980; Mackenson and Douglas, 1989). Corliss and Emerson (1990) in their analysis of deep sea benthic foraminifera found that they reside in depths of 3-13 cms and related this variation to the difference of organic carbon flux to the seafloor. Foraminiferans are thought to actively migrate through the sediment column. The presence of abundant foraminifera in depths more than 5 cms in the present study also confirms the above reports.

Trawling resulting in inordinate ploughing of the sea bottom creates an unsuitable habitat for the growth and survival of sea bottom dwellers, which are habitat dependent to a very large extent. The trawl gear is directly destructive to the critical fish habitat because they alter the physical and biological characters of the sea bed (Watling and Norse, 1998; Hall, 1999). The gear is also responsible for indirect destruction of benthic organism because they can add large volumes of sediment to the water column and thereby alter the natural pattern of sediment deposition and resuspension (Schubel *et al.*, 1979).

In the present context, it could be seen that nematodes underwent changes in abundance after trawling at 0-10, 10-20 and 20-30 m depth zones both in 0-5 and 5-10 cm layers to a significant extent (P<0.05). Nematodes were found to increase in number immediately after trawling and moreover it could be inferred that sea floor sediment was disturbed upto atleast 10 cms during trawling. Harpacticoids also showed a significant increase in the inshore depth zones especially the 0-10 and 10-20 m zones at the topmost layer. On the other hand, disturbance was noticed to a significant extent (P<0.05) in the 5-10 cm layer in the 30-40 m zone where significant increase in harpacticoids community was observed immediately after trawling. The 30-40 m zone in the study area comprises sandy silt sediments which allow for moderate penetration of the otter boards and the trawl net to atleast a depth of 10 cm. After trawling, the polychaetes were found to be disturbed in the 10-20 m zone in the upper sediment layer while in the 30-40 m zone the disturbance extended to 5-10 cms of sediment (P<0.05). The 0-5 cm layer in zones 10-20 and 30-40 m was significantly disturbed in the case of foraminiferans, while in the 0-10 and 40-50 m zones , the 5-10 cm layer was significantly disturbed (P<0.05). The kinorhynchs and ostracods also exhibited disturbances in the inshore area in the 0-5 cm layer but notable traces of trawl penetration could not be seen in the 5-10 cm layer.

Owing to the pressure of trawl gear on sea bed, parts of the gear penetrate to some extent into the sea bottom and penetration depth is largely dependent on the nature of seabed (Margetts and Bridger, 1971; Bridger, 1972). The weight of the trawl doors, the towing speed and tidal condition have also been postulated to create distinct tracks on the seabed , which is most distinct on muddy/ soft sandy grounds (Margetts and Bridger, 1971). The successive layers are brought into suspension and settle after the gear passes. The resuspension of the top layers of sediment (Kaiser and Spencer, 1996; Kaiser *et al.*, 1999) makes the benthic fauna more vulnerable to be within the reach of the sediment grab and thus the after trawling samples manifest an increase in the abundance immediately after trawling. Only those species which live at depths greater than the penetration depth of trawl gear (greater than 10 cm in the present study) survive resuspension and are slightly affected by it (Laban and Lindeboom, 1991). In the study area, the meiobenthos as a whole was seen to be highly aggregated in the upper sediment layer (0-5 cm) compared to the lower segment and the possibility of otter trawl to be extremely harmful to the growth and survival of these organisms could not be ruled out .The most vulnerable species were those that were physically the most fragile or lived in the uppermost layer of the sediment where they were within the reach of the trawl (Santbrink and Bergman, 1994). A characteristic feature of trawl fishing is that the muddy sediments are subjected to regular fishing disturbance (Pauly and Christensen, 1995) and the soft nature of the muddy sediments makes them more susceptible to the physical impacts of trawl gear compared with harder and coarser sediments(Ball *et al.*,2000). The inshore depth ranges, 0-10m, 10-20m and 20-30 consisted of clayey and muddy sediments and in turn showed evidence of the maximum disturbed area with the maximum penetration depth and consequently the most disturbed site. It is assumed that subsequent recovery of infaunal communities in muddy habitats following experimental disturbance appears to take longer than in other habitats (Ball *et al.*, 2000).

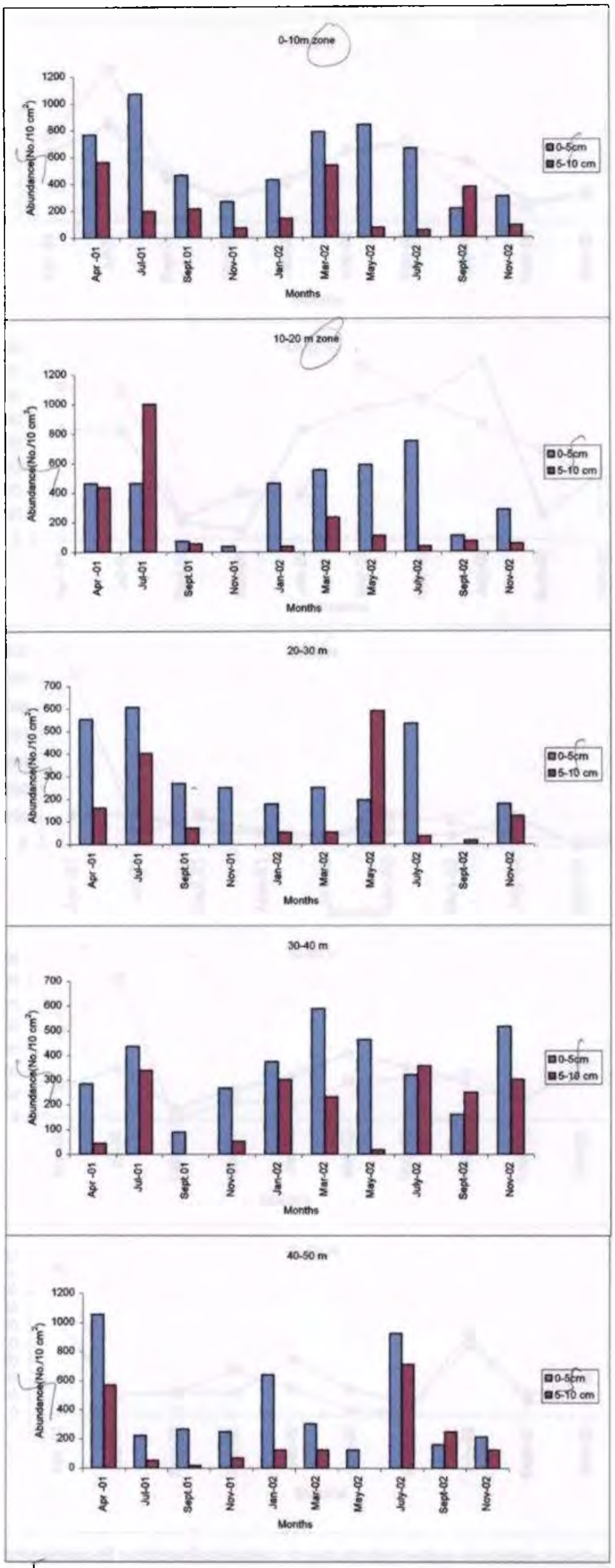


Fig.9.1. Comparison of vertical distribution of nematodes at different depth zones before trawling during April 2001 to November 2002

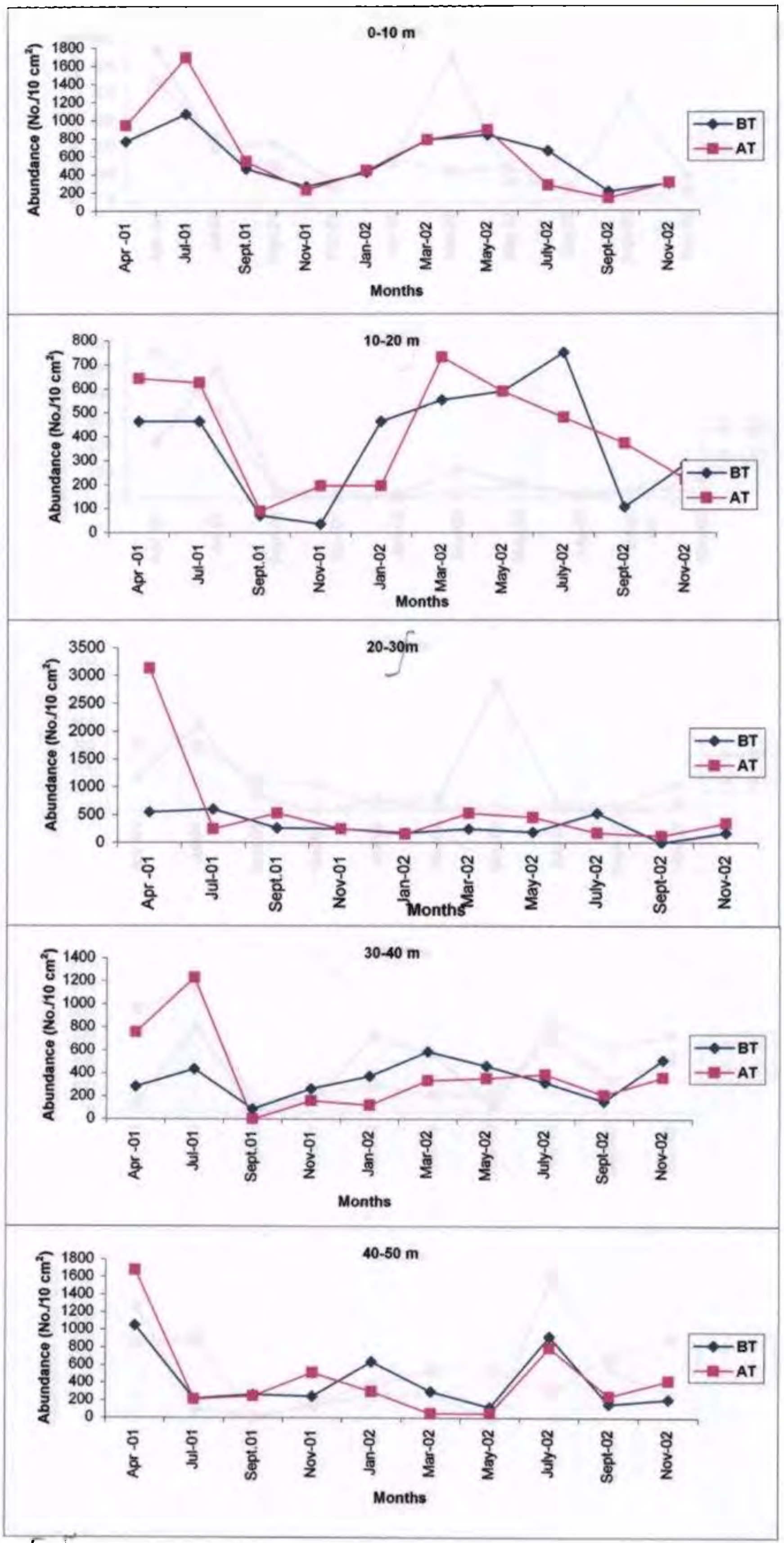


Fig 9.2 Comparison of vertical distribution of nematodes before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer

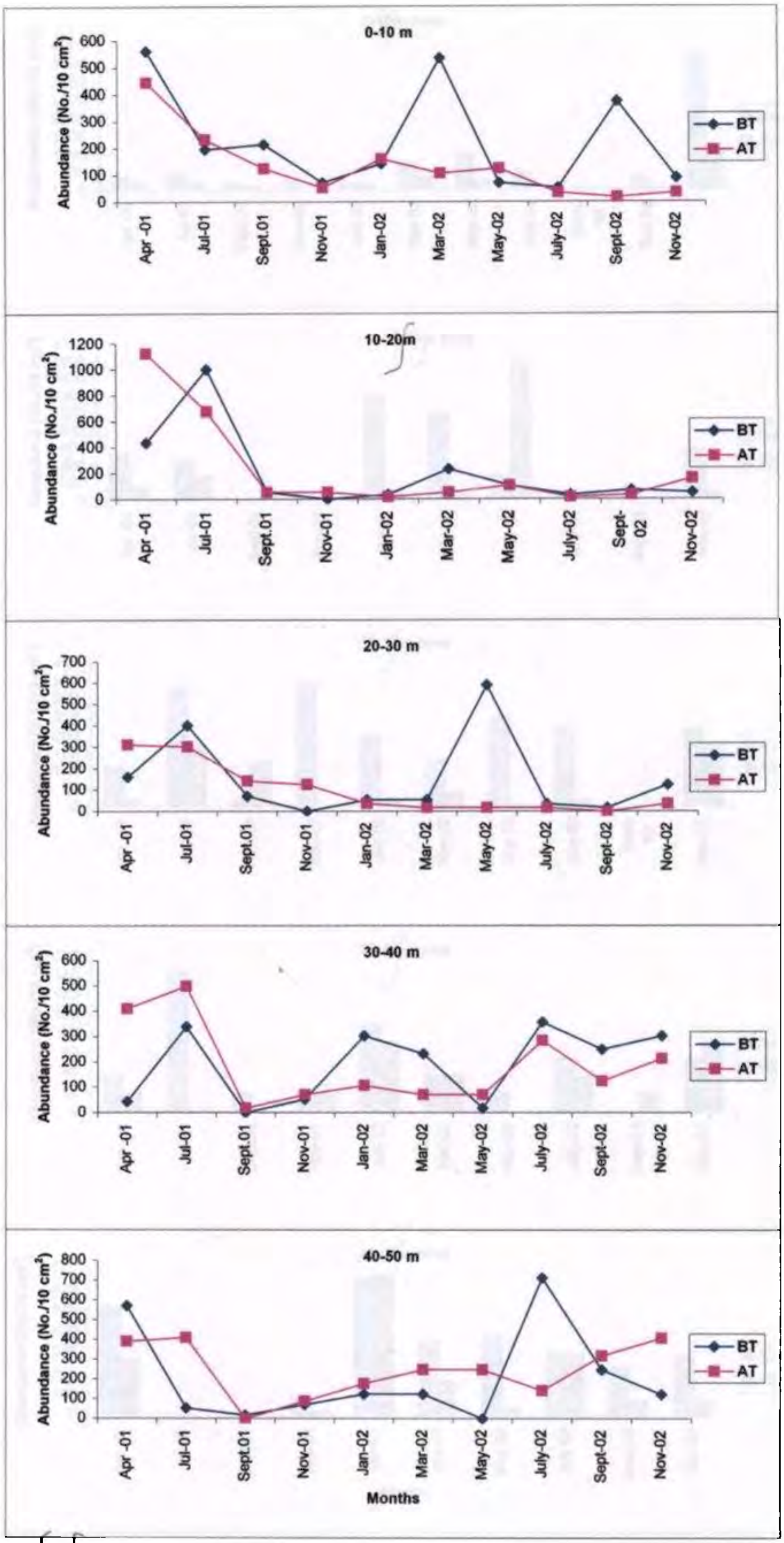


Fig.9.3.Comparison of vertical distribution of nematodes before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer

