IMPACT OF TRAWLING ON SEA BOTTOM AND ITS LIVING COMMUNITIES ALONG THE INSHORE WATERS OF SOUTHWEST COAST OF INDIA

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DOCTOR OF PHILOSOPHY

BY

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Dedicated to My Beloved Parents

DECLARATION

I, Joice V. Thomas do hereby declare that the thesis entitled "**Impact of trawling on sea bottom and its living communities along the inshore waters of southwest coast of India**" 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 Shri. **Joice V. Thomas** under my supervision and guidance in 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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Joice V. Thomas

CONTENTS

LIST OF ABBREVIATIONS

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

Chapter 1

GENERAL INTRODUCTION

A. Introduction

Marine ecosystems are highly complex inter linked and interactive in which organisms, habitats and external forces (Ocean currents, weather) are acting together to shape communities and regulate population abundance. Living organisms are constantly adapting and evolving to their environment. Marine ecosystems are generally extensive and open and the properties characterizing marine ecosystems are always subjected to variations due to natural and artificial forces. Ecosystems are continually changing and these changes are driven by a multiplicity of factors. These factors like El Nino sometimes go without any bounds for longer time. Ecosystems have real thresholds and limit which, when exceeded, can effect irreversible major system restructuring (Holling and Meffe, 1996). When an ecosystem is radically altered it may never return to its original state, even after the stress is removed.

Human interactions on the marine ecosystems cause severe perturbation than any other natural forces. Today, fishing is recognised as the most widespread human exploitative activity in the marine environment (Jennings and Kaiser, 1998) and therefore has significant direct and indirect effects on habitat, diversity, structure and productivity of benthic communities (Collie *et al.*, 1997; Tuck *et al.*, 1998). Fishing has altered and magnified natural declines in the abundance of many fishes. Bottom fishing activity has been practiced for centuries, but the extent and intensity of trawling has expanded immensely during the last century. 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 14th century in the United Kingdom and from the 16th century in the Netherlands (Graham, 1955; De Groot, 1984; Lindeboom and de Groot, 1998). The complaints were raised regarding the mesh size as well as the deleterious effects of this gear such as wanton destruction of juveniles of fish and other benthic organisms. In the United Kingdom, acts had already been passed in the parliament to ban the use of this gear in 1350 and 1371 for the preservation of fry of fishes. Steam powered trawlers began operating in European waters since 1881's and in USA and Japan by early 1900"s. Beam trawls which were prevalent in 1880's and still continues to be used in certain fisheries is considered to be the forerunner of the present otter trawls. The otter trawls net in its present form appeared first in Ireland in 1885 and was adopted by commercial trawl fisheries during 1892-1905. In the 19th century, the use of beam and otter trawls came out with the similar criticism as the Dutch fishermen protested against the use of trawls in the shallow Zuiderzee (Now ljesselmeer). They argued that the trawl would affect the yield of commercial species since it destroyed large amount of juveniles and eggs. In the United Kingdom, trawl came under attack again in 1863 quoting the same problems as cited above. With the advances in technological developments of trawling gears (weight and size), particularly over the later part of 20th century, an increase was noticed in the number of fishing vessels, their engine power, size of the gear etc. and these concerns are increasingly gaining international public and political importance.

The trawl net is basically a large bag made of netting, which is drawn along the seabed to scoop up fish on or near the bottom. The net is wide at one end called the mouth, which is open, leading to the body of the net, which tapers to the closed end called the "cod end", where the fish entering through the mouth are trapped. The mouth is of an oval shape when viewed from the front, and is attached to two wings that stretch out in front on either side to increase the area swept and to guide the fish to the cod end. Around the upper edge of the mouth runs the "head rope" or "head line" to which a number of floats are fixed and around the lower edge of the mouth is a "ground rope" which is in contact with the bottom and is weighted. The combined effect of the floats on the head rope and weighted ground line keeps the mouth open vertically. The ground rope may be weighted with chain or it may be merely wire when the net is being operated on a clear bottom. When used on rough bottom iron or rubber rollers are rigged to assist its passage. Otter trawls derive their names by the use of two large boards or doors attached to the towing warps, which act as paravanes to maintain the lateral opening at the mouth of the net. The boards can weigh several kilograms in air and are towed at an oblique angle across the seabed.

Wide cry has echoed in 1970, at the International Council for the Exploration of the Sea (ICES) to put forth the idea to study the possible impact of trawl and dredges on the seabed and the benthic fauna (De Groot, 1984). In 1998, ICES study group studied the effect of bottom trawling (Linnane *et al.*, 2000). Based on this, many countries started studies on the direct effect of fishing activities on the benthos (Bergman *et al.*, 1990; Bergman and Hup, 1992). Following to this, many multi-national studies also conducted to evaluate the direct and indirect effect of trawling on the marine environment (De Groot and Lindeboom, 1994; Lindeboom and de Groot, 1998). Over the past 25 years, there had been an increasing interest to investigate the effect of fishing –not only for target but also for non-target species. Experimental studies were also conducted in many countries such as New Zealand (Thrush *et al.*, 1995, 1998), Australia (Moran and Stephensen, 2000), Canada (Prena *et al.*, 1999), U. S. A (Collie *et al.,* 1997, 2000a; Freese *et al.*, 1999), Great Britain (Kaiser *et al.*, 1998a; Tuck *et al.,* 1998), the Netherlands (Bergman and Hup, 1992) and Sweden (Hansson *et al.*, 2000).

Trawling and dredging can be expected to cause a number of direct and indirect changes in the ecosystem (Riemann and Hoffmann, 1991). Direct effects of bottom trawling are a) mortality of marine organisms by killing, injuring and sung or exposing them to scavengers or predators b) increasing food availability to scavengers by way of discard fishes and dead benthic organisms c) loss of habitat by the heavy disturbance and destruction of seafloor habitat.

Indirect effects are the downstream consequence of direct effect in the form of high turbid clouds, and increase in oxygen demand, removal of organic matter by dispersion or burying under, shift in benthic assemblages and reduction in benthic primary productivity. Trawl gear can crush, bury or expose marine flora and fauna and reduce structural diversity (Auster and Langton, 1999). The variations on these flora and fauna had showed that the original benthic structure and species population might not have an opportunity to recover to the pre trawl conditions.

Bottom trawling is a form of active fishing with an aim to catch fish and crustaceans that live in or in association with the benthic environment and the gear is therefore designed to have a best possible contact with the seabed (Bergman and Hup, 1992). Direct contact of trawling gear with the substratum, via ground rope, chains, sweeps, doors and net may result in scraping, ploughing and sediment re-suspension (Jones, 1992). Based on the study report of ICES, the effect on the bottom was classified as scraping, penetration, burying and mortality in benthos (by removal of non-target invertebrates and damages and exposure of benthos in the trawl path). The environmental consequence due to trawling activities has gained more attention during the past decade. Demersal trawls have two major effects on the environment; first, the net removes, destroys and damages a number of organisms per unit area. Secondly, the trawl gear (wires, doors, sweeps and net) disturbs the sediment surface.

Studies conducted on the fish stocks and human activities revealed drastic collapse of many fish stock (Myers *et al.*, 1995) during the past few decades. Wide concerns have been raised on the rate of increase in global catch, which is declining as demand is increasing (Myers *et al.*, 1997; Cook *et al.*, 1997) and that unwanted by-catch forms a relatively large proportion of the total catch (Alverson *et al.,* 1994). Fishing is responsible for increasing the mortality of target and by -catch species and disturbing marine habitats

(Beverton and Holt, 1957; Cushing, 1968; Nikoloski, 1969; Gulland, 1977; Poiner *et al.*, 1990; Anedrew and Pepperell, 1992; Smith, 1994; Alverson *et al.*, 1994; Jeffersen and Curry, 1994; Simmonds and Hutchinson, 1996). The direct effect of fishing has much indirect implication for other species by removing the prey that piscivorus fishes, birds and mammals would otherwise consume or by reducing the predators that otherwise control prey populations. Moreover, reduction in the density of some species may decrease the competitive interaction, which results in the proliferation of non-target species (Francis *et al.*, 1992; Briitton and Morton, 1994).

Fishing has affected the flora and fauna of a given habitat in many ways depending on the type of gear used and the magnitude of the effort depending upon several factors, including gear configuration, towing speed, water depth and the substrate over which tow occurs (Auster and Langton, 1999). Variations in substrate include alterations in sediment type, bed form (sand wave and ripples, flat mud) and biological structures (shell, microalgae, vascular plants, sponges, corals burrows). Trawls and dredges have marked impacts on the substratum. Physical disturbance of the substratum results from the direct contact with the fishing gear and the turbulent re-suspension of sediment surface. Many studies revealed that trawling reduces the overall surface roughness of the seabed (Churchill, 1989; Krost *et al.*, 1990; Schwinghamer *et al.*, 1996). The physical disturbance of sediments can result in a loss of biological organization and reduce species richness (Hall, 1994).

Many studies reported that bottom trawling caused damage to the infaunal communities. The infaunal organisms, which live inside the sediments, may be dispersed off during the trawling operations. The studies conducted in the stable sediments reported that penetration of otter boards and net into the sediments while dragging reduced the number of species and individuals drastically (Kaiser and Spencer, 1996a). Tube–building worms, amphipods and bivalves were identified among the most sensitive animals affected by trawl disturbance.

The activities of fishers also provide food for scavenging species since fishes, benthic organisms and other unwanted by-catch are often discarded and also include species which are damaged or killed on the way of towing gear but not caught in the net. These fishing activities subsidize marine food webs with carrion that would be unavailable under natural conditions, which may have profound effect on scavenger species (Jennings and Kaiser, 1998). Seafloor structure serves as nurseries for juvenile fish and provides refuge and food for adults (Steele, 2002). Benthic organisms (plants, corals and sponges) and sediment forms (mud burrows and gravel) add structure to the seafloor forming a complex ecosystem at bottom. Habitat complexity improves the survivorship of many species. Areas of the seafloor that lack these structures do not support the variety of fish population observed in marine complex region (Collie *et al.*, 1977).

Repeated trawling and dredging result in discernible changes in benthic communities. Many studies reported that repeated trawling and dredging causes a shift from communities dominated by species with relatively large adult body size towards dominance by high abundance of small-bodied organisms (Auster et *al.*, 1996; Kaiser and Spencer, 1996b; Watling and Norse, 1998; Kaiser *et al.*, 2000a; Jennings *et al.*, 2001a). The highly trawled areas are reported to be remaining permanently altered, inhabited by fauna that are adapted to frequent disturbance.

Mechanized fishing started in Indian waters in mid –fifties and large-scale operation of trawl fishing began in the mid sixties by the surfeit of individual entrepreneurs. The southwest coast of India especially the coastal waters of Kerala are the most productive area in the subcontinent and the state has been in the forefront in marine fish production (Kurup, 2001a). Though the coastline of Kerala is one tenth of the coastline of India, the state occupies the foremost position in the marine fish production of the country, accounting for more than 30% of the marine fish landings (Thomas, 2000). The coastal waters of Kerala have rich and diversified fishery resources, which are prone to heavy exploitation by a unprecedently high number of fishing gears, among them, mechanized bottom trawlers with a numerical strength of 4550 (Kurup, 2001a) against the permissible number of 1145 (Kalawar, *et al.*, 1985) are the most destructive. Trawling operations during monsoon periods in Kerala has been a subject of controversy between traditional fishermen and trawl fishers on a subject that trawl fishing destroys large amount of juveniles and young ones of fishes since this period is the major breeding season of most of the fish and prawns (John, 1996). Therefore Government of Kerala imposed a ban on bottom trawling activities from 1988 onwards for a period varying from 21-70 days, which usually commences from June 15th. Though many studies revealed that large amount of non-target groups were destroyed in the commercial trawl fishing in the Indian waters, no concerted study has been conducted so far to evaluate the real impact of bottom trawling on the sea bottom and its living communities. The present study was conducted to assess the impact of excessive bottom trawling exerted on the sea bottom habitat and its living communities, which would be useful in impressing up on the seriousness of habitat degradation and biotic devastation, enabling the concerned to adopt relevant conservation and management steps to conserve the resources for sustainable exploitation.

Against this background the present study was undertaken with the following objectives

1. To study the immediate effect of bottom trawling on the physico-chemical parameters
2. To study the immediate effect of bottom trawling on productivity.
3. To estimate the immediate effect of bottom trawling on the sediments
4. To quantify the amount of destruction on the epifauna due to bottom trawling
5. To estimate the immediate effect of bottom trawling on the infaunal organisms

The results of the present study are depicted in nine chapters. The first chapter deals with the general introduction and the review of literature in which the rationale of the study and the present scenario of our waters are clearly depicted. Second chapter clearly illustrate the materials and methods adopted in the study. The results of the variations on the physico-chemical parameters in the seawater due to bottom trawling are given in the chapter 3 while, chapter 4 presents the results of the variations on the nutrients due to bottom trawling. The results on the variations on the chlorophyll concentration in water due to bottom trawling are given in the chapter 5. Chapter 6 gives the results of the effect of trawling on the sediments. The quantification of the epibenthic organisms discarded in the commercial bottom trawlers were analysed and are presented in chapter 7 The immediate effect of bottom trawling on the abundance and biomass of the infaunal macrobenthos are given in chapter 8. The results of the study is summarized in the chapter 9 and the appropriate recommendations on the basis of the results for mitigating the deleterious effect of the bottom trawling on the marine ecosystem in order to conserved the rich fishing grounds are also suggested in this chapter. This chapter is followed by a list of references cited and appendices.

B. REVIEW OF LITERATURE

The concerted attempts made by the scientific community revealed that fishing has led to widespread disturbance of marine ecosystems and this recognition is now beginning to be acted upon by policy-makers and authorities. Marine ecosystem is a complex adaptive system composed of 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. Jones (1992) reported that the direct contact of trawling gear with the substratum by means of ground rope, chains, bobbins, sweeps, doors, chaffing mats or parts of the net might result in scraping, ploughing and sediment re-suspension. 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). Caddy (1973) examined fishing trawl and dredge impacts on bottom sediment in Chaleur Bay, Gulf of St. Lawrence. He also found that the passage of the dredge stirred up a load of suspended sediment, which reduced the visibility from 4- 8 metres to less than 2 metres for 10-15 minutes. Caddy (2000) observed that re-suspension of particles, toxic substance and nutrients affect the oxygen budget and nutrient level.

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 (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. Researchers have also estimated the penetration depth from the benthos species caught by a gear (Houghton *et al.*, 1971; Bergman and Hup, 1992), while Laban and Lindeboom (1991) measured changes in sedimentary characteristics before and after trawling.

Apart from creating mortality and discards, towed gears in contact with the seabed disturb it physically and cause re-suspension of fine particles and relocation of stones and boulders, which increase the turbidity of water (Gislason, 1995). Redant (1987) noticed the rise of sediments into the water column during bottom trawling as the trawl net scrape the bottom. Caddy (1973) also had made similar observation in the study conducted along the continental shelf of Middle Atlantic Bight. Churchill (1989) observed that the transport of bottom sediments during bottom trawling would bring the low oxygen waters to the surface.

Trawling on muddy grounds generate heavy sediment clouds in the water column (Clerk and Hovart, 1972). 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 Combe and Mac Donald (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). He postulated the effect of increased turbidity on sessile organisms and larval survival. Re-suspension of sediments causes smothering of sessile organisms, prolonged hatching time as well as reduction in growth, lessened feeding efficiency and impaired growth of bottom vegetation due to lesser light penetration (Sanchez - Jerez and Ramos - Espla, 1996). 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) found 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). Sankaranarayanan and Qasim (1969) also noticed heavy upwelling along the west coast of India. West coast of India is subjected to extreme seasonal changes of atmosphere, which are manifested as northeast and southwest monsoons (Sastry and D 'Sousa, 1972). Though upwelling creates a favourable boost in phytoplankton production by the rise of nutrients from bottom water

(Banse, 1972; Kumar and Prasad, 1996), the negative effect of upwelling is more prominent by way of increase in turbidity and subsequent decrease in dissolved oxygen as well as possible lethal algal blooms notorious for massive fish kills (Naqvi *et al.*, 1998). In addition to these natural processes, bottom trawling exacerbates this condition by increasing turbidity, reducing oxygen content and abrupt release of nutrients along with lethal gases like ammonia, hydrogen sulphide etc so as to create an unfavorable environment in the benthic ecosystem for the living communities (Watling and Norse, 1998). Dredging and trawling causes 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 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 blooms 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. Variations in fish landings based on the physico-chemical parameters of the fishing grounds in the west coast of India was reported by

Rivonker *et al.* (1990). Dissolved oxygen and salinity play an important role in controlling the distribution of fish and other living organisms in the marine environment (Pillai, 1993). Studies along the southwest coast of India revealed that bulk of the pelagic fish populations consisting of oil sardine, mackerel and white bait avoided temporarily areas of intense upwelling activity because of low dissolved oxygen concentrations and high turbidity (Sankaranarayanan and Qasim, 1969; Muraleedharan and Kumar, 1996). Heip *et al.* (1992) studied the role of chlorophyll content of the sediments in the benthic productivity. Organic production in marine ecosystems is truly connected to the environmental parameters and the variations on the physico-chemical parameters will definitely affect the organic production in water (Triantafyllou *et al.*, 2000). 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).

Physical parameters like temperature, salinity and dissolved oxygen play vital role in abundant production of pelagic fish (Suresh *et al.*, 1978). 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. Krishnamurty *et al.* (1974) reported the influence of salinity variation on the distribution and dispersal of aquatic organisms in their study conducted at Porto Novo.

The increase in turbidity and consequent decrease in the oxygen content in the marine waters due to the bottom trawling activities has 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). Muller and Puls (1996) stated that re-suspended sediments act as carriers for organic and inorganic pollutants. High level of turbidity and sedimentation has been reported to prevent settlement of benthic larvae, thus affecting re-colonization after disturbance (Gattsoft, 1964; Stevens, 1987). Dayton *et al.* (1995a & b) reported that the turbid clouds formed due to trawling may result in changes to fish communities, from ones dominated by fish that find food using their eyesight, to ones that find food by touch or by sensing it through chemical attraction. Humborstad *et al.* (2002) found that the scraping and ploughing on the seabed reduce the roughness of the sea bottom causing the reduction of habitat complexity and diversity. Auster (1998) made a conceptual model of the impacts of fishing gear on the integrity of fish habitat.

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.

Oceans comprise 71% of the Earth's surface and the marine phytoplankton clearly plays a significant role in the global biogeochemical cycling of carbon, nitrogen, phosphate, silicate and many other elements (Kilham and Hecky, 1988). Primary productivity sustains the higher trophic levels of the marine ecosystem, as it is the only source of energy. Pauly and Christensen (1995) estimated that 8 % of the world aquatic primary production is required to sustain the fisheries. Cahoon *et al.* (1993) also studied the role of benthic microalgae in the benthic productivity in their study on the benthic microalgal production at Stellwagen Bank, Massachusetts Bay, USA. Disturbance on the sea bottom would reduce the primary production due to the removal of microalgae present on the sediments surface. Cahoon *et al.* (1990) and Cahoon and Cooke (1992) made a detailed study on the benthic microalgal biomass in sediments of Onslow Bay, North Carolina. Segar and Hariharan (1989) obtained high phytoplankton production in Indian waters during monsoon and post monsoon months due to the input of large amount of nutrients.

Nair *et al.* (1968) stated that shallow waters exhibit high productivity due to the accumulation of more nutrients and minerals. High productivity of the Arabian Sea has been reported by D' Souza and Sastry (1975) and this region of the Indian Ocean is known to be the most productive (Ryther and Menzel, 1965). High rate of production was also noticed in the shallow waters of the coastal region of Laccadive and Minicoy islands (Prasad and Nair, 1960) where primary productivity showed a decreasing trend toward more depths (Nair *et al.*,1968). High productivity in the surface waters contributes to the organic rich sedimentary deposits on the continental shelves and slopes (Demaison and Moore, 1980).

The growth and development of phytoplankton population depends on several environmental factors, which are variable according to seasons and regions (El-Gindy and Dorgham, 1992). Sen Gupta *et al.* (1975) stated that nutrients especially nitrogen and phosphate have a strong influence in regulating the phytoplankton productivity. Smith *et al.* (1991) reported high primary production during postmonsoon periods while the lowest was during May in the Arabian Sea. The high productivity in the monsoon and postmonsoon periods was reportedly due to the accumulation of enormous amount of nutrients and minerals in the coastal waters from the river discharge (Subramanyan and Sarma, 1965).

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. The dispersion of sediment surface due to the scraping action of bottom trawls may reduce the productivity at sea bottom (Collie *et al.*, 1997). Brylinski *et al.* (1994)

demonstrated that the biomass of benthic diatoms (measured as chlorophyll a) was significantly less in trawl door furrows on a muddy substratum in shallow water. Guillen *et al.* (1994) observed a reduction in primary productivity due to the loss of meadows on the sea bottom, one of the major sources of primary production, during bottom trawling.

The major primary producers on the sea bottom are the microphytobenthos, which form an important component of all shallow water ecosystems, which are characterized by ample light penetration on the sediment surface (Cahoon, 1999). Miller *et al.* (1996) investigated the ecological role of microphytobenthos in the shallow water marine habitats. Muddy bottom sediments are characterized by very small mineral grains bound loosely with organic material and associated microorganisms (Holland *et al.*, 1974). Patterson (1989) noted that the diatoms protect the underlying sediments from erosion as it forms a brownish mucous mat or carpet over the sediments. Delegado *et al.* (1991) studied the effect of sand movement on the growth of benthic diatoms. The removal of microphytobenthos from the sediment surface due to trawling may affect the growth of macro, meio and other micro benthos since microphytobenthos act as a major food resource of these organisms (Blanchard, 1990). Rasheed *et al.* (2000) also noticed high chlorophyll values in the dredged bottom waters due to the transport of microflora from sediments to the water column due to the churning action of dredging.

Mirachi (1998) suggested that the present day trawlers are more powerful than those in the past and improved technologies allow trawlers to fish deeper, farther offshore and on rougher bottoms. 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 study 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). Walting *et al.* (2001) stated that the bottom trawling is the most dangerous destructive force in the ecosystem. Caddy (1968) made underwater observations on tracks of dredges and trawls. DeAlteris *et al.* (1999) made an attempt in Narragansett Bay, Rhode Island, to study the significance of seabed disturbance by mobile fishing gear. Passage of heavy mobile gears such as bottom trawl, beam trawl and dredges over sea bed induce sediment re-suspension that result in extensive expulsion of the suspended sediment in the fishing grounds (Watling and Norse, 1999). Kutti (2002) came across alteration in seabed communities due to bottom trawling at Bear Islands.

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. Heip (1995) observed the decrease of phytoplankton production due to the high amount of nutrients in the marine environment. The marine ecosystem is dominated by a microbial food web with nutrients being recycled through phytoplankton, zooplankton groups and bacteria along with detritus resulting in strong coupling between pelagic and benthic systems (Dounas and Koutsoubas, 1996; Koutsoubas *et al.*, 1997). 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. Morrison *et al.* (1998) noticed high algal production at the coastal upwelling zone due to the heavy nutrient concentration. Nutrients are taken up by the phytoplankton in large amounts for their growth (Nair, 1990). The excessive organic production at the surface waters due to the abnormal rise in nutrient concentrations due to monsoon along with upwelling reduces the oxygen content in the water column (Mantoura *et al.*, 1993). The over–enrichment of water with nutrients and the resulting enhancement of growth and decay of aquatic vegetation would lead to the depletion of oxygen (Ryther and Dustan, 1971).

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. Under water observations made by Korotkow and Martyschewski (1977) reported turbulence of bottom sediments during bottom trawling. Thressiamma *et al.* (1998) made a preliminary study on the effect of dredging on seabed at Cochin harbour in the Kerala state southwest coast of India. Gislason (1995) 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). The incessant perturbations on the substratum may leave the seabed in an altered condition (Eleftheriou and Robertson, 1992). Black and Parry (1994) studied the sediment transport rates and sediment disturbance due to scallop dredging in Port Phillip Bay. Similarly 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).

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.*, 2000). Korotkow and Martyschewski (1977) used an underwater device "Atlant" for the study of fish behaviour and trawl net operation. 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. Bohlen and Winnick (1984) made observations of the near-bottom suspended matter concentration at central Long Island Sound. The effect of dragging has a strong and immediate impact on the sediment milieu by suspension of fine sediments into the water column (Caddy, 1968).

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. Laban and Lindeboom (1991) worked on the penetration of trawl gear under the 1990 BEON programme. Under the framework of the IMPACT-I programme, the penetration depth of a 12 m beam trawl was estimated by recording changes in the depth-frequency distribution of nematodes in sandy sediments (Santbrink and Bergmann, 1994), which revealed that persistence of trawl marks depend on grain size, current strength and biological activity (Smith *et al.*, 2000). On sandy sea bottom, the tracks are short lived where as in muddy bottom the tracks will be deeper and last longer, even for years together (Schwinghamer *et al.* 1998a & b).

The tickler chains were seen to affect only a thin layer of top sand, although protruding or irregularly shaped boulders were regularly pulled out of the sediments (Linnane *et al.*, 2000). 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. Arts and Weber (1970) measured a penetration depth of 10-15 cm in muddy/ fine sand. Due to the pressure of the trawl gear on the seabed, parts of the gear penetrate to some extent into the sea bottom. The pressure exerted by a beam trawl on the seabed is relatively low, an average of about 2 Newton cm^{-2} and does not increase considerably with the size of the gear (Fonteyne *et al.*, 1998). The penetration depth largely depends on the nature of the bottom (De Groot, 1972). Depending on the sediment type, weight of beam, shoes, weight per unit length, number of spacing of tickler chains towing speed and tidal condition, a beam trawl will cause a more or less distinct tracks estimated to persist for up to 523 hours (Bergman *et al.*, 1990). 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).

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 re-suspension 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). Brown (1989) studied the problems and policies of bottom trawling in Strangford Lough. Watling *et al.* (2001) discussed that the dragging of heavy nets along the sea bottom reduce the organic matter of the top layer of the sediments and also make the surface more coarse which in turn changes the natural sediment milieu. The reduction of organic matter may affect the growth and development of benthic organisms since most of the bottom dwelling organisms depend on the organic deposit on the sea bottom for their food (Levinton, 1989).

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 (2000a) made a study on the impact of fishing gear on the sea floor in New England. Roggers *et al.* (1999) studied the ecosystem effects of demersal fishing in European waters. Gordon *et al.* (1998) evaluated the effect of mobile fishing gear on the benthic habitat and communities in Eastern Canada.

Bottom trawling causes intense perturbation on the sea bottom by killing and destroying the benthic organisms and also causes immense changes to the bottom sediment structure (MacDonald *et al.*, 1996). Jennings *et al.* (2001) made systematic research on the impact of trawling/ dredging on the marine ecosystem. In the study conducted by Thrush *et al.* (1995) on the short term impacts of bottom trawling on benthos revealed that bottom trawling inflict heavy alteration on the benthic community. Investigations on the effects of mobile fishing gears on epifaunal communities were extensively reviewed in the IMPACT II report (Tuck *et al.*, 1998).

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) studied the effect of fishing on marine ecosystems. Hall (1999) made thorough studies on the effect of fishing on marine ecosystems and communities.

Dayton *et al.* (1995a & b) conducted a study on the response of macrobenthos to the disturbance in the marine environment. Auster and Langton (1999) evaluated the effect of mobile fishing gear on seafloor habitats in the Gulf of Maine. Scallop dredging removes maerl thalli and in turn cause the destruction of the associated benthic fauna (Hall -Spencer, 1995). Hall - Spencer and Moore (2000) studied the long-term impact of scallop dredging on maerl habitats. Norse and Watling (1999) stated that the passage of heavy otter boards followed by the large trawl net causes injury and damage to the epibenthic organisms. Bergmann *et al.* (2001a,b & c) conducted a survey on the Nephrops fishery in the Clyde Sea area in Scotland. 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.

Hutchings (1990) stated that trawling physically removes or damages much of the macro epibenthic fauna in his studies on the effect of trawling on these communities. In addition to long- term changes in sediment characteristics and the benthic community structure, demersal fishing gears directly affect benthic species. In some fisheries, a large proportion of the catch comprises the bycatch of non-target fish and benthic invertebrate species. Because these species are often of no commercial value, the fishers, together with undersized target fish, discard them. Worldwide commercial exploitation of marine stocks has resulted in the exploitation of organisms at lower trophic levels suggesting that direct and indirect threats to invertebrate infauna and epifauna will increase (Pauly *et al.*, 1998). Hutchings (1990) observed that over much of the world's continental shelves, trawls and dredges capture benthic dwelling fish and shellfish. Menon (1996) stated that the incessant operation of bottom trawlers along the sea bottom resulted in the disproportionate destruction non- target groups along with juveniles/ sub adults of heterogeneous species of commercially important shellfishes and finfishes and a wide spectrum of benthic organisms. Alverson *et al.* (1994) estimated the global discards as 27 million tonnes per year. Clucas (1997) documented the reasons by which various species were discarded into the sea. Pauly and Christensen (1995) estimated that about 27 million tonnes of bycatch are discarded every year worldwide. Fonds (1994) reported the mortality of fish and invertebrates in beam trawl catches and observed the chance of survival of discards. Gueguen and Charuau (1975) reported that the discards amounted to more than 60 % of the total trawl catch. Lindholm *et al.* (1999) observed the presence of more than 60 % of fish in trawl discards during their study on the survival rate of juveniles in bottom trawl fishing. Camphuysen *et al.* (1993) estimated that about 475,000 million tonnes of fish offal and benthic invertebrates were discarded in the North Sea annually. Morrissery and Robles (1992) estimated that between 350,000 and 700,000 tonnes of by-catch were harvested each year in Mexican waters. Juhl and Drummond (1976) investigated the by-catch in shrimp trawling in the United States of America. Hill and Wassenberg (1990) estimated that around 70% of the tropical prawn fishery was discarded. Many of the epibenthic invertebrate fauna of the European continental shelf are scavengers of both discarded and damaged fauna, and their presence is often indicative of areas of trawl disturbance (Berghahn, 1990).

It was estimated that between 20 and 70 % of the total discarded material may be consumed by seabirds (Blaber and Wassenberg, 1989). Blaber *et al.* (1995) studied the trawl discards in the diets of tropical seabirds of the northern Great Barrier Reef. Blaber and Wassenberg (1989) also studied the feeding ecology of the piscivorous birds in Moretan Bay. The remaining discards sinks to the bottom whereupon it becomes available to midwater and benthic predators and scavengers (Wassenberg and Hill, 1990). The authors also investigated the rate of survival of animals discarded from trawlers. Wassenberg and Hill (1990) studied the fate of discards in Moretan Bay and found that large percentage of the dead discards that sink to the sea bottom are scavenged by crabs and fish. Bottom trawling destroys large amount of epifaunal organisms and heavy destruction of these organisms may lead to substantial changes in the habitat complexity and community structure (Rogers *et al.*, 1999). Pranovi *et al.* (2000) observed that 50% of the catch comprised of epifaunal organisms in the rapido trawling operations. Bergmann and Moore (2001) observed that about 90% of the total discard in the Nephrops fishery was constituted by decapod crustaceans and echinoderms. Bergman and Santbrink (2000) estimated the mortality of megafaunal benthic population caused by trawl fisheries on the Dutch continental shelf in the North Sea. Sainte-Marie (1986) observed heavy mortality of epibenthic organisms by the scraping action of the otter boards and net. Nickell and Moore (1992) studied the behavioral ecology of epibenthic scavenging invertebrates in the Clyde Sea area. Sainsbury *et al.* (1997) estimated 80 % mortality to the epibenthic organisms from a single trawl pass in the study regarding Australian multispecies fishery. Moran and Stephenson (2000) estimated more than 15% destruction of epifauna in the single pass of trawl net. Kaiser and Spencer (1995) estimated 60 to 90% mortality of the epifaunal communities in the trawl net discards in a study conducted to assess the fate of discards.

Chen and Gordon (1997) assessed discarding at sea using length-structured yield-recruit model. Philippart (1998) observed the long-term impact of bottom fisheries on several bycatch species of demersal fish and benthic invertebrates in the southeastern North Sea. Stratoudakis *et al.* (1999a & b) made an assessment on the discarding practices of commercial gadoids in the North Sea. Greenstreet and Rogers (2000) correlated the time-series trends in the abundance of non-target species with fishing disturbance in their study on the effect of fishing on non-target species. Seasonal variations in the shrimp bycatch and discards were noticed by Ye *et al.* (2000). Prena *et al.* (1999) analysed the trawl bycatch and also measured the effect trawling on a sandy bottom ecosystem of the Grand Banks of Newfoundland.

Edward and Bennett (1980) studied the survival of discards in the bottom trawl fishery. Among discards the chances of survival are very small and most of them sink to the bottom as dead. Survival experiments using fish bycatch taken from beam trawls have shown mortality rates of up to 40.5% for rays, compared to higher rates of 60 to 90 % for plaice and dab. Trawl / dredge decrease the survivorship of scallop spat (Bull, 1986). Van Beek *et al.*(1990) studied the survival of plaice and sole discards in the otter trawl and beam trawl fisheries in the North Sea. Britton and Morton (1994) observed that a large number of invertebrate epifauna survived the discarding process in their study on the marine carrion and scavengers. Bergmann and Moore (2001) examined the mortality of echinoderms discarded in the Nephrops fishery in the Clyde Sea area. Pope and Knights (1982) compared the length distribution of the hauls of all demersal trawlers during surveys in the North Sea and at Faroe Bank. Fonds *et al.* (1992) analyzed the catch composition and survival rate of fish and benthic invertebrates in commercial beam trawls for sole and plaice fishery in the southern North Sea. Van Beek *et al.* (1990) looked into the survival of sole and plaice discarded in the otter trawl and beam trawl fisheries in the Netherlands. Fonds (1994) estimated the mortality of fish and invertebrates in the beam trawl catches and the survival changes of discards.

Bridger (1970) made direct observation on the sea bottom with a view to analyze the extent of variations on the seabed brought about of 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. Ramsay *et al.* (1996,1998) observed the changes in hermit crab feeding pattern in repose to trawling disturbance. Rice and Gislason (1996) observed that the size structure of the fish assemblages were strongly affected by fishing pressure in the study on the pattern of changes in the size spectra of numbers and diversity the North Sea. 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. Poiner *et al.* (1998) opined that successive trawling would lead to dislodging and loss of many sessile organisms. The flourish of the scavenger and predatory species significantly impair the fitness of frequently trawled areas (Bergmann *et al.*, 2001b). Bergman *et al.* (1990) observed large amount of echinoderms and crustaceans discarded in the Nephrops fishery. Pauly (1979) pointed out the proliferation of these organisms in the fishing grounds. Thomas and Kurup (2001) reported profound abundance of non-edible crabs in the fishing grounds of Kerala with a CPUE of 120-200 kg as a tangible proof for the destruction of target species contributing to a higher rate of survival in the trawl discards. Britton and Morton (1994) noticed that a large number of invertebrate epifaunal facultative scavengers that had physiological or behavioral adaptation enabled them to survive the capture and discarding processes, which lead to the proliferation of these organisms in the trawled grounds. Abundance of organisms such as crabs, gastropods and echinoderms in the trawl catches attribute to the high rate of survival among the discards as noticed by Hill and Wassenberg (1990).

Trawling significantly removes the three-dimensional cover provided by epifaunal organisms (Collie, 1998). Engel and Kvitek (1998) reported that repeated trawling and dredging causes a shift from communities dominated by species with relatively larger adult body towards dominance of higher abundance of smaller bodied organisms. Kaiser *et al.* (2000a) explained effect the chronic fishing disturbance on shelf benthic communities. Lindeboom and de Groot, (1998) suggested that if heavy trawling pressure on the communities were persistent, the disturbed communities would never recover. Lindholm *et al.* (1999) studied the survival of juvenile cod in the bottom fishing.

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.