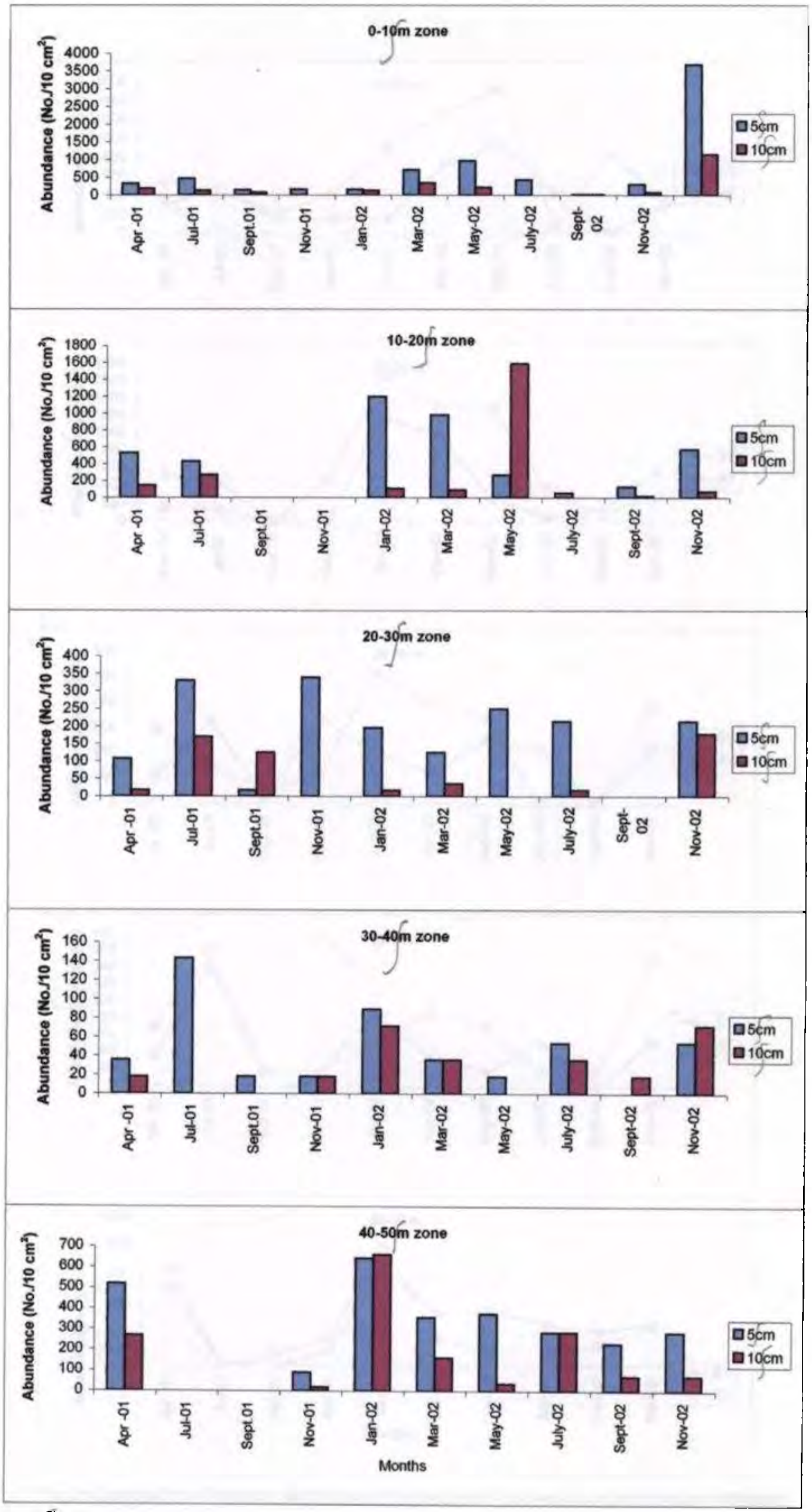


Fig.9.4. Comparison of vertical distribution of harpacticoids before trawling at different depth zones during April 2001 to November 2002

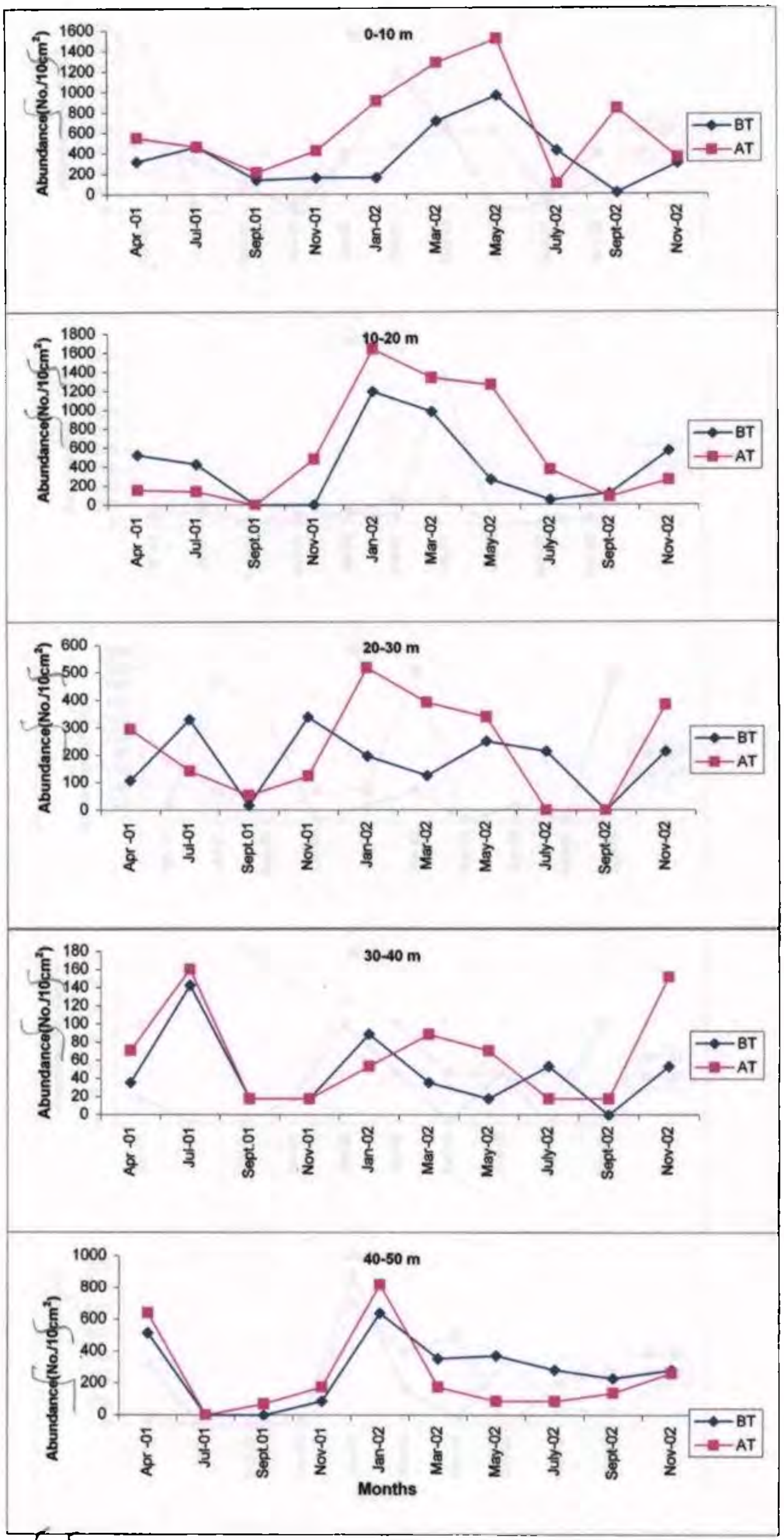


Fig.9.5.Comparison of vertical distribution of harpacticoids before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer

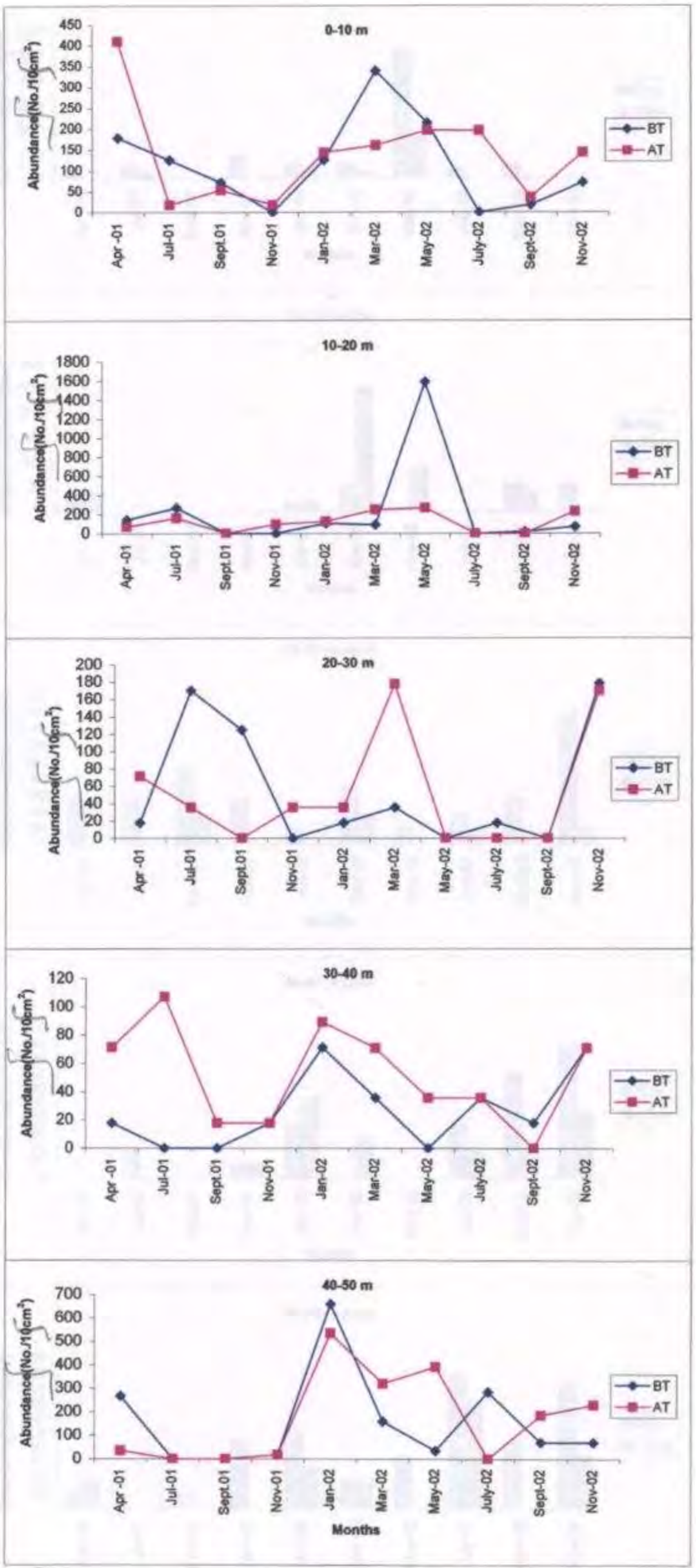


Fig.9.6. Comparison of vertical distribution of harpacticoids before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer

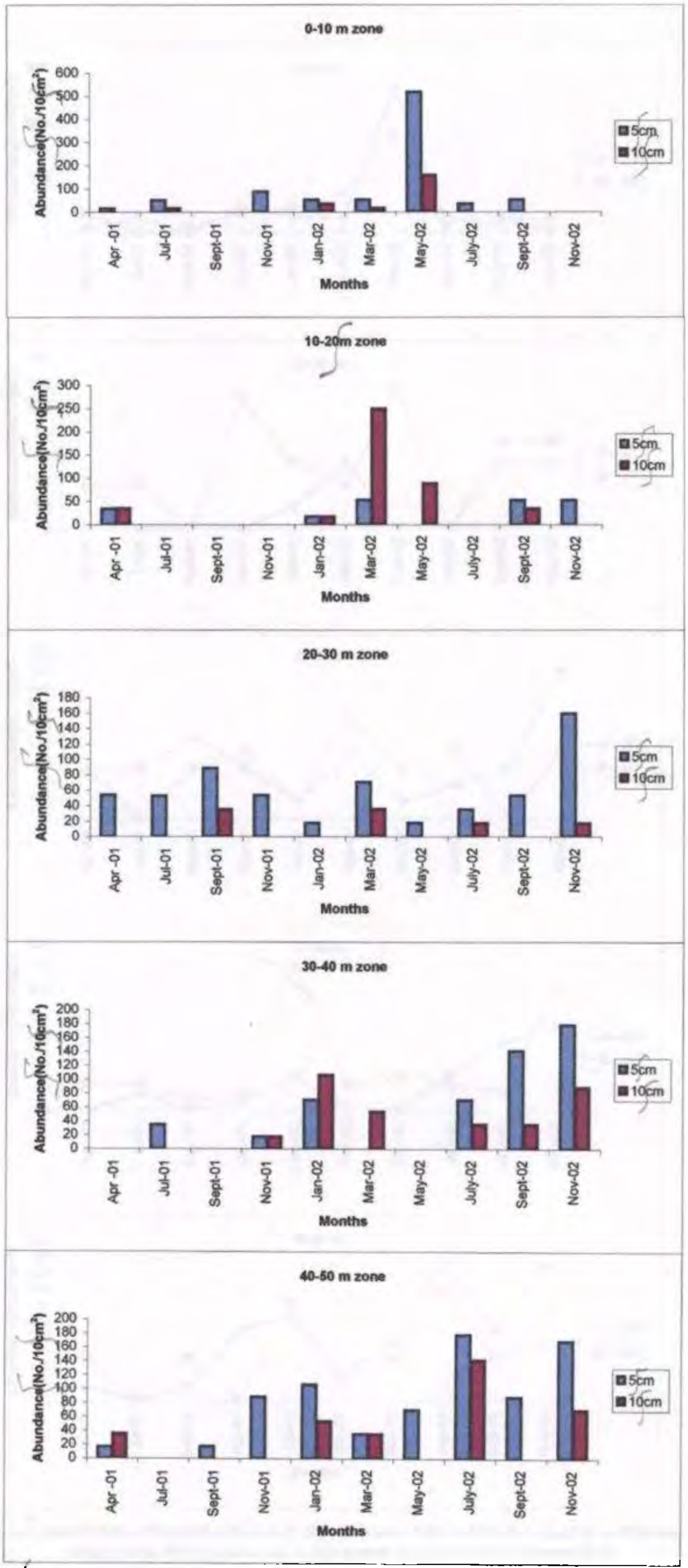


Fig.9.7. Comparison of vertical distribution of polychaetes at different depth zones before trawling during April 2001 to November 2002

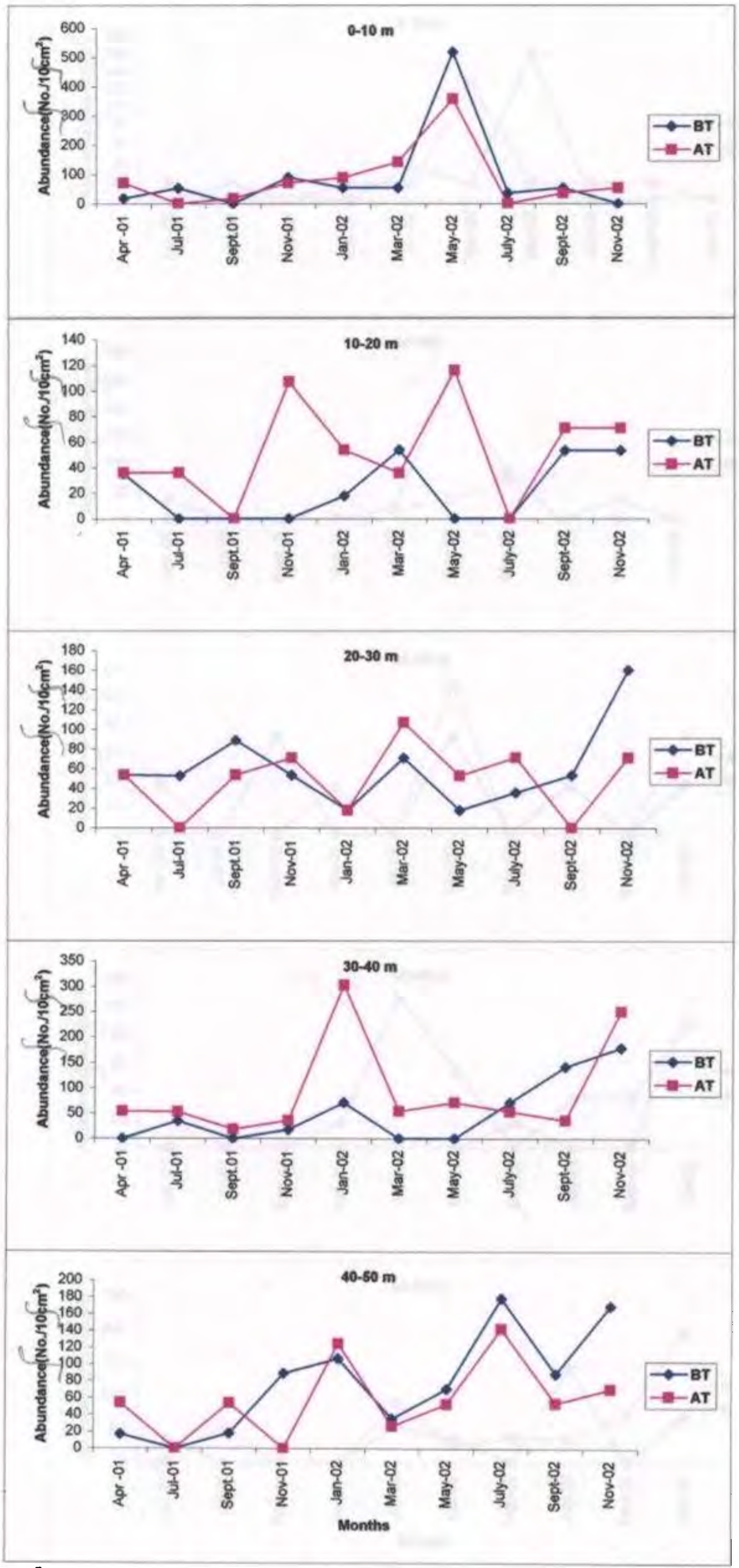
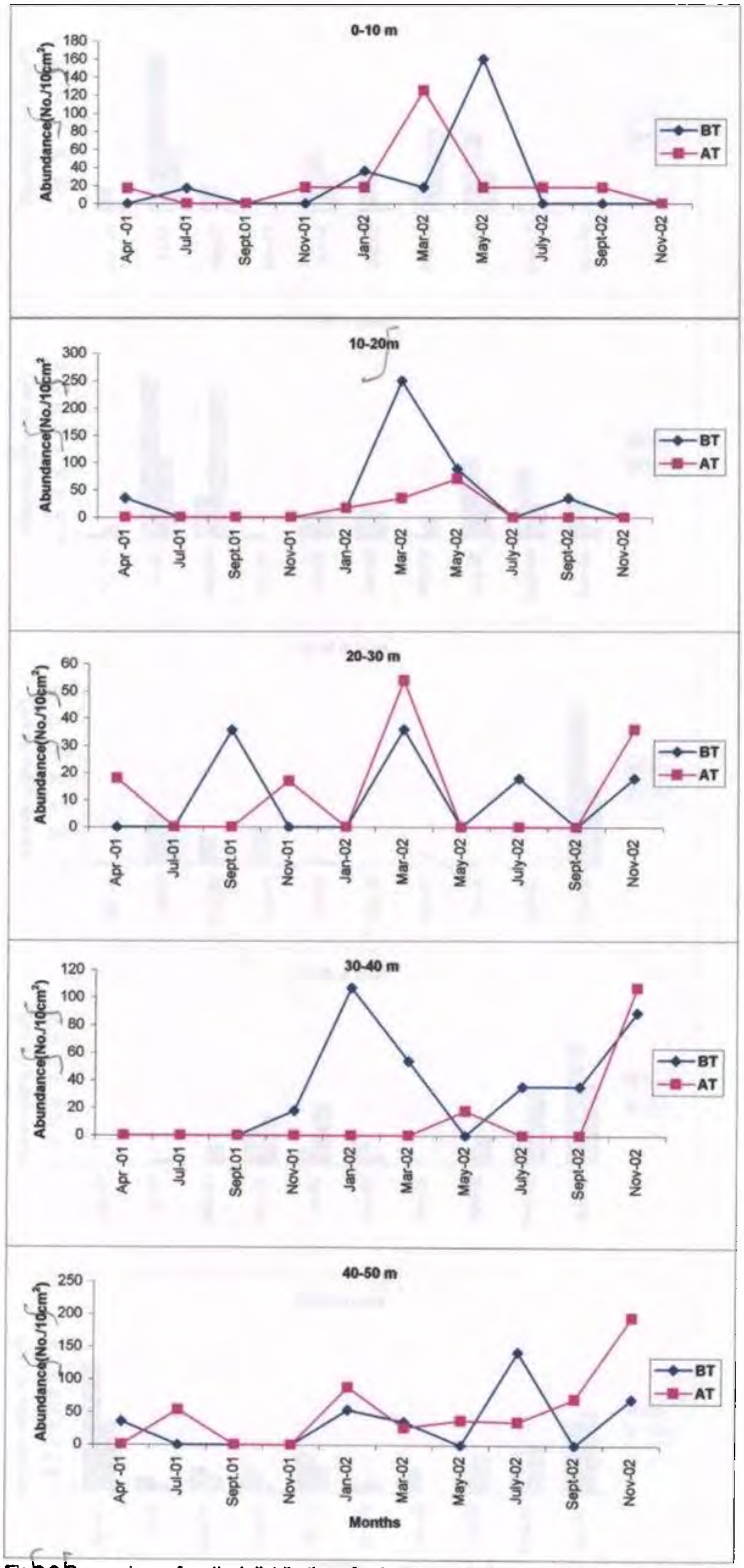


Fig.9.8 Comparison of vertical distribution of polychaetes before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer



✓ Fig.9.9.Comparison of vertical distribution of polychaetes before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer

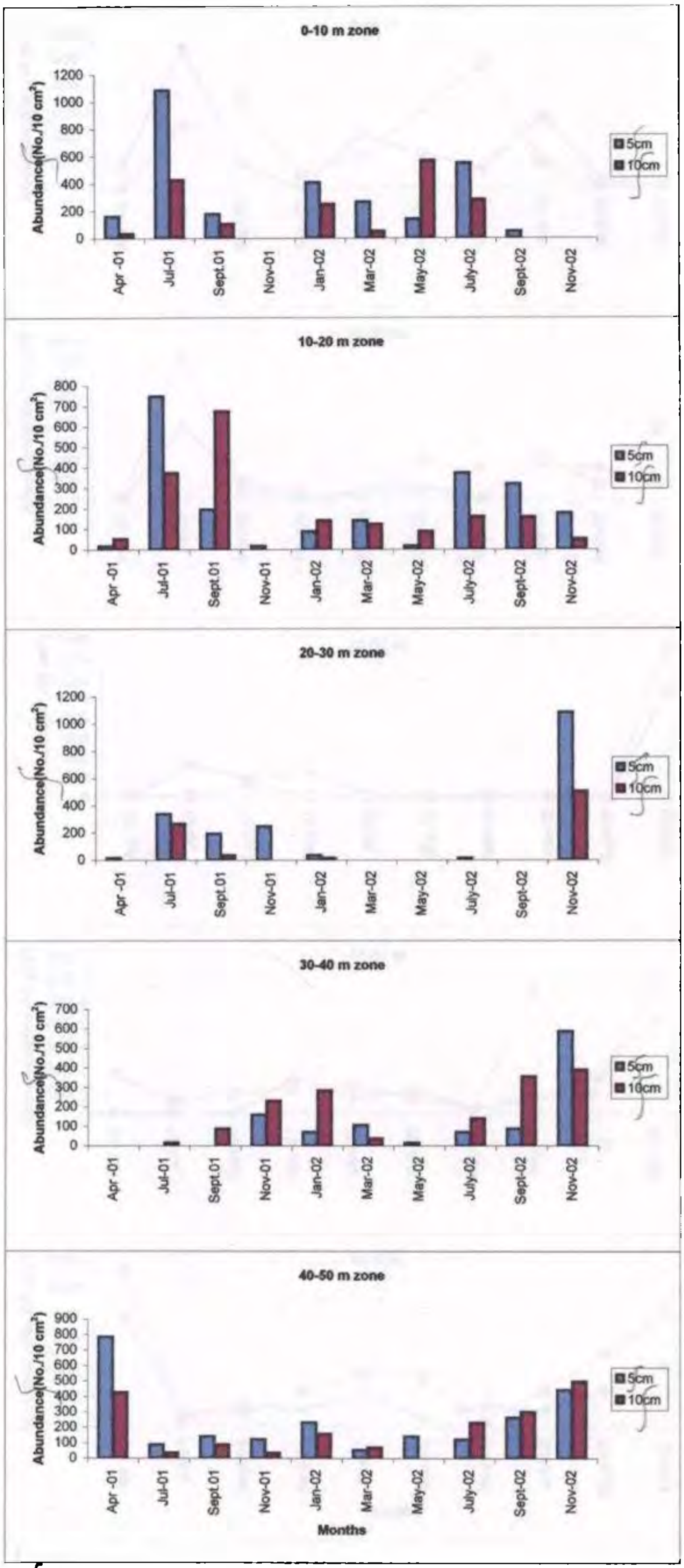


Fig.9.10. Comparison of vertical distribution of foraminiferans at different depth zones before trawling during April 2001 to November 2002