Overholtz and Tyler (1985) studied the long-term responses of the demersal fish assemblages of George Bank. Pearson and Rosenberg (1978) observed that trawling and dredging affects organic enrichment, which reduced species diversity, and produces communities comprising large number of a few opportunistic species. Greenstreet and Hall (1996) made a study on the long – term and spatial trends of fishing and the ground-fish assemblage structure in the northwestern North Sea. Veale *et al.* (2000 a & b) noticed that removal of target species and consequent destruction of epifaunal organisms affected the number of organisms and diversity. Rogers *et al.* (1998) stated that any adverse effect of fishing on these organisms might lead to substantial change in the habitat complexity and community structure.

Hughes and Croy (1993) observed that many predator and scavenger fish and other marine invertebrates aggregate over a recently trawled site for their food. Ramsay *et al.* (1998) observed the responses of benthic scavengers to fishing disturbance by towed gears in different habitats. Frid and Hall (1999) observed high quantity of polychaetes in the diet of fish obtained from the intensely trawled areas. Brown *et al.* (1976) observed the decline of many invertebrates due to the increase in exploitation levels in mid 60's. Rice and Kronlund (1997) made community analysis on the flatfish assemblages. De Veen (1976) noticed changes in some biological parameters in the study conducted in the North Sea sole. Rijnsdrop and Vingerhoed (2001) studied the feeding habits of plaice and sole in relation to the effects of bottom trawling. Millner and Whiting (1996) examined the long – term changes in growth and population abundance of sole in the North Sea from 1940. Rijnsdrop and Beek (1991) studied the changes in growth of plaice and sole in the North Sea.

Duineveld *et al.* (1991) studied the macrobenthos in the North Sea. 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, 1955). The distribution of macrofaunal species on the sea bottom is closely related to the sediment grain size, salinity, water movement and organic content of the sediment (Crecutzberg *et al.*, 1984). 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.

Johnson *et al.* (1996) made a study on the biodiversity and the productivity of the ecosystems. Kunin and Lawton (1996) observed the variations in diversity and alteration of ecosystem with respect to the human activities in it. 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.*, (2002a & 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 in trawl nets (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 Santbrink (2000) 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. A large fraction of the mortality occurs in the trawl path because many animals that are not caught in the net are damaged or killed by the fishing gear as it passes over the seabed (Craeymeersch *et al.*, 2000).

Benthic scavengers may benefit from the additional food supply from discards or animals damaged in the trawl path (Ramsay *et al.*, 2000; Groenewold and Fonds, 2000). Demersal fishing activities provide food for scavengers in the form of damaged animals which are left in the trawled / dredged track (Ramsay *et al.*, 1988). Frid *et al.* (1999) demonstrated that consumption of benthos by fish predators has changed both in quantity and composition during the period of heavy trawling. 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 form the coastal ocean (Moore 1999). Fishing has a great role in the changes in 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 smaller benthos 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. Thrush *et al.* (1995) reported the reduction of benthic communities during dredging. Trawling destroys the tubiforms, which have important role in maintaining the structure and oxygenation of muddy sediment habitats (Reise, 1981). Of the many natural and anthropogenic factors that disturb the seabed and reduce structural complexity, the leading factor is fishing with mobile gear (Watling and Norse, 1998).

Langton and Robinson (1990) found that direct mortality might occur when animals are hit by the gear but not retained by the net in their study on the faunal associations on scallop grounds in the western Gulf of Maine. 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. Walker (1992) pointed out the human intervention in the marine ecosystems. Huston (1994) examined the diversity changes in the ecosystems while Lawton (1994) opined about the redundancy in ecosystems. 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 about the decline of diversity in the various ecosystems. Many strategies are being worked out to protect the marine ecosystems forms subjected to total depredation by way of fishing especially bottom trawling. Many steps have been taken to reduce the bycatch and discards in the trawl fishing as well as to reduce the perturbation on the seabed (Jones 2000). Pope (1989) made a review on fisheries research and management of the North Sea. Broadhurst *et al.* (1997) conducted escapement studies with trouser-trawl in the Hawkesbury River prawn trawl fishery. Brewer *et al.* (1998) made an assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Sherman (1991) made research on the management strategies for the living marine resources.

Chapter 2

MATERIALS AND METHODS

2.1 Description of the study area:

The state of Kerala, situated in the southwest tip of Indian Peninsula, has a total continental shelf area of about 40,000 km^2 of which 15993 km^2 is within 0 - 50 m depth zone (Kurup, 2001b). The coastline of Kerala is less than one tenth of the coastline of India (Thomas, 2000), but the state occupies the foremost position in the marine fish production of the country. Cochin coast is well known as the most productive fishing grounds ever since exploratory bottom trawling commenced with the establishment of Indo – Norwegian Project in Kerala in the middle of fifties. Fishing effort has increased enormously in the state during the past four decades and this is all the more pertinent in the case of bottom trawling.

The region along the coastline encompassing Cochin and Munambam was selected for conducting bottom trawling experiments (Fig. 2.1), due to the following reasons.

A. This region is situated between two major fisheries harbours Cochin and Munambam, (Lat 9^0 58'N to 10^0 10' and Long.75^0 56'00" to 76^0 10"94") and is therefore subjected to heavy bottom trawling pressures.

B. This ground is ideal for bottom trawling

C. Proximity to the University.

2.2 Fishing boat used for the study:

A commercial trawler of 45 ft OAL was hired on contract basis to carry out the experimental trawling (Plate 2.1). The technical specifications of the boat are given below.

Name of the vessel *LAWRENCE*

Registration no. MFV ALP 1275

Engine Ashok Leyland ALM 402

Facilities onboard: Echo sounder, GPS, Fishing equipments and accessories

2.3 Selection of stations:

The study area was divided into five depth zones 0-10, 10-20, 20-30, 30-40 and 40-50 m, with two stations in each zone. The selection of stations was done with the help of a GPS, in a linear manner with a distance of 5 km between stations in the same depth contour. Thus a total of 10 stations were fixed, (viz S1, S2, S3,......S10). Trawling was done more or less at the mid depth of these depth zones, at 5, 15, 25, 35 and 45 metres. The samples collected from these stations after trawling, have been designated as A1, A2, A3, ...A10. However,

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	

no stations could be treated as control in this region as incessant commercial trawling operations were in vogue at the depth zones irrespective of even the shallow coastal waters less than 5 m depths.

2.4 Experimental trawling and sampling:

Experimental trawling was carried out onboard *Lawrence,* commencing from December 2000 to November 2002, using standard fishing equipments (Plate 2.2). The stations were sampled at bimonthly intervals with uniform representation of premonsoon, monsoon and postmonsoon seasons. Trawling operations were also conducted during the period just prior to the lifting of ban on bottom trawling imposed along the Kerala coast during southwest monsoon (in July 2001 and 2002). Experimental trawling was carried out once in every two months in each of the ten stations, thus making a total of 12 cruises with in a span of two years. As soon as the fishing vessel reached the fixed station, water samples were collected in duplicate from the surface, bottom, 5 and 10 metres from bottom at all stations using 1.5 litre horizontal water sampler (Hydro Bios- Kiel) (Plate 2.3) for generating data on hydrographical parameters viz. temperature, salinity, pH, dissolved oxygen and turbidity. Water samples for analyzing nitrite and phosphate were also collected and stored in ice for later analysis at the shore laboratory. Water samples were also collected in duplicate in clean opaque polythene cans, passing through a 0.3 mm nylon screen for the estimation of chlorophyll concentration of column waters. Sediment samples from each station were collected in duplicate using a Van Veen grab of area $0.1m^2$ From the grab samples a small portion was separated for the analysis of organic matter, sediment texture, and the rest for analyzing the macrofaunal communities inhabiting the sediment (Plate 2.4). The trawler was then propelled for 30 minutes and experimental trawling was carried out along the same corridor propelling back for one hour through the same corridor (Fig. 2.2). The net was then hauled in after passing the station and the vessel was maneuvered back to the station at the original position in the same depth zone where the samples had previously been collected, with the help of the GPS. The sampling protocols carried out before the trawling would be repeated. The epifaunal organisms hauled up by the trawl net were identified, sorted and weighed. Thereafter, the fishing vessel was preceded to the next station and the above strategy was repeated at all the ten stations from 0 - 50 m depth. The sampling was completed within three days, covering 0 -10 and 10 - 20 m depth zone in one day and the 30 - 40 and 40 - 50 m depth zones in the second and third day of the survey. The samples collected were analysed using standard procedure as given below.

2.5 Analytical procedure

Temperature:

Temperature was measured using a standard thermometer as soon as the water sample was collected onboard.

pH :

pH measurements were made using a portable pH meter (pH scan 1) after calibrating with standards at pH 4 and pH 7.

Salinity:

Salinity was determined using Knudsen's method, following standard argentimetric technique.

Dissolved oxygen:

Dissolved oxygen was estimated by modified Winkler's method of Strickland and Parsons (1972) with standard iodimetric titration.

Turbidity:

Turbidity was determined using Nepheloturbidity 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 form 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-nitrogen was measured by the method of Grasshoff *et al.* (1983). In this method, nitrite in the seawater sample when treated with sulphanilamide in a solution results 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 543 nm. 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 solution 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.

Chlorophyll pigments:

Chlorophyll pigments were estimated following the method of Strickland and Parson (1972). A known volume of water samples was filtered onboard through 0.3 mm nylon mesh to remove larger zooplankton. Chlorophyll samples were concentrated on Whatman GF / C glass filter paper with the help of a vacuum pump. Extraction was done using 90 % acetone and the solution was centrifuged at 4000 - 5000 rpm for about 20 minutes. The clear supernatant liquid was decanted into a 5 cm path length spectrophotometer. The extinction of the solutions was read immediately at 750, 665, 645 and 630 nm. The concentration of Chlorophyll a, b, and c were calculated using the standard formulae prescribed by Strickland and Parson (1972).

Sediment organic carbon:

The organic carbon of the sediment was determined using wet digestion method (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 obtained by multiplying the organic carbon values by a factor 1.724 (Trask, 1955).

Sediment texture:

Sediment sample was thoroughly mixed and a portion was subjected to textural analysis (Krumbein and Pettijohn, 1938). The samples were dried at 65 °C and 20 gms of the dried sample were kept overnight in 0.25 N solution of Sodium hexametaphosphate after separating the sand fractions by washing through a 63 μ sieve. The coarse fractions 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). The coarse fractions were also separated into its finer fractions and weighed. The grain size parameters such as mean size, standard deviation, skewness and kurtosis were calculated based on Folk and Ward (1957).

Analysis of Benthic organisms:

Mud samples, after removal of a portion for sediment structure and organic matter analysis, were sieved through 0.5 mm aperture screen and the animals retained in it categorized as macrofauna were carefully removed and preserved in 4 % neutralized formalin for later identification (Holme and

MacIntyre, 1975). The sorting of samples was done after washing and re-sieving using tap water, to remove the residual sediment and formalin. The washed materials were transferred to a petridish and the organisms were sorted carefully. All animals in each sample were identified upto generic level, counted and stored in 4% neutralized formalin. Polychaetes were identified following Fauvel, 1953 and Day, 1967 Numerical abundance and wet weight were used as the basis of faunal evaluation in this study. For estimating biomass of macrobenthos, the excess water was removed using tissue paper and wet weight was taken. The wet weight was always taken 4 weeks after preservation and was not likely to be influenced by the changes during preservation. The animals belonging to the group Mollusca were very small and since it was difficult to remove hard parts; the weight of these species was taken including the shell (Damodaran 1973).

2.6 Statistical Analysis of data:

ANOVA was used to study the significance of seasonal variations in the physico chemical parameters concerned with the present work (Snedecor and Cochran, 1967). Paired t-test was performed to test the significance of the before and after trawling values of all the parameters involved in the study. These tests were performed in SPSS 7.5 for Windows package.

The statistical package applied for the analysis of abundance and biomass data of macrofaunal polychaetes was Primer v5 (Plymouth Routines In Multivariate Ecological Research, Clarke and Warwick, 2001).

a) Univariate methods: Four indices of diversity were calculated based on both abundance and biomass.

1. Shannon – Weiner (Shannon and Weaver, 1949), diversity index was used to emphasize species richness

$H' = -\Sigma_i p_i \log_e (p_i)$ where p_i is the proportion of the total count arising from the i^{th} species. The natural logarithm is used for biological interpretation.

2. Margalef's index was used to measure the number of species present for a given number of individuals.

$d = (S-1) / \text{Log } N$ where S is the total number of species and N the total number of individuals.

3. Simpson's index λ is a dominance index, its largest values correspond to assemblages whose total abundance is dominated by one or a very few, of the species present. This index has the natural interpretation as the probability that any two individuals chosen at random, are from the same species.

$\lambda = \Sigma p_i^2$ where p_i is the proportion of the total count (or biomass) arising from the i th species

4. Evenness of the community was calculated using Pielou's evenness index (Pielou , 1984)

$J' = H' / H'_{max} = H' / \log S$ where H'_{max} is the maximum possible value of Shannon diversity and S is the total number of species.

b) Multivariate Methods: Multivariate analyses are more sensitive in detecting responses of benthic communities to environmental change. Both abundance and biomass data have been subjected to multivariate analyses. A cluster analysis using Bray – Curtis similarity index (Bray and Curtis, 1957) was performed on double root-transformed data, and dendrograms formed using the group average. The similarity matrices were used to perform non metric multidimensional scaling MDS, (Kruskal and Wish 1978) identifying separate clusters from the dendrograms.

2.7 Quantification Of Epifauna Onboard Commercial Trawlers:

Study area:

Data regarding onboard discards was collected from 375 fishing boats (155 – onboard participation and 220 Boats at the vicinity, including 100 boats from above 100 m depth) during April 2000-March 2002 using a standard proforma with an average of four single day/ mutli day trips per month (Plate 2.5). Above 100 m depth fishermen were entrusted with plastic tubs for collecting trawl samples from the last haul. Five major harbours along the coast of Kerala were selected for the study, viz. Saktikulangara, Neendakara, Puthiyappa, Ponani and Kochi. The location of these fishing harbours is shown in Fig. 2.3. Data during second half of June and full month of July could not be collected due to the ban imposed for bottom trawling along Kerala coast. The units of bottom trawlers for monthly onboard participation from various harbours were selected following Alagaraja (1984). The fishing endurance of the selected units varied from 1-3 days. The number of hauls in each voyage varied from 1-8 depending on the endurance and availability of fish. The details in respect of discards from trawl fishery was also observed with the help of a hired trawler, which sampled at least 20 trawl units on a daily basis operated along Cochin-Alappuzha coast. Epifaunal organisms hauled onboard by the commercial trawlers were identified, sorted, quantified and weighed. The trawl catch composition was identified following Dance (1977), FAO (1984), Sethuramalingam & Khan (1991) and Munro (2000). The trawl catches were sorted in to Target, Non-target and discards following McCaughran (1992). The marketable catches were sorted out by the crew and were weighed using standard sampling trays of 20kg. The numbers of boxes so separated were counted, and then the discarded fraction also was weighed in the same manner. In cases where the discarded fraction was high, sub samples of (10%) were analysed. Details such as cruise time, facilities onboard, OAL, cod end mesh size, fishing endurance and actual fishing hours together with the number of hauls, number of units operated in the vicinity and details of crew, duration and number of hauls performed, depth of fishing, fishing ground, etc. were also collected and entered on to proforma. The daily discarded fraction from the trawl catch was computed by multiplying the average catch arrived at from individual units multiplied by total units operated from the harbour on a daily basis. The monthly catch was estimated by multiplying the daily landings with actual fishing days of each month. The catch per hour and catch per unit of the discards were computed following Scariah *et al.* (1999). The sampling technique followed that of Alagaraja (1984).

Catch / hour = Total catch / Actual time spend for fishing

$$\text{Estimated catch} = \text{Total catch} \times \frac{\text{total number of fishing units in Kerala}}{\text{Number of units landed}} \times \frac{\text{Number of fishing days}}{\text{Days observed}}$$

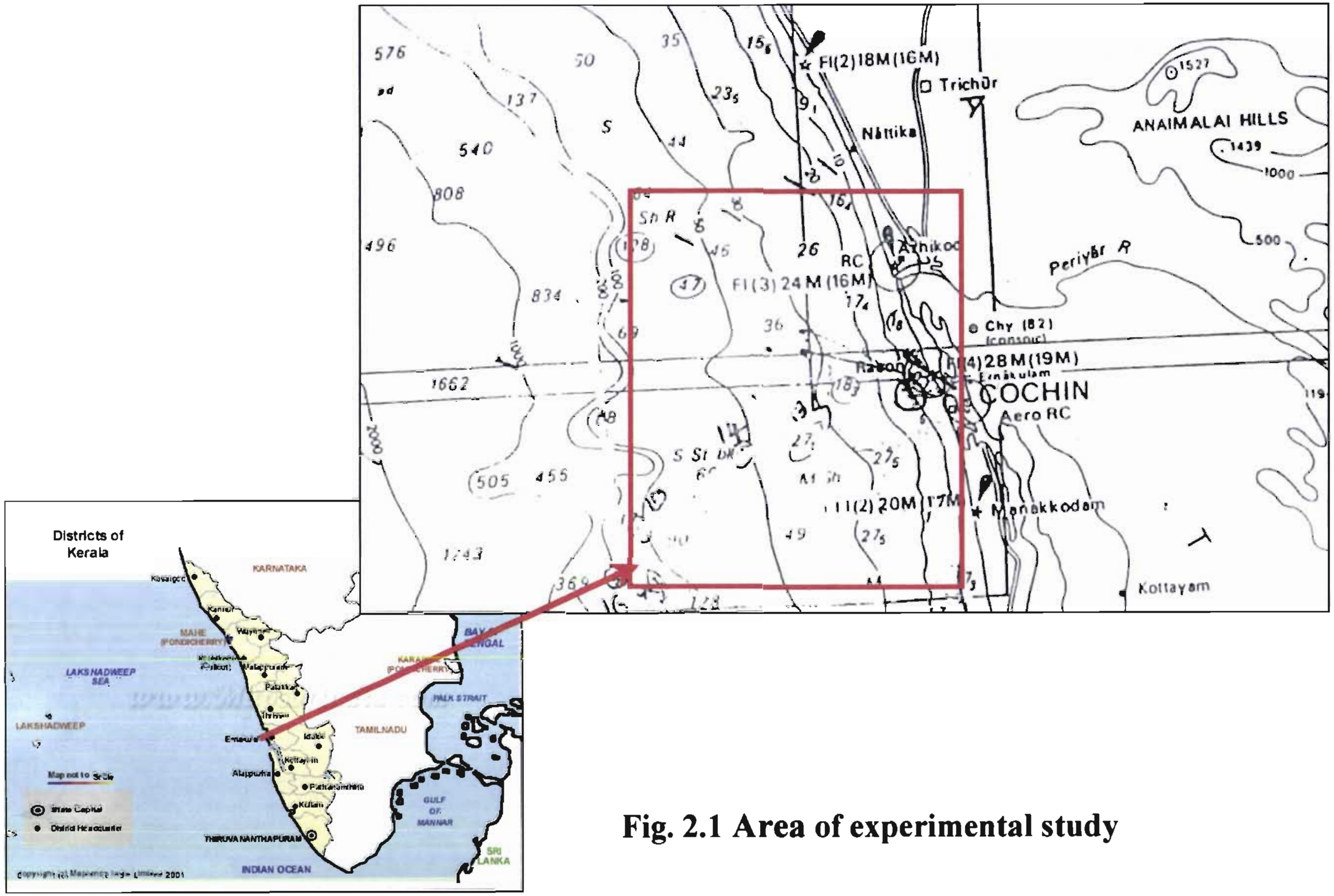


Fig. 2.1 Area of experimental study

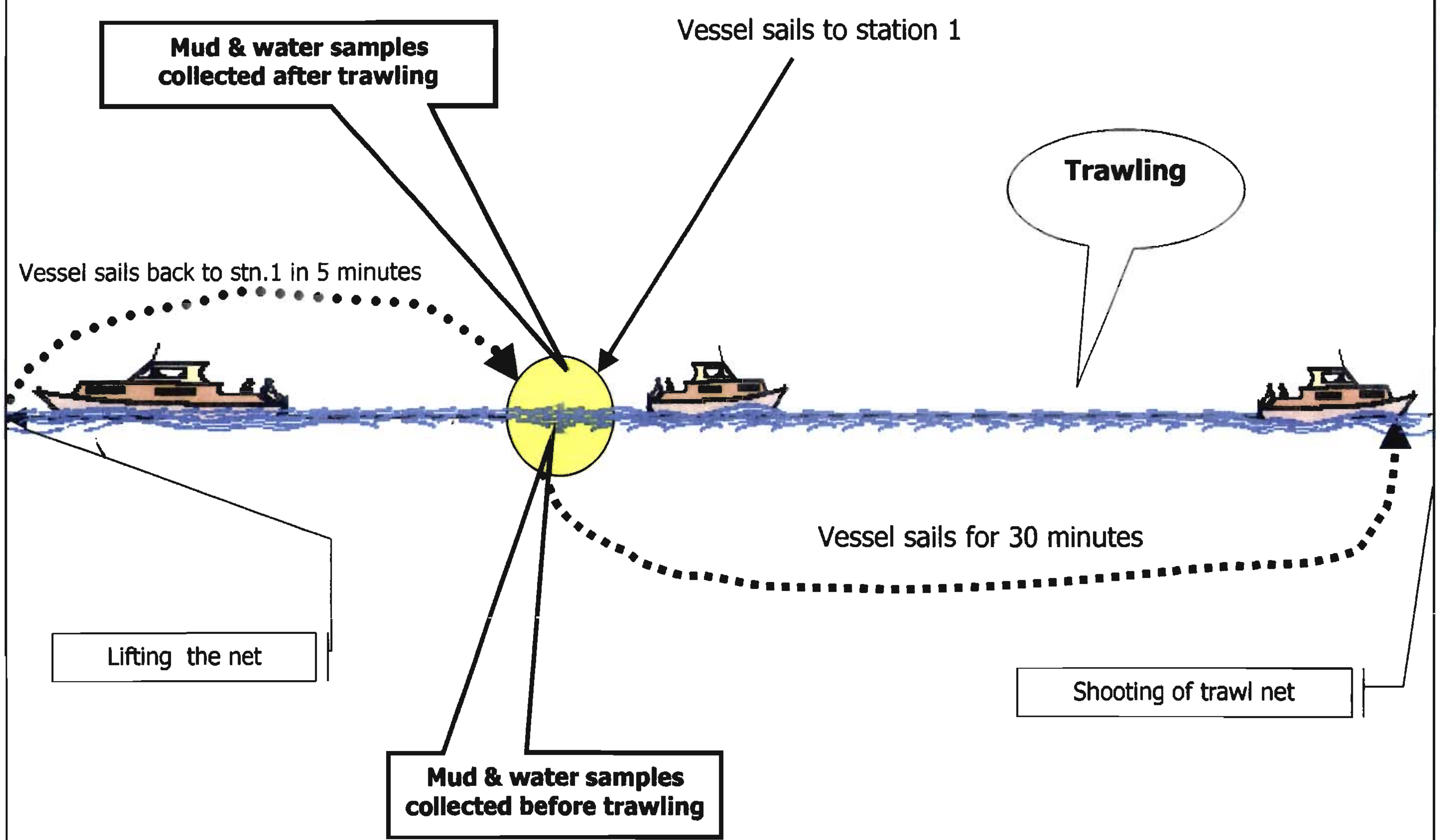


Fig. 2.2 Protocol of experimental trawling

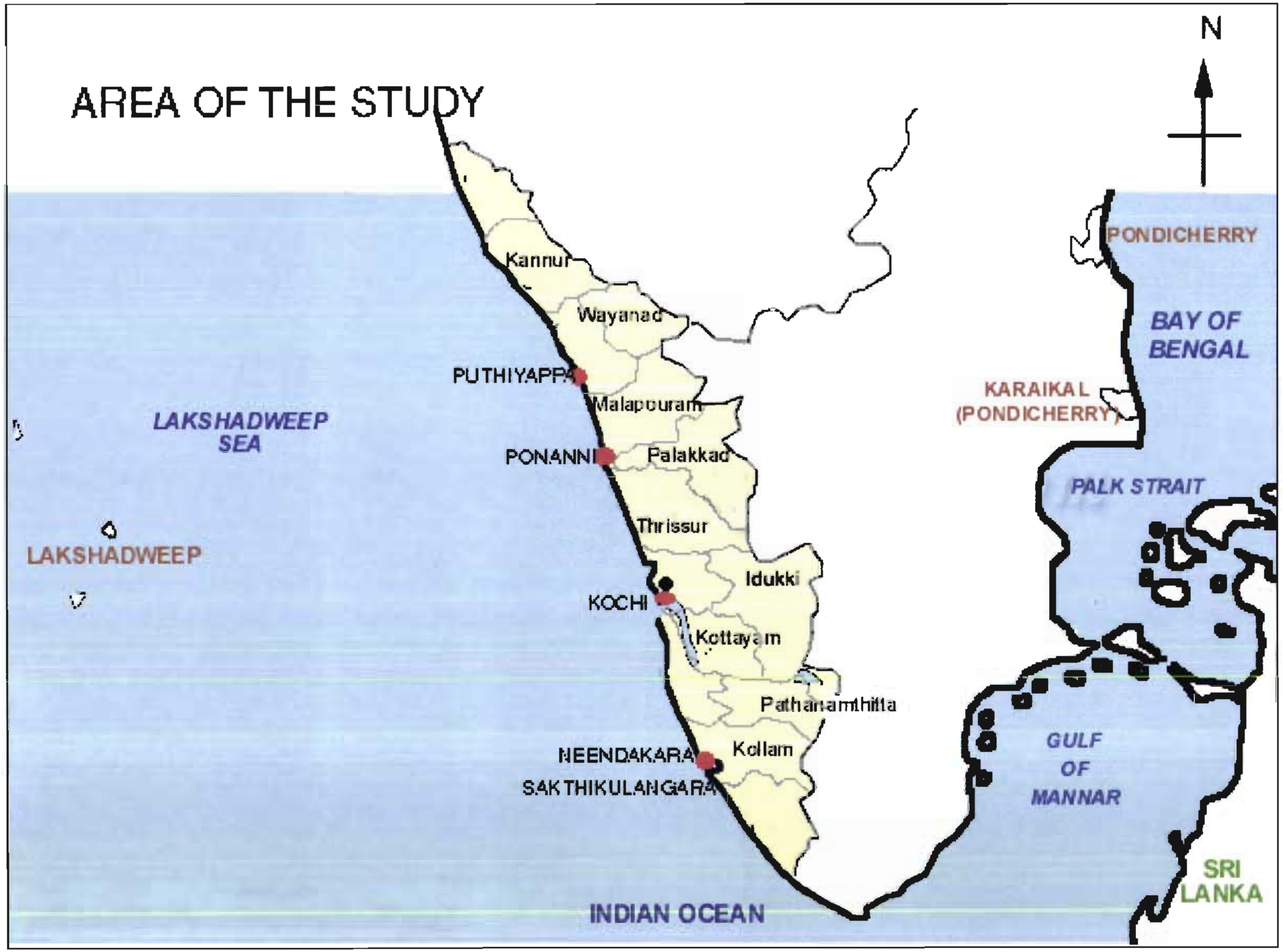


Fig. 2.3 Five major harbours of Kerala coast

Plate 2.1

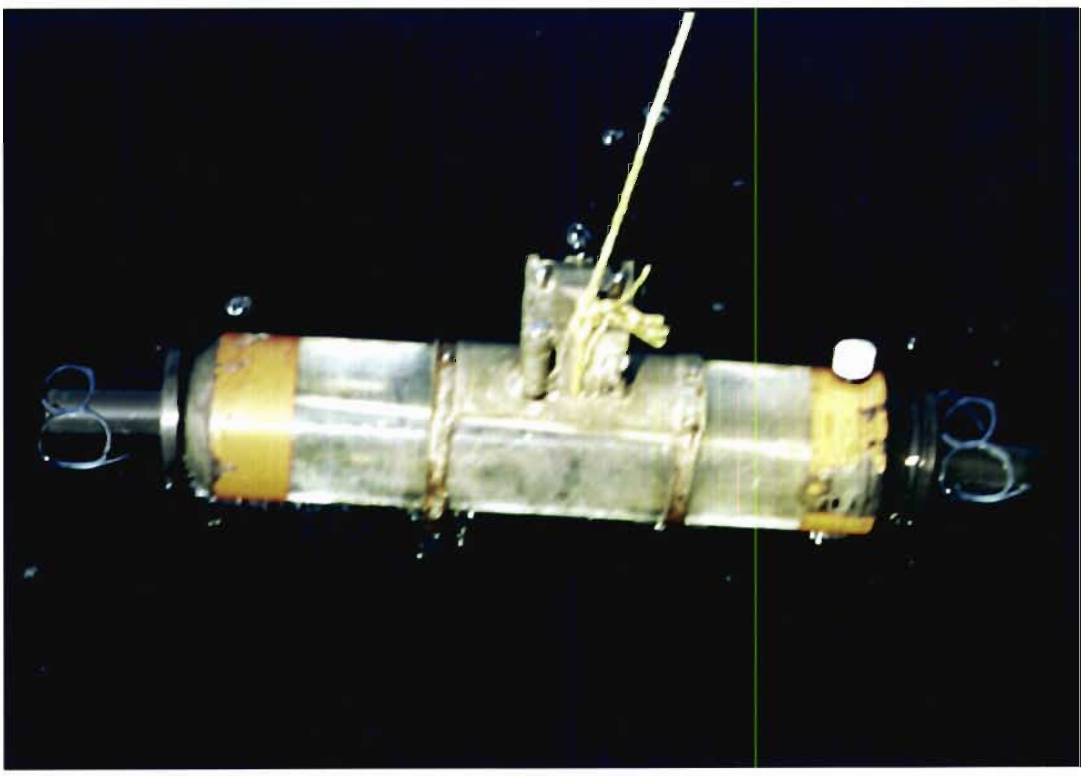
Commercial shrimp trawler “Lawrence”

Plate 2.2

A. Shooting of the trawl net

B. Hauling of the trawl net

Plate 2.3



Horizontal water sampler

Plate 2.4

A. Operation of Van Veen grab

B. Collection of sediment samples

Plate 2.5

Collection of epibenthic samples from boats in the vicinity

Chapter 3

EFFECT OF BOTTOM TRAWLING ON PHYSICO-CHEMICAL PARAMETERS

3.1 Introduction

Marine ecosystem is a complex adaptive system composed of interconnected groups of living organisms and their habitats (Fluharty, 1998). Environmental parameters have direct effect on the prosperity of the marine ecosystem and the fluctuations of these parameters cause serious perturbations on the marine organisms (Mooney, 1990). The major environmental factors that influence the life of marine organisms are salinity, dissolved oxygen, turbidity, pH and temperature. The nature and abundance of fauna and flora vary from place to place depending primarily on the physico-chemical characters of the water (Pillai, 1993).

The study of physical and chemical parameters of the inshore waters provides background information indispensable for the understanding of the coastal processes (Nair, 1990). Compared to open ocean system where the compositions are temporally invariant and chemical processes are in rather steady state, the coastal region exhibits environmental gradients occurring spatially and temporally on micro and macro scales. Coastal region is more productive than the open ocean (Qasim, 1977). In the shallow areas the high productivity is accounted by the increased regeneration rate of nutrients due to high temperature accelerating all bacterial processes at the bottom (Nair *et al.*, 1968). Western region of Arabian Sea exhibits higher productivity than any other regions of the world (D' Souza and Sastry, 1975; Ryther and Menzel, 1965). The highest production was reported from near the coast within 50 m depths, which are gradually decreases towards the open sea (Nair *et al.*, 1968).

High rate of production was also noted in the shallow waters of the coastal region of Lakshadweep and Minicoy islands (Prasad and Nair, 1960).

Hydrographic condition of the inshore waters of India had been studied fairly well by many workers (Ramamirtham and Patil, 1965; Gopinathan and Joseph, 1980; Ramesh Babu *et al.*, 1980; Sen Gupta *et al.*, 1980; Lakshmanan *et al.*, 1982; De Sousa and Singbal, 1986; Rivonker *et al.*, 1990; Nair and Balchand, 1992; Pillai, 1993). A series of studies were also conducted on the physico-chemical parameters of the open Arabian Sea (Jayaraman *et al.*, 1959, Banse, 1959; Rao, 1984; Meschanov and Shapiro, 1998; Morrison *et al.*, 1998). West coast of India is subjected to extreme seasonal changes of atmosphere manifested as northeast and southwest monsoon. These differing atmospheric regimes produce drastic physical, chemical and biological changes in the water column (Banse, 1959; Pankajakshan and Rama Raja, 1987). Upwelling also triggers various changes in the physico-chemical parameters of water (Sastry and D'Sousa, 1972; Ramamirtham and Rao, 1973; Basil, 1983; Kumar and Prasad, 1996; Muraleedharan and Kumar, 1996). According to Charney (1955), presence of stratifications like thermocline, displacements due to upwelling or downwelling affects only a strip of a few kilometers adjacent to the shore. Dissolved oxygen and salinity play major roles in deciding the distribution of fish and other living organisms in marine environment (Pillai, 1993). Studies along the southwest coast of India revealed that most of the pelagic fish populations consisting of oil sardine, mackerel and whitebait avoid temporarily areas of intense upwelling activity because of low oxygen concentrations and high turbidity (Sankaranarayanan and Qasim, 1969a; Muraleedharan and Kumar, 1996). Upwelling creates high plankton blooms and extremely high productivity in monsoon months (Banse, 1972). Inter-relationship between dissolved oxygen and nutrients showed that intense suboxic conditions generated in marine environment would expedite the denitrification process, which in turn modulates oceanic combined nitrogen inventory and consequently biological productivity (Naqvi *et al.,* 1978; Naqvi and Jayakumar, 2000). Physical parameters like temperature, salinity and dissolved oxygen play vital role in abundant production of pelagic fish (Suresh *et al.*, 1978; Rivonker *et al.*, 1990). Variations in the physico-chemical parameters in water certainly affect the density, survival, reproduction and distribution of the benthic organisms (Parulekar *et al.*, 1982; Bhat and Neelakandan, 1988).

In addition to the above mentioned natural changes which bring about variations in physical and chemical parameters in water, human interventions also create powerful disturbance on the marine environment. Fishing is the major anthropogenic activity in sea (Jennings and Kaiser, 1998; Jennings *et al.*, 2001b). Trawling and dredging are known as the most destructive fishing practices, which cause a number of direct and indirect changes in ecosystem. Direct changes in the fish populations and in the benthos can occur (De Groot, 1984) by the scraping of the trawl gear on the sea bed (Riemann and Hoffmann, 1991). 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). The consequence of trawling includes variations in the fish stock and changes in mortality, recruitment/settlement, diversity and production of benthos (Graham, 1955; Pearson and Rosenberg, 1978; Caddy, 2000). In addition, resuspension of sediment particles, toxic substances and nutrients, which are getting suspended, are reported to affect the oxygen budget and nutrient level (Graham, 1955; Pearson and Rosenberg, 1978; Caddy, 2000). Riemann and Hoffmann (1991) examined the ecological consequence of dredging and bottom trawling in the Limfjord, Denmark. Unfortunately, the effect of bottom trawling on physico-chemical parameters is poorly studied and no concerted effort has been carried out in Indian waters to study the effect of bottom trawling on the physico-chemical parameters. Against this background, a pioneer attempt was made to study the immediate effect of bottom trawling on physico- chemical parameters in the south west coast of India.

3.2 Materials and methods

The details of collection of samples and analysis are illustrated in chapter 2.

3.3 Results

3.3.1 Temperature

Water temperature measured both before and after trawling at surface, bottom, five and ten meters above bottom showed uniform trend throughout the stations in all seasons except during monsoon. The seasonal variations of temperature showed that it was high during premonsoon period followed by the postmonsoon while the monsoon season marked the lowest. The results of the present study revealed that the bottom trawling could not make any significant changes in the water temperature. Vertical distribution of temperature showed a slightly decreasing trend down the water column.

3.3.1a Temperature at surface

Temperature measured at surface waters before trawling is shown in Fig. 3.1. During the first year, highest temperature of 32.7 °C was recorded at station 3 in November 2001 while the lowest was at station 3 (23.4 °C) in July 2001. In the second year, the highest temperature of 32.8 °C was registered at station 6 in January 2002 whereas the lowest of 24 °C was noted at stations 1 and 2 in July 2002. Overall, temperature ranged from 23.4 - 32.8 °C in the samples collected before trawling and a significant reduction was observed in the monsoon months of July 2001 and 2002 ($P<0.01$, Appendix I, Table 1). Samples collected after trawling operations also showed similar seasonal trend. Temperature measured in the after trawling samples ranged between 23° – 33.3°C and 25.5° - 32.8 °C respectively in the first and second years (Fig. 3.2). Tantamount to that in surface water collected before trawling, high temperature was noticed in premonsoon and postmonsoon periods after trawling, where the highest temperature of 33.3 °C was noticed at station1 in November 2001 and the lowest of 23 °C at station 5 during July. In the second year, high temperature was recorded in January with highest of 32.8 °C at station 7 while the lowest of 25.5 °C was registered at station 1 in July. Significant seasonal variation was also noticed in the samples collected after trawling ($P< 0.01$, Appendix I, Table 2). While comparing the temperature recorded both before and after trawling (Fig. 3.3 a & b), no significant variations were noticed (t test, $P>0.01$) due to bottom trawling (Table 3.1).

3.3.1b Temperature at bottom

Bottom water also showed similar pattern of distribution as noticed at surface on the temperature measured before trawling. Temperature ranged from 23.2 ° to 31.3 °C during first year and 23.2 ° to 31.5 °C in the second year (Fig. 3.4). Seasonal variation of temperature recorded at bottom was closely similar to that recorded at surface. In the first year highest temperature of 31.3 °C was recorded in November 2001 at station 4 and the lowest of 23.2 °C at station 5 in July 2001 while, in the second year high temperature values were recorded in premonsoon period with highest value of 31.5 °C in January at station 2 and the lowest of 23.2 °C at stations 9 and 10 in July. Uniform pattern of distribution was noticed in almost all stations and also at different seasons except monsoon during when significant reduction was noticed ($P<0.01$, Appendix I, Table 3). During November 2001 - March 2002, temperature was high with an average of 29 °C (Fig. 3.4). Temperature during July 2001 and 2002 was less with an average of 24 and 23.4 °C respectively. Samples collected after trawling showed almost similar trend as that recorded before trawling, which varied between 23.3 ° - 31.9 °C and 23.5 °C – 31.6 °C in first and second year respectively (Fig. 3.5). Moreover, low values were observed in July during when the lowest temperature of 23.3 °C was registered at station 2 and 3 in 2001 and 23.5 °C at stations 6 and 9 in the year 2002. In the samples collected after trawling during the first year, highest temperature was recorded in

November with 31.9 °C at station 5 and during the second year the highest temperature of 31.6 °C was recorded at the same station (station 5) in March. After trawling samples also showed significant reduction during monsoon periods ($P < 0.01$, Appendix I, Table 4). The temperatures recorded before and after trawling (Fig. 3.6 a & b) showed that there were no significant variations in the area of Investigation ($P > 0.01$, Table 3.1).

3.3.1c Temperature at five meter above bottom

Temperature measured at five meter above bottom before trawling ranged from 23.4 ° to 32.6 °C and 23.2 ° - 32.7 °C respectively in the initial and final year of this study (Fig. 3.7). Premonsoon and postmonsoon periods showed high values of temperature in the samples collected before trawling. In the first year, highest temperature of 32.6 °C was recorded at station 3 in November, while July showed the lowest (23.4 °C) at stations 3, 4 and 5. Second year, the higher values of temperature were recorded during premonsoon period with the highest of 32.7 °C registered in January at station 10 whereas lower values were recorded during monsoon period where a lowest of 23.2 °C was registered at station 7 in July. Samples collected at five meters above bottom also showed high values during premonsoon and postmonsoon seasons. The premonsoon months showed a high average of 30.5 °C in the first year whereas the postmonsoon season showed only 30 °C. The average temperature recorded during the premonsoon months of the second year was 31 °C while it was only 29 °C during the postmonsoon season. During monsoon season, average values of 26 ° and 26.5 °C were recorded in the first and second years respectively. Significant variations were observed in temperature recorded before trawling in the entire period of study ($P<0.01$, Appendix I, Table 5). After trawling, temperature measured was similar to that recorded before trawling and ranged from 23.1 ° to 31.3 °C and 24.1 ° to 32 °C in the first and second years of study respectively (Fig. 3.8). Highest temperature recorded during the first year was at station 8 in April 2001 while the lowest was at stations 4 and 5 in July 2001. Similarly, during second year the lowest temperature (24.1 ° C) was recorded at station 3 in July 2002 and the highest (32 °C) at station 7 in January. Significant variation could be observed (Table 3.1) in the seasonal distribution of temperature observed after trawling ($P<0.01$, Appendix I, Table 6). Invariably, temperature was high during premonsoon followed by postmonsoon periods (Fig. 3.8). However, no significant variation was noticed while making a comparison of the temperature measured before and after trawling operations (Fig. 3.9 a & b, Table 3.1).

3.3.1d Temperature at ten meters above bottom

Significant seasonal variations were noticed in temperature (Fig. 3.10) measured at ten meters above bottom in the samples collected before trawling ($P< 0.01$, Appendix I, Table 7) which ranged between 24.1 to 31.6 °C and 24.2 °C to 32.1 °C in the first and second year of the study. High temperature was noticed during premonsoon and postmonsoon periods, the highest temperature in the year 2001 was noticed at station 5 in November whereas in the second year, the highest of 32.1° C was obtained at stations 10 and 7 in January and May respectively. At this subsurface layer also the monsoon months recorded the low temperature values with the lowest of 24.1 °C at station 5 in the year 2001 and that of 2002 (24.2° C) recorded at station 5 and 6 in July. Almost similar distribution trend was observed throughout the stations. Similar seasonal variations could be seen in the temperature recorded after trawling which ranged from 23.2 ° to 31.9 °C and 24.2 ° to 31.9 °C in the first and second year of the study respectively (Fig. 3.11) with significant reduction during monsoon months ($P<0.01$, Appendix I, Table 8). In the samples collected after trawling, the highest temperature (31.9 °C) was recorded at stations 8 and 6 in April 2001 and January 2002 respectively while the lowest values of the first and second year were respectively 23.2 °C and 24.2 °C at station 5 in July 2001 and 2002. As noticed at other depth layers studied, samples at ten meters above bottom also showed uniform pattern of distribution of temperature throughout the stations. Trawling on sea bottom did not bring about any significant variations on the temperature (t test, $P> 0.01$) as the values recorded both before and after trawling showed not much variations (Table 3.1) when compared to each other (Fig. 3.12 a & b).

3.3.2 Salinity

Monsoon had much influence on the distribution of salinity of seawater. High salinity was recorded during premonsoon and postmonsoon periods and low in monsoon. Vertical distribution of salinity showed that the high saline water tends to persist at the bottom. Salinity measured at surface, bottom, five and ten meters above bottom could not show any significant variations due to trawling operation.

3.3.2a Salinity at surface

Uniform distribution of salinity was observed at surface in the inshore waters through out the study period (Fig. 3.13). In the samples collected before trawling, first year showed a range of 27.4 to 36.2 ‰ and that of second year was between 27.2 and 36.2 ‰. Salinity recorded during November 2001 showed high average value of 35.5 ‰ and the lowest was recorded in July 2001 (31.2 ‰). In the second year, the highest average salinity was recorded in January (35.8 ‰) while the lowest average was in July (30.72 ‰). Highest salinity of 36.2 ‰ was recorded at station 5 in November 2001 with the lowest of 27.4 ‰ at station 2 in July 2001. During the second year, salinity was found more or less steady from November to May 2002 and afterwards, it decreased due to the heavy monsoon in July. The highest salinity (36.2 ‰) recorded during the second year was at stations 2 and 3 in January and the lowest (27.2 ‰) at station 3 in July. Predominant seasonal variations were observed in the study period with distinct variations during monsoon ($P < 0.01$, Appendix I, Table 9). After trawling, the values showed similar pattern of distribution as noticed before trawling, where salinity ranged from 28.1 - 36.4 ‰ and 27.7 - 36.4 ‰ in the years 2001 and 2002 respectively (Fig. 3.14). Highest salinity (36.4 ‰) was recorded at station 10 in November 2001 while the lowest was in July (28.1 ‰) at station 2. In the second year, the highest of 36.4 ‰ was at station 5 in May and the lowest of 27.7 ‰ recorded at station 3 in July. Seasonal distribution of salinity significantly varied during monsoon period ($P< 0.01$, Appendix I, Table 10). But significant variation could not be observed (Fig. 3. 15 a & b) while comparing the salinity recorded both before and after trawling to that recorded before trawling (P>0.01,Table 3.2).

3.3.2b Salinity at bottom

Bottom layer showed slightly higher salinity values than surface. Salinity was uniform in all stations except in July 2001 and 2002, the monsoon months, where it was low (Fig. 3.16). Bottom salinity recorded at bottom ranged between 27.6 - 36.2 ‰ in first year while in the second year, it ranged between 29.1 - 36 ‰. Higher salinity was observed during premonsoon followed by postmonsoon periods with the highest values of 36.2 ‰ recorded at stations 2 and 3 in December 2000 in the first year while salinity as high as 36 ‰ was recorded at station 7 in November 2002 during the second year. Similar values with the highest of 36.1 ‰ was also recorded in April 2001 at station 3 while the lowest was registered in July with 27.6 ‰ at station 9 and 29.1 ‰ at station 4 in years 2001 and 2002 respectively. Seasonal variations of salinity were found significant (P< 0.01, Appendix I, Table 11). During the first and second years of the study, salinity recorded after trawling ranged from 28.4 to 36.1 ‰ and 28.4 to 36.1 ‰ respectively. Highest value of 36.1 ‰ was recorded at stations 2 and 8 in December 2000 and also at station 8 in April 2001 while the lowest was observed at station 9 in September 2001 (Fig. 3.17). During the second year, higher salinity value was registered in May with 36.1 ‰ at station 5 while the lowest (28.4 ‰) was in July at station 8. Salinity values showed significant reduction during monsoon (P< 0.01, Appendix I, Table 12). No significant variation (P> 0.01, Table 3.2) was found when salinity values were compared before and after trawling (Fig. 3. 18 a & b).

3.3.2c Salinity at five meter above bottom

Salinity values recorded before trawling were almost comparable to that of bottom waters (Fig. 3.19). Moreover, significant variations were also noticed during monsoon months (P< 0.01, Appendix I, Table 13). Highest salinity of 35.8 ‰ was registered at station 3 in December 2000, at station 10 in February 2001 and also at station 7 in April 2001 (Fig. 3.19). The lowest of 28.3 ‰ was recorded at station 8 in July 2001. A steady trend in salinity values was noticed after July 2001 till next monsoon period (July 2002) with an average salinity of 34.7 ‰. In the second year, the highest salinity of 35.7 ‰ was registered at station 7 in March 2002 and the lowest (28.4 ‰) at station 6 in July 2002. The salinity values in the samples collected after trawling were similar to that of before trawling (Fig. 3.20). Seasonal variations were found significant in the samples collected after trawling (P< 0.01, Appendix I, Table 14). In samples collected after trawling during the first year, highest value was recorded at station 6 in April 2001 (36.8 ‰) and it was lowest at the same station in July 2001 with 28 ‰. Second year, the salinity recorded in the samples collected after trawling ranged from 28.7 - 35.4 ‰ where the maximum value (35.4 ‰) was noticed in March 2002 at station 5 and the lowest (28.7 ‰) at station 7 in July. While comparing the salinity values recorded before and after trawling (Fig. 3.21 a & b), no significant variations were noticed (P>0.01, Table 3.2).

3.3.2d Salinity at ten meter above bottom

Salinity recorded at ten meters above bottom showed close similarity to that of surface and the values recorded were within the range 27.9 to 35.2 ‰ and 28.9 to 35.2 ‰in the first and second years of the study (Fig. 3.22). Highest salinity (35.2 ‰) was observed at stations 6 and 9 in December 2000 and April 2001 in the first year and at station 9 in March 2002 in second year. Low salinity was observed in July months with 27.9 ‰ at station 10 and 28.9 ‰ at station7 in the first and second years respectively. Seasonal variation was found significant (P<0.01, Appendix I, Table 15). Salinity recorded after trawling showed close similarity to that recorded before trawling with significant seasonal changes (P< 0.01, Appendix I, Table 16). Salinity values registered after trawling ranged from 28 – 35.1 ‰ in the first and second years. As noticed in the samples collected before trawling, higher values were noticed in December 2000 and March 2002 with the highest of 35.1 ‰ at stations 7 and 9 respectively while the lowest of 28 ‰ was recorded at stations 10 and 5 during July 2001 and 2002 (Fig. 3.23). No significant variation could be observed (P>0.01, Table 3.2) in the salinity of samples collected before and after trawling (Fig. 3.24 a & b).

3.3.3 pH

Uniform pattern of distribution was observed in the pH of inshore waters. Distinct spatial and temporal variation could not be observed in the pH of the study area except during monsoon where slight decrease was noticed. Higher pH values were recorded during premonsoon while it was and low in monsoon.

Based on the present study it can be asserted that bottom trawling could not make any distinct changes on the pH of seawater.

3.3.3a pH at surface

pH values observed at surface water before trawling is shown in Fig. 3.25 and the annual variations ranged from 6.8 to 8.4 and 7 1 to 8.0 respectively in the first and second years of the study. Low pH was recorded during monsoon, the lowest of 6.8 at station 6 in July 2001 and 7 1 at station 6 in July 2002. Highest pH of 8.4 was recorded at station 2 in December 2000 in the first year and during second year, the highest of 8 at stations 8 and 9 in January 2002. pH at surface recorded in the before trawling samples denoted significant seasonal variations during monsoon ($P< 0.01$, Appendix I, Table 17). pH showed a steady pattern after July 2001 upto next monsoon period. After trawling, pH values were more or less similar to that of before trawling (Fig. 3.26). In both the years of study the pH recorded after trawling varied from 7 1 - 8.1. The highest of 8.1 was observed at station 3, 5 and 10 during December in the first year and at station 9 in the second year during January 2002. Samples collected after trawling showed significant reduction in pH during monsoon periods ($P< 0.01$, Appendix I, Table 18). Lowest pH in after trawling samples were recorded at stations 6 and 7 in July and September 2001 respectively with a value of 7 1 in the first year and at station 7 in July 2002 during the second year. Comparison of before and after trawling pH values (Fig. 3. 27 a & b) did not reveal any significant variation ($P> 0.01$, Table 3.3) due to bottom trawling.

3.3.3b pH at bottom

Uniform pattern of distribution of pH was noticed at bottom in the water samples collected before trawling (Fig. 3.28). More or less same values of pH were recorded at all stations studied. Annual seasonal variations of pH ranged from 6.9 - 8.2 in the first year and between 7 1 and 8.0 in the second year. Highest of 8.2 was recorded at stations 7 and 10 in December 2000 while the lowest of 6.9 was recorded at station 6 in July 2001. Highest values of 8.0 obtained at stations 8, 9 and 10 in January while the lowest of 7 1 was registered at station 5 in July in year 2002. Variation in pH values was found significantly low during monsoon months ($P<0.01$, Appendix I, Table 19) in the first and second years of study. The pH of samples collected after trawling showed more or less similar pattern of pH values with high values in premonsoon and low ($P<0.01$, Appendix I, Table 20) during monsoon period (Fig. 3.29). pH recorded from the after trawling samples ranged from 6.9 to 8.2 in the first year and from 7 1 to 8.1 in the second year. Highest value of 8.2 was recorded at almost all stations in December 2000 while the lowest of 6.9 was recorded at station 7 in July 2001. Second year also represented high values in January and November 2002 as seen before trawling where the highest of 8.0 was registered from many stations during the same months. pH recorded in samples collected after trawling figured insignificant changes ($P< 0.01$, Table 3.3) when compared to that of samples collected before trawling (Fig. 3.30 a & b).

3.3.3c pH at five meter above meter

Distribution of pH at five meters above bottom showed almost similar values as noticed at bottom except during monsoon. pH recorded in the samples collected before trawling ranged from 7 1 to 8.2 and 7 1 to 8.0 in the first and second years of the study respectively. The highest pH of 8.2 was noticed at stations 7 and 10 in December 2000 and the lowest of 7 1 was recorded from many stations in July and September 2001 in the first year. Almost similar values were recorded during second year with the highest of 8.0 at stations 7, 8, 9 and 10 in January 2002 while the lowest of 7 1 was registered in July at station 9 (Fig. 3.31). Distinct variation was seen in July in both years ($P< 0.01$, Appendix I, Tables 21 & 22) and a uniform distribution was noticed during the rest of the months. In the samples collected after trawling, pH ranged between 7 1 8.2 and 7 1 – 8.0 respectively in the first and second years (Fig3.32). Similar to the pH values recorded in the samples before trawling, after trawling samples also showed the higher values in December 2000 with highest of 8.2 at stations 6, 7 and 10 in the first year. During the second year, higher values of pH were recorded in January 2002 where the highest pH of 8.0 was recorded at stations 9 and 10. The low values were recorded in monsoon months during the both years, the lowest of 7.1 was recorded at stations 2, 4, 6, 8 and 9 in July and September 2001 in the first year but during the second year it was recorded from station 5 in July 2002. Similar to that of bottom and surface waters, trawling could not contribute to any significant variation (Fig. 3.33 a & b) in the pH recorded at five meter above bottom ($P> 0.01$, Table 3.3).

3.3.3d pH at ten meters above bottom

Ten meters above bottom also showed with similar pattern of distribution of pH in the samples collected before and after trawling operations (Fig. 3.34). Quite distinct seasonal variations were noticed with ostensibly significant reduction in pH during monsoon months. July 2001 and 2002 registered the lowest of 7.1 at many stations. pH recorded before trawling ranged from 7 1 to 8.2 in the first year and 7.1 to 8.0 in the second year (Fig. 3.34). Highest pH of 8.2 was registered in December 2000 at stations 7 and 10 in the first year while the lowest of 7 1 was recorded in July and September 2001 from many stations. In the second year, the highest pH of 8 was noticed at stations 9 and 10 and the lowest (7.1) was at station 9 in July 2002. Significant seasonal variation in pH was found both before and after trawling ($P< 0.01$, Appendix I, Tables 23 & 24). Samples collected after trawling represented similar pattern of temporal and spatial variations (Fig. 3.35) ranging from 7.1 to 8.2 in the first year and 7 1 to 8.0 in the second year. Highest value of 8.2 was recorded in December 2000 from stations 7 and 10 in the first year samples, identical to that of samples collected before trawling. During the second year highest pH of 8.0 was recorded at station 9 and 10 in January 2002. pH was very low during monsoon in both years where the lowest of 7 1 was recorded at stations 7 and 9 during July in the first year while in the second year, many stations in July and September registered the lowest (7 1). Significant changes in pH could not be observed when the samples collected before trawling was compared against those of after trawling ($P>0.01$, Table 3.3). Trawling could not make any significant changes in the pH at ten meters above bottom as seen in the case of surface, bottom and five meters above bottom (Fig. 3.36 a & b).

3.3.4. Dissolved Oxygen

Dissolved oxygen measured in the study area showed more or less a uniform distribution pattern and was also in the super saturated condition throughout the inshore waters. Moreover, distinct seasonal variation was also observed in the samples collected both before and after trawling. Premonsoon and postmonsoon periods registered higher values of oxygen while it was lowest in monsoon during when wide variations were noticed. The oxygen concentrations in the after trawling samples were found reduced when compared to that of before trawling.

3.3.4a Dissolved Oxygen at surface

Dissolved oxygen recorded at surface waters before trawling ranged from 2.8 to 5.36 mg L^{-1} and 2.89 to 5.48 mg L^{-1} in the first and second years respectively (Fig. 3.37). High values were recorded during premonsoon months while it was lowest during monsoon. Highest D.O of 5.36 mg L^{-1} was recorded in the samples collected before trawling at station 7 in April 2001 during the first year whereas in second year, the highest of 5.48 mg L^{-1} was recorded from station 7 in March 2002. July 2001 and 2002 were characterized by the lowest oxygen concentrations with 2.8 at station 6 in the former and 2.89 mg L^{-1} at station 6 during the latter year (Fig. 3.37). During monsoon period there was very significant decline in the dissolved oxygen concentrations ($P<0.01$, Appendix I, Table 25). In the samples collected after trawling, the dissolved oxygen concentrations showed a decrease in almost all stations where experimental trawling was conducted. The seasonal variations of dissolved oxygen measured after trawling at all stations showed similar pattern of distribution as observed in the samples collected before trawling (Fig. 3.38). Meanwhile, monsoon period also contributed to significant reduction in the dissolved oxygen concentration ($P < 0.01$, Appendix I, Table 26). In the samples collected after trawling, the dissolved oxygen concentrations ranged between 3.01 and 5.38 during the first year and from 2.93 -5.44 mg L^{-1} in the second year. Highest value of 5.38 mg L^{-1} was observed at station 1 and 5 in April 2001 in the first year while in the second year it was at station 9 in March 2002 with 5.44 mg L^{-1} Lower values were recorded during monsoon in the samples collected after trawling where the lowest of 3.01 mg L^{-1} was recorded at station 6 in July in the preceding year. During the second year, the lowest oxygen concentration of 2.93 mg L^{-1} was registered at station 6 in July 2002 (Fig. 3.38). Though there was a decrease of dissolved oxygen concentration in the samples collected after trawling, no significant variations could be obtained while comparing the D.O obtained in the samples analyzed before trawling ($P > 0.05$, Table 3.4). Highest variation was seen at station 7 in March 2002 as dissolved oxygen decreased to 4.44 mg L^{-1} from 5.22 mg L^{-1} before trawling (Fig. 3.39 a & b).

3.3.4b Dissolved Oxygen at bottom

Distribution of dissolved oxygen at bottom water before trawling was more or less similar to that of surface and ranged from 2.56 - 5.83 mg L^{-1} in the first year and 2.43 to 5.14 mg L^{-1} in the second year. D.O values obtained within 0 – 50 m depth zone showed more or less similar concentrations except in July 2001 and 2002, where steep decline in values were noticed ($P<0.05$, Appendix I, Table 27). D.O values showed a steady trend from December 2001 to May 2002 (Fig. 3.40). Highest oxygen concentration (5.83 mg L^{-1}) was noticed at station 1 in April 2001 and it was lowest (2.56 mg L^{-1}) at station 3 in July 2001 in the first year. During the second year, highest values were noticed again in premonsoon months where the highest of 5.14 mg L^{-1} was registered at station 9 in May 2002 while the lowest of 2.43 mg L^{-1} was recorded at station 10 in July 2002. After trawling, D.O values at bottom waters were drastically lowered in almost all stations. The values recorded after trawling ranged from 2.22 to 5.12 mg L^{-1} and 2.13 to 4.88 mg L^{-1} respectively in the first and second years (Fig. 3.41). Highest concentration (5.12 mg L^{-1}) was registered at station 1 in April 2001 while the lowest (2.22 mg L^{-1}) was at station 3 in July 2001 in the first year. In the second year, the highest concentration of dissolved oxygen was noticed at station 7 in May 2002 with 4.88 mg L^{-1} while the lowest of 2.13 mg L^{-1} was registered at station 10 in July 2002. Invariably higher values were recorded in premonsoon and postmonsoon months while during monsoon months there was a significant reduction ($P<0.01$, Appendix I, Table 28). While comparing the D.O concentrations obtained in the samples collected before and after trawling, highly significant variation was noticed after trawling ($P<0.01$, Table 3.4) and the highest variation was obtained at station 2 in July 2001 where 3.98 mg L^{-1} was recorded in the samples collected was recorded after trawling against 5.10 mg L^{-1} recorded before trawling (Fig 3.42 a & b). Similarly, at station 1, the dissolved oxygen of 5.10 mg L-1 recorded before trawling in July 2001 declined to 4 mg L^{-1} after trawling.

3.3.4c Dissolved Oxygen at five meters above bottom

Dissolved oxygen concentrations recorded before trawling at five meter above bottom are given in Fig. 3.43. Like wise at surface and bottom layers, distinct seasonal variation was also noticed at this subsurface layer where the highest values were recorded in premonsoon and postmonsoon while the monsoon months registered lowest oxygen concentrations ($P<0.01$, Appendix I, Table 29). D.O recorded at five meter above bottom was in the range between 2.56 - 4.99 mg L^{-1} and 2.84 – 4.68 mg L^{-1} respectively in the first and second years of the study. Highest D.O of 4.99 mg L^{-1} in the first year was recorded at station 4 during February 2001 while July 2001 marked the lowest (2.56 mg L^{-1}) at station 1. In the second year, the highest oxygen concentration of 4.68 mg L^{-1} was recorded at station 7 in March 2002 and the lowest of 2.84 registered at station 10 during July 2002. Higher values were noticed during February – April 2001 with an average of 4.4 mg L^{-1} July and September 2002 showed the lowest values of D.O distribution with an average 3.5 mg L^{-1} As observed at surface and bottom waters, uniform pattern of D.O was observed throughout the 0 - 50m depths. Samples collected after trawling showed a decline in D.O concentrations in almost all stations studied (Fig. 3.44). The D.O values recorded after trawling ranged from 2.55 to 4.91 mg L^{-1} in the first year and 3.03 to 4.86 mg L^{-1} in the second year. Highest value of 4.91 mg L^{-1} was noticed at station 3 in February 2001 while the lowest of 2.55 mg L^{-1} was recorded in July 2001 in the first year. During second year, high oxygen concentrations were recorded in January 2002 with the highest of 4.86 mg L^{-1} at station 7 Lower values were recorded in July where the lowest of 3.03 mg L^{-1} was registered at station 10. Significant reduction ($P<0.01$, Appendix I, Table 30) in D.O was noticed during monsoon period (Fig. 3.44). While comparing the dissolved oxygen values recorded in the samples collected both before and after trawling (Fig. 3.45 a & b), D.O concentrations were found to be decreased significantly ($P<0.05$, Table 3.4) at the trawled stations and the highest variation was observed at station 7 in March 2002 where 4.86 mg L^{-1} recorded before trawling was reduced to 4.03 mg L^{-1} after trawling. The extent of reduction in dissolved oxygen at five meters above bottom was less when compared to the variations observed at bottom waters however, it was higher when compared to that in surface waters.

3.3.4d Dissolved Oxygen at ten meters above bottom

Dissolved oxygen recorded at ten meters above bottom in the samples collected before trawling ranged from 2.91 to 5.18 and 2.52 to 5.96 mg L^{-1} during first and second years respectively (Fig. 3.46). During the first year, highest value of 5.18 mg L^{-1} was observed at station 5 in April 2001, while the lowest was at station 6 in July 2001 ($P<0.01$, Appendix I, Table 31). Second year showed highest oxygen concentration of 5.96 mg L^{-1} at station 9 in March 2002 and the lowest of 2.52 mg L^{-1} at station 10 in July 2002. Seasonal variation of D.O recorded in the samples collected at ten meters above bottom also showed similar pattern as noticed at surface, bottom, and five meters above bottom. Higher values were obtained during premonsoon and postmonsoon periods while the monsoon showed lowest values. A steady pattern of distribution could not be observed at this subsurface zone as noticed at surface, bottom and five meters above bottom (Fig. 3.46). In samples collected after trawling, similar variation was seen with lesser values in monsoon and higher concentration during premonsoon and postmonsoon periods (Fig. 3.47, $P<0.01$ Appendix I, Table 32). D.O concentration in the samples collected after trawling ranged from 3.47 in July 2001 to 5.31 mg L^{-1} in November in the first year while it was 3.54 mg L^{-1} in July 2002 to 5.94 mg L^{-1} in March 2002 in the second year (Fig. 3.47). Similar to other depth layers, samples at ten meters above bottom also showed a decreasing trend in the D.O concentrations recorded after trawling Higher variations were observed in May 2002 during when there was a perceptible reduction in the D.O concentrations in the samples collected after trawling, at stations 9, 8 and 7 where D.O concentrations of 5.96, 5.94 and 5.92 mg L^{-1} were reduced to 4.31, 4.27 and 4.55 mg L^{-1} respectively (Fig. 3.48 a & b). Though there was a reduction in D.O concentrations in the samples collected after trawling compared to that of before trawling, it was not statistically significant ($P>0.01$, Table 3.4).

3.3.5 Turbidity

Turbidity showed distinct seasonal variations with high values in monsoon period and the low in premonsoon and postmonsoon periods. Turbidity was measured at surface, bottom, five meter and ten meter above bottom. The extent of turbidity was more at bottom and showed a decreasing trend towards the upper layers. The lowest turbidity values were recorded at surface. After trawling, the turbidity of water column was found to increase tremendously at all stations and the degree of variation was more pronounced at bottom.

3.3.5a Turbidity at surface

Turbidity measured at surface water both before and after trawling is depicted in Fig. 3. 49 & 3.50. Highest turbidity before trawling was recorded during monsoon months and the lowest in premonsoon (Fig. 3.49). Significant seasonal variation of turbidity was noticed in the samples collected before trawling ($P<0.01$ Appendix I, Table 33). Highest turbidity was observed in July 2001 with 24 NTU at stations 2 and 7 and the lowest value of 1 NTU at station 3 in November 2001 in the first year of study showing an annual variation between 1 and 24 NTU. The trend was more or less similar in the second year with highest turbidity at station 2 in July 2002. The lowest of 1 NTU was registered at many stations in January 2002 (Fig. 3.49). The seasonal variation in the second year ranged between 1 15 NTU. When compared to open seawater, near shore regions registered higher turbidity. After trawling, turbidity values were significantly increased ($P<0.01$ Appendix I, Table 34) and the highest variation was registered during July (Fig. 3.50). The highest turbidity of 39 NTU was recorded at station 4 during July 2001 while the lowest of 3 NTU was recorded at stations 6 and 8 during February and April 2001 in the first year. Second year showed comparatively lesser variations and it was in the range of 5 - 18 NTU. Highest turbidity (18 NTU) was registered in the second year at station 2 in

September 2002 and the lowest of 5 NTU was at station 8 in January 2002. While comparing the samples collected before and after trawling, turbidity was more in the samples collected after trawling (Fig. 3.51 a & b) and a pronounced increase was noticed at near shore waters. Highest variation was noticed at station 5 in July 2001 where 38 NTU was noticed after trawling against 18 NTU recorded before trawling. During the second year, the highest variations were noticed at station 2 in September where the turbidity increased to 18 NTU after trawling from 9 NTU recorded in the samples collected before trawling. Variations in turbidity in the samples collected before and after trawling were significant in almost all stations studied (P<0.01,Table 3.5).

3.3.5b Turbidity at bottom

Turbidity registered at bottom waters both before and after trawling is depicted in Fig. 3.52 & 53. When compared to surface waters, bottom waters showed higher turbidity range from 2 - 80 NTU in the first year and 5 – 35 NTU in the second year. July 2001 registered the highest turbidity (80 NTU) at station1 and the lowest (2 NTU) in November 2001 at station 7 (Fig. 3.52). During the second year, the highest turbidity of 35 NTU was recorded at station 1 in July 2002 and the lowest (5 NTU) at station 5 and 1 in January and March 2002 respectively. Uniform turbidity was noticed at various depth zones except in monsoon periods during when perceptible variations were observed (P<0.01, Appendix I, Table 35). As in the case of surface waters, bottom waters also showed high turbidity at the near shore stations (stations1-6). In the samples collected after trawling, turbidity at bottom waters increased throughout the seasons, ranging from 11 to 96 NTU in the first year and from 8.0 to 62 NTU in the second year (Fig. 3.53). Highest value (96 NTU) was registered at stations 1 and 2 in July and September 2001 respectively in the initial year while lowest of 11 NTU was recorded at station 6 in April 2001. Second year also showed the similar pattern of distribution where the highest of 62 NTU was observed at station 1 in July 2002 and the lowest of 8.0 NTU was recorded at various stations in March and May 2002 ($P < 0.01$, Appendix I, Table 36). Highest variations were observed at stations 6 and 8 in July 2001 and May 2002 where 38 NTU was recorded after trawling against 10 NTU observed before trawling in July 2001 and May 2002 registering a four fold increase in turbidity due to trawling. A turbidity value of 40 NTU was recorded after trawling compared to 11 NTU before trawling (Fig. 3.53). Temporal variations showed that trawling operations further aggravated the turbidity at sea bottom during monsoon period and the highest value of 96 NTU was recorded at station 1 in July 2001. Significant variations were registered when comparing the turbidity recorded in samples collected both before and after trawling (Fig. 3.54 a & b) in all the stations studied ($P < 0.05$, Table 3.5).

3.3.5c Turbidity at five meter above sea bottom

Temporal and spatial variations of turbidity in water samples collected before trawling at five meters above bottom is given in Fig. 3.55 & 56. Seasonal variations in the turbidity registered before trawling samples showed similar pattern as observed at surface and bottom waters with higher values during monsoon and relatively low in premonsoon and postmonsoon seasons ($P<0.01$,

Appendix I, Table 37). Turbidity values measured at five meters above bottom was slightly higher when compared to surface waters but low when compared to bottom waters. During the first year, turbidity was in the range of 2 - 20 NTU where the highest value (20 NTU) was recorded at station 3 and 4 in April and July 2001 while the lowest of 2 NTU was observed at stations 7, 8 and 9 in November 2001. Turbidity recorded in the second year ranged between 2 and 16 NTU where the lowest of 2 NTU was obtained at many stations in January 2002 and the highest of 16 NTU was recorded at station 3 in July 2002 (Fig. 3.55, Appendix I, Table 38). In the samples collected after trawling, turbidity increased in the trawled areas and ranged from 9 to 39 NTU and 5 – 18 NTU in the first and second years respectively (Fig. 3.56). Higher values were observed at near shore areas with the highest of 39 NTU at station 5 in July 2001 and the lowest of 9 NTU was recorded at station 7 in April in the first year. During the second year higher values were observed in the after trawling samples with highest turbidity of 18 NTU recorded at station 3 in July 2002 and the lowest of 5 NTU registered at station 8 and 9 in January 2002. Seasonal pattern of variations were also similar to that recorded before trawling. Significant variations in the turbidity ($P<0.05$, Table 3.5) were observed when comparing the values recorded in the samples collected before and after trawling (Fig. 3.57 a & b). Variations were also observed in the monsoon month of July 2001 where after trawling samples showed a steep increase in turbidity with 36, 38 and 39 NTU when compared to 11, 14 and 15 NTU recorded respectively at stations 10, 4, and 5 in the samples collected before trawling. In the second year, highest variation was noticed at station 3 in January 2002 where the turbidity of 9 NTU was recorded after trawling against 3 NTU before trawling.

3.3.5d Turbidity at ten meters above bottom

Turbidity at ten meters above bottom recorded before trawling ranged from 2.4 to 16 NTU in the first year and that of second year was within 1 - 12 NTU. Highest turbidity (16 NTU) was recorded in July 2001 at station 7 and the lowest (2.4 NTU) at station 10 in November 2001(Fig. 3.58) in the first year (P<0.01, Appendix I, Table 39). In the second year the highest value of 12 NTU was recorded at station 6 in July 2002 and the lowest of 1 NTU at station 10 in January 2002. Uniform turbidity was noticed in almost all depth zones as well as at different seasons except in monsoon where high variations were observed. After trawling samples also showed higher values during monsoon periods. In the samples collected after trawling, the increase registered in turbidity values was significant (P<0.01, appendix I, Table 40) and ranged from 1.3 to 38 NTU in the first year and 1.6 – 14 NTU in the second year. Highest turbidity of 38 NTU was recorded in samples collected after trawling at station 7 in July 2001 and the lowest of 3.1 NTU registered at station 10 in November 2001 (Fig. 3.59). During the second year also, monsoon period showed the higher values of turbidity with highest of 14 NTU recorded at station 9 in July 2002 and the lowest (1.6 NTU) recorded at station 10 in January 2002. The highest variation was seen at station 9 when 36 NTU was observed in the samples collected after trawling when compared to 4 NTU in the samples collected before trawling in July 2001. Moreover, station 10 also showed similar trends as 36 NTU was recorded after trawling against 10 NTU before trawling (Fig. 3.60 a & b). Similar variations were also noticed in other stations where 37 and 36 NTU were recorded after trawling compared to 12 and 16 NTU recorded before trawling. Second year also showed wide variations in turbidity in the samples collected after trawling but it was not as intense as observed in the first year. Likewise at bottom and five meters above bottom, highly significant variations were also registered at this area (Table 3.5).