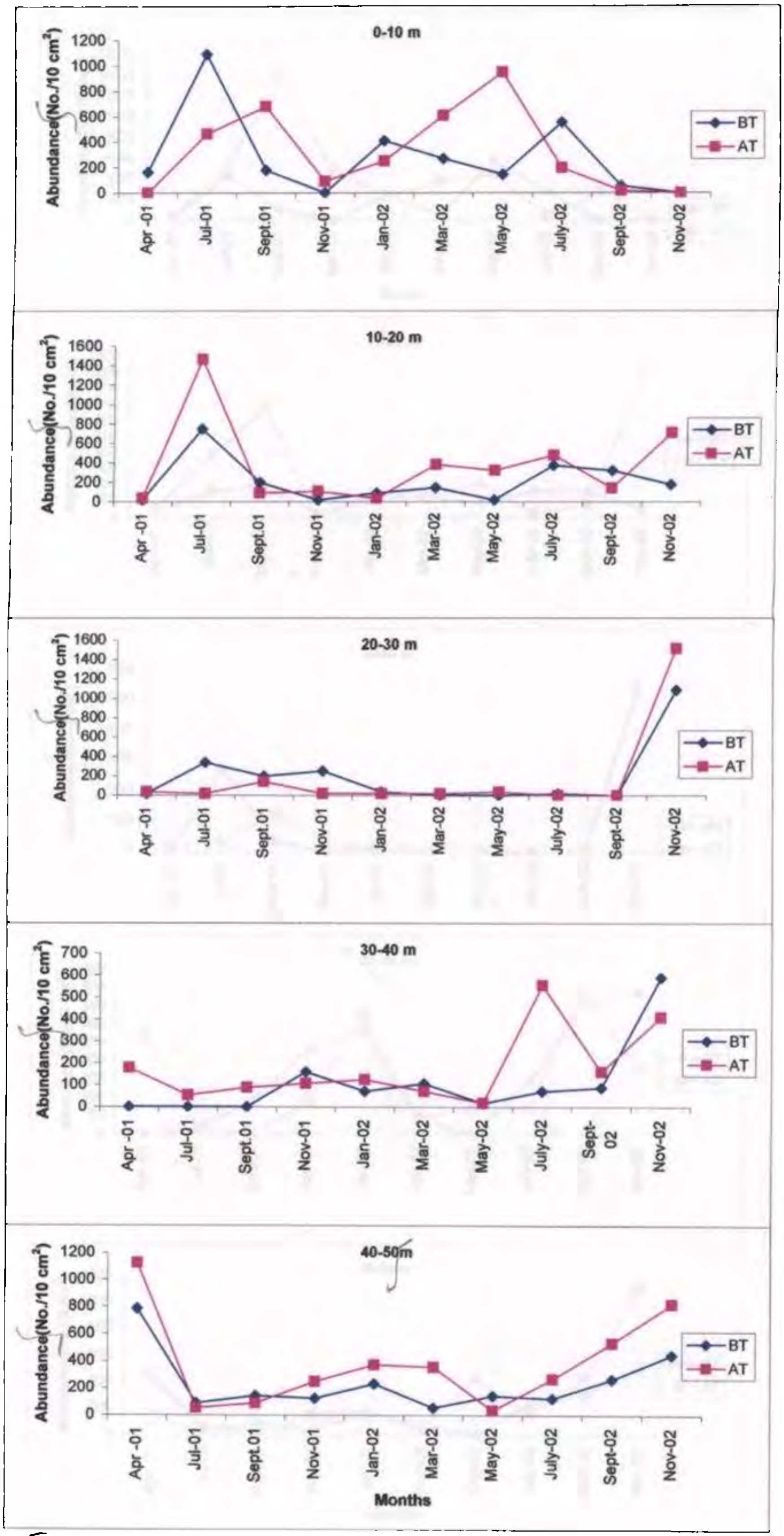
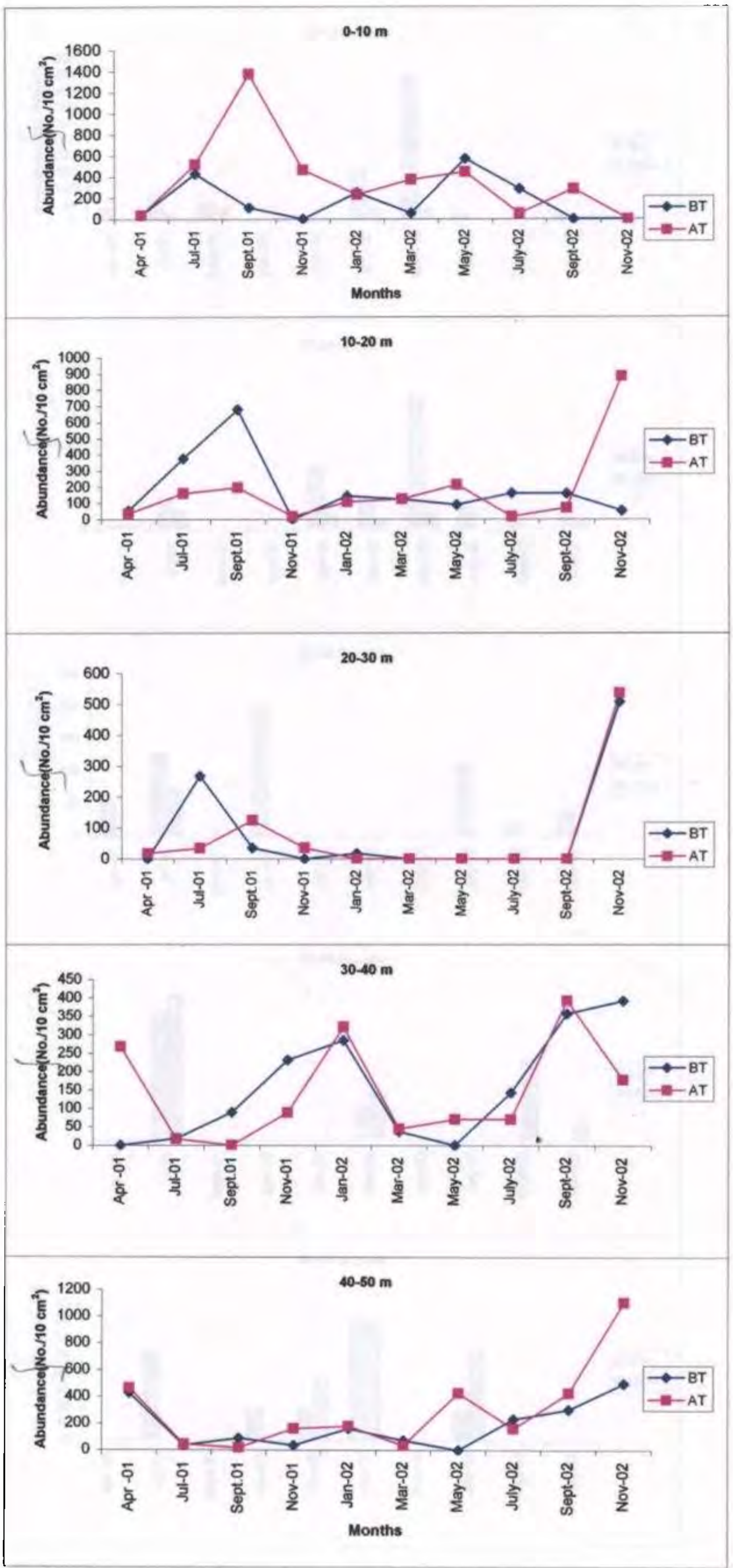
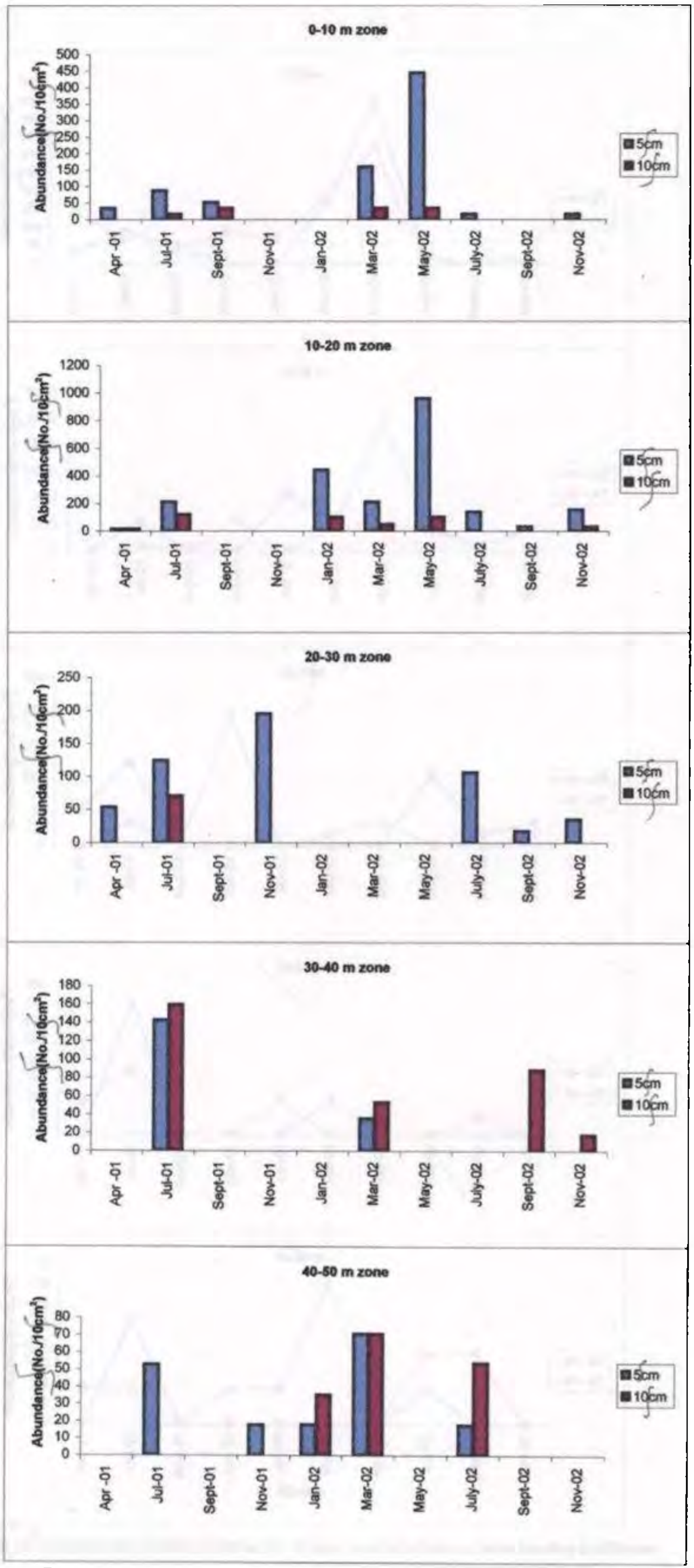


Fig.9.11 Comparison of vertical distribution of foraminiferans before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer



✓ Fig 9.12 Comparison of vertical distribution of foraminiferans before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer



✓ Fig.9.13. Comparison of vertical distribution of kinorhynchs at different depth zones before trawling during April 2001 to November 2002