3.4 Discussion

Physico chemical parameters have a direct role in the growth and distribution of flora and fauna (Pillai, 1993). Investigations on physico chemical or hydrographical studies conducted along the west coast of India as well as the entire Arabian Sea (Jayaraman *et al.,* 1959; Banse, 1959; Ramamirtham and Patil, 1965; Gopinathan and Joseph, 1980; Ramesh Babu *et al.*, 1980; Sen Gupta *et al.*, 1980; Lakshmanan *et al.*, 1982; Rao, 1984; De Sousa and Singbal 1986; Rivonker *et al.*, 1990; Nair and Balchand 1992; Pillai, 1993; Meschanov and Shapiro, 1998; Morrision *et al.*, 1998) clearly established the importance and influence of these parameters in the marine environment. The physico-chemical parameters like temperature, salinity, pH and dissolved oxygen play vital roles in the high production of pelagic fishes and other living organisms (Suresh *et al.*, 1978). Krishnamurty *et al.* (1974) reported the influence of salinity variation on the distribution and dispersal of aquatic organisms. Salinity is the major ecological influencing factor for the distribution of benthic fauna (Parulekar *et al.*, 1982; Harkantra, 1982). 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 (Sen Gupta *et al.,* 1975,1976, 1979, 1980; Naqvi *et al.*, 1978; De Sousa and Singbal, 1986; Rivonker *et al.,* 1990).

Natural variation in the physico–chemical parameters in the west coast of India is highly dependent on the onset and strength of southwest and northwest monsoon. In the present study, uniform pattern of distribution of temperature, salinity, pH, dissolved oxygen and turbidity were observed in the water samples collected at different depths before trawling except in monsoon period where distinct variations were observed. Seasonal variation of these parameters observed in this study strongly coroborates with the previous studies conducted in the area (Ramasastry and Myrland, 1959; Ramamirtham and Jayaraman, 1960; Darbyshire, 1967; Banse, 1968; Damodaran, 1973; Gopinathan and Joseph, 1980). In the case of temperature, D.O, pH and salinity, higher values were observed during postmonsoon and premonsoon periods. Lowering of temperature and salinity in July can be attributed to the large influx of river run off due to monsoon rains as reported by Nair and Balchand (1992). Lower temperature was recorded during July and August at Cochin harbour (Ramamirtham and Jayaraman, 1963). Banse (1968) reported the influence of river runoff on the sea water surface temperature as it fell rapidly from the annual maximum of 30° - 32°C in April – May to 25° - 26°C towards the end of June and the first weeks of July. Temperature observed in the present study strongly corroborate to his findings. Narayanan and Pillai (1974) also reported surface temperatures below 26°C off Kerala coast during southwest monsoon period (June – September) and the seasonal variations in the range 22 - 30°C. Rao (1984) reported the lowering of temperature during summer monsoon in the central Arabian Sea. Moreover the uniform temperature gradient obtained in the study area in all seasons except monsoon showed that the inshore waters (below 50 meters) are characterised with a uniform temperature. Hareesh Kumar *et al.* (1990) also showed that the upper few meters of the ocean is well mixed having uniform temperature and salinity and the present findings are in close agreement with this.

Salinity showed an increasing trend from surface to bottom but the gradation was very subtle. Vertical distribution indicated that the surface salinity values were lower than those of the bottom (Rivonker *et al.*, 1990). Darbyshire (1967) studied the hydrography off Kerala and recorded a slight decrease in salinity with depth within the top 100 meters. The present findings also corroborates to this. High salinity values observed in premonsoon and postmonsoon periods and the low values recorded during monsoon were within the range of 27 – 36 ‰ and these findings were in strong agreement with the earlier studies (Ramamirtham and Patil, 1965; Ramesh Babu *et al.*, 1980; Rivonker *et al.*, 1990). Monsoon season was characterised by low salinity, low oxygen, low temperature and high turbidity at near shore waters (Gopinathan and Joseph, 1980; Satyanarayana *et al.*, 1992). Joseph and Kurup (1990) reported high salinity, >32 ‰ in May (premonsoon) at the bottom and also pointed out the sudden changes brought about in the environment with the onset of monsoon. Ramesh Babu *et al.* (1980) also pointed out the lowering of salinity (< 34 ‰) in the coastal waters of Kerala due to the influence of summer monsoon. In general, salinity of bottom waters was slightly higher when compared to that of surface waters (Kurup and Varadachari, 1975). Vertical distribution of pH during the entire study did not show any regular pattern between surface and bottom waters. A slight decrease of pH values was registered in monsoon months. Rivonker *et al.* (1990) also pointed out trifle variation in pH during their study conducted along the west coast of India.

Dissolved oxygen was found to be lower during monsoon period at all depth zones studied. This lowering may be due to the heavy monsoon and river run off from land as well as intense upwelling widely seen in this region as reported by Pillai (1993). Gopinathan and Joseph (1980) also reported low dissolved oxygen content during monsoon months. Relatively low values of temperature and dissolved oxygen indicated the presence of upwelled cool and oxygen poor waters at the surface layers during the monsoon period. Banse (1959); Sankaranarayanan and Qasim (1969b) reported heavy upwelling in this region during southwest monsoon. Upwelling effects are strongest during July and August and bring low oxygenated bottom water to surface (Banse, 1959). Low temperature, low salinity and low dissolved oxygen were reported by Banse (1972) and Varadachari *et al.* (1974) while studying the seasonal changes of hydrographic parameters due to upwelling during May – September in the west coast of India. In the present study area, the distribution of dissolved oxygen at different depth layers showed more or less similar values that indicate that the inshore waters are characterised by uniform distribution of dissolved oxygen. Jayaraman *et al.* (1959) registered the distribution of dissolved oxygen at surface and sub surface layers upto 50 meters and were of the opinion that there exits more or less uniform oxygen content in the coastal waters of Kerala. In general, inshore waters were well aerated during major part of the year except during the southwest monsoon season.

Turbidity values showed inverse relationship to oxygen throughout the stations. High turbidity values were noticed during monsoon, which could be the result of increased river and land run off and the churning action of the sea. Upwelling is the dominant factor responsible for the high turbidity in the coastal waters (Banse, 1959). Highly turbid waters were noticed at the near shore waters, which may be due to the rise of clayey soil by the action of currents and waves as well as the river flow into the sea. Coastal waters exhibited highly dense water at surface during southwest monsoon (July –August) due to intense upwelling (Muraleedharan and Kumar, 1996). Moreover heavy winds prevailing in the south west coast during monsoon season also generate heavy upwelling (Krishnamurthi, 1981).

Trawling is a major anthropogenic activity, which cause many direct or indirect impacts in the marine ecosystem (Kaiser *et al.*, 2000 b), among them the most obvious is that it causes mortality of the target species while non-target species were separated as bycatch (Kaiser and Spencer, 1996b). Apart from creating mortality and discards, towed gears in contact with the seabed will disturb it physically and cause resuspension of fine particles and relocation of stones and boulders (Gislason, 1995). In the five major physico – chemical parameters studied, both dissolved oxygen and turbidity showed wide variations in the trawled grounds when compared to the samples collected before and after trawling. Salinity, temperature and pH did not exhibit any noticeable changes due to bottom trawling. Dissolved oxygen concentration was found reduced after trawling. Significant variations (P>0.01) were noticed at bottom waters followed by five meters while ten meters above bottom and the surface waters showed no significant changes. The diminution of oxygen content at the trawled grounds is due to the formation of turbidity clouds arise during trawling. During bottom trawling trawl net scrape the sea bottom leading to the rise of sediments of few centimeters to the water column (De Groot, 1984; Redant, 1987). Bottom sediments are transported to the water column by the action of heavy otter boards and trawl nets (Caddy, 1973), bringing the low oxygen bottom waters to the surface (Churchill, 1989). Bottom waters are reported to be less in oxygen content when compared to that of surface (Damodaran, 1973). In addition to this, low dissolved oxygen concentration observed during July – September (Pillai, 1993), the heavy upwelling associated with monsoon rains as well as the inflow of turbid river waters during monsoon create high oxygen diminution zone in marine ecosystem (Banse, 1959,1968). Trawling pressure is more in the months of August and September in the inshore waters (<100 meters). Besides the low dissolved oxygen concentration during rainy season, intense trawling operations during monsoon periods may create a persistent hypoxic condition in water, which may destroy the eggs, larvae and juveniles of fish and other living organisms as discussed by Morgan *et al.* (1983). In the present study, turbidity values were found alarmingly increased due to bottom trawling. Variations in turbidity were found more chronic in all depth layers of which bottom waters showed the highest variations. The significant increase in the turbidity values noticed immediately after bottom trawling indicated that the seabed was highly disturbed by the dragging of bottom trawl. These findings strengthen the report by Gislason (1995) on the resuspension of the fine particles at sea bottom due to the passage of trawl gear in the North Sea.

Banse (1959) observed highly turbid water concentration during monsoon months due to the river runoff from land also due to intense upwelling that prevailed in the southwest coast during monsoon months. Increase of turbidity in the trawled area is due to the rise of sediment plumes by the stirring up of soft sediment surface due to the passage of heavy trawl net and otter boards (Churchill, 1989). Trawling on muddy grounds generate heavy sediment clouds in the water column (Ganz, 1980; Main and Sangster, 1981). High turbidity values recorded immediately after trawling in the present study also agree to this. Monsoon season exhibited high turbidity values, the further increase of turbidity during this period due to trawling activities created extreme turbidity water making this area unfavorable for the survival of larvae and juveniles of fish and other organisms as reported by Newcombe and MacDonald (1991). Turbidity increase due to trawling on sea bottom will reduce the visibility as noticed by Caddy (1973). Physical parameters play a dominant role in the proliferation of marine organisms (Suresh *et al.,* 1978). The variations of these parameters may affect the growth and dispersion of organisms in water. D.O, salinity and temperature showed strong positive correlation with the sardine and mackerel catch (Rivonker *et al.*, 1990). Natural variations in the physico-chemical parameters due to monsoon and subsequent upwelling sometimes disturb the marine ecosystem by way of abnormal variations on these parameters. Salinity and dissolved oxygen variations seem to extend profound influence on the abundance, distribution, composition and dispersal of species (Lakshmanan *et al.*, 1982). Earlier studies along the southwest coast of India revealed that bulk of the pelagic fish populations constituted by oil sardine, mackerel and white bait avoided temporally, areas of intense upwelling activity because of low oxygen concentrations (Pillai, 1993). Intense upwelling formed by the action of heavy winds prevail in the south west coast of India during south west and north west monsoon (Krishnamurthi, 1981) create a zero oxygen zone a few meters above sea bed which in turn affect the distribution and dispersion of bottom fauna, demersal fishes and prawns (Banse, 1968). The incessant bottom trawling during the monsoon season, and the upwelling periods in southwest coast of India by all means poses a threat to the growth of marine animals.

Abrupt rise in the turbidity and subsequent reduction in dissolved oxygen may create an unfavorable niche for the animals living in the marine ecosystem. High turbidity level could reduce larval survival (Morgan *et al.*, 1983), cause smothering of sessile organisms, prolonged hatching time as well as cause reduction in growth, lessened feeding efficiency, impair growth of bottom vegetation due to lessened light penetration (Newcombe and MaCDonald, 1991; Sanchez Jerez and Ramos Espla, 1996). Churchill *et al.*, (1994) also discussed the adverse effect on shellfish and other benthic organisms due to the rise of turbidity plumes during trawling. In the present study average four - fold increase of turbidity was noticed after trawling. Turbidity of bottom water was reported to be increasing during dredging in Cochin harbour (Thressiamma *et al.*, 1998). They found that the turbidity increased to 1300 ppm from 50 ppm immediately after dredging at bottom waters while at surface and mid depth the turbidity values were increased to 150 and 900 ppm after dredging when compared to 15 and 25 ppm respectively in the samples collected before dredging. In the present study almost all stations showed steep increase in turbidity after trawling.

Oxygen level decreased significantly after dredging / trawling probably because of mixing of reduced products such as methane and hydrogen sulphide and/ or because the resuspended particulate material like bacteria attached to sediments exerting an increase in oxygen demand in the water column (Riemann and Hoffmann, 1991). Dredging and trawling causes high oxygen demand that has the potential to form a barrier which may hamper the movement of migratory fishes (Eliott *et al.*, 1988a & b). Trawling may bring the bottom nutrients up to the water surface along with the turbidity clouds formed during trawling (Messieh *et al.*, 1991). Though the nutrients may increase the productivity of water column the possible rise of lethal gases such as ammonia, methane and hydrogen sulphide will adversely affect the living organisms in water (Churchill *et al.*, 1988). Abnormal bloom formation due to the presence of nutrients and minerals at the surface would deplete dissolved oxygen (De' Sousa and Singbal, 1986) and the temporary hypoxic condition created by dredging or bottom trawling may exacerbate the condition by eliminating macrophyte benthos and near bottom fish that are already close to their limits of tolerance of hypoxia (Hansson, 1985).

High nutrient levels could increase phytoplankton such as those in red tides, notorious for causing fish kill, and shift the balance of phytoplankton which in turn could affect the balance of fish and other marine life that feed on them (Churchill, 1989). Release of sediments clouds and reduction of dissolved oxygen may affect the natural balance between physico-chemical parameters in the marine ecosystem. The high productivity due to the influx of nutrients and minerals by dint of trawling operations may reduce the dissolved oxygen further. So in summary, bottom trawling had a strong and immediate impact on the marine milieu. Variation in the major physico-chemical parameters due to human intervention in the form of bottom trawling activities are highly deleterious so as to inflict irreparable perturbations in the marine ecosystem.

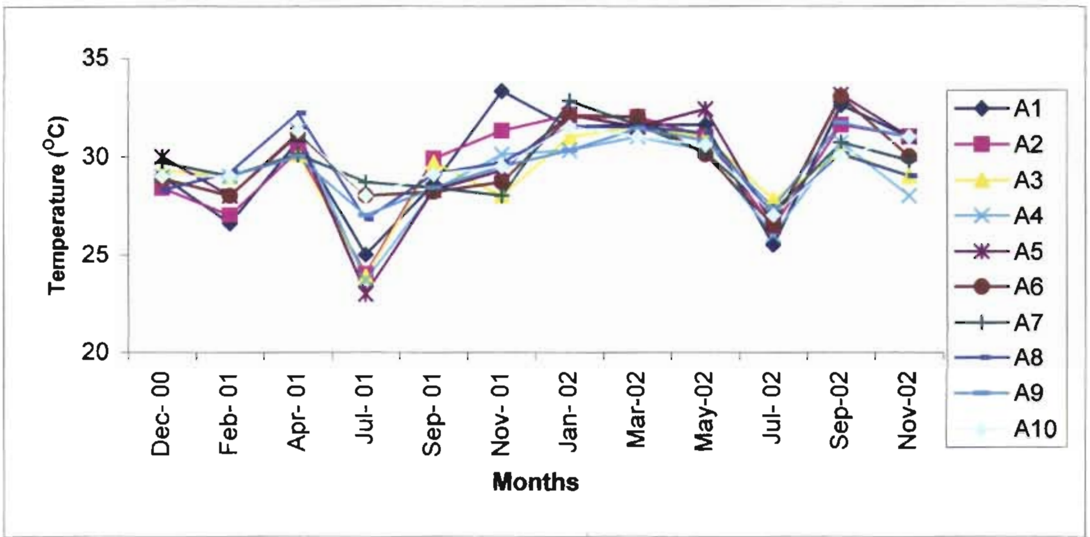


Fig. 3.1 Temperature recorded at surface before trawling during Dec.2000 to Nov.2002

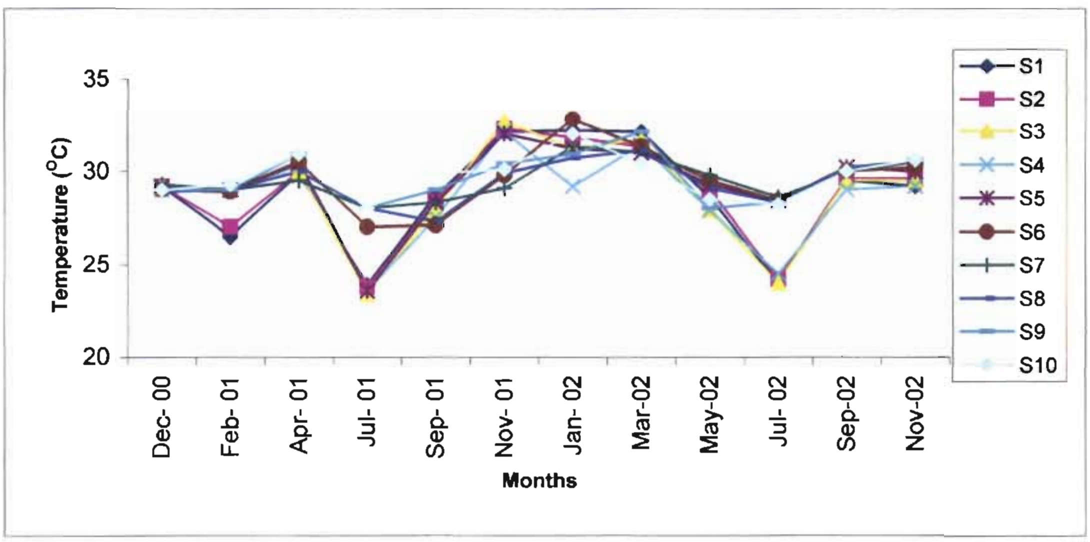


Fig. 3.2 Temperature recorded at surface after trawling during Dec.2000 to Nov.2002

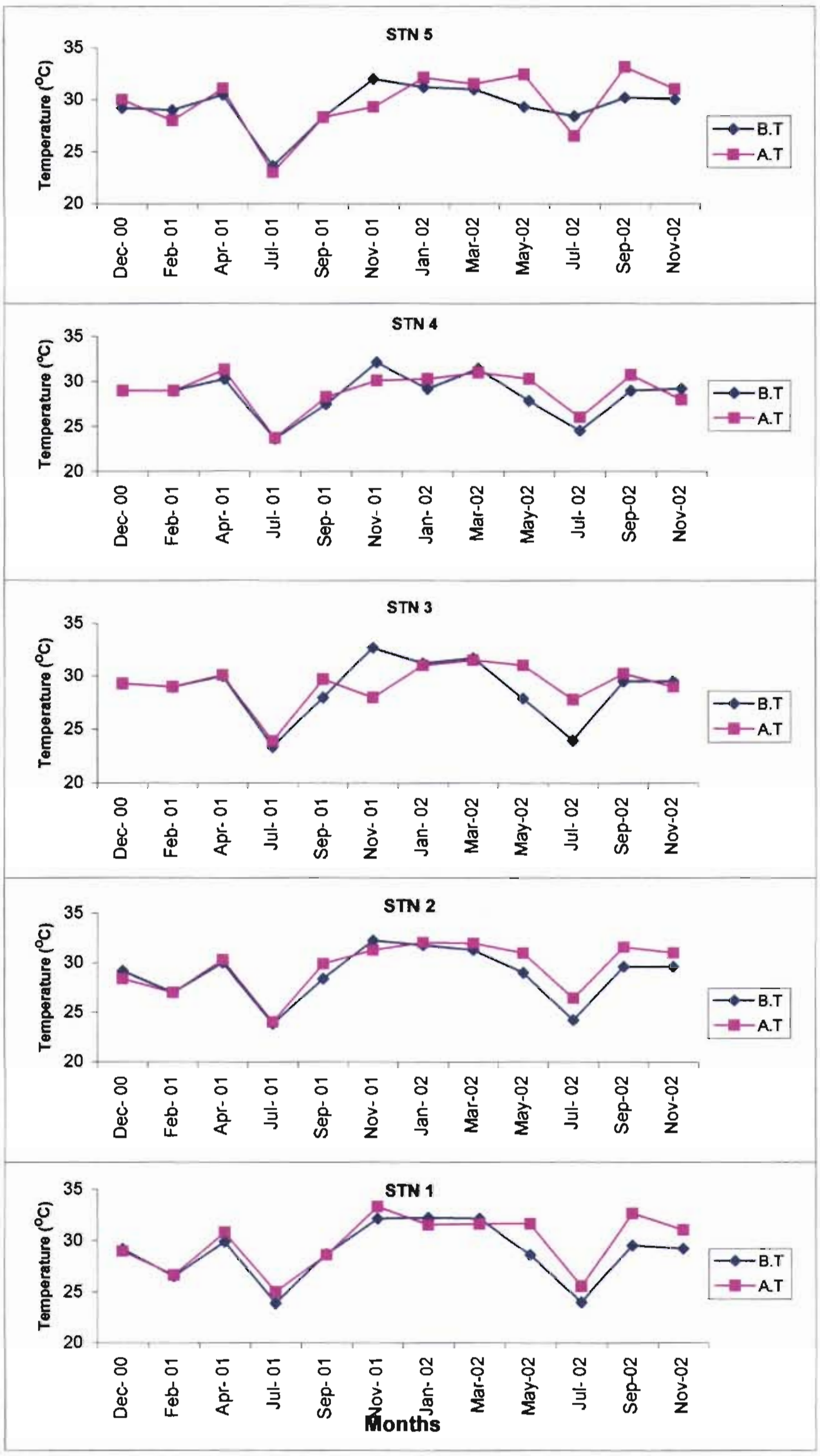


Fig. 3.3a Pattern of variations in temperature at surface before and after trawling during Dec.2000 to Nov. 2002 .

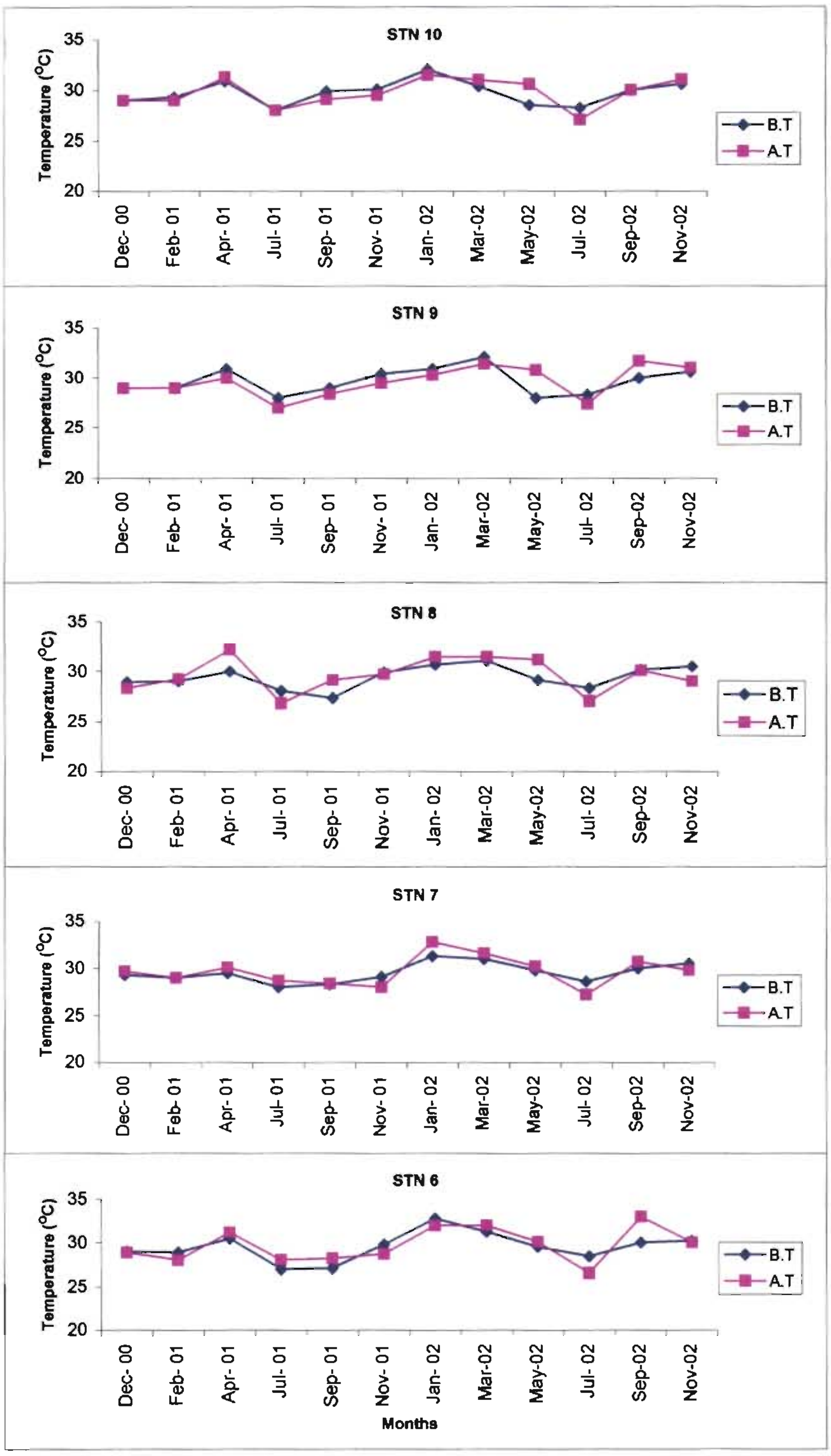


Fig. 3.3b Pattern of variations in temperature at surface before and after trawling during Dec.2000 to Nov. 2002

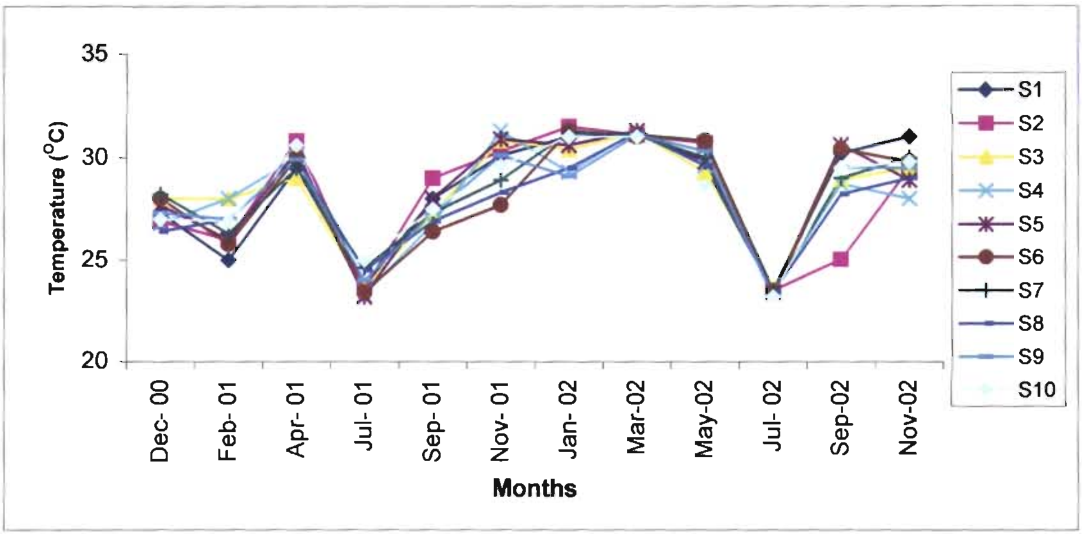


Fig. 3.4 Temperature at bottom before trawling during Dec.2000 to Nov.2002

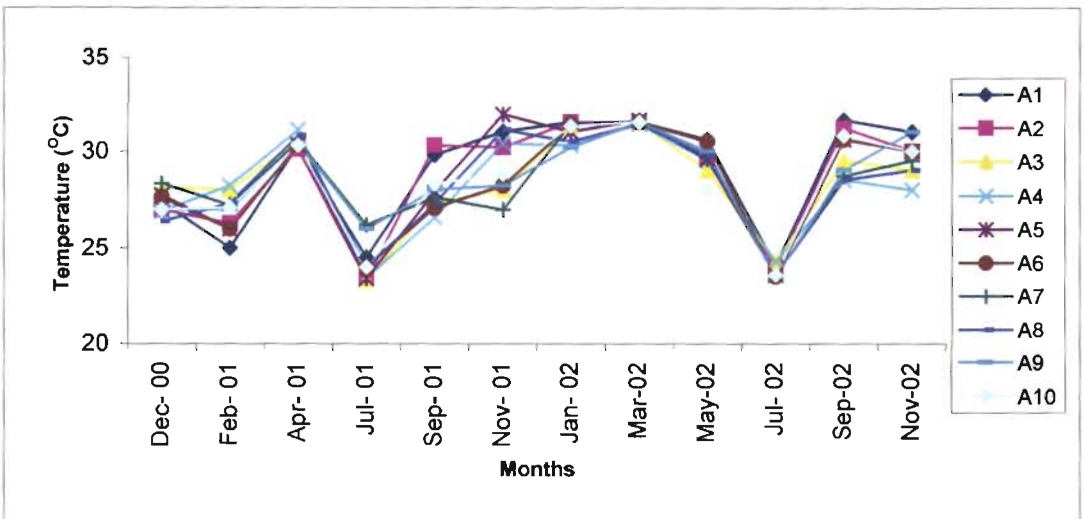


Fig 3.5 Temperature at bottom after trawling during Dec.2000 to Nov.2002

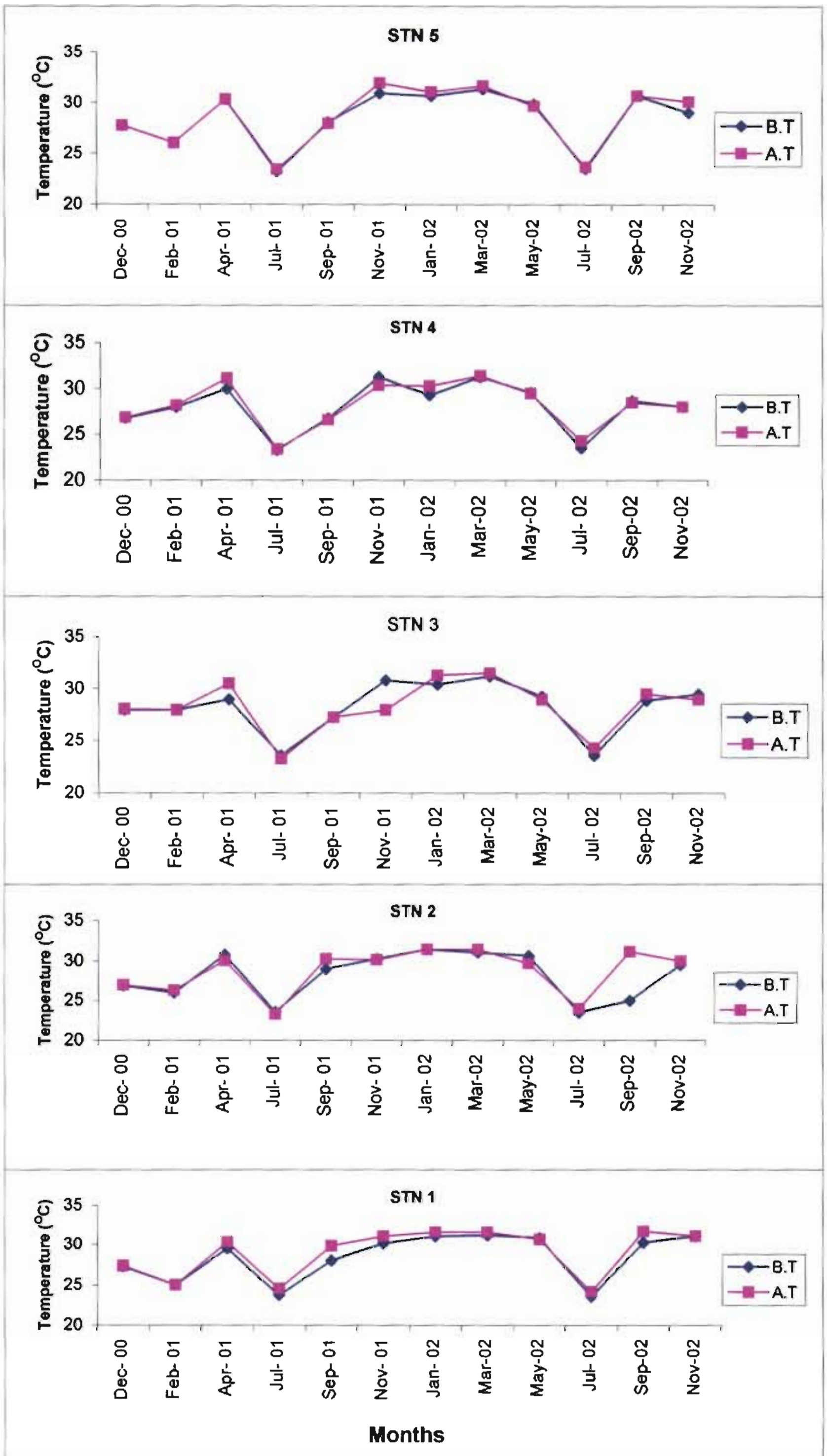


Fig. 3.6a Pattern of variations in temperature at bottom before and after trawling during Dec.2000 to Nov.2002

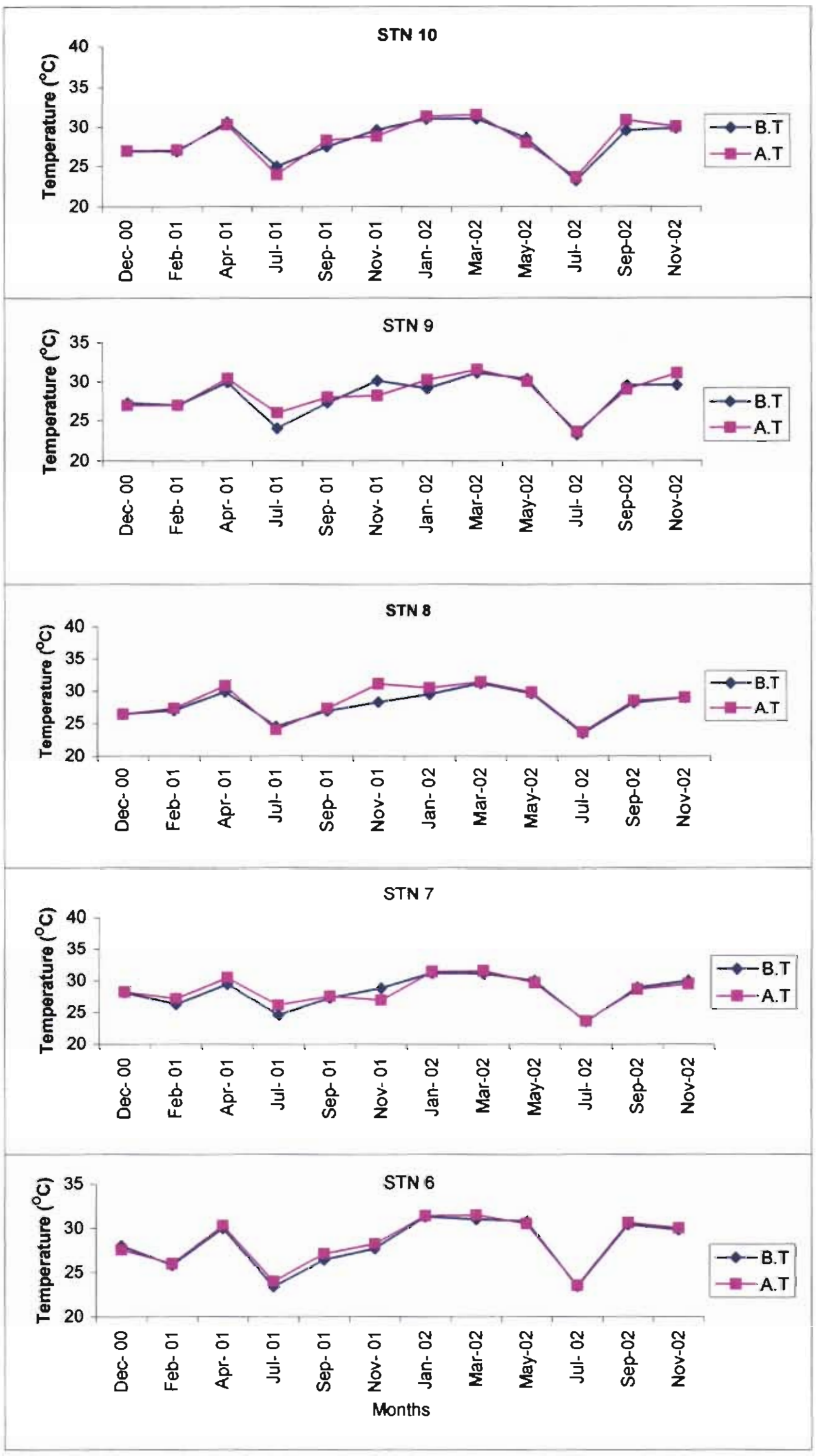


Fig. 3.6b Pattern of variations in temperature at bottom before and after trawling during Dec.2000 to Nov.2002

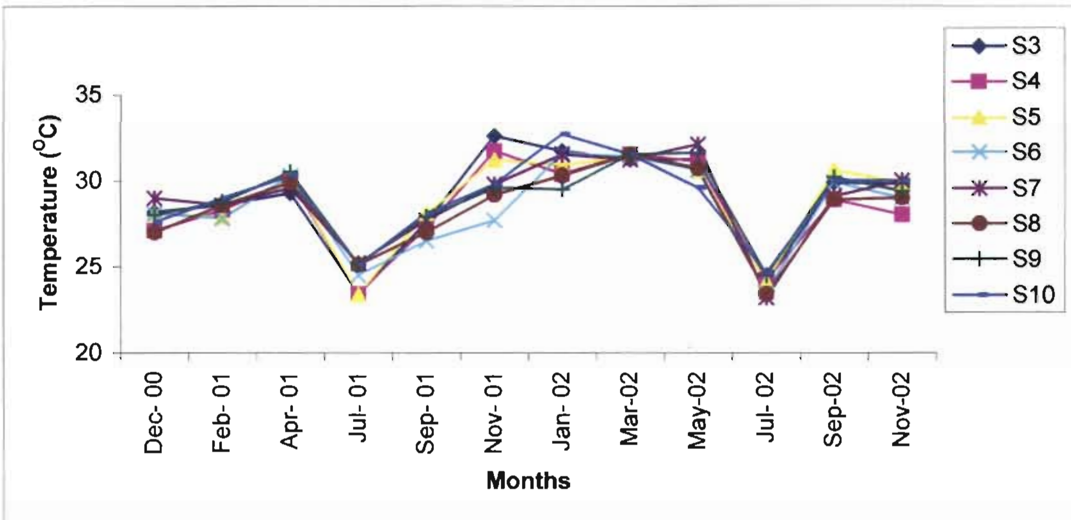


Fig. 3.7 Temperature recorded at five meter above bottom before trawling during Dec.2000 to Nov.2002

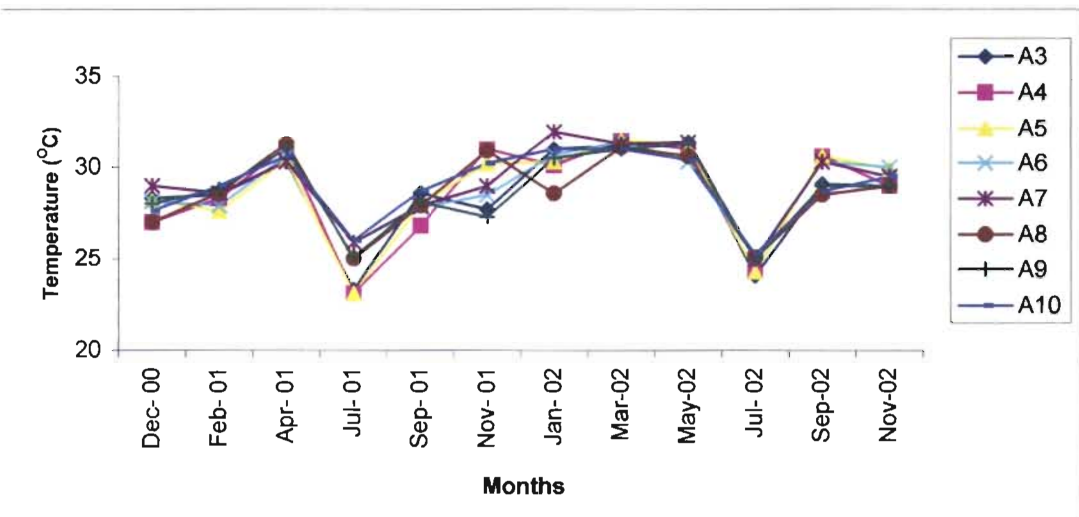


Fig. 3.8 Temperature recorded at five meter above bottom after trawling during Dec.2000 to Nov.2002

Fig. 3.9a Pattern of variations in temperature at five meters above bottom before and after trawling during Dec.2000 to Nov.2002

Fig. 3.9b Pattern of variations in temperature at five meter above bottom before and after trawling during Dec.2000 to Nov.2002

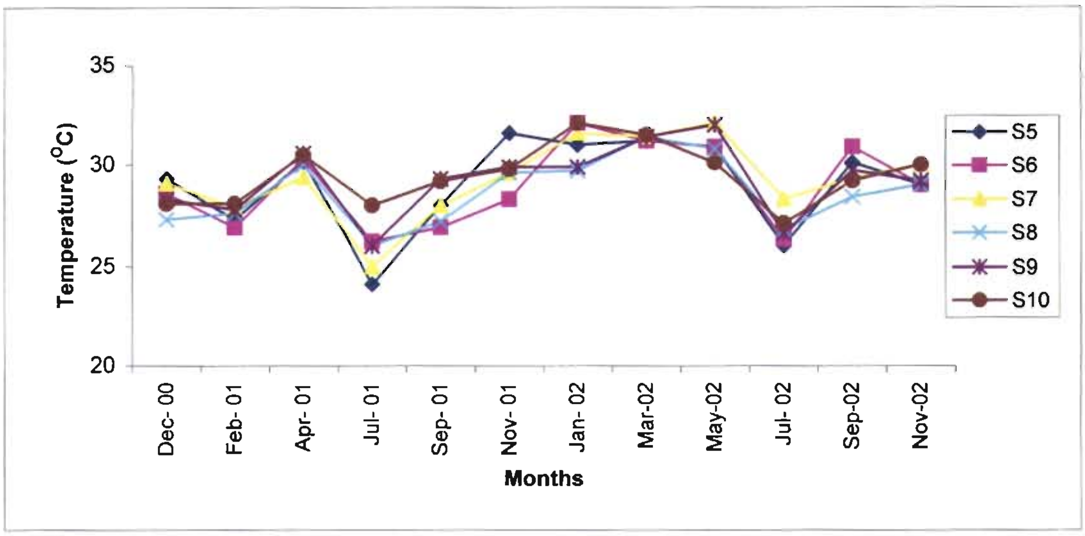


Fig. 3.10 Temperature recorded at ten meter above bottom before trawling during Dec.2000 to Nov.2002

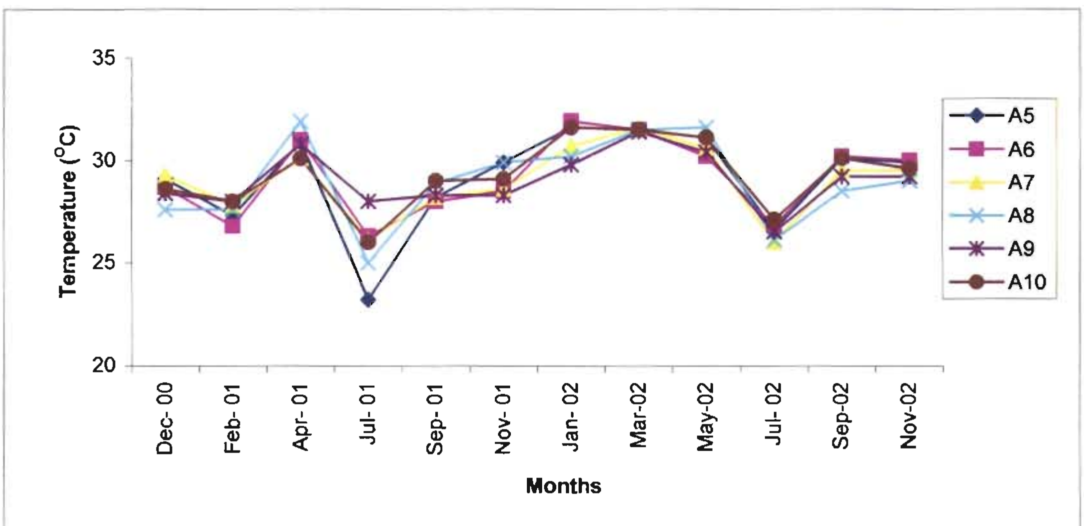


Fig. 3.11 Temperature recorded at ten meter above bottom after trawling during Dec.2000 to Nov.2002

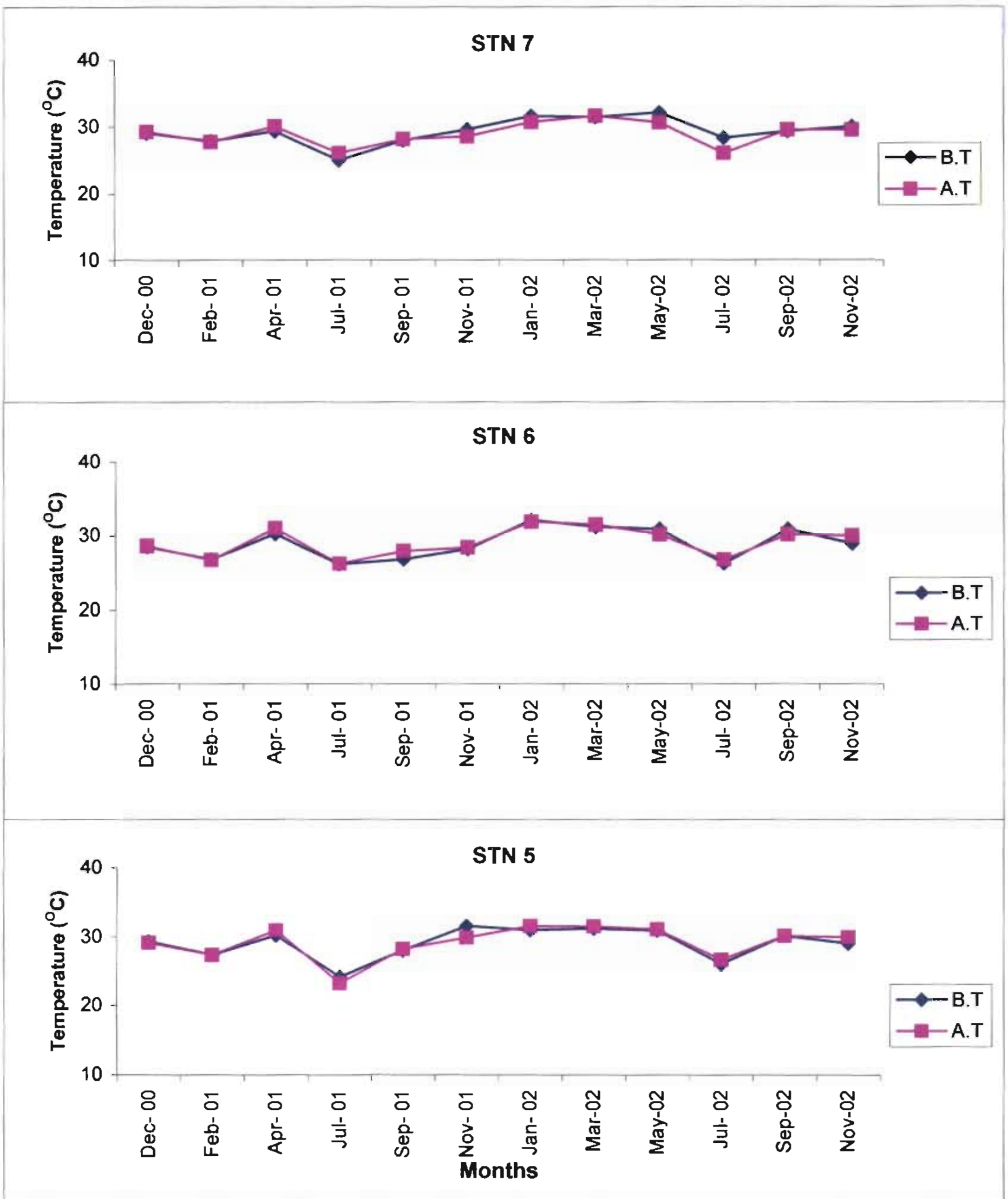


Fig. 3.12a Pattern of variations in temperature at ten meters above bottom before and after trawling during Dec.2000 to Nov.2002

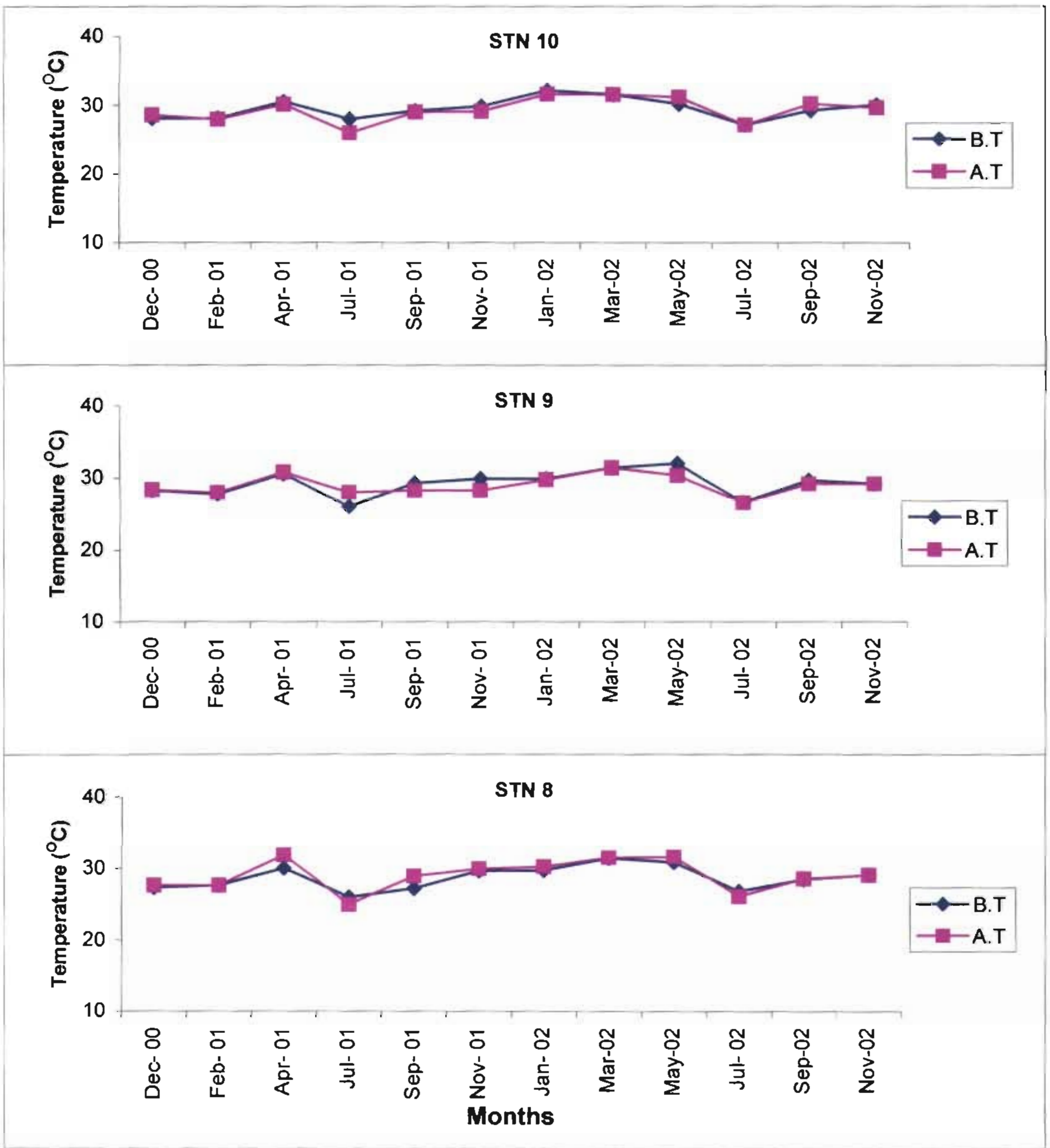


Fig. 3.12b Pattern of variations in temperature at ten meters above bottom before and after trawling during Dec.2000 to Nov.2002

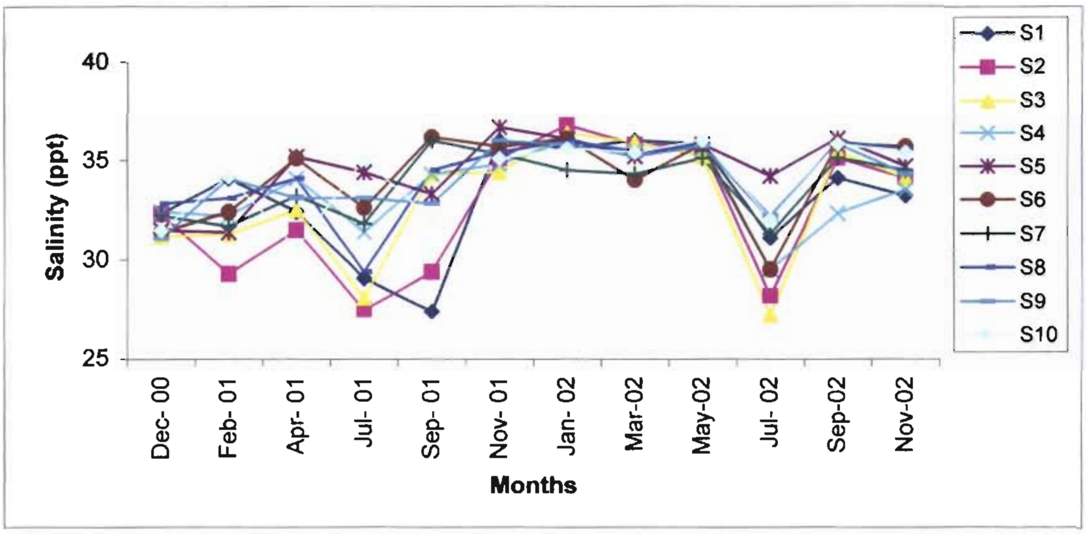


Fig. 3.13 Salinity at surface before trawling during December 2000 to November 2002

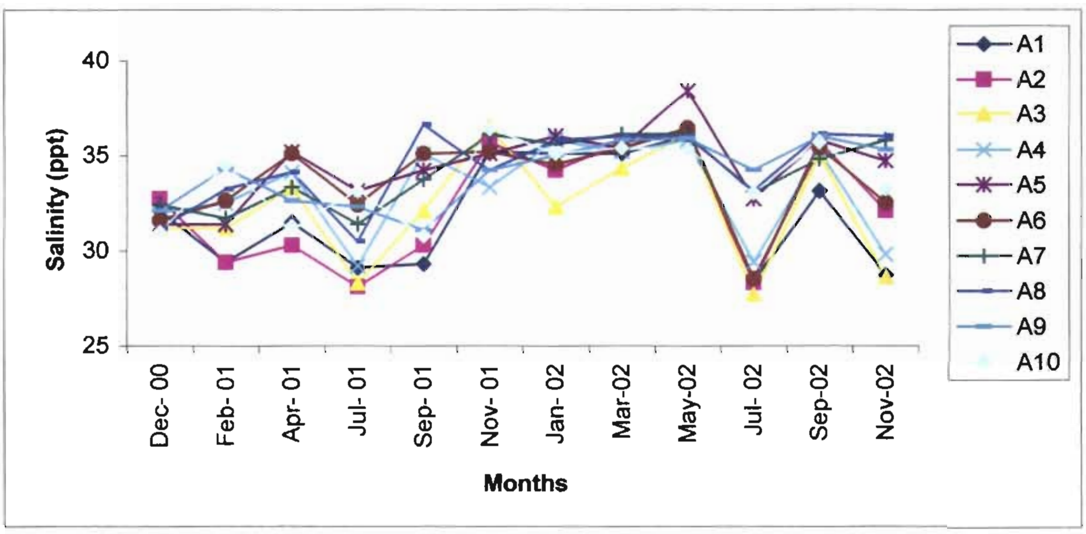


Fig. 3.14 Salinity at surface after trawling during December 2000 to November 2002

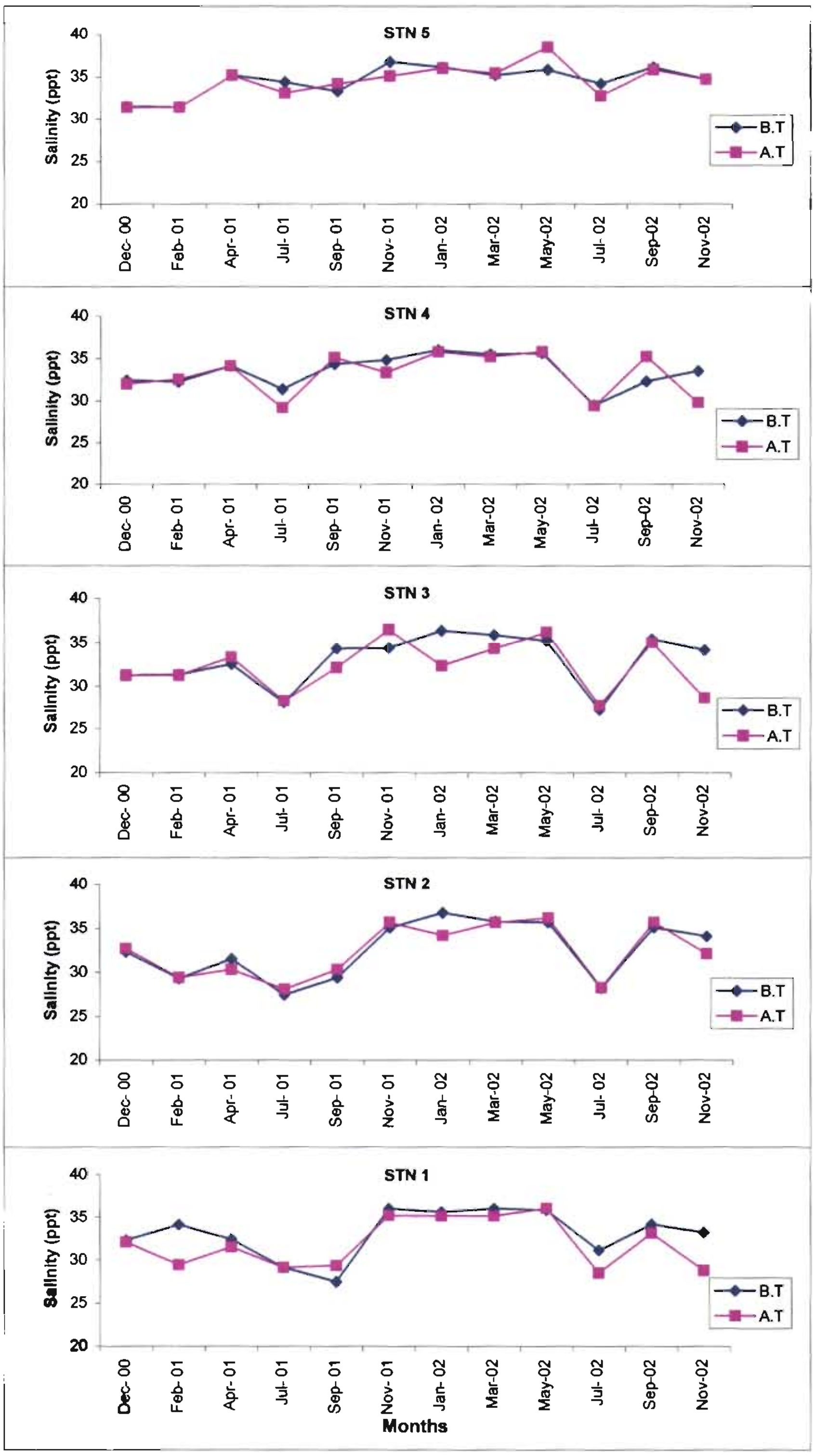


Fig.3.15a **Pattern** of variations in salinity at surface before and after trawling during **December** 2000 to November 2002

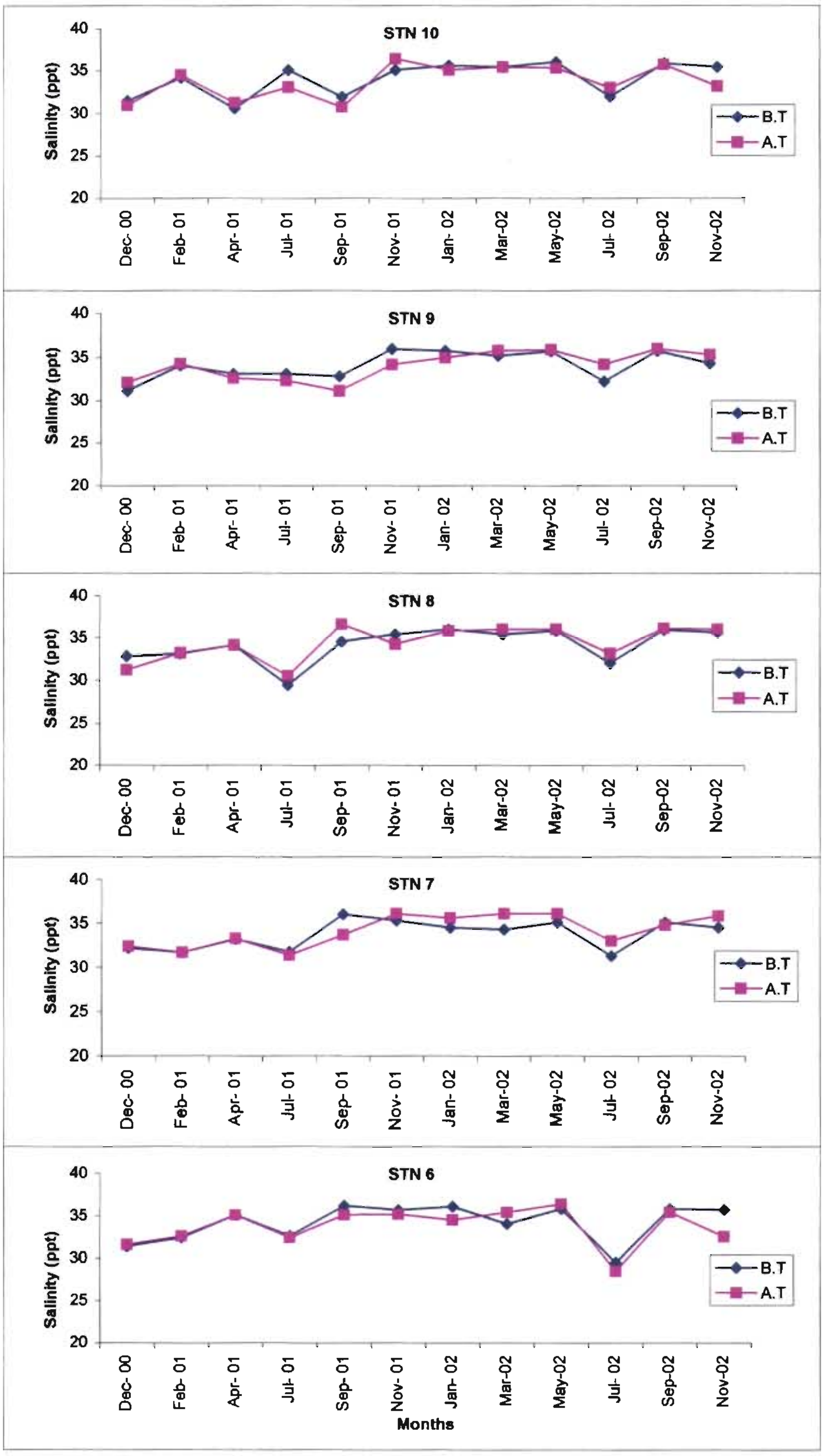


Fig.3.15b Pattern of variations in salinity at surface before and after trawling during December 2000 to November 2002

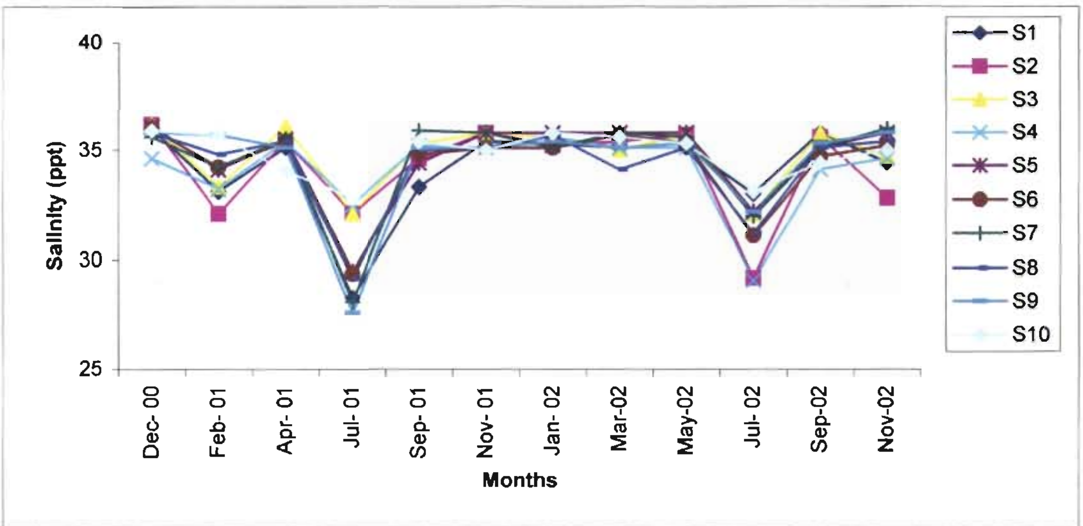


Fig. 3.16 Salinity at bottom before trawling during December 2000 to November 2002

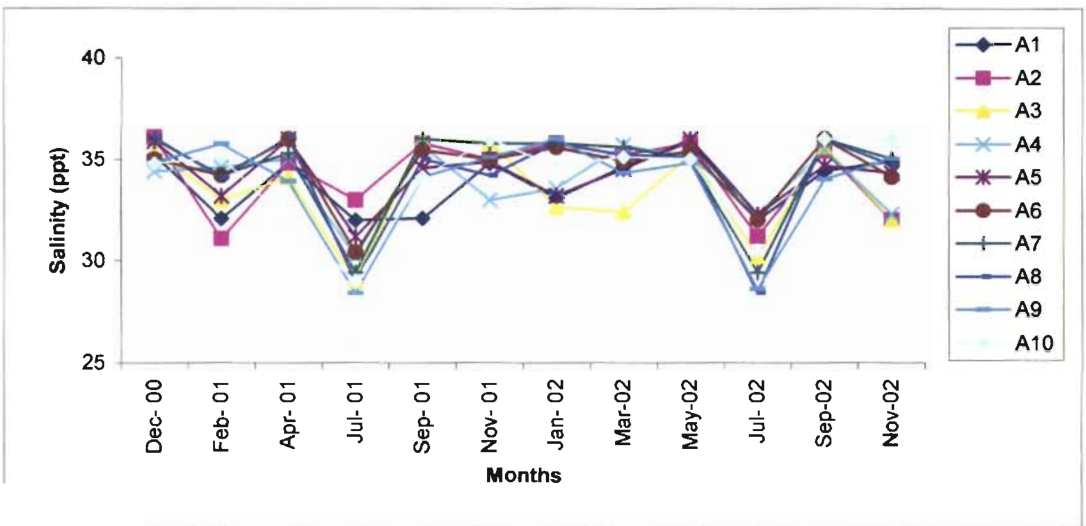


Fig. 3.17 Salinity at bottom after trawling during December 2000 to November 2002

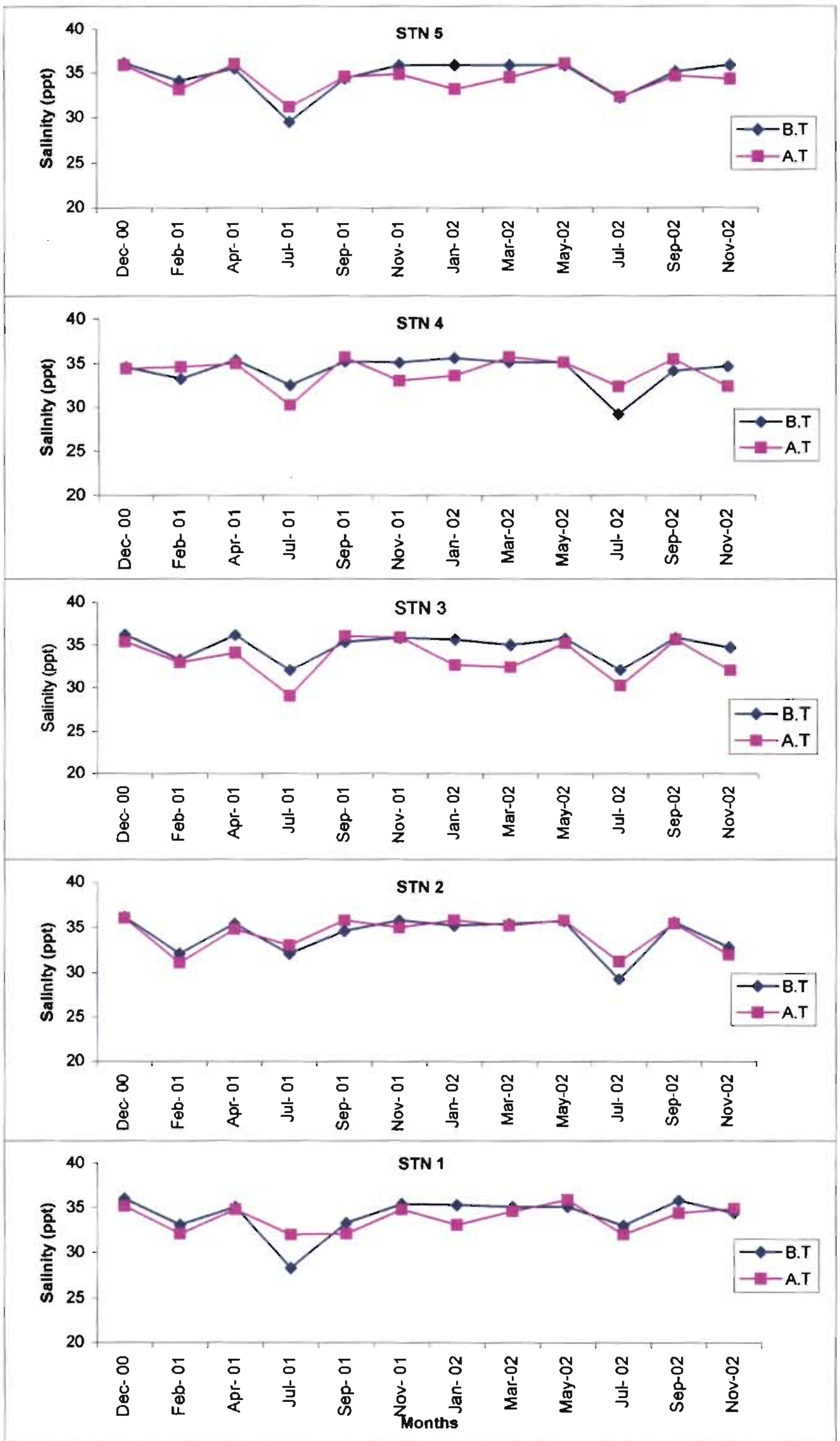


Fig. 3.18a Pattern of variations in salinity at bottom before and after trawling during December 2000 to November 2002