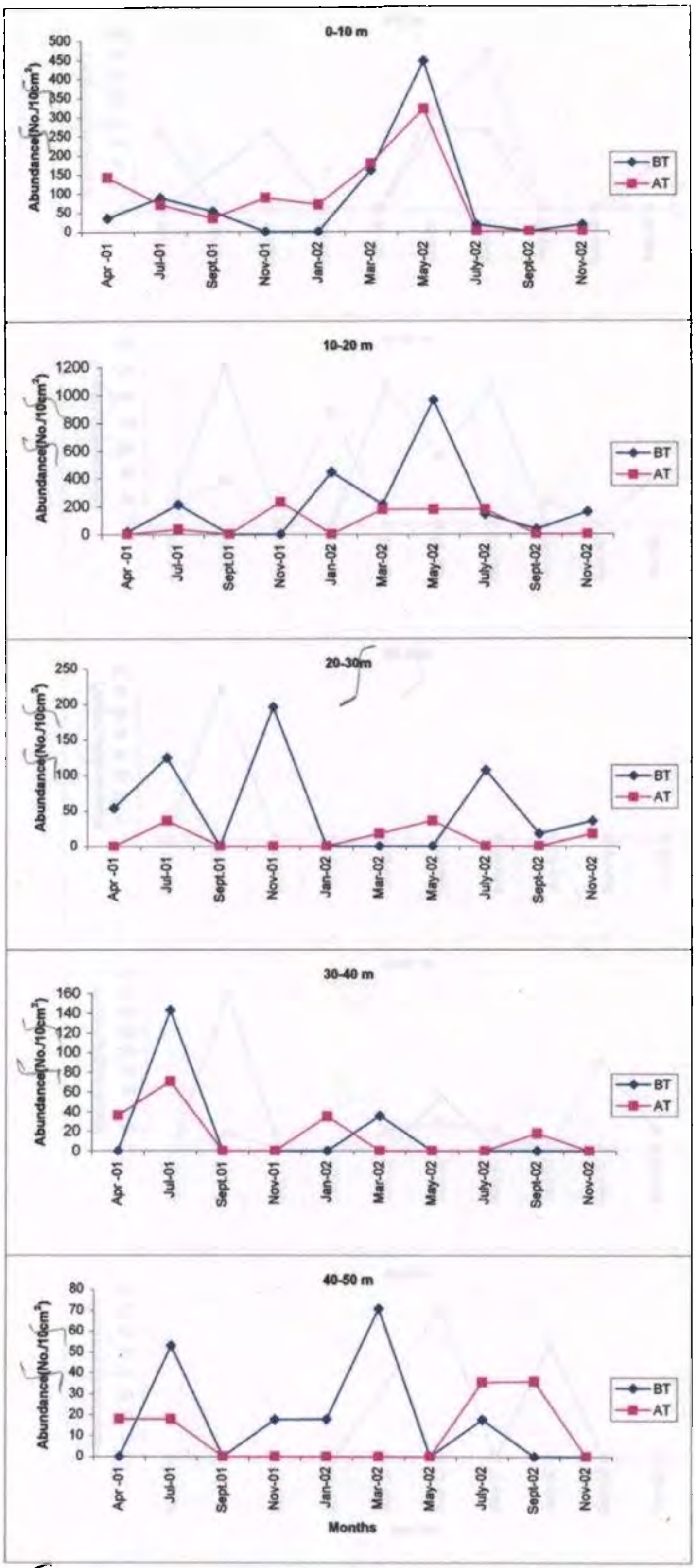


Fig.9.14 : Comparison of vertical distribution of kinorhynchs before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer

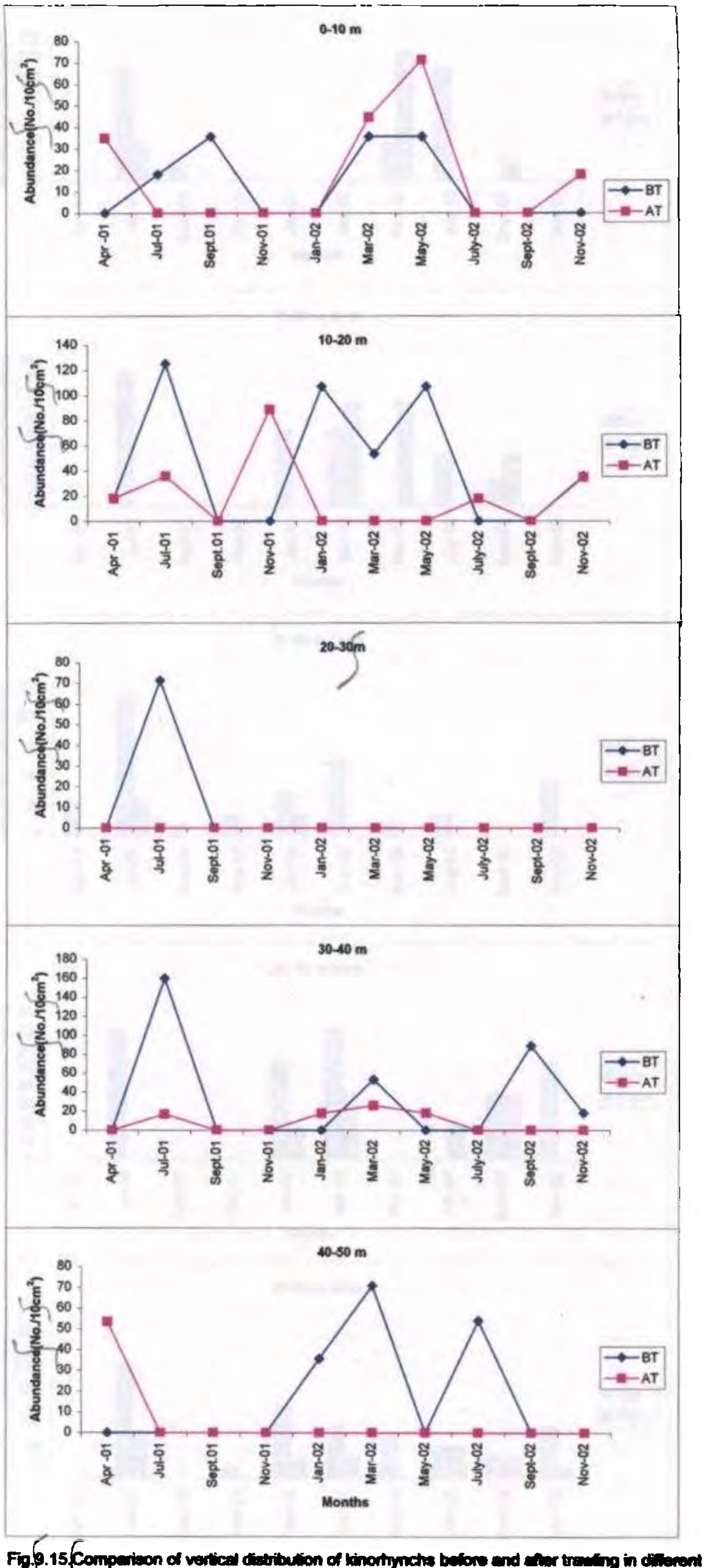


Fig.9.15 Comparison of vertical distribution of kinorhynchs before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer

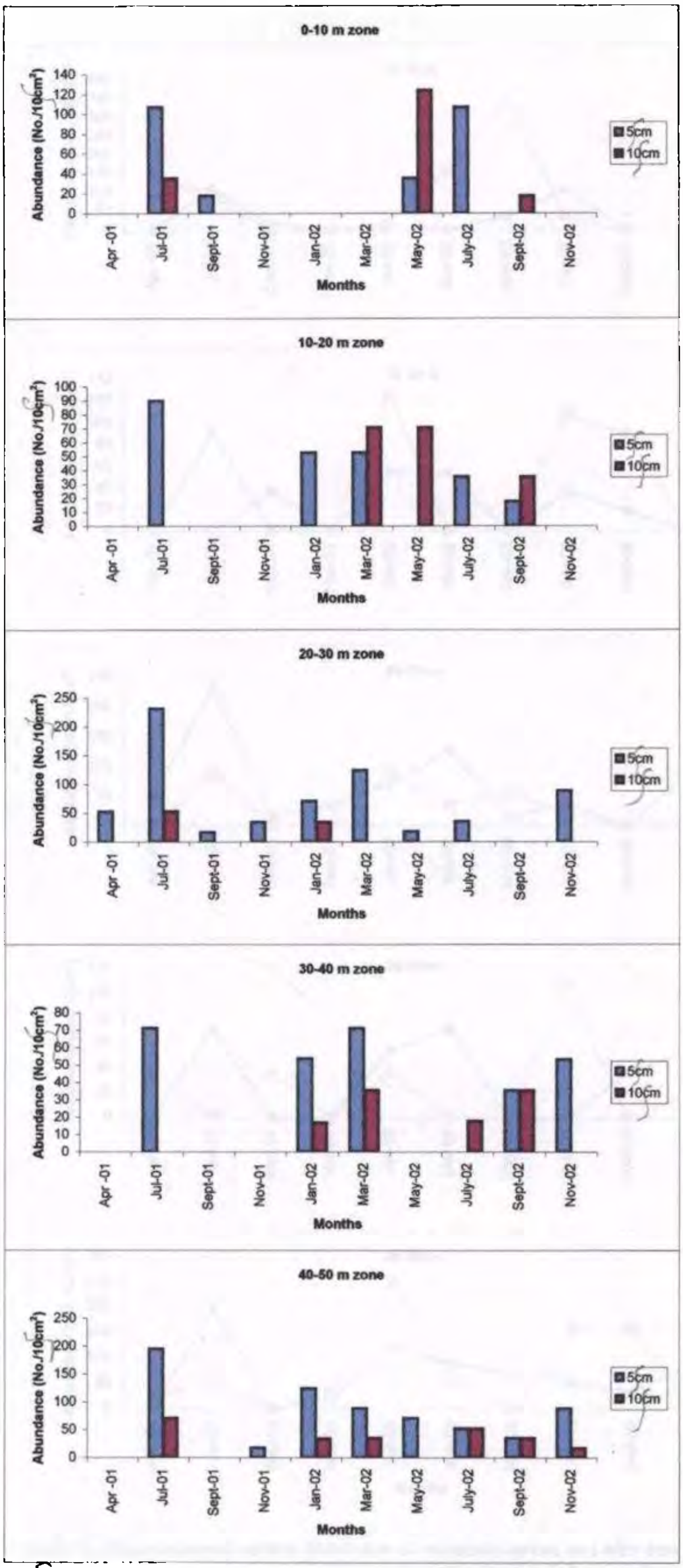


Fig.9.16. Comparison of vertical distribution of ostracods at different depth zones before trawling during April 2001 to November 2002