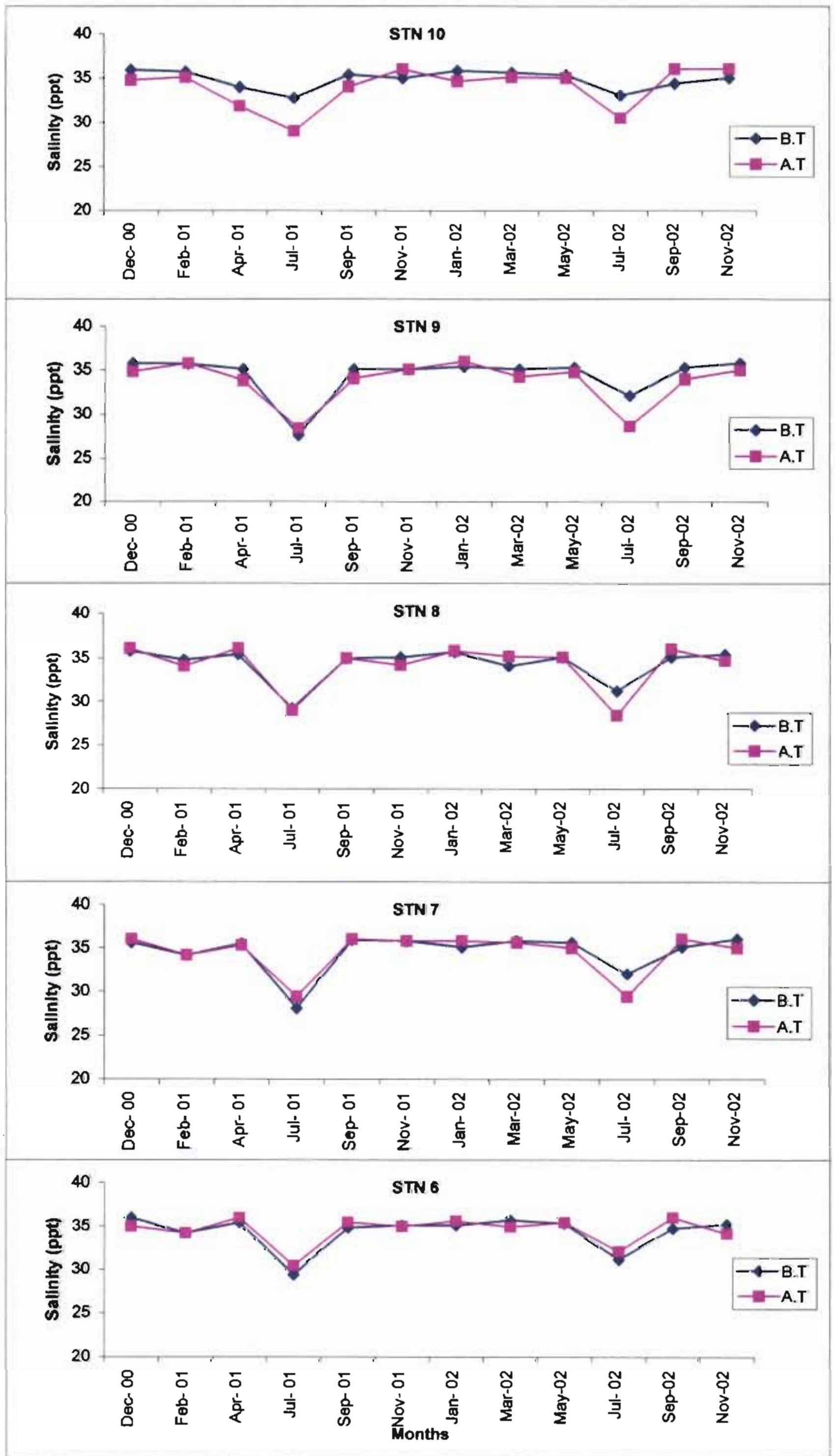


Fig.3.18b Pattern of variations in salinity at bottom before and after trawling during December 2000 to November 2002

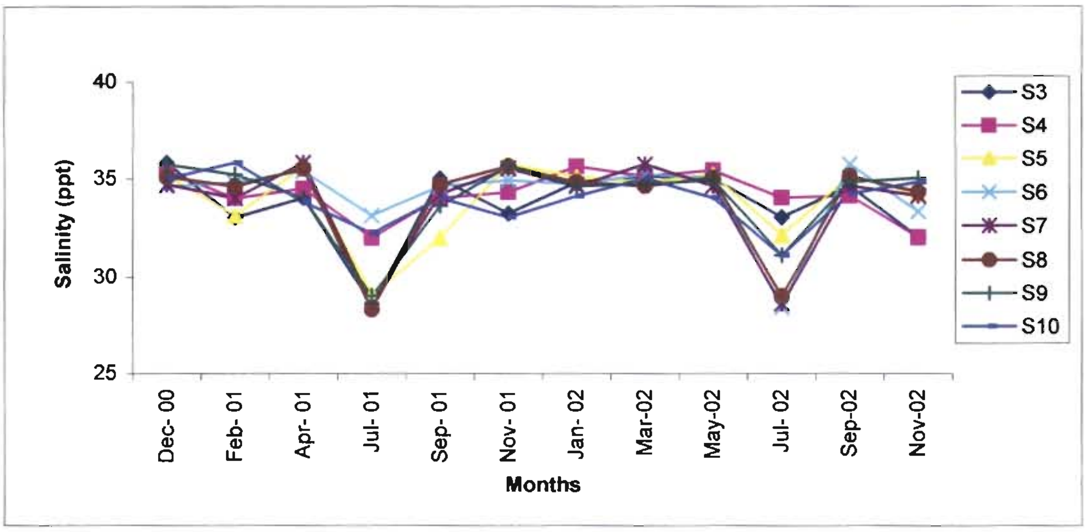


Fig.3.19 Salinity at five meter above bottom before trawling during Decemebr 2000 to November 2002.

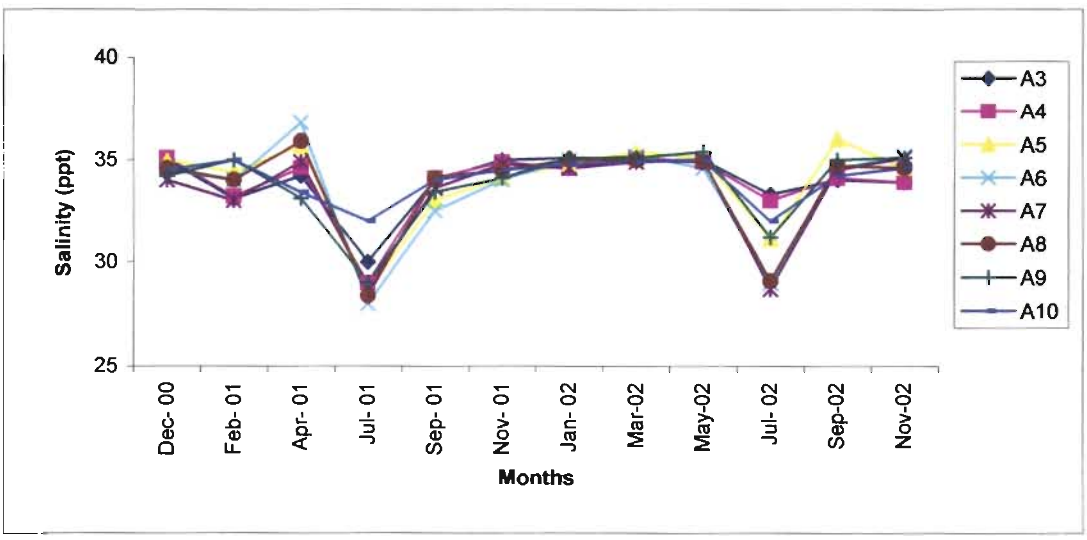


Fig.3.20 Salinity at five meter above bottom after trawling duriing December 2000 to November 2002

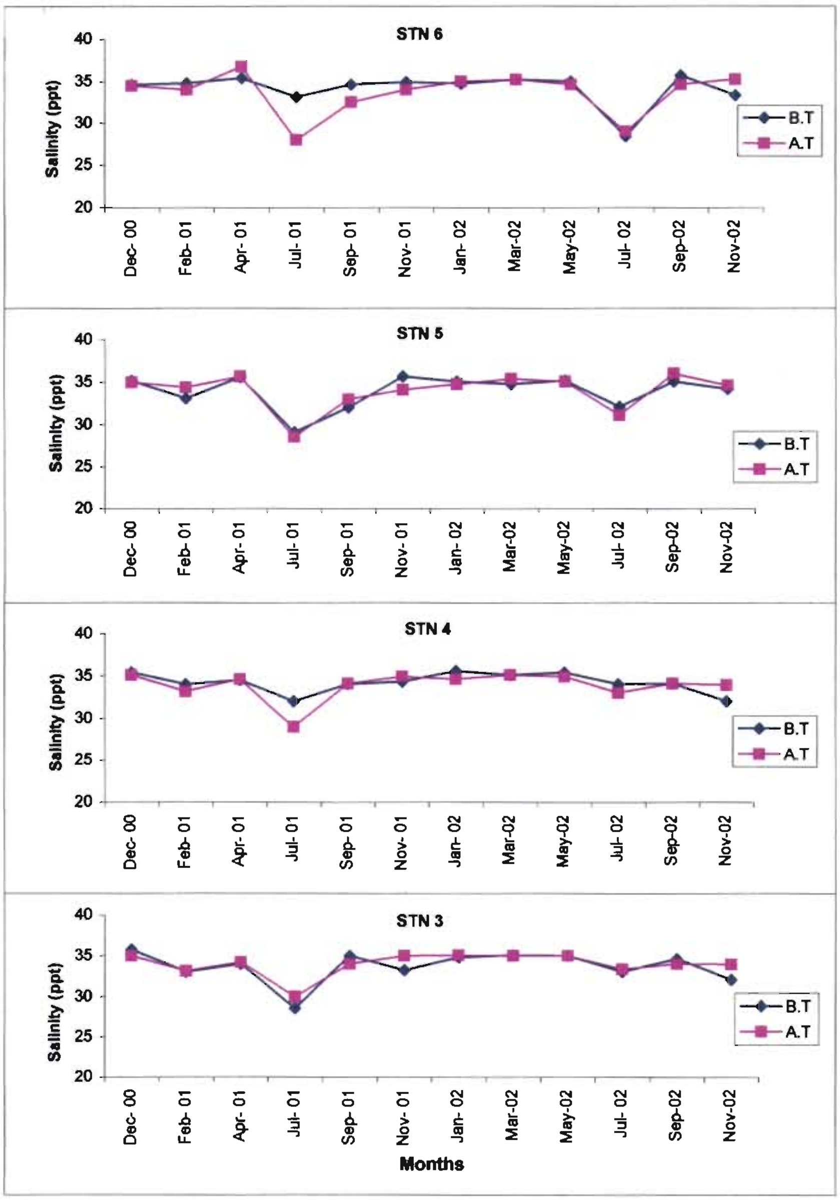


Fig. 3.21a Pattern of variations in salinity at five meter above bottom before and after trawling during December 2000 to November 2002

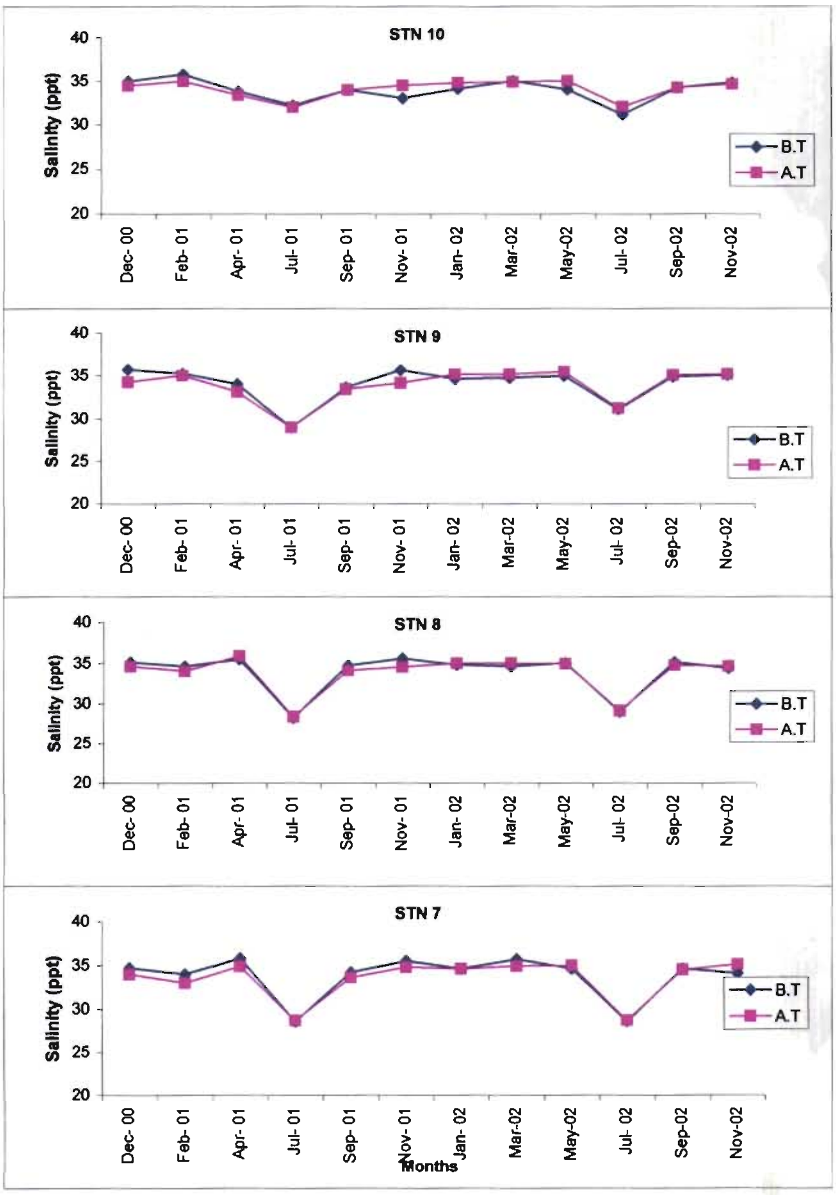


Fig.3.21b Pattern of variations in salinity at five meter above bottom before and after trawling during December 2000 to November 2002

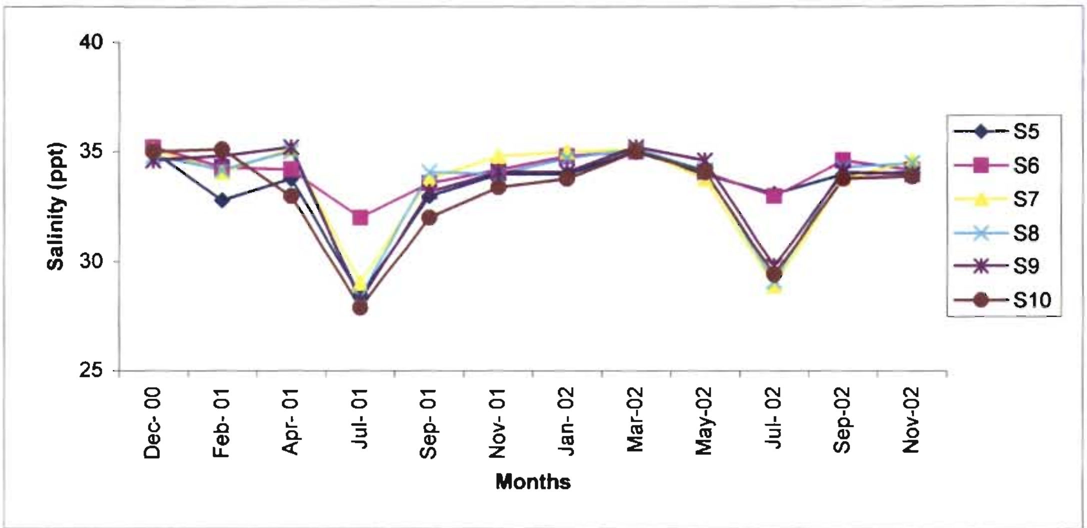


Fig. 3.22 Salinity at ten meter above bottom before trawling during December 2000 to November 2002.

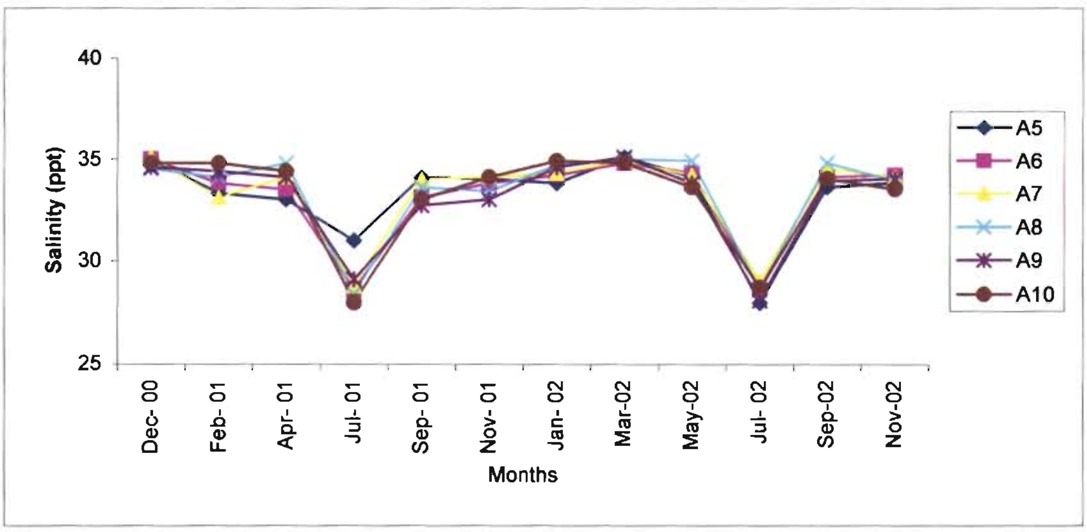


Fig.3.23 Salinity at ten meter above bottom after trawling during December 2000 to November 2002.

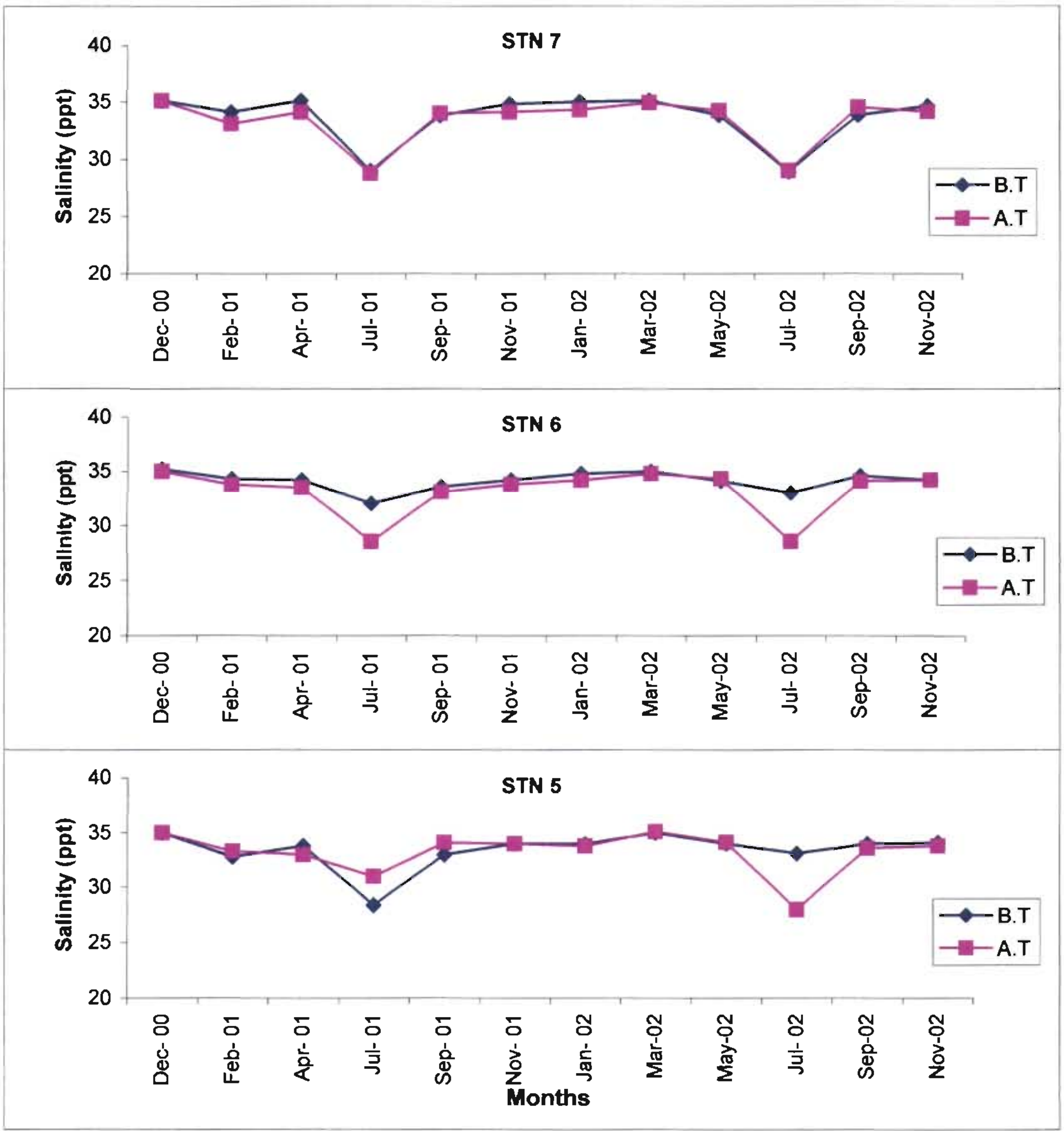


Fig.3.24a Pattern of variations in salinity at ten meter above bottom before and after trawling during December 2000 to November 2002

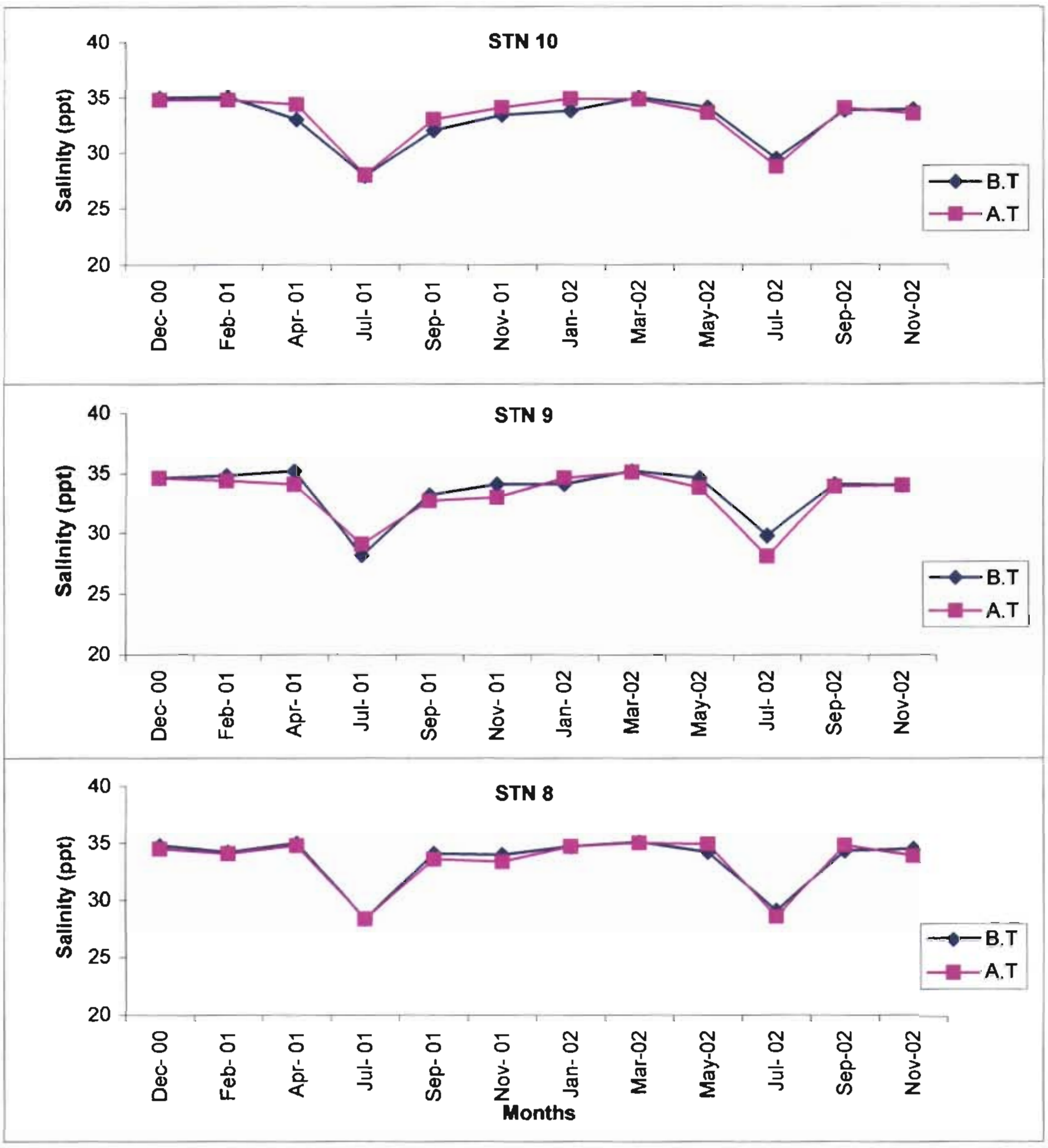


Fig.3.24b Pattern of variations in salinity at ten meter above bottom before and after trawling during December 2000 to November 2002

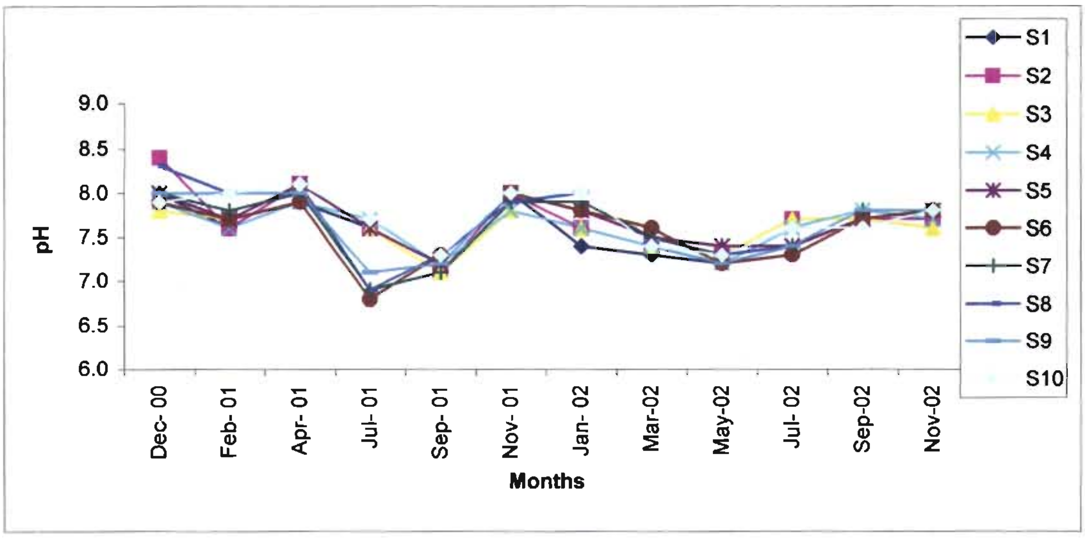


Fig. 3.25 pH recorded at surface before trawling during Decmebr 2000 to November 2002

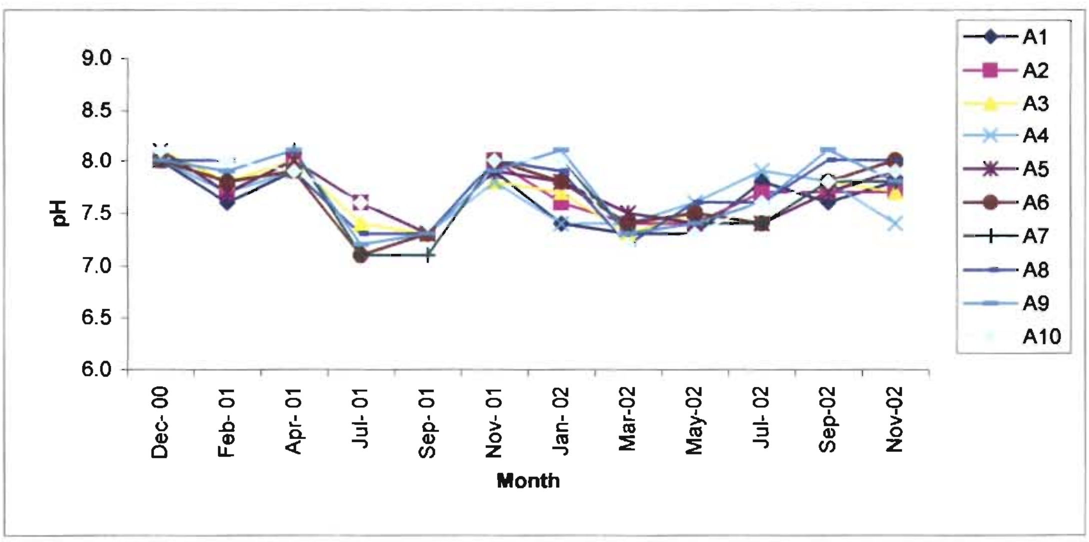


Fig. 3.26 pH recorded at surface after trawling during Decmber 2000 to November 2002

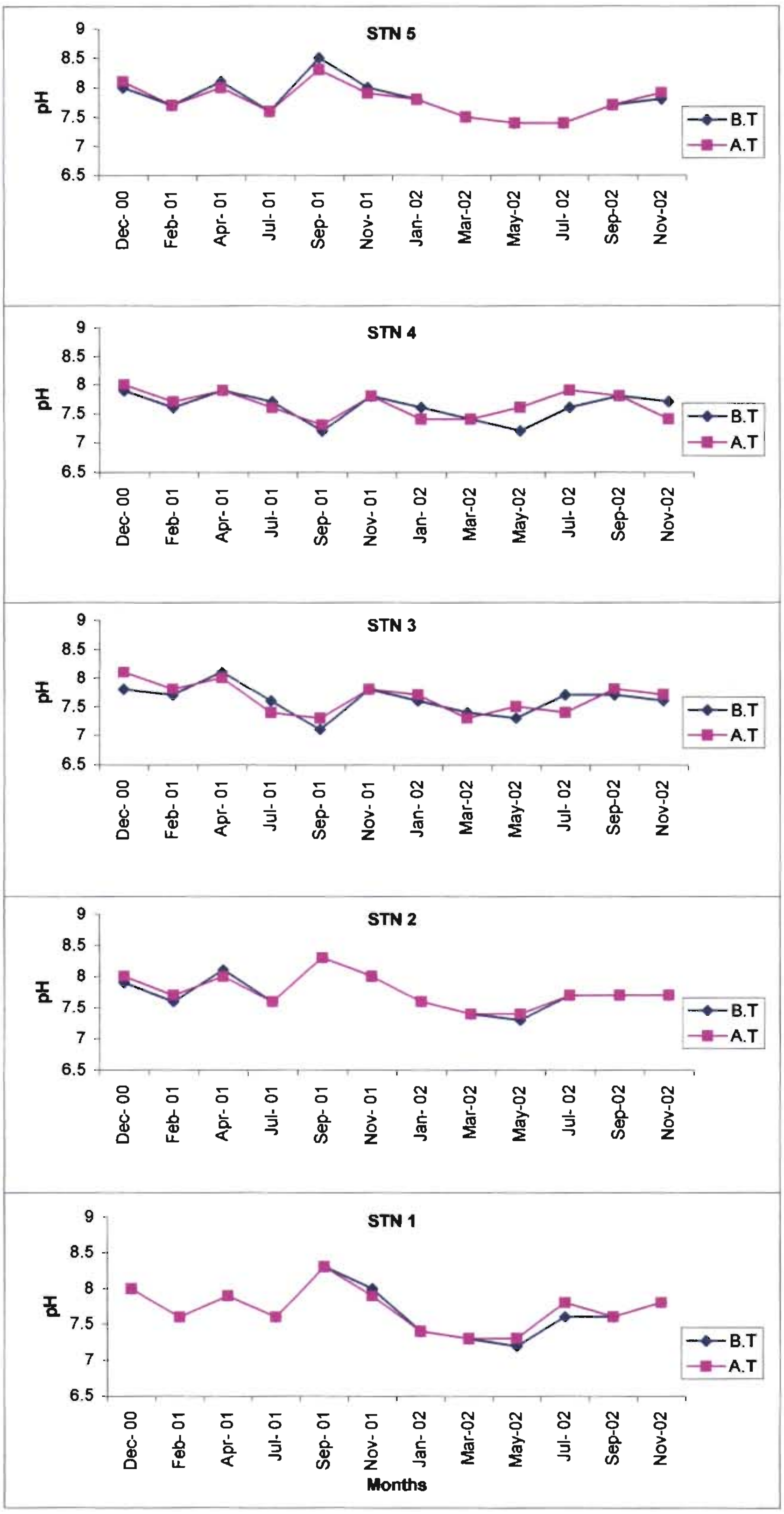


Fig. 3.27a Pattern of variations in pH at surface before and after trawling during December 2000 to November 2002.