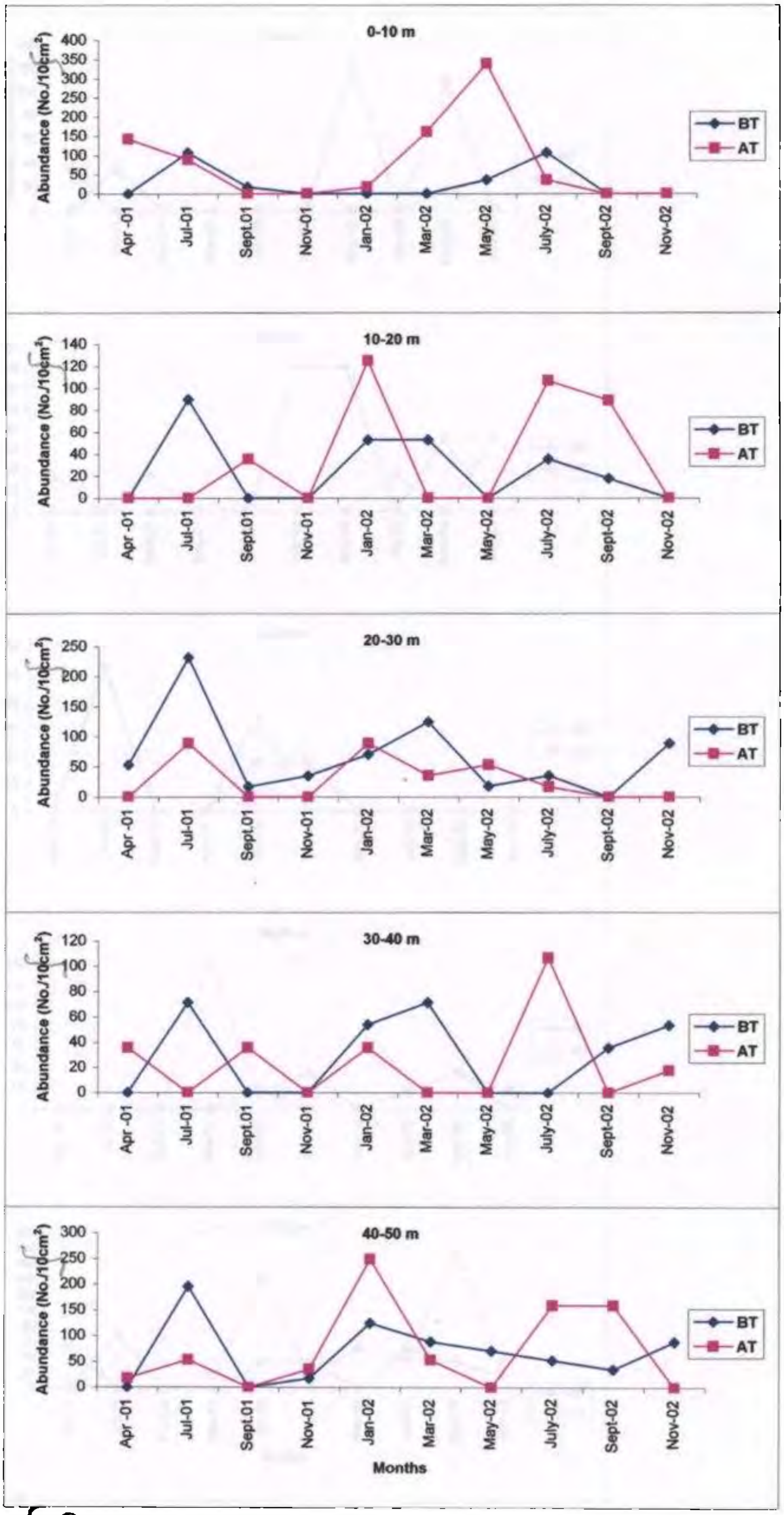
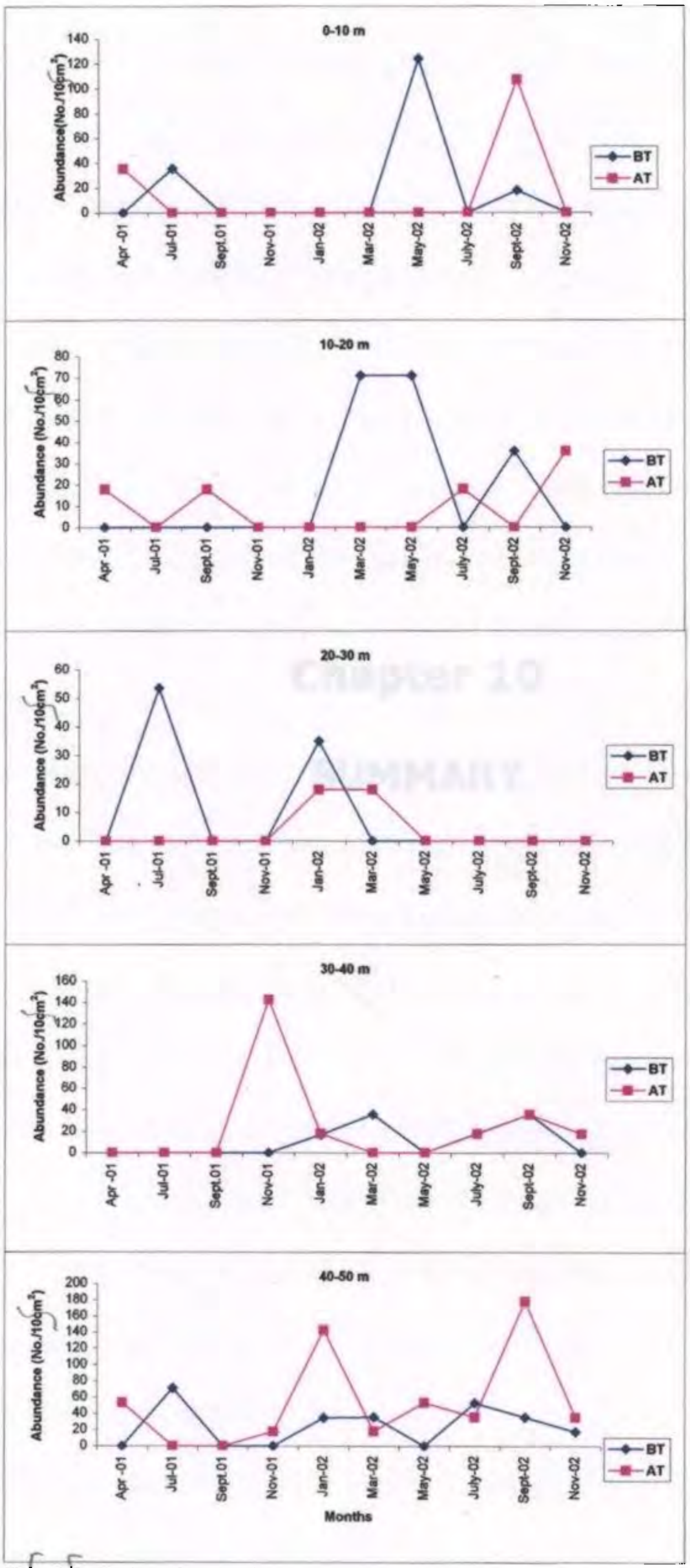


Fig.9.17 . Comparison of vertical distribution of ostracods before and after trawling in different depth zones during April 2001 to November 2002 in 0-5 cm sediment layer



✓ Fig.9.18.Comparison of vertical distribution of kinorhynchs before and after trawling in different depth zones during April 2001 to November 2002 in 5-10 cm sediment layer

Chapter 10

SUMMARY

Bottom trawling is a source of chronic and widespread anthropogenic disturbance taking place in the shallow shelf waters which modifies the diversity, community structure, trophic structure and productivity of macrobenthic invertebrate communities. Experimental and field studies have demonstrated that trawling brings about reduction in the abundance of macrobenthic infaunal and epifaunal species, and that fragile species with larger body size and slow life histories are generally more vulnerable than those species with smaller body sizes. As a result, in an area subjected to persistent trawling, the sea bed communities are increasingly dominated by small infaunal species with fast life histories, which help~~s~~ them sustain a surviving population in that area.

Previous studies on effects of trawling have focused on macrofauna because they are conspicuous, relatively easy to sample and process, killed directly by trawling gears and provide habitat structure. However, meiofauna (animals that pass through a 500 μm mesh sieve but are retained on 63 μm mesh sieve) can make a greater contribution to benthic production than the macrofauna, and their role in the benthic ecosystem should not be overlooked. Meiofauna are more productive as a result of their abundance and fast turnover times. Schwinghamer *et al.* (1986) quotes turnover times of 24 days and less for organisms less than 2.1X 10^{-7}g wet weight, an order of magnitude greater than those for most macrofauna.

A commercial shrimp trawler of 45 feet OAL was hired on contract basis to carry out the experimental trawl fishing and sample collection. The study area between Cochin and Munambam was divided into 5 depth zones, 0-10, 10-20, 20-30, 30-40 and 40-50metres with two stations in each depth zone. Stations were fixed with the help of a GPS, providing a distance of 5 kms between each station. Thus a total of 10 stations were demarcated, namely S1, S2, S3, S4, S5.... S10. Trawling, with a trawl net having mesh size 25mm was carried out at approximately the mid depth of these stations. After trawling, these stations were designated as A1 , A2, A3 , A4, A5, ...A10. Depth ranges of 0-10 and 10-20 m were covered on the first day of experimental trawling, while 20-30 and 30-40 m zones were sampled on the second day while the 40-50 m depth zone was sampled on the third consecutive day of trawling.

Samples of water and sediment were collected from each station before and after trawling from bottom. The parameters such as dissolved oxygen; temperature, salinity, turbidity, pH and nutrients in water were analyzed to bring out the effect of trawling if any, on the physico-chemical parameters of seawater. Effect of trawling on the sediments was studied by analyzing the organic matter and sediment pattern in the sediment samples collected from the sea bottom. Variations, if any, on the meiofaunal community were delineated by analyzing the quantitative variation of infauna sorted out from the sediment samples.

Variations in the temperature- salinity regimen are recognized to be of direct influence on the marine organisms. In the present study, all the parameters were found to be influenced to a great extent by the monsoons, especially the southwest monsoon. Temperature of the bottom waters remained almost the same towards the offshore regions, each station showing characteristic temperature of the respective season. Bottom trawling process did not inflict any disturbance in the temperature regime of the coastal waters which was obvious from the identical readings of temperature registered both before and after trawling.

The bottom water samples at stations 1 to 10 showed only slight fluctuations in salinity throughout the year, except during monsoon season (June – August). Lower values of salinity were recorded, coinciding with that of rainfall. The salinity range during July 2001 was 27.6 ppt at station 9 to 32.8 ppt at station 10 while that of 2002, it was 29.1 at station 4 to 33.1 ppt at station 10. It may be seen that southwest monsoon had a glaring influence on salinity variation during the preceeding year of sampling, when compared to the succeeding year. The trends shown in bottom salinity immediately after trawling were almost identical, with the general plummetting during monsoon. Bottom trawling thus does not make any change in respect to the salinity structure of sea bottom.

The pH of seawater in the study area was in the range 7.8 to 8.3 except during southwest monsoon period during when the pH drops by a few units. The average pH during monsoon in the first and second years was 7.51 and 7.29 respectively, which represented the lowest average for both the years. pH was also found to be consistent after trawling.

The distribution of oxygen, profoundly influenced by the southwest monsoon, has shown significantly lower values during the southwest monsoon due to the influx of turbid river waters and heavy downpour. More or less uniform distribution of oxygen prevailed upto 50 m depth in the Cochin - Munambam belt. There was a significant decrease in oxygen concentration of bottom waters immediately after trawling. The heavy influx of organic matter further depletes the oxygen content of the bottom waters. This situation can further be aggravated by the turbulent churning of sediments during trawling, creating a zone of very low oxygen. Along Kerala coast, where trawling pressure is very high immediately after monsoon, the above said conditions might exist in the bottom waters. Further decrease in dissolved oxygen concentration was observed during this period owing to the trawling operations which leads to the formation of a near - zero oxygen zone in the bottom water lethal to all living communities in the ecosystem. The hypoxic condition might prove to be hazardous for the survival of eggs, larvae, and juveniles of fish and an abrupt rise in turbidity and subsequent reduction in dissolved oxygen may create an unfavourable niche for organisms in the marine ecosystem. Wide variations in oxygen content was noticed at near shore (0-30 m depth) stations where the sea bottom is clayey and silty in nature than the sandy stations located beyond 30 m depth~~s~~. Oxygen concentration was found less in the monsoon period due to the influx of turbid river waters and heavy downpour. Interestingly, the intensity of trawling was found high in August, immediately after the lifting the ban imposed on monsoon trawling, especially at the inshore waters, due to the heavy shrimp trawling. The results of this study clearly demonstrated the formation of hypoxic conditions in the water column due to intense trawling operations carried out along the coastal waters of Kerala.

Turbidity of sea water especially at bottom is directly proportional to the sediment load, higher the sediment the more turbid the waters become. The shelf waters become highly turbid due to increased river and land run off and the increased wave action of the sea. The increase of turbidity observed after trawling experiments revealed that bottom trawling caused heavy perturbation on the sea bottom. The increase of turbidity in the water column was due to the release of heavy sediment clouds generated from the sea bottom, which is promulgated by the scraping of sediment surface during dragging. Significant variations were observed in the turbidity at bottom in the samples collected after trawling compared to that of before trawling which brings to light the disturbance of the communities on the sea floor. At bottom waters, an average 2 – 4 fold increase after trawling was detected which confirmed the role of bottom trawlers in the release of sediment clouds at bottom. In the marine milieu, turbid waters are formed during the monsoon period due to heavy monsoon rains, river discharge and upwelling. Besides the natural disturbance, inordinate bottom trawling activities also play a major role in the alteration of turbidity in the water column. The results of the study clearly establishes the fact that the bottom trawling activities carried out at the coastal waters brought out changes in turbidity and dissolved oxygen concentrations in the water column in general and at bottom layers in particular, making the marine ecosystem inhospitable for sustenance of life supporting system.

Studies on the nutrients at the bottom waters showed that lower values of nitrite nitrogen were present in the bottom waters during premonsoon season of both the years. Nitrite nitrogen content was found to be increasing in the bottom waters in the peak of monsoon season, as observed during July 2001 and 2002. The nitrite–N concentration showed prominent seasonal variation. The concentration increased from June onwards with the entry of land run off and was found to be maximum in July/ September. Spatially, the stations close to the shore had a slightly higher nitrite nitrogen content compared to those offshore. Analysis of nitrite concentration revealed around two - fold increase in the samples collected after trawling when compared to that of before trawling. From the results, it was clear that trawling brought about the increase of nitrite content of the bottom waters to a significant extent. This resuspension may have resulted in an increase in nutrients in the bottom waters immediately after trawling. The interstitial water may also contribute to an increase in the nitrite content of sea water.

The bottom water samples show higher concentration of phosphate phosphorus compared to nitrite during all months, showing high regenerative action and leaching into the overlying waters. After trawling, there was a notably significant increase in the phosphate content, which can be attributed to the churning and mixing of sediment and interstitial water into the overlying water column, due to the action of the trawl gear. Phosphate concentrations were elevated after trawling with an average 2 - 3 fold increase when compared to the values recorded before trawling. It appears that additional concentration of phosphate is thus released into the overlying waters by way of bottom trawling. Phosphate concentration was found to be amplified after trawling at almost all stations throughout the experiment, indicating that the event was independent of the seasonal changes in concentration. Along Kerala coast, the ban imposed on trawling during the monsoon season got lifted by the 29th of July during the study period, thus permitting the trawlers to fish in the coastal waters. The after trawling concentration of phosphate was found to be significantly high in September also, which is indicative of the heavy trawling pressure exerted along the coastal waters.