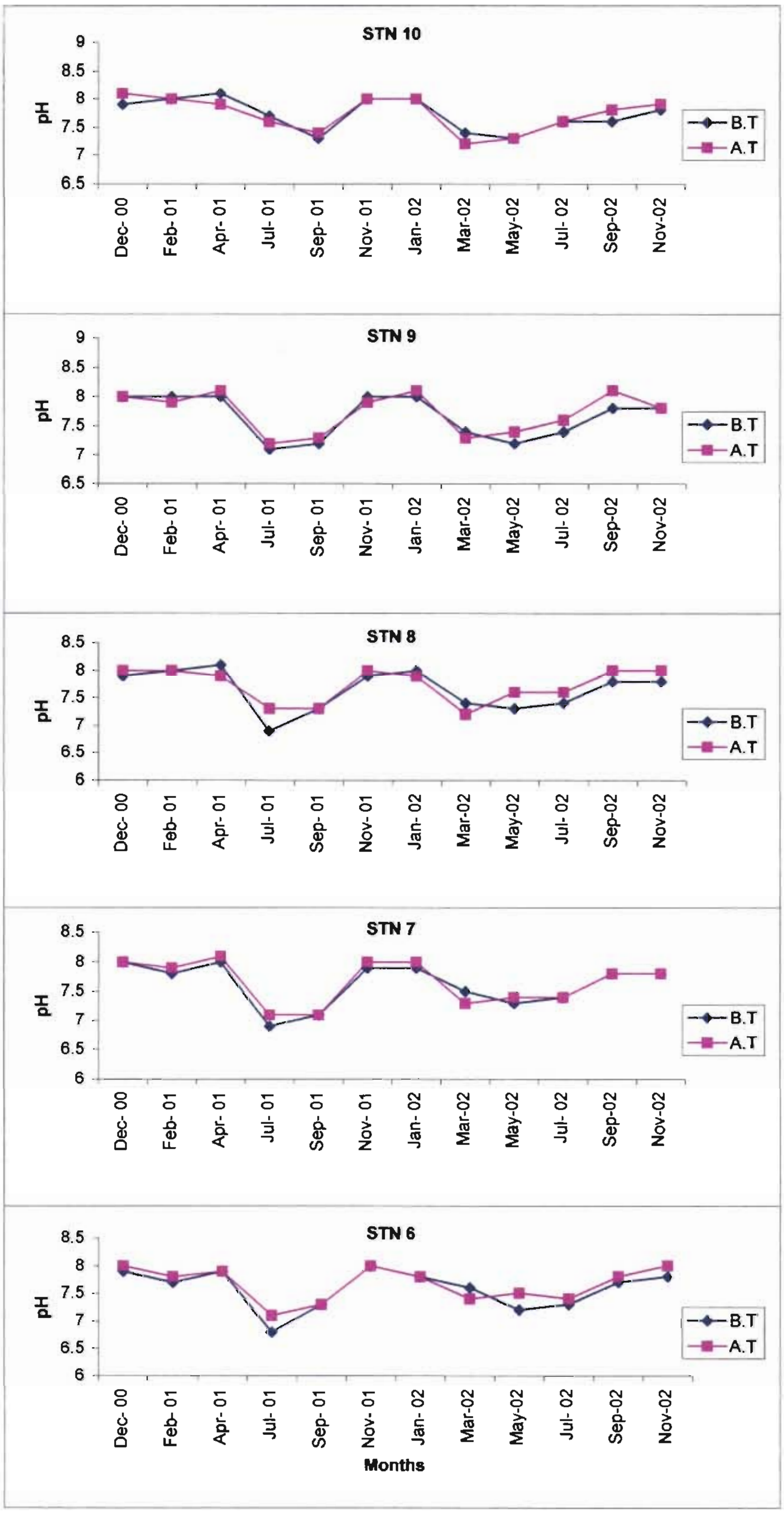


Fig. 3.27b Pattern of variations in pH at surface before and after trawling during Decmber 2000 to November 2002

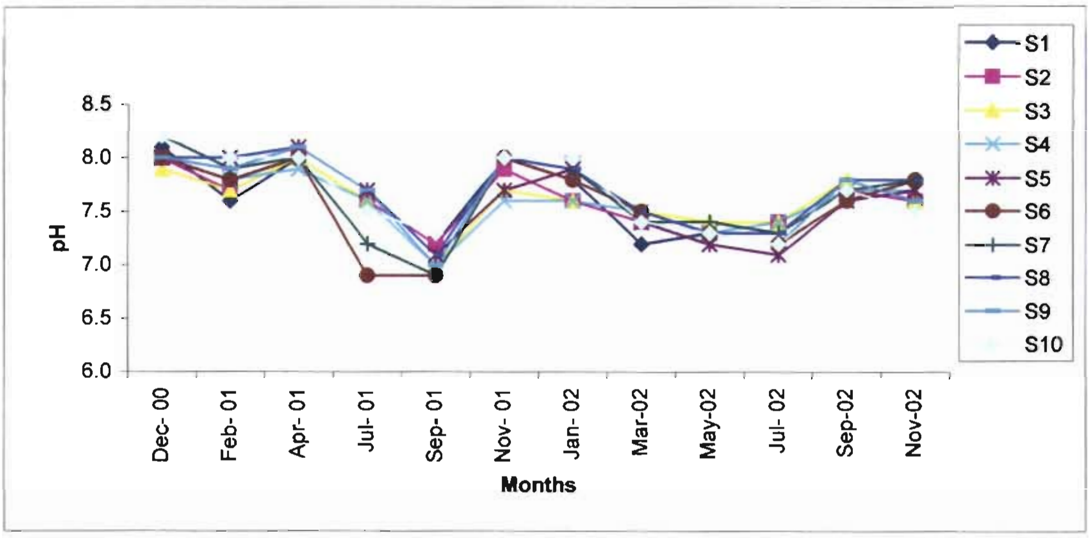


Fig.3.28 pH recorded at bottom before trawling during December 2000 to November 2002.

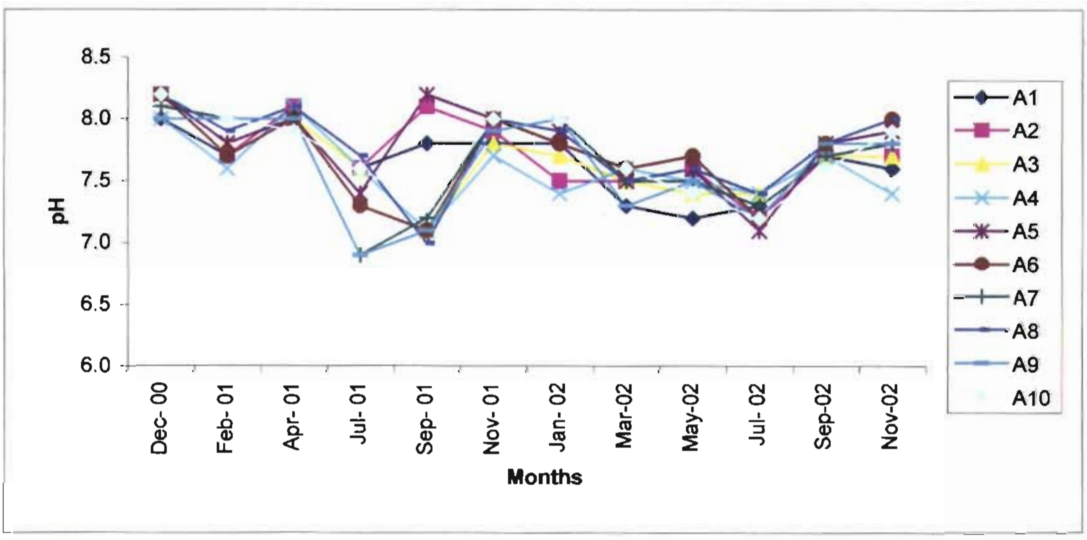


Fig. 3.29 pH recorded at bottom after trawling during Decmber 2000 to November 2002.

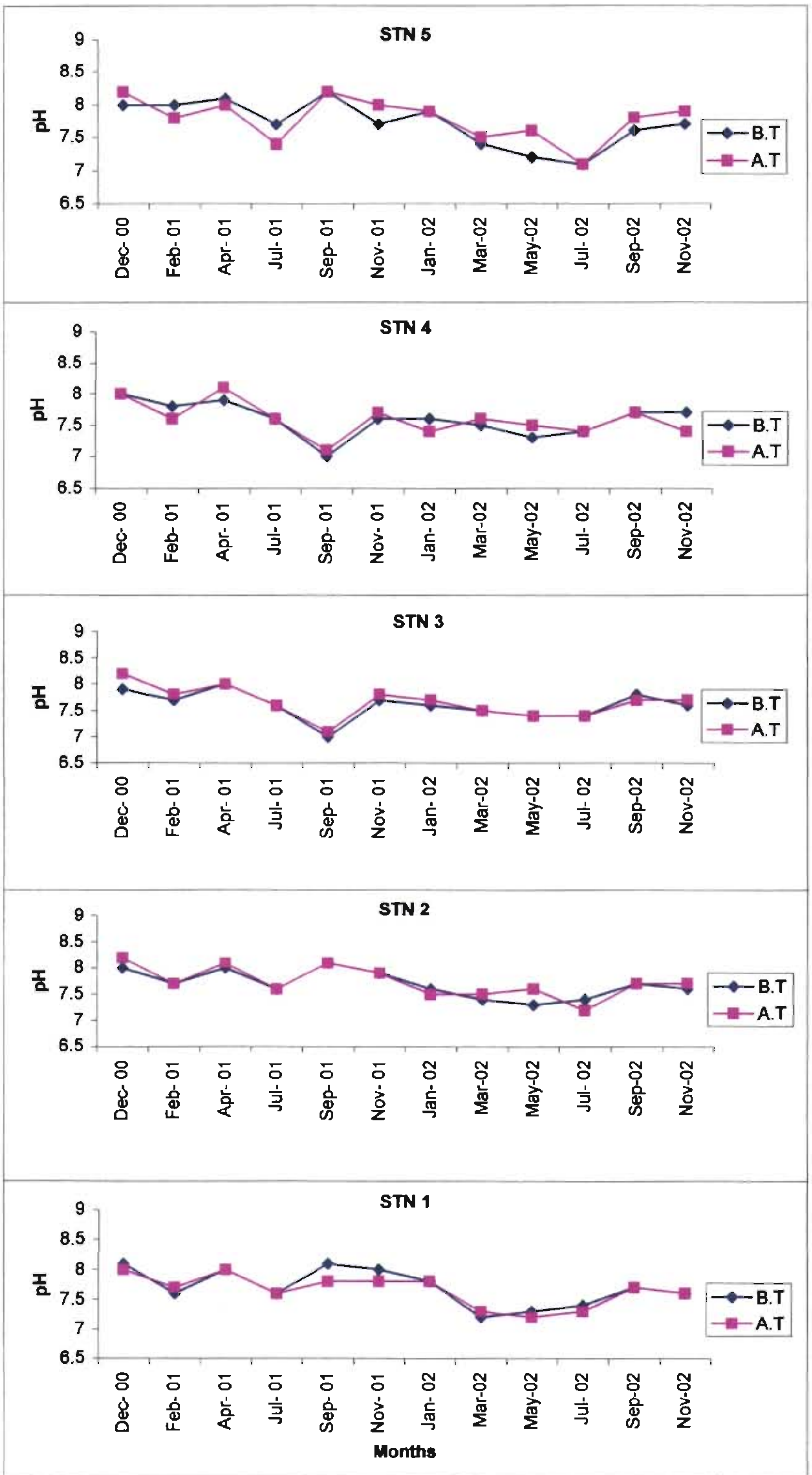


Fig. 3.30a Pattern of variations in pH at bottom before and after trawling during December 2000 to November 2002.

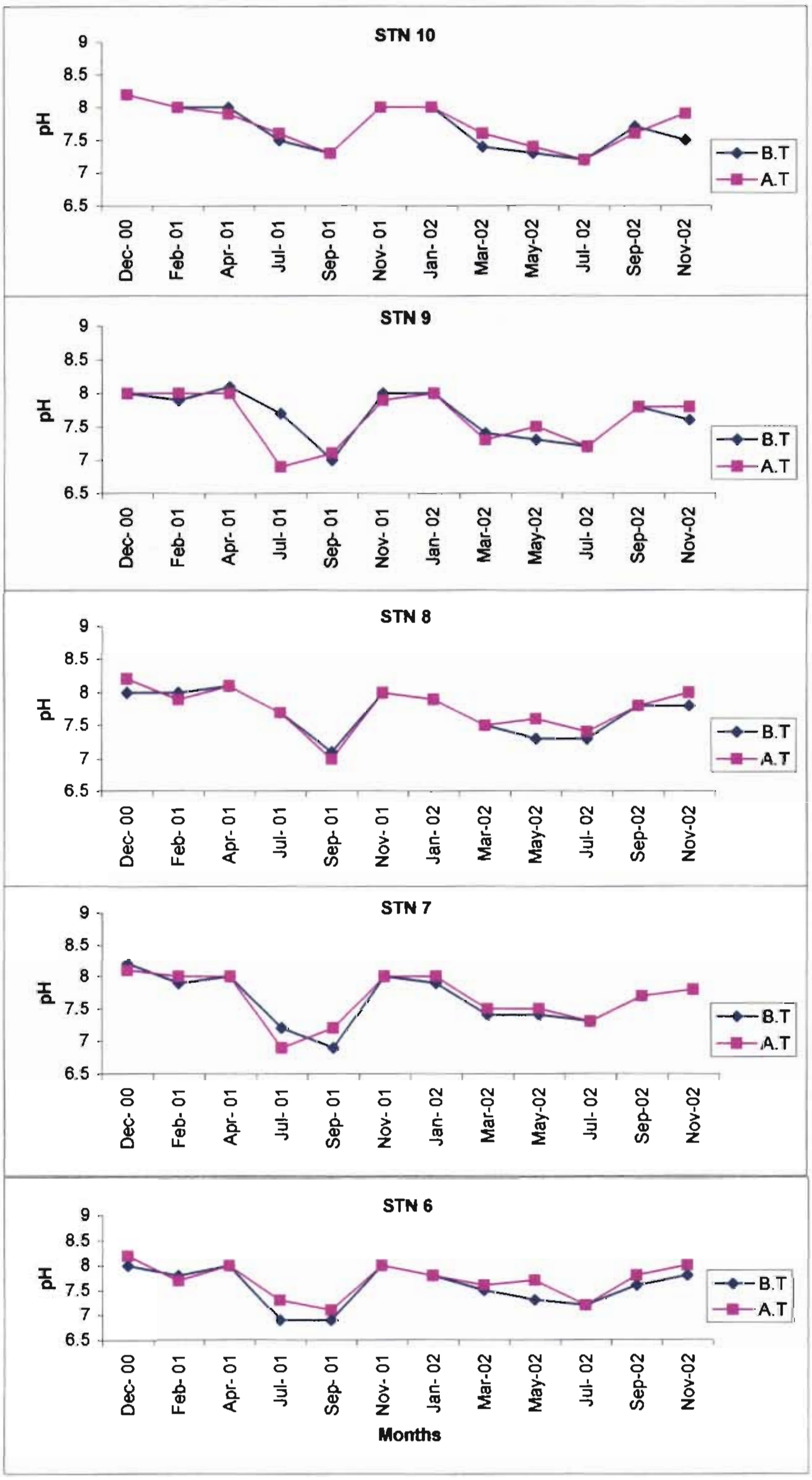


Fig. 3.30b Pattern of variations in pH at bottom before and after trawling during December 2000 to November 2002.

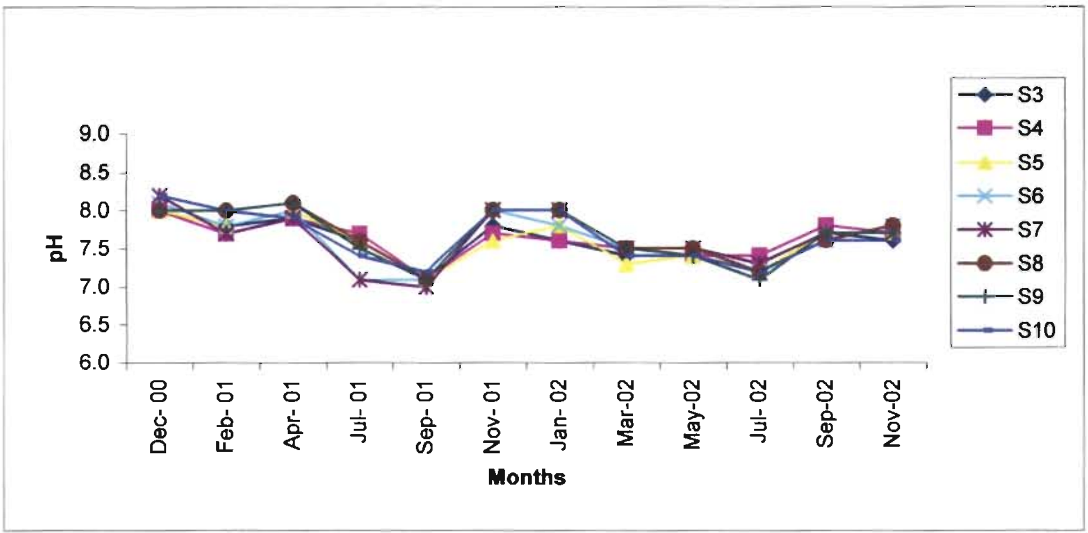


Fig. 3.31 pH recorded at five meter above bottom before trawling during December 2000 to November 2002.

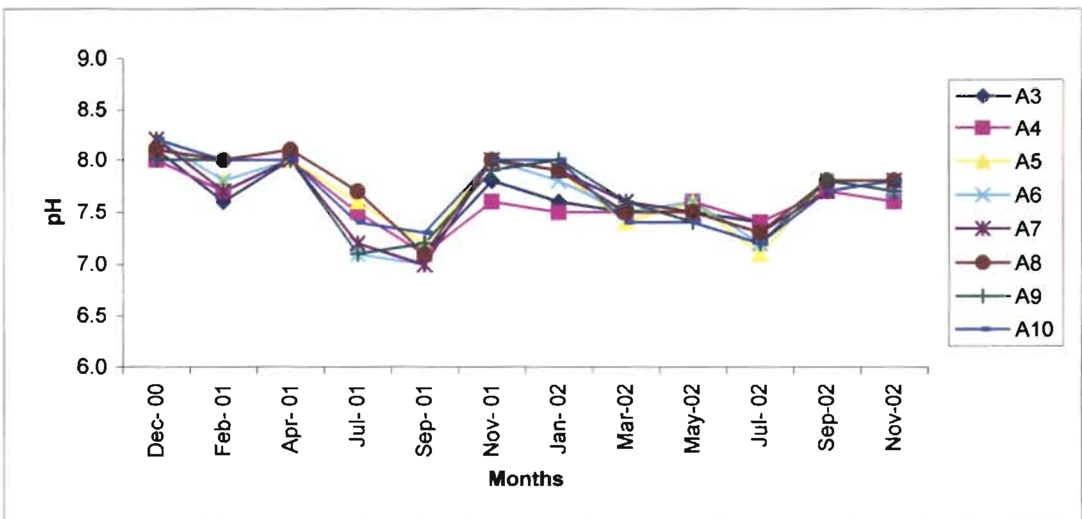


Fig. 3.32 pH recorded at the five meter above bottom after trawling during December 2000 to November 2002.

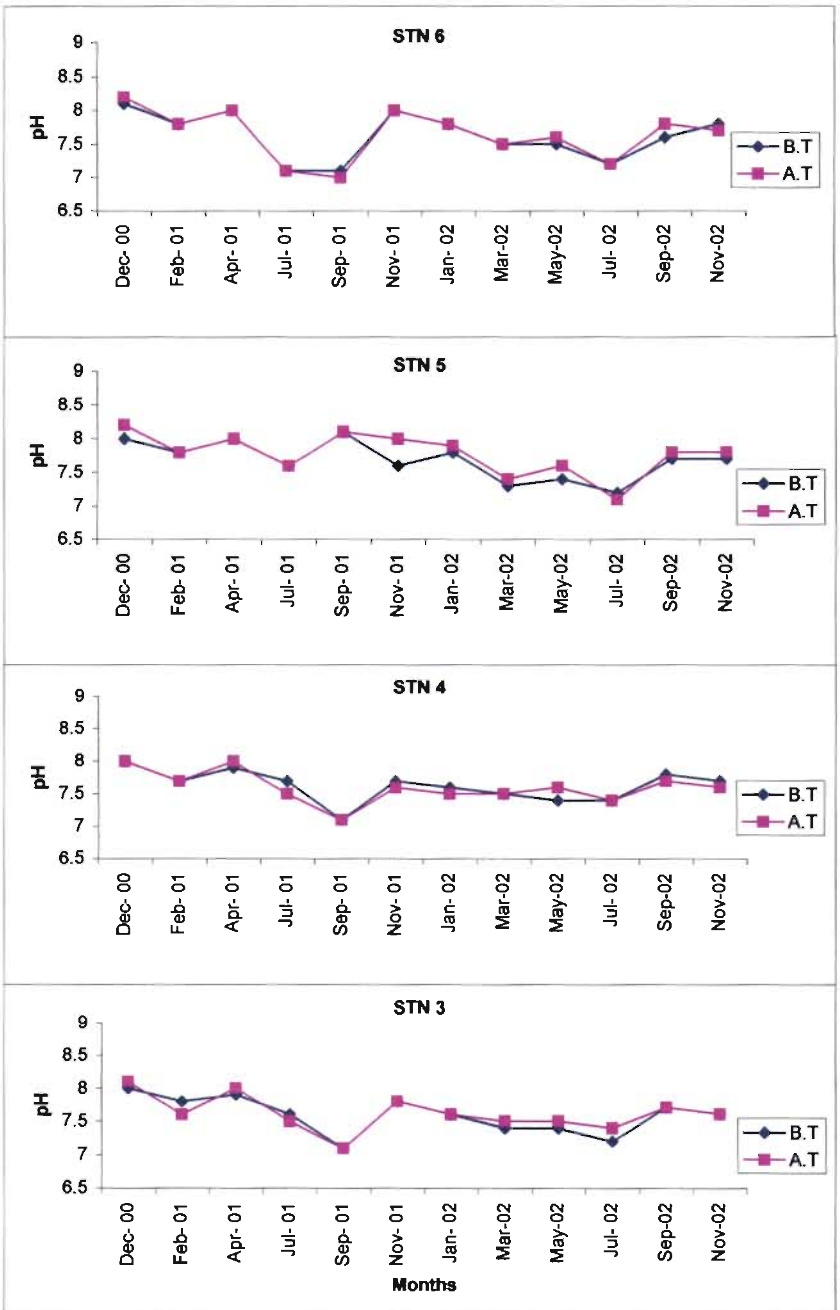


Fig. 3.33 a Pattern of variations in pH at five meter above bottom before and after trawling during December 2000 to November 2002.

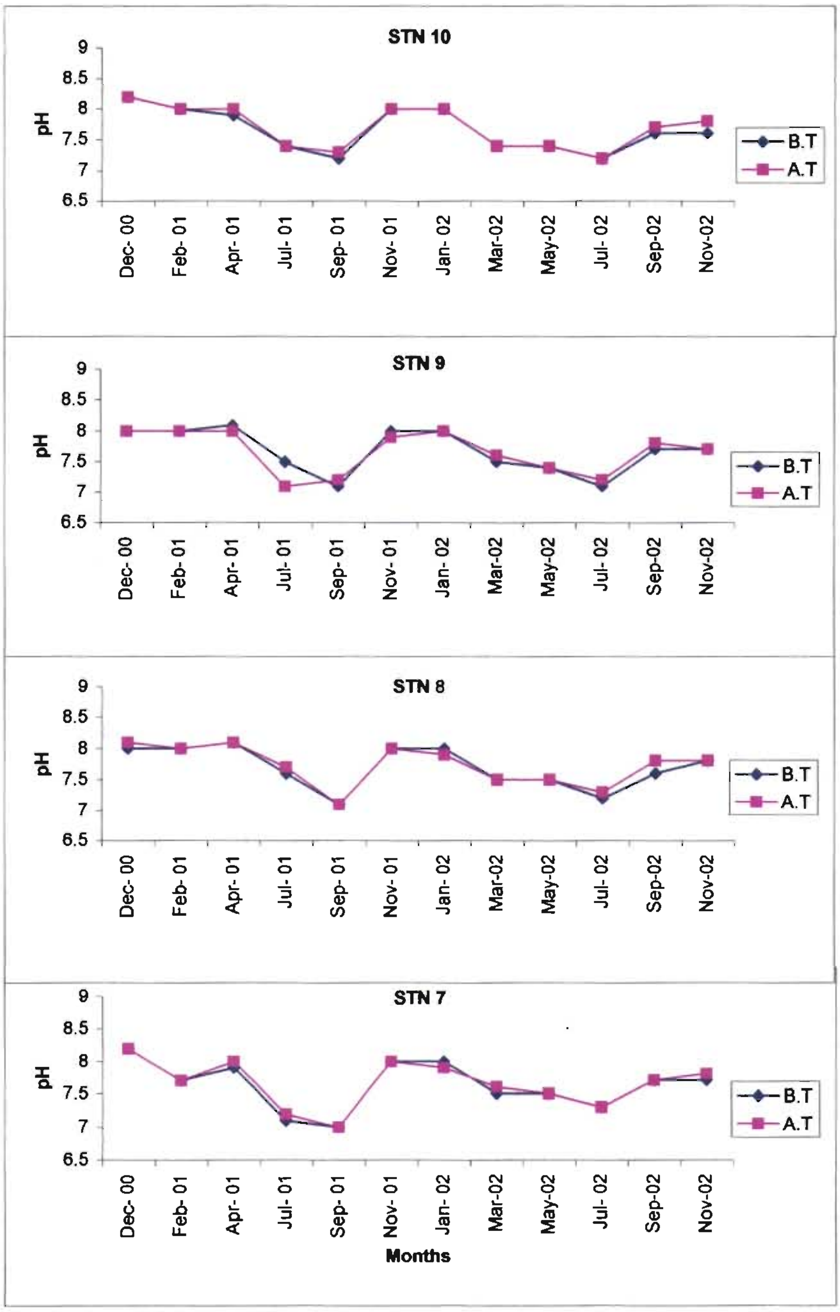


Fig.3.33b Pattern of variations in pH at five meter above bottom before and after trawling during December 2000 to November 2002.

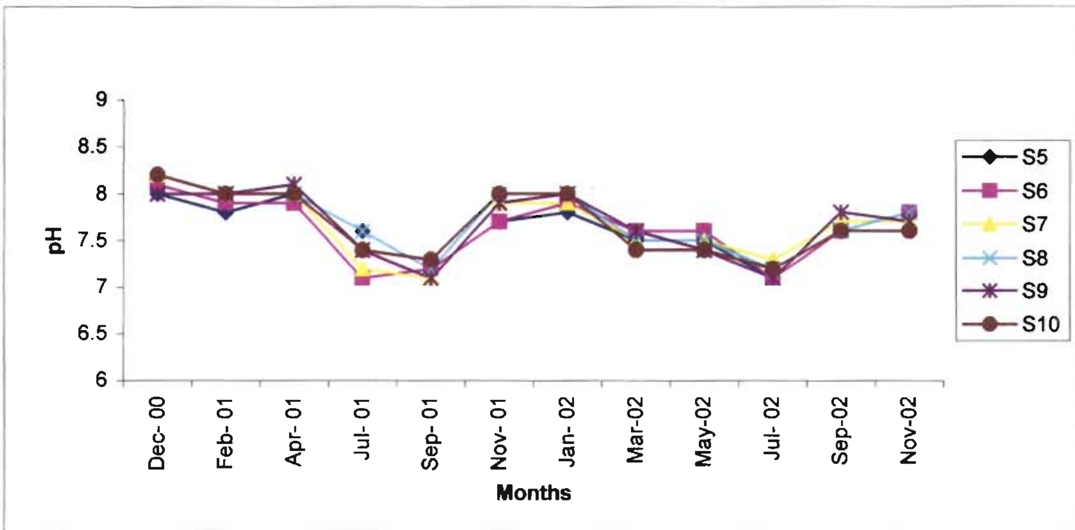


Fig. 3.34 pH recorded at ten meter above bottom before trawling during December 2000 to November 2002.

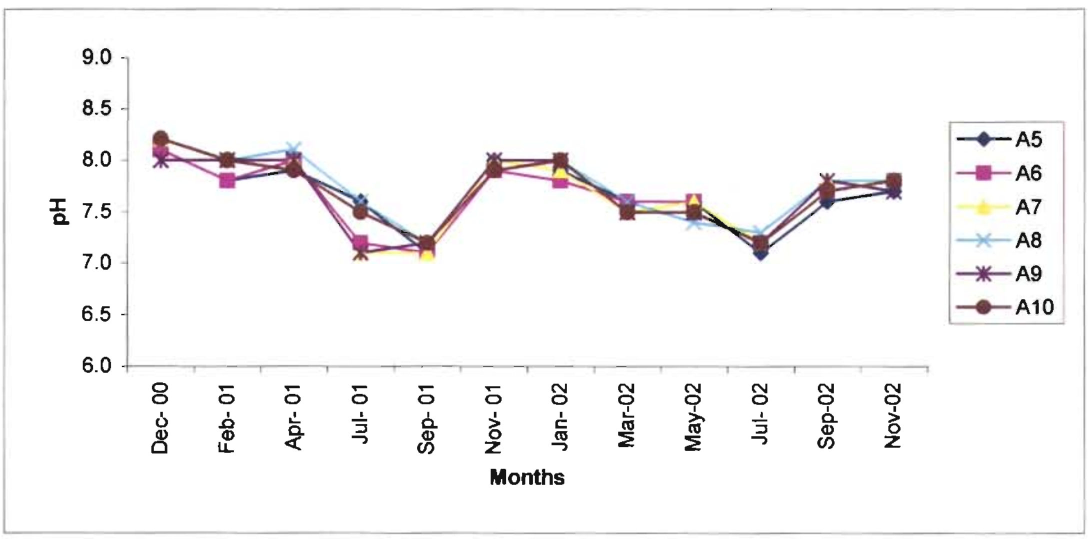


Fig. 3.35 pH recorded at ten meter above bottom after trawling during December 2000 to November 2002.

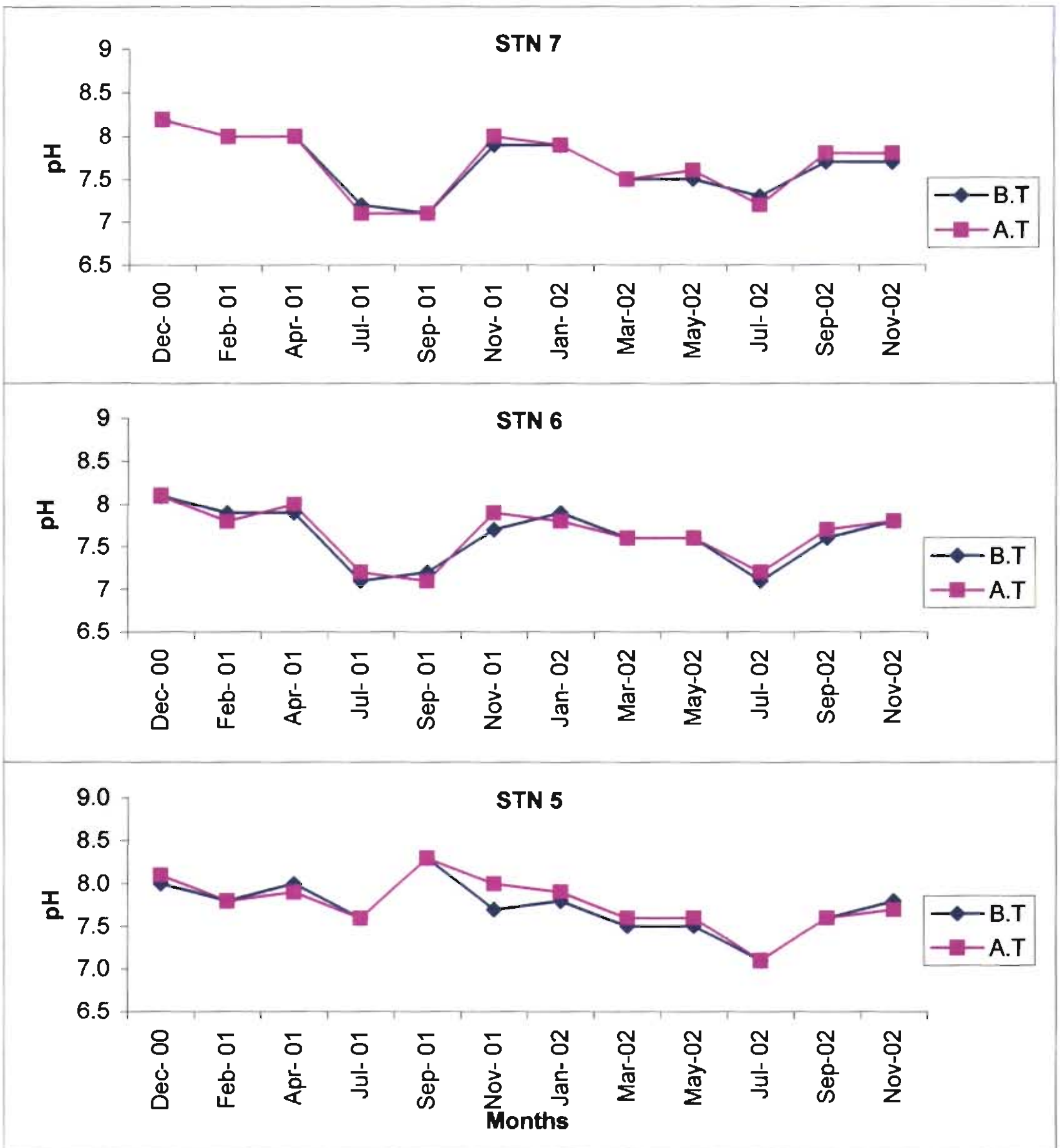


Fig. 3.36a Pattern of variations in pH at ten meter above bottom before and after trawling during December 2000 to November 2002.

Fig. 3.36b Pattern of variations in pH at ten meter above bottom before and after trawling during December 2000 to November 2002.