Variations in the sediment structure due to bottom trawling were studied by analyzing the sediment pattern in the samples collected both before and after trawling experiment. The results revealed that the shelf up to 50m was covered dominantly by fine sediments with clayey silt grading to silty clay, while the region from 35m upto a depth of 50m was covered by sand of predominantly medium and fine nature. In the present study, trawling was found to be responsible for a great number of changes in the grain size parameters. Significant differences in the grain size parameters, mean and skewness have been elucidated, which is indicative of profound physical impact of trawl gear on sediment. After trawling, the samples showed a perceptible decrease in the phi size, concomitant with increase in the sediment particle size. Most of the stations in the 0-30 m depth zone which was previously clayey was transformed with a predominance of silt immediately after trawling. Statistically significant differences in mean indicated an overall reduction in the phi size of sediments pointing to an increase in grain size immediately after trawling. After trawling, the heavier component of sediment obviously settles faster than the lighter ones, reworking the sediment to a significant extent. Thus the stations with silty clay sea floor was metamorphosed into clayey silt with the loss of clay in the 0-35 m depth while in the sandy stations the sand fractions was found to increase in proportion to other component. Stations 1 - 6, which were clayey silt and silty clay in nature in the samples collected before trawling turned into clayey silt after trawling, thus suggesting a loss of clay particles in water. At station 9 and 10, an increase in percentage of sand was noticed after trawling when compared to clayey sand in the samples collected before trawling. Bottom fishing gear can change sediment grain size distribution or characteristics, suspended load and the magnitude of sediment transport processes. Alteration of the chemistry and texture of sediments may render the sea bed habitat less suitable for some species. The sediment resuspension affects the filter feeders and gills of marine organisms as well as eggs and larvae and also cause the outspread of toxic components and increased rates of nutrient flux.

Organic matter analyzed from the trawled grounds showed that trawling process removes the organic content at the sea bottom. The decrease in organic matter was attributed to the loss of sediment surface, rich with organic matter, during the scraping of otter boards and nets. The dispersed sediments may be transported off the grounds along with the currents formed during trawling and eventually reduce the organic load at the trawled areas. Though the heavier particles are refilled at trawled grounds, the lighter particles and organic matter will be washed off along the currents. Maximum quantity of organic matter was observed in the near shore stations which were predominantly muddy in nature. Therefore, the extent of variations in the organic matter was more pronounced at these stations when compared to sandy stations. Based on the results of this study, it can be inferred that the removal of organic food reserve from the sediment surface during bottom trawling might have severely affected the growth of many benthic organisms, which depend on these food reserves for their growth and subsistence.

Effect of trawling on the meiobenthic organisms was studied by examining the meiobenthos from the sediment samples collected before and after trawling experiments. Among meiobenthos, Nematodes formed the dominant group followed by Harpacticoids, Foraminiferans, Polychaetes, Kinorhynchs and Ostracods. Among the various meiobenthos studied, Nematodes were the most prominent of all meiofauna groups and averaged a density of 770 and 1000 ind./10 cm^2 during the first and second years. In the present study, nematodes were at peak density during the monsoon season while the post monsoon witnessed a slight decline in the samples collected before trawling, during both the years. Interestingly, the increase in nematodes coincided with the ban on bottom trawling imposed along Kerala coast. During this period, there are no anthropogenic disturbances to the sea floor, but for natural forces acting upon it. It appears that in the scale of disturbances, man made disturbances would always outweigh that of natural ones, causing the nematode fauna to decline, immediately after the monsoon during when the trawl ban is lifted. Within intensively fished grounds, the background levels of natural disturbance may have been exceeded, leading to long term changes in the benthic community. The harpacticoid copepods, on the other hand, followed the normal cycle of reproduction and the abundance pattern and unlike the nematodes, their density showed a declining trend during the southwest monsoon which was followed by an increase in the post monsoon season. Post trawling increase in abundance of nematodes was found significant when compared to the pretrawling densities. Otter trawls have been observed to overturn rocks and scrape off the upper sediment layer , which is resuspended to expose the subsequent layers. Trawling exposes the burrowing benthic fauna including the nematodes and harpacticoids thus bringing them to the surface, which justify their sudden increase in their abundance in the samples collected after trawling. The benthic nematodes are either resuspended and /or exposed after the passage of trawl which justifies the increase in abundance immediately after trawling.

Polychaetes in the present study had a trivial representation in the meiobenthos compared to that of copepods and nematodes, but their presence could not be ignored due to the fact that they represented more than 10 % of the total meiofauna. In the present study, a range of 0-350 ind./10 cm^2 was observed during the first year and 0-1000 during the second. The polychaetes, in the present study, were found concentrated in the inshore region (0-35m) compared to the offshore region (35-50 m). Sediment characteristics such as grain size, interstitial space and porosity of sediment are considered important in the distribution and abundance of polychaetes. In the present study, the inshore region of 0-35m , with its silty clay and clayey silt texture form an ideal substrate for the juvenile polychaetes to thrive on. Since the oxygen values of the bottom waters were almost at the saturation level, this factor could not be considered as a limiting factor in respect of the study area. In the present study, the highest abundance of polychaetes was recorded during the post monsoon, followed by premonsoon and monsoon. Organic matter was correlated negatively with foraminiferan abundance. Abundance of foraminifera was highest during post monsoon and lowest during premonsoon, an observation fully in agreement with the general pattern of meiofaunal reproduction. During the study, the number of polychaetes was found to increase in the samples collected after trawling. The sediments in the study area, upto a water depth of 35 m are fine and soft, fluctuating between silty clay and clayey silt. The soft nature of the muddy sediments makes them more susceptible to the physical impacts of the trawl gear compared to harder and coarser sediments. The trawl doors penetrate deeply into mud and this result in a potentially greater effect on infaunal communities. In the present study, foraminiferans showed an increase in the post trawling samples. The meiobenthic studies concerning this particular taxa are scarce and so far the impact of trawling on this group has not been elucidated, though a general increase in meiofaunal population has been observed immediately after trawling. The study area, which is also characterized by upwelling waters during the southwest monsoon also sustains a populous density of foraminifera.

The trawl gear with its otter boards scrape away a layer of sediment, exposing the fauna beneath, thus the grab comes into contact with more number of foraminiferans after trawling as opposed to before trawling. In effect, the polychaetes and foraminiferans are likely to be affected through habitat modifications, exposure to predators, resuspension and subsequent transport in the water column.

The results of the present study also revealed the presence of kinorhynchs along the south west coast and remarkably, with lower percentages when compared to nematodes and copepods. The kinorhynchs were ranked 5th in the order of abundance along the study area. These organisms ranged between 0-606 ind./10cm^2 in the first year and from 0-1927ind./10 cm^2 in the second. Statistical analysis of the abundance values before trawling did not reveal any spatial or temporal significance ($P>0.05$), showing that neither the location of stations or seasons had apparently influenced the distribution or reproduction of these fauna. But a close examination of data, it could be seen that spatially the fauna were concentrated more in the inshore clayey silt sediments than in the sandy offshore sediments. The ostracods also formed an undeniable part of the meiofaunal group along the west coast and though ranked 6th on order of abundance , made its presence felt in the offshore stations with more or less silty sand substrata. Seasonality could not be demonstrated statistically in ostracods during the present study presumably due to dearth in ostracod numbers in the samples throughout the experiment, though the post monsoon months showed a slight increase in values during both the years. Horizontally, the ostracods showed a patchy distribution and presumably, such variations in spatial distribution of meiofauna are controlled by variations in more localized physical, chemical and biological factors. A comparison of the spatial distribution of the kinorhynchs before and after trawling revealed significant differences bringing to light the havoc caused by the dragging of the heavy net across seafloor. There was a general decrease of kinorhynchs after trawling , which may be attributed to their dispersal immediately after trawling. Ostracod samples did not show any significance when before and after trawling values were compared (P>0.05). The present experimental site with small organisms such as kinorhynchs and ostracods are affected by trawling through modifications to their habitat, exposing them to predators and resuspension and subsequent transport in the water column. Ostracods are known to moult 4 to 5 times a year and constitute and important component of the scavenging community, cleaning up dead and decayed on the ocean floor. Kinorhynchs, with almost equal number of generation times also constitute an important fauna on the seafloor, with tasks such as scavenging and nutrient regeneration. Being short lived, this community is better equipped to cope with disturbance than the macro or mega fauna, but even this equilibrium can be disturbed when incessant trawling takes place.

Vertically the bulk of meiofauna resides in the top 5 cm layer of the substratum. The results from the present study also did not deviate from this natural phenomenon, with the upper 5 cm sediment teeming with meiofauna, especially the nematodes. Such high aggregations are attributed to the availability of food and oxygen in the top layer. In the case of nematodes it could be observed that at depth zones 0-10 m, 30-40 m and 40-50 m, there existed significant differences in the abundance between the 0-5 and 5-10 cm layers ($P<0.05$). Nematodes were more abundant in the fine sedimentary environment 0-10, 10-20 and 20-30m zones) which was characterized by lower penetration of oxygen in the deeper layers, leading to aggregation in the top layers. Harpacticoids showed extreme preference for surface and in the present study their occurrence was significantly higher in the upper sediment (0-5 cm). In the present study, the population density of meiofauna was not too low in the 5-10 cm layer due to the presence of nematodes, harpacticoids and a lesser number of polychaetes. The population density of kinorhynchs and ostracods in the 5-10 cm layer was found to be very low when compared with that of the former taxa. Moreover the coarse sedimentary environment in 30-40 and 40-50 m depth range in the study area characterized by easy penetration of oxygen could also be helpful in maintaining favourable conditions for the survival of meiofauna. Comparison of abundance of foraminiferans in the study area, in 0-5 and 5-10 cm layers showed almost uniform distribution within the sediment with significant differences only in the 20-30 m zone. Studies have shown that in soft sediments most living benthic foraminiferans are encountered below the sediment surface and can thrive at 6-15 cms within the sediment. In the present context, it could be seen that nematodes underwent changes in abundance after trawling at 0-10, 10-20 and 20-30 m depth zones both in 0-5 and 5-10 cm layers to a significant extent ($P<0.05$). Nematodes were found to increase in number immediately after trawling and moreover it could be inferred that sea floor sediment was disturbed upto atleast 10 cms during trawling. Harpacticoids also showed a significant increase in the inshore depth zones especially the 0-10 and 10-20 m zones at the topmost layer. After trawling, the polychaetes were found to be disturbed in the 10-20 m zone in the upper sediment layer while in the 30-40 m zone the disturbance extended to 5-10 cms of sediment($P<0.05$). The 0-5 cm layer in zones 10-20 and 30-40 m was significantly disturbed in the case of foraminiferans, while in the 0-10 and 40-50 m zones , the 5-10 cm layers were significantly disturbed($P<0.05$). The kinorhynchs and ostracods also exhibited disturbances in the inshore area in the 0-5 cm layer but notable traces of trawl penetration could not be seen in the 5-10 cm layer.

Trawling resulted in inordinate ploughing of the sea bottom and this in turn provided an inhospitable habitat for the growth and survival of sea bottom dwellers, which are habitat dependent to a very large extent. Owing to the pressure of trawl gear on sea bed, parts of the gear penetrate to some extent into the sea bottom and penetration depth is largely dependent on the nature of seabed. The successive layers are brought into suspension and settle after the gear passes. The resuspension of the top layers of sediment makes the benthic fauna more vulnerable to be within the reach of the sediment grab and thus the after trawling samples invariably register an increase in the abundance of meiobenthic population. Only those species which live at depths greater than the penetration depth of trawl gear (greater than 10 cm in the present study) survive resuspension and are slightly affected by trawling. In the study area, the meiobenthos as a whole was seen to be highly aggregated in the upper sediment layer (0-5 cm) compared to the lower segment and the possibility of otter trawl to be extremely harmful to the growth and survival of these organisms could not be ruled out. The inshore depth ranges, 0-10m, 10-20m and 20-30 consisted of clayey and muddy sediments which in turn showed evidence of the maximum disturbed area with the maximum penetration depth and consequently the most disturbed site. It is assumed that subsequent recovery of infaunal communities in muddy habitats following bottom trawling disturbance appears to take longer than in other habitats.

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Appendix I

Table 1. Results of two way ANOVA on temperature recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	701.5343	11	63.77584	87.58443	6.41E-46	1.886683
Columns	3.44875	9	0.383194	0.526247	0.852393	1.975806
Error	72.08825	99	0.728164			
Total	777.0713	119				

Table 2. Results of two way ANOVA on temperature recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	698.4789	11	63.49808	76.77131	2.16E-43	1.886683
Columns	6.465417	9	0.71838	0.868545	0.555893	1.975806
Error	81.88358	99	0.827107			
Total	786.8279	119				

Table 3. Results of two- way ANOVA on salinity recorded before trawling from bottom wate

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	341.3209	11	31.02917	36.92621	3.62E-30	1.886683
Columns	7.445083	9	0.827231	0.984445	0.457741	1.975806
Error	83.18992	99	0.840302			
Total	431.9559	119				

Table 4. Results of two- way ANOVA on salinity recorded after trawling from bottom waters

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	344.7482	11	31.34074	23.0874	1.14E-22	1.886683
Columns	11.74022	9	1.304469	0.960947	0.476923	1.975806
Error	134.3908	99	1.357483			
Total	490.8792	119				

Appendix I

Table 5. Results of two - way ANOVA on pH recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	10.62367	11	0.965788	56.19886	1.44E-37	1.886683
Columns	0.194667	9	0.02163	1.258621	0.269089	1.975806
Error	1.701333	99	0.017185			
Total	12.51967	119				

Table 6. Results of two - way ANOVA on pH recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	9.51425	11	0.864932	33.2763	1.99E-28	1.886683
Columns	0.25175	9	0.027972	1.076168	0.387114	1.975806
Error	2.57325	99	0.025992			
Total	12.33925	119				

Table 7. Results of two way ANOVA on dissolved oxygen of bottom waters before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12.54529	11	1.140481	4.567078	1.38E-05	1.886683
Columns	3.743397	9	0.415933	1.665612	0.107454	1.975806
Error	24.72206	99	0.249718			
Total	41.01075	119				

Table 8. Results of two - way ANOVA on dissolved oxygen of bottom waters after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	14.06311	11	1.278465	4.75096	7.92E-06	1.886683
Columns	3.746313	9	0.416257	1.546872	0.142168	1.975806
Error	26.64051	99	0.269096			
Total	44.44993	119				

Appendix I

Table 9. Results of two - way ANOVA on turbidity of bottom waters before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3360.436	11	305.4942	4.573771	1.36E-05	1.886683
Columns	2734.146	9	303.794	4.548315	5.01E-05	1.975806
Error	6612.471	99	66.79264			
Total	12707.05	119				

Table 10. Results of two - way ANOVA on turbidity of bottom waters after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	13916.51	11	1265.138	12.56398	1.58E-14	1.886683
Columns	6649.353	9	738.817	7.337131	3.99E-08	1.975806
Error	9968.868	99	100.6956			
Total	30534.74	119				

Table 11. Results of two - way ANOVA on nitrite-nitrogen of bottom waters before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	43.90834	11	3.991667	12.41987	2.16E-14	1.886683
Columns	6.248626	9	0.694292	2.160254	0.031179	1.975806
Error	31.81796	99	0.321394			
Total	81.97493	119				

Table 12. Results of two - way ANOVA on nitrite nitrogen of bottom waters after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	50.19057	11	4.562779	10.58668	1.34E-12	1.886683
Columns	8.059622	9	0.895514	2.077794	0.038559	1.975806
Error	42.66826	99	0.430993			
Total	100.9185	119				

Appendix I

Table 13. Results of two- way ANOVA on phosphate phosphorus of bottom waters before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	228.7201	11	20.79273	24.49221	1.46E-23	1.8866828
Columns	3.701173	9	0.411241	0.48441	0.882013	1.9758062
Error	84.04632	99	0.848953			
Total	316.4675	119				

Table 14. Results of two - way ANOVA on phosphate phosphorus of bottom waters after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	230.5089	11	20.95535	24.07782	2.65E-23	1.8866828
Columns	4.37949	9	0.48661	0.559118	0.827314	1.9758062
Error	86.16144	99	0.870318			
Total	321.0498	119				

Appendix II

Table 1. Results of the two- way ANOVA on percentage sand content before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	11541.2	11	1049.2	3.190235	0.000967	1.886683
Columns	113293.1	9	12588.12	38.27588	2.09E-28	1.975806
Error	32558.99	99	328.8787			
Total	157393.3	119				

Table 2. Results of two way ANOVA on percentage sand content after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	8558.41	11	778.0373	1.935782	0.043457	1.886683
Columns	108439.1	9	12048.78	29.97776	1.57E-24	1.975806
Error	39790.48	99	401.9241			
Total	156788	119				

Table 3. Results of two - way ANOVA on silt content before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	11161.46	11	1014.678	11.21634	3.13E-13	1.886683
Columns	30339.1	9	3371.011	37.26344	5.73E-28	1.975806
Error	8955.967	99	90.46431			
Total	50456.53	119				

Table 4. Results of two way ANOVA on silt content after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	14088.49	11	1280.772	11.55403	1.46E-13	1.886683
Columns	33336.12	9	3704.014	33.41445	3.21E-26	1.975806
Error	10974.21	99	110.8506			
Total	58398.82	119				

Appendix II

Table 5. Results of two -way ANOVA on clay content of sediment before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2278.655	11	207.1504	1.49241	0.146267	1.886683
Columns	29598.21	9	3288.69	23.69329	4.72E-21	1.975806
Error	13741.46	99	138.8026			
Total	45618.32	119				

Table 6. Results of two -way ANOVA on clay content of sediment after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2499.975	11	227.2704	1.259322	0.25938	1.886683
Columns	22673.76	9	2519.307	13.95966	2.88E-14	1.975806
Error	17866.57	99	180.4704			
Total	43040.3	119				

Table 7. Results of two-way ANOVA on the percentage organic matter of sediment before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	103.7977	11	9.436158	6.363946	7.06E-08	1.886683
Columns	40.77669	9	4.530744	3.05563	0.002862	1.975806
Error	146.7925	99	1.482753			
Total	291.3669	119				

Table 8. Results of two-way ANOVA on the percentage organic matter of sediment after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	44.66497	11	4.060452	3.339768	0.000608	1.886683
Columns	44.08393	9	4.898214	4.028837	0.000203	1.975806
Error	120.3631	99	1.215789			
Total	209.112	119				

Appendix IV

Table 1. Results of two - way ANOVA on abundance of polychaetes before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	280159.3	11	25469.03	1.289069	0.241904	1.886683
Columns	108847.8	9	12094.2	0.612126	0.784136	1.975806
Error	1956012	99	19757.69			
Total	2345019	119				

Table 2. Results of two- way ANOVA on abundance of polychaetes after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	360290.7	11	32753.7	3.434946	0.000452	1.886683
Columns	54349.26	9	6038.807	0.633302	0.766127	1.975806
Error	944008	99	9535.434			
Total	1358648	119				

Table 3. Results of two way ANOVA on abundance of foraminiferans before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	4530662	11	411878.3	1.679854	0.088973	1.886683
Columns	589896.1	9	65544.01	0.267323	0.981933	1.975806
Error	24273509	99	245187			
Total	29394067	119				

Table 4. Results of two-way ANOVA on abundance of foraminiferans after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2955754	11	268704.9	0.753714	0.684601	1.886683
Columns	3342371	9	371374.5	1.0417	0.412821	1.975806
Error	35294294	99	356508			
Total	41592419	119				

Appendix V

✓ **Table 1**. Results of two-way ANOVA on abundance of kinorhynchs before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	828269.8	11	75297.25	1.590208	0.11324	1.886683
Columns	701607.6	9	77956.4	1.646367	0.112505	1.975806
Error	4687707	99	47350.57			
Total	6217584	119				

✓ **Table 2**. Results of two-way ANOVA on the abundance of kinorhynchs after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	209342.3	11	19031.11	1.91392	0.046264	1.886683
Columns	344754	9	38306	3.852355	0.000328	1.975806
Error	984409.3	99	9943.528			
Total	1538506	119				

✓ **Table 3**. Results of two-way ANOVA on abundance of ostracods before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	318413.9	11	28946.72	4.254742	3.59E-05	1.886683
Columns	115898.9	9	12877.65	1.892826	0.061604	1.975806
Error	673536.7	99	6803.401			
Total	1107849	119				

✓ **Table 4**. Results of two-way ANOVA on abundance of ostracods after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	148627	11	13511.55	0.923007	0.521713	1.886683
Columns	195304.2	9	21700.46	1.482412	0.164883	1.975806
Error	1449224	99	14638.62			
Total	1793155	119				

Appendix VI

Table 9.1 Results of the t test on comparing the abundance of meiofauna in 0-5 and 5-10 cm layers before trawling

Item	Depth zone(m)	t	df	Significance
Nematoda	0-10	3.56	9	*
	10-20	1.61	9	N.S
	20-30	1.95	9	N.S
	30-40	3.04	9	*
	40-50	3.76	9	*
Harpacticoida	0-10	3.52	9	*
	10-20	0.90	9	N.S
	20-30	3.00	9	*
	30-40	1.36	9	N.S
	40-50	3.01	9	*
Polychaeta	0-10	1.91	9	N.S
	10-20	0.95	9	N.S
	20-30	4.34	9	N.S
	30-40	1.10	9	N.S
	40-50	3.22	9	*
Foraminifera	0-10	1.31	9	N.S
	10-20	0.37	9	N.S
	20-30	1.91	9	*
	30-40	1.06	9	N.S
	40-50	1.34	9	N.S
Kinorhyncha	0-10	1.74	9	*
	10-20	2.11	9	*
	20-30	2.33	9	*
	30-40	1.62	9	N.S
	40-50	0.23	9	N.S
Ostracoda	0-10	0.54	9	N.S
	10-20	0.51	9	N.S
	20-30	3.32	9	*
	30-40	1.94	9	*
	40-50	2.98	9	*

N.S - Not significant

* - $P < 0.05$ ** - $P < 0.01$

Appendix VI

Table 9.2 Results of the t test on comparing the abundance of meiofauna before and after trawling at 0-5 cm depth layer

Item	Depth zone(m)	t	df	Significance
Nematoda	0-10	0.61	9	*
	10-20	0.60	9	*
	20-30	1.12	9	*
	30-40	0.41	9	*
	40-50	0.03	9	N.S
Harpacticoida	0-10	2.59	9	*
	10-20	1.17	9	*
	20-30	0.72	9	N.S
	30-40	1.55	9	N.S
	40-50	0.62	9	N.S
Polychaeta	0-10	0.16	9	*
	10-20	2.17	9	N.S
	20-30	0.75	9	*
	30-40	1.53	9	N.S
	40-50	1.31	9	*
Foraminifera	0-10	0.29	9	N.S
	10-20	1.84	9	*
	20-30	0.23	9	N.S
	30-40	1.19	9	N.S
	40-50	2.75	9	*
Kinorhyncha	0-10	0.41	9	N.S
	10-20	1.53	9	*
	20-30	1.92	9	*
	30-40	0.18	9	N.S
	40-50	0.72	9	N.S
Ostracoda	0-10	1.43	9	N.S
	10-20	0.62	9	N.S
	20-30	2.24	9	*
	30-40	0.31	9	N.S
	40-50	0.18	9	N.S

N.S - Not significant

* - $P< 0.05$ ** - $P< 0.01$

Appendix VI

Table 9.3 Results of the t test on comparing the abundance of meiofauna before and after trawling at 5-10 cm depth layer

Item	Depth zone(m)	t	df	Significance
Nematoda	0-10	1.85	9	*
	10-20	0.33	9	*
	20-30	7.83	9	*
	30-40	0.05	9	N.S
	40-50	0.46	9	N.S
Harpacticoida	0-10	0.59	9	N.S
	10-20	1.07	9	N.S
	20-30	1.41	9	N.S
	30-40	2.19	9	*
	40-50	0.24	9	N.S
Polychaeta	0-10	0.00	9	N.S
	10-20	1.44	9	N.S
	20-30	0.31	9	N.S
	30-40	1.76	9	*
	40-50	0.85	9	N.S
Foraminifera	0-10	1.81	9	*
	10-20	0.00	9	N.S
	20-30	0.29	9	N.S
	30-40	0.24	9	N.S
	40-50	1.63	9	*
Kinorhyncha	0-10	0.63	9	N.S
	10-20	1.25	9	N.S
	20-30	1	9	N.S
	30-40	1.47	9	N.S
	40-50	0.97	9	N.S
Ostracoda	0-10	0.2	9	N.S
	10-20	0.74	9	N.S
	20-30	0.88	9	N.S
	30-40	0.83	9	N.S
	40-50	1.43	9	N.S

N.S - Not significant

* - $P < 0.05$ ** - $P < 0.01$

Appendix VII

Papers published

Thomas, J.V., Sreedevi, C. and Kurup, B.M., 2006. Variations in the infaunal polychaetes due to bottom trawling along the inshore waters of Kerala (Southwest coast of India). *Indian Journal of Marine Sciences*, 35(3): 249-256.

Papers in press

1. Joice V.Thomas, Premlal, P., Sreedevi, C. and B. Madhusoodana Kurup 2001. Immediate effect of bottom trawling on physico-chemical parameters in the inshore waters (Cochin – Munambam) of Kerala (South India). *Indian Journal of Fisheries.*
2. B.Madhusoodana Kurup, Sreedevi.C and Joice V. Thomas 2004. Immediate effect of trawling on sea bottom and its living communities along the Kerala coast. Paper presented at the Ocean Life-Food and Medicine expo International Conference And Exposition On Marine Living Resources o India for Food and Medicine, in Chennai, 27-29 February 2004.
3. Sreedevi, C., Joice V. Thomas and B. Madhusoodana Kurup. 2002. Tempora and spatial variations in meiofaunal polychaete assemblages at 0-50m along Cochin waters, Kerala. *Indian Journal of Fisheries*

Papers communicated

1.Joice V.Thomas; C.Sreedevi and Madhusoodana Kurup 2001. Immediate effect of trawling in the regeneration of inorganic phosphate along the inshore waters of Kerala. *Journal of Marine Biological Association of India.*

2.Joice V.Thomas, C.Sreedevi and Madhusoodana Kurup 2002. Immediate effect of bottom trawling on nutrients with special reference to nitrite and phosphate along the inshore waters of Kerala. *Journal of Marine Biological Association of India* (JMBAI).

3.Sreedevi, C and B. Madhusoodana Kurup. Effects of experimental bottom trawling on Nematodes of the shelf waters of Kerala, Southwest coast of India. Paper presented at the *Sixth Asian Fisheries Forum*, conducted at CIFE, Mumbai, 16 – 20th December 2002.

4\. C.Sreedevi and B. Madhusoodana Kurup.2003.Immediate impact of bottom trawling on sea bottom ecology of the shelf waters of Kerala, southwest coast of India, with special reference to Nematodes. *Journal of Marine Biological Association of India .*