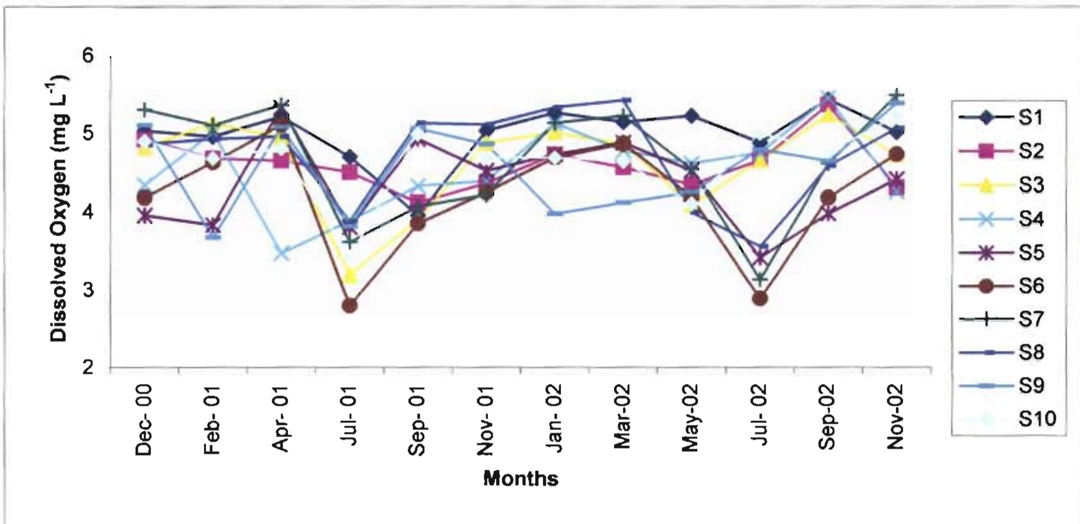


Fig. 3.37 Dissolved oxygen at surface before trawling during Dec.2000 to Nov.2002

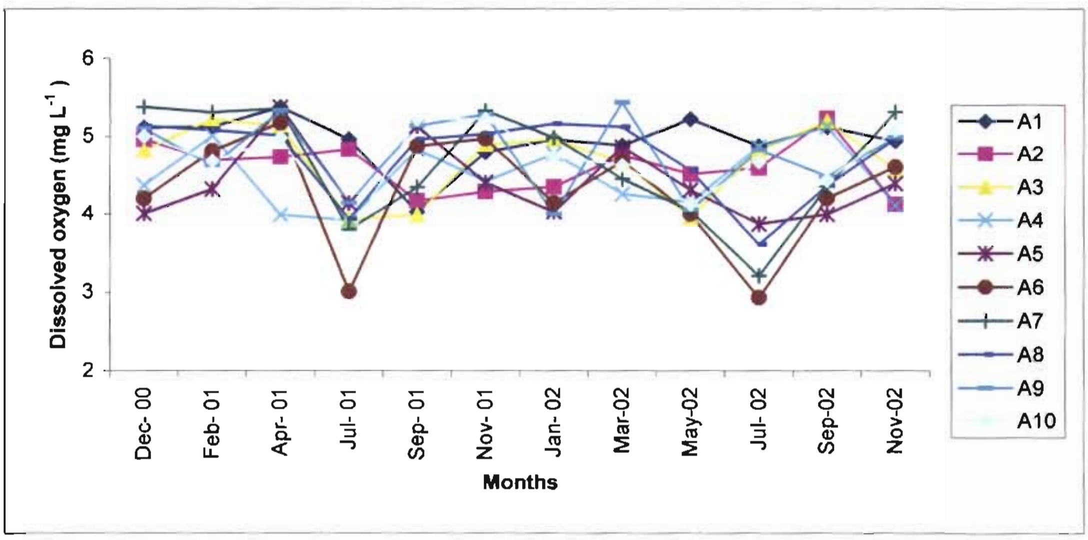


Fig. 3.38 Dissolved oxygen at surface after trawling during Dec.2000 to Nov.2002

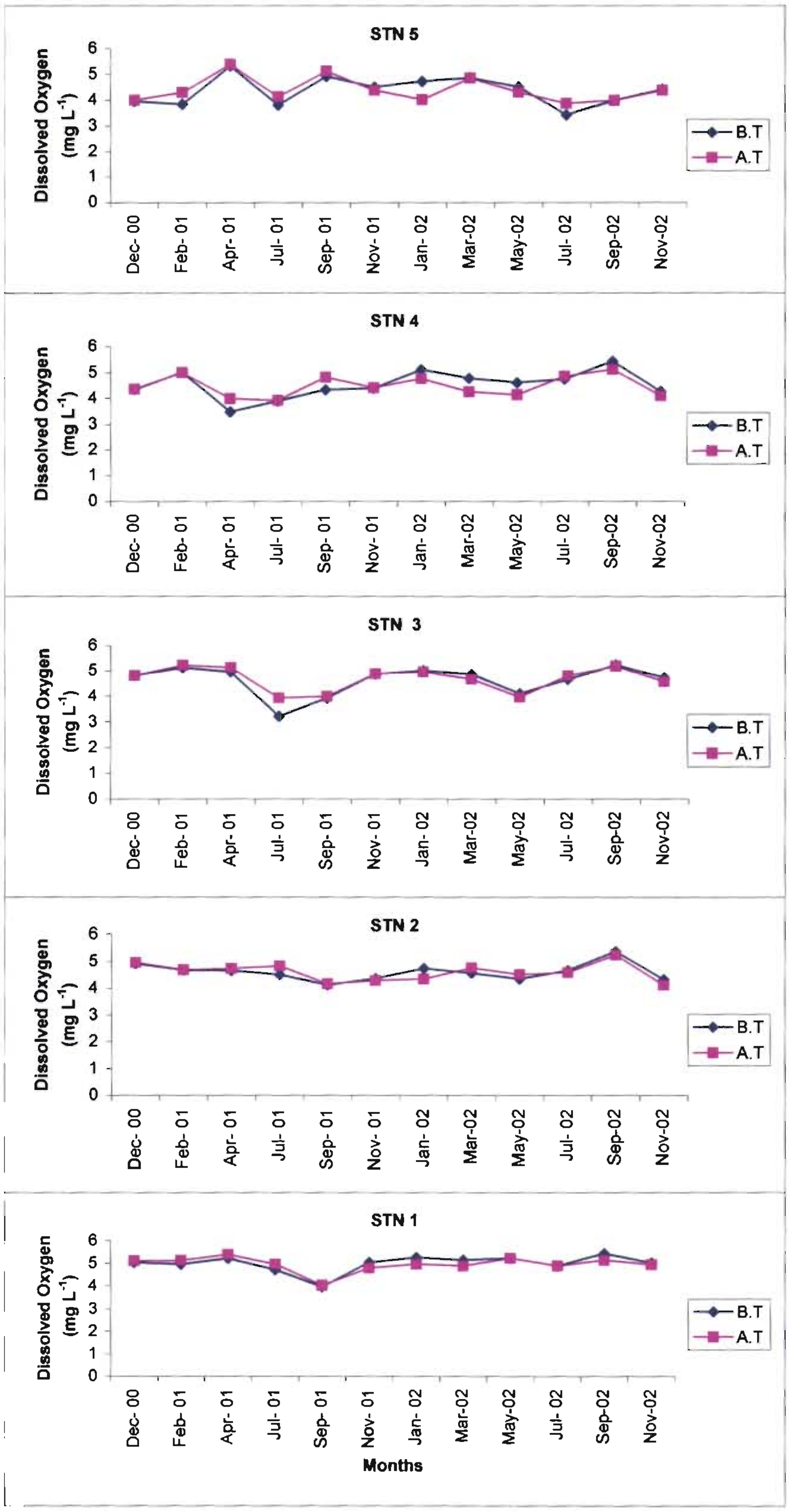


Fig. 3.39a Pattern of variations in dissolved oxygen at surface before and after trawling during Dec.2000 to Nov.2002

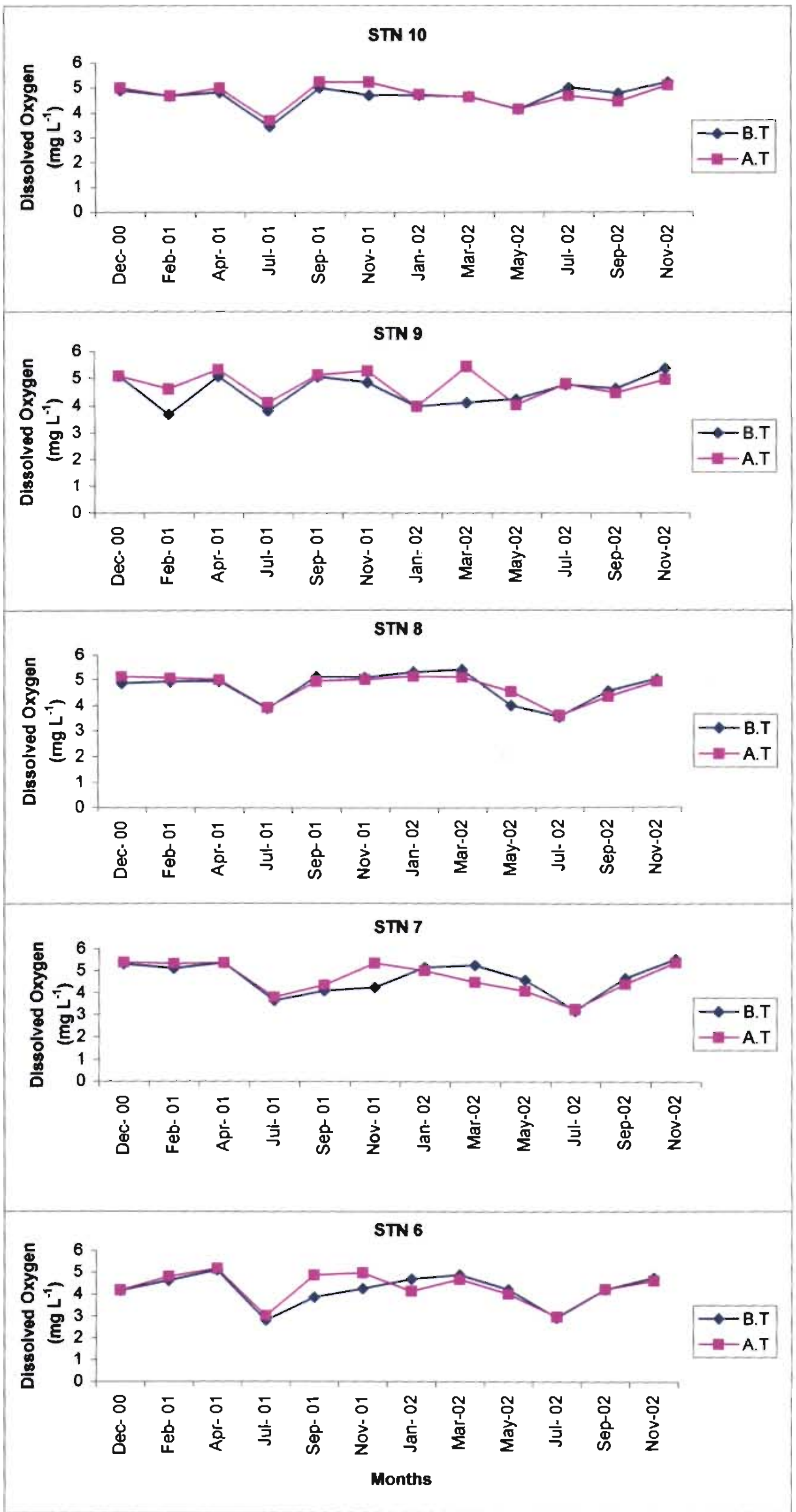


Fig. 3.39b Pattern of variations in dissolved oxygen at surface before and after trawling during Dec.2000 to Nov.2002

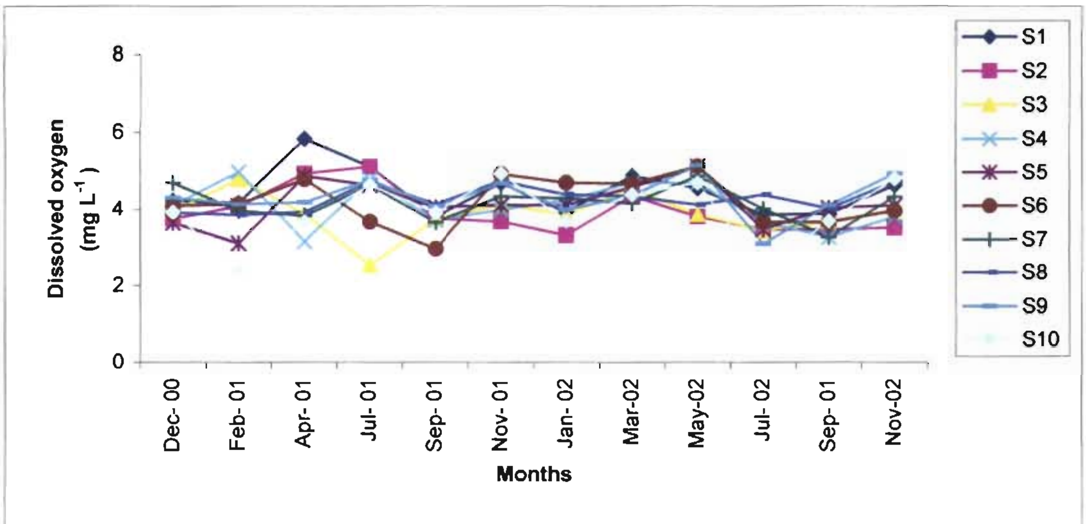


Fig. 3.40 Dissolved oxygen recorded at bottom before trawling during Dec.2000 to Nov. 2002

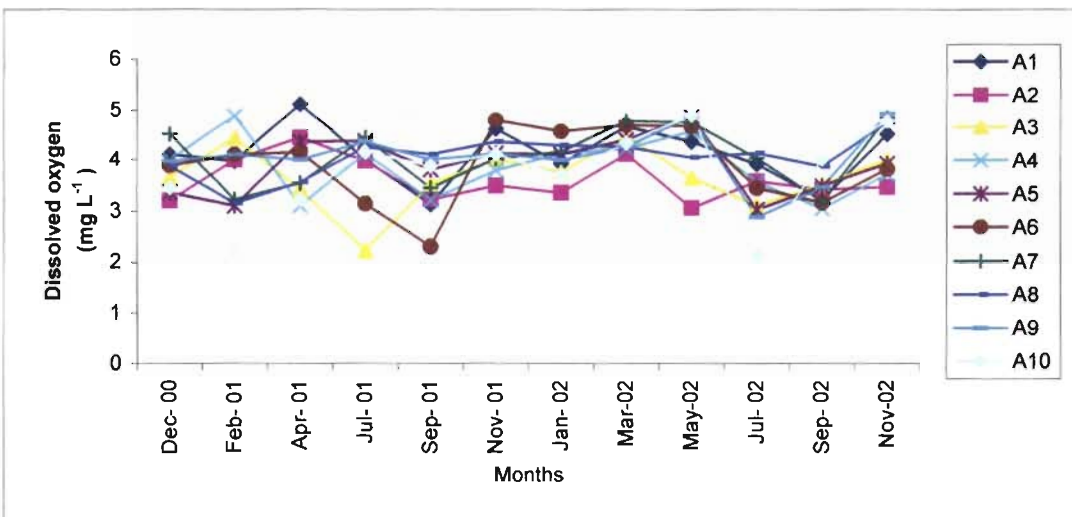


Fig. 3.41 Dissolved oxygen recorded at bottom after trawling during Dec.2000 to Nov. 2002

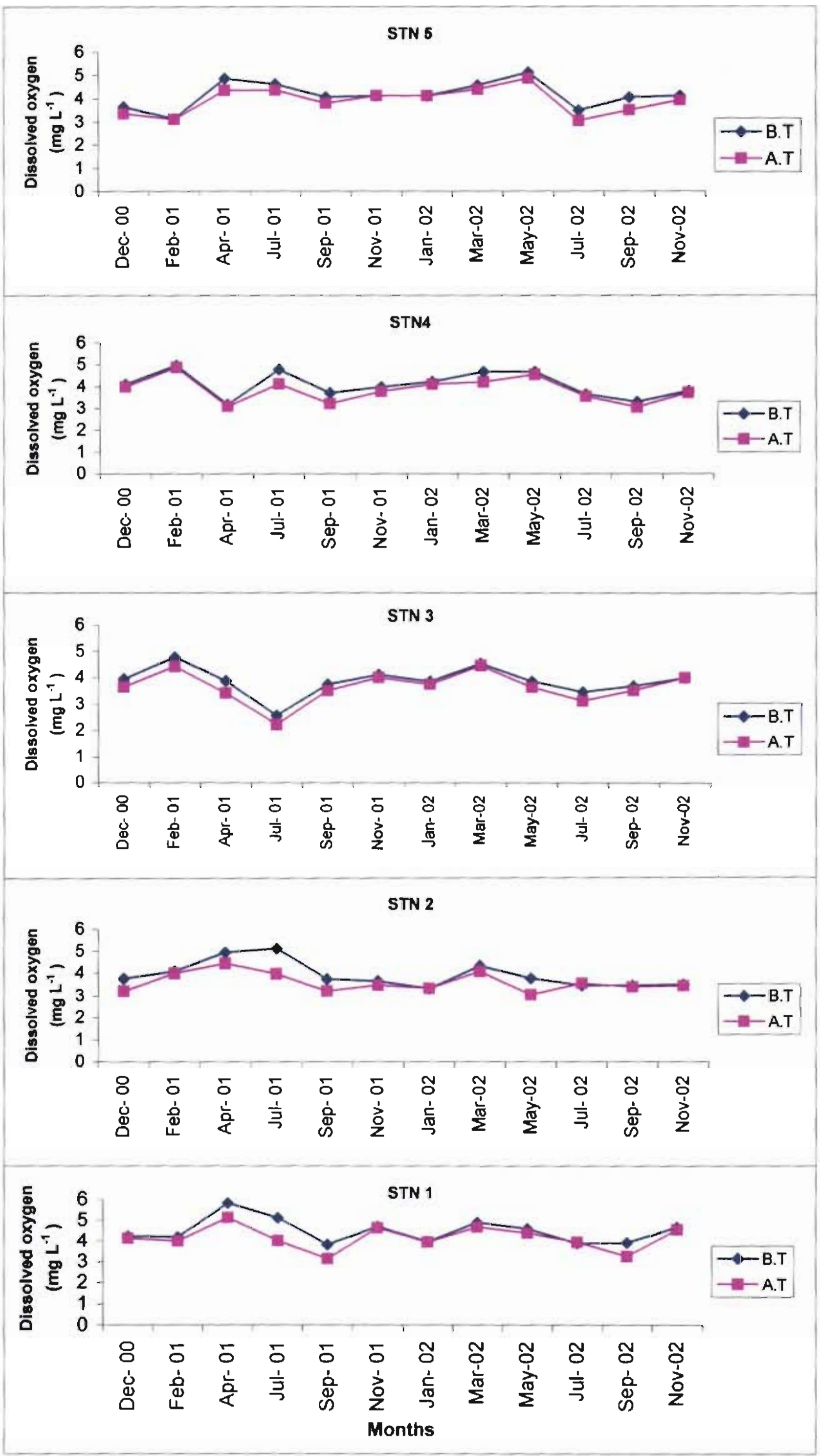


Fig 3.42a. Pattern of variations in dissolved oxygen at bottom before and after trawling during Dec.2000 to Nov. 2002

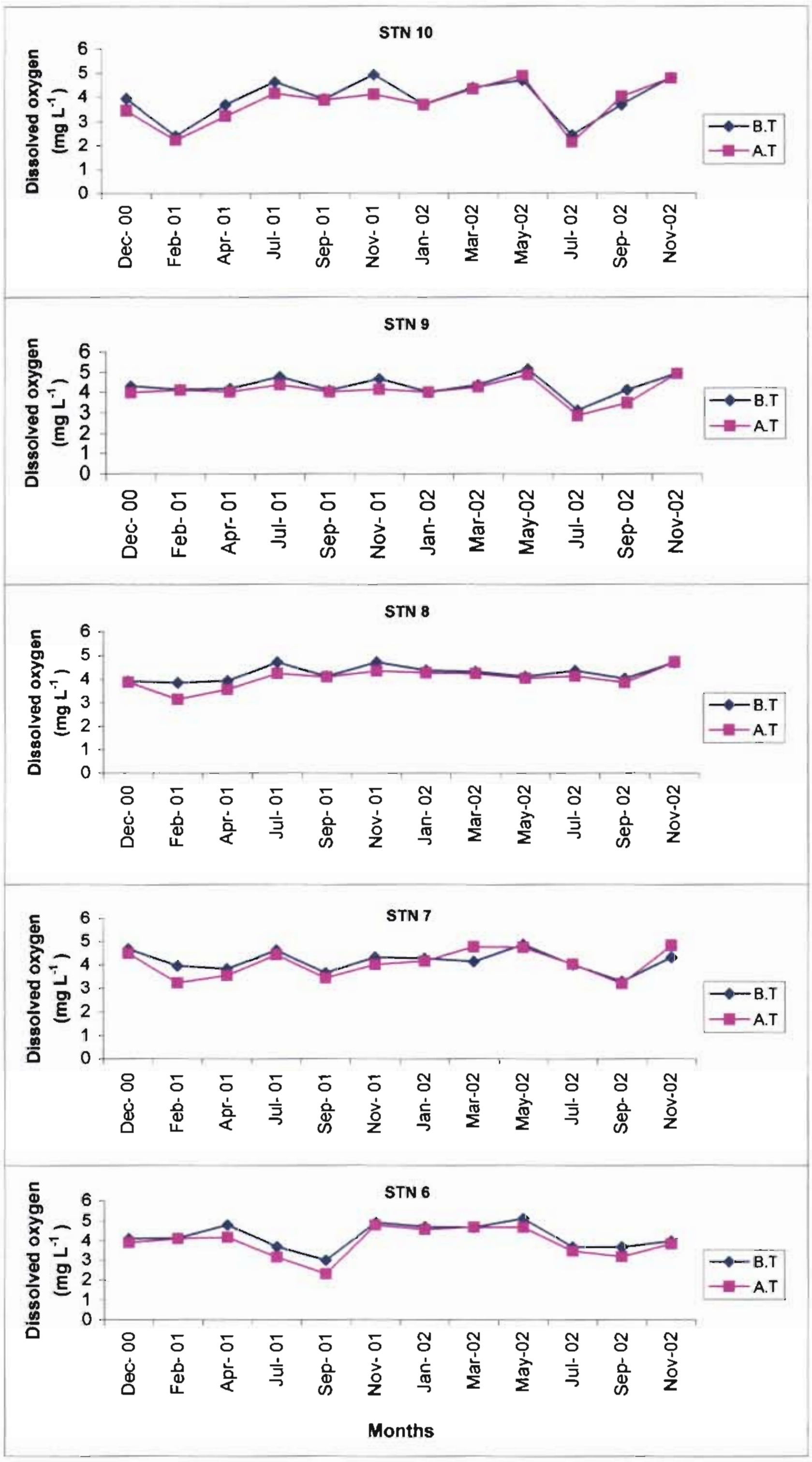


Fig. 3.42b. Pattern of variations in dissolved oxygen at bottom before and after trawling during Dec.2000 to Nov. 2002

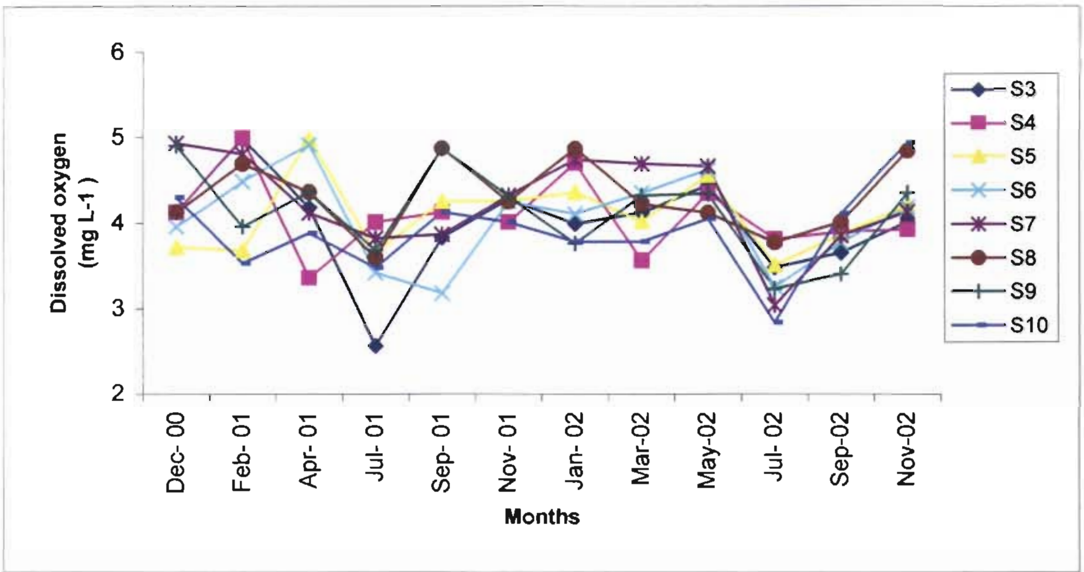


Fig. 3.43 Dissolved oxygen recorded at five meter above bottom before trawling during Dec.2000 to Nov. 2002

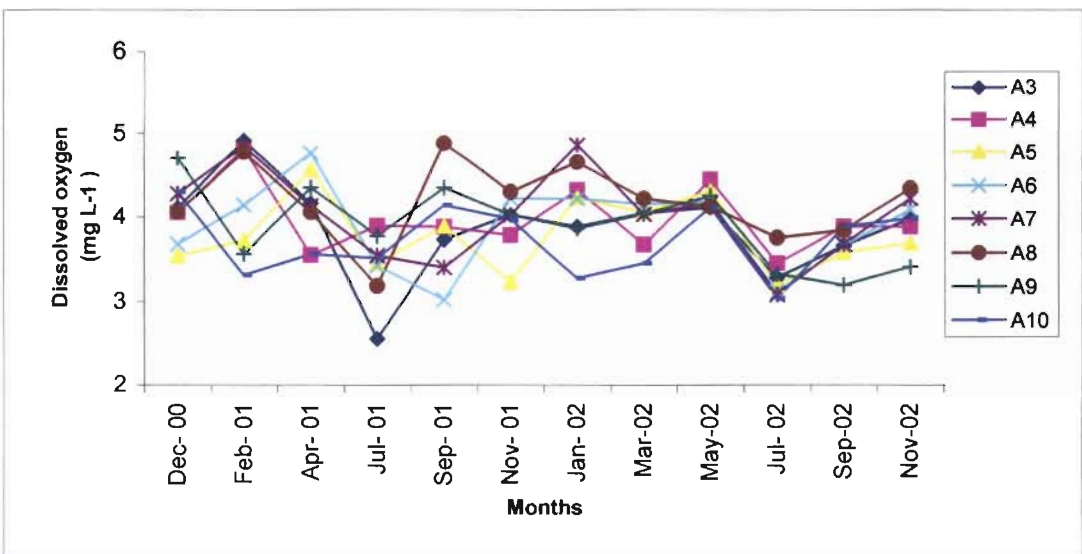


Fig. 3.44 Dissolved oxygen recorded at five meter above botom after trawling during Dec.2000 to Nov. 2002

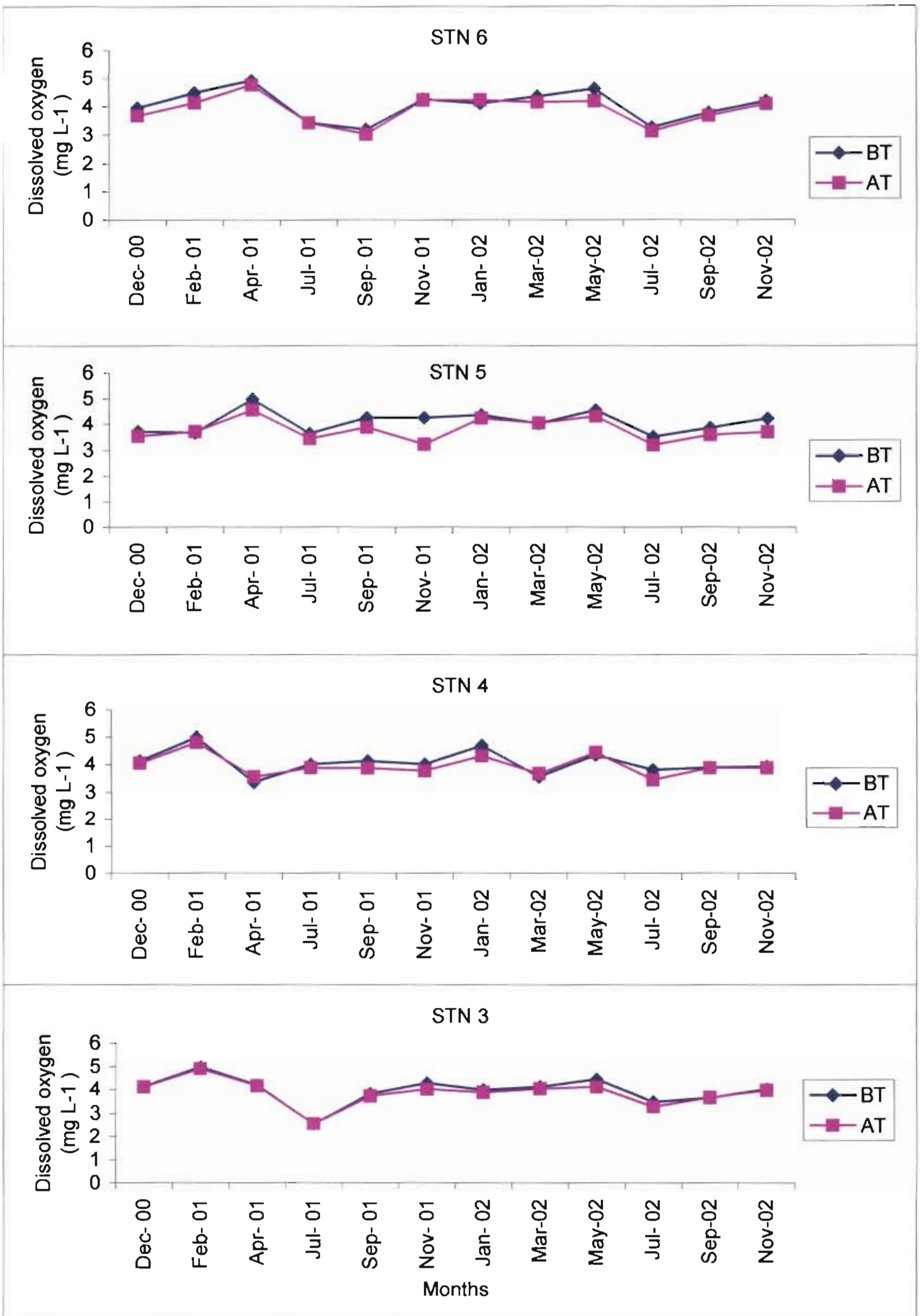


Fig. 3.45a Pattern of variations in dissolved oxygen at five meter above bottom before and after trawling during Dec.2000 to Nov. 2002

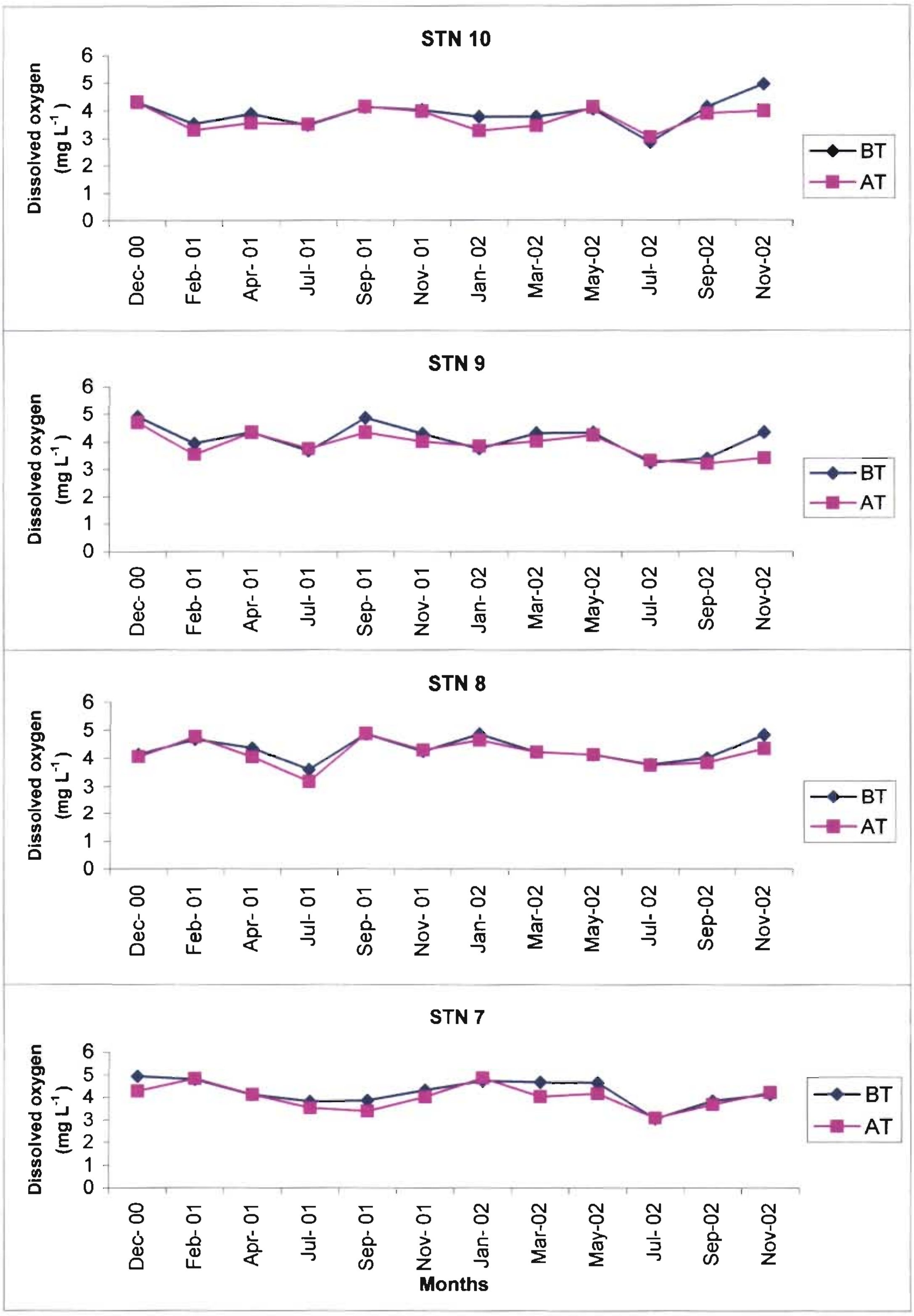


Fig. 3.45b. Pattern of variations in dissolved oxygen at five meter above bottom before and after trawling during Dec.2000 to Nov. 2002

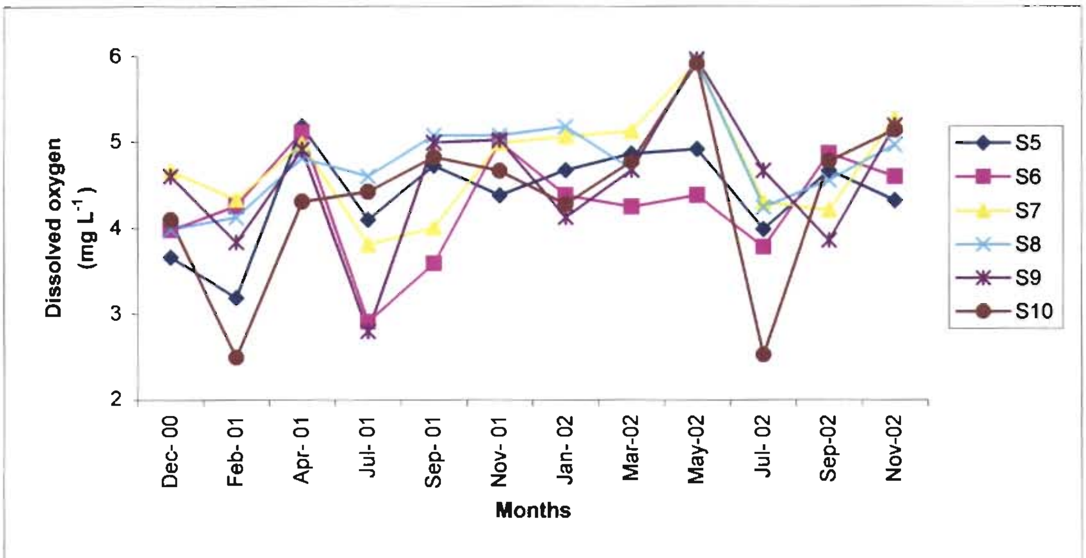


Fig. 3.46. Dissolved oxygen recorded at ten meter above bottom before trawling during Dec.2000 to Nov. 2002

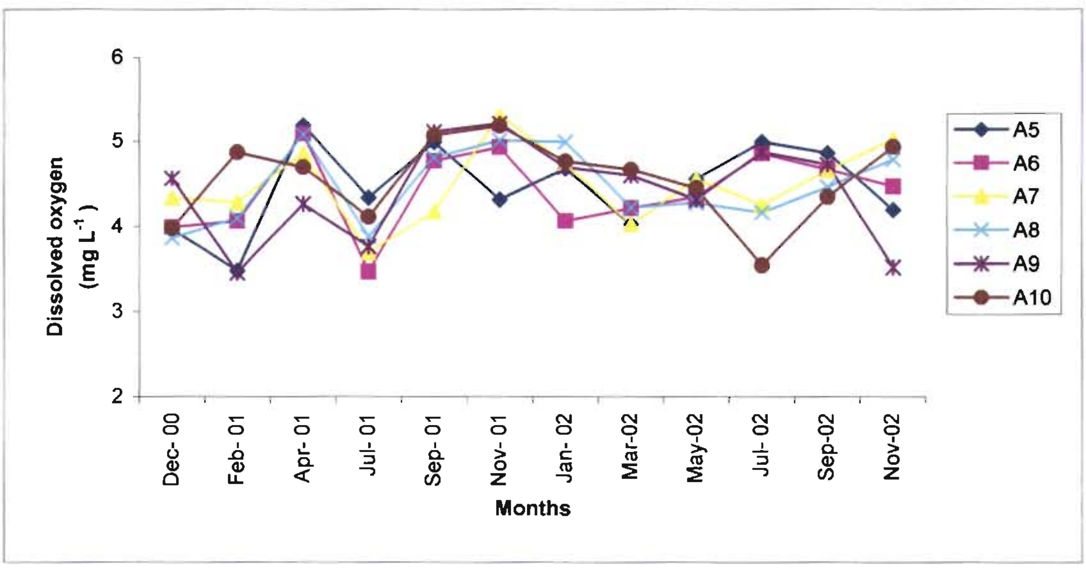


Fig. 3.47. Dissolved oxygen recorded at ten meter above bottom before trawling during Dec.2000 to Nov. 2002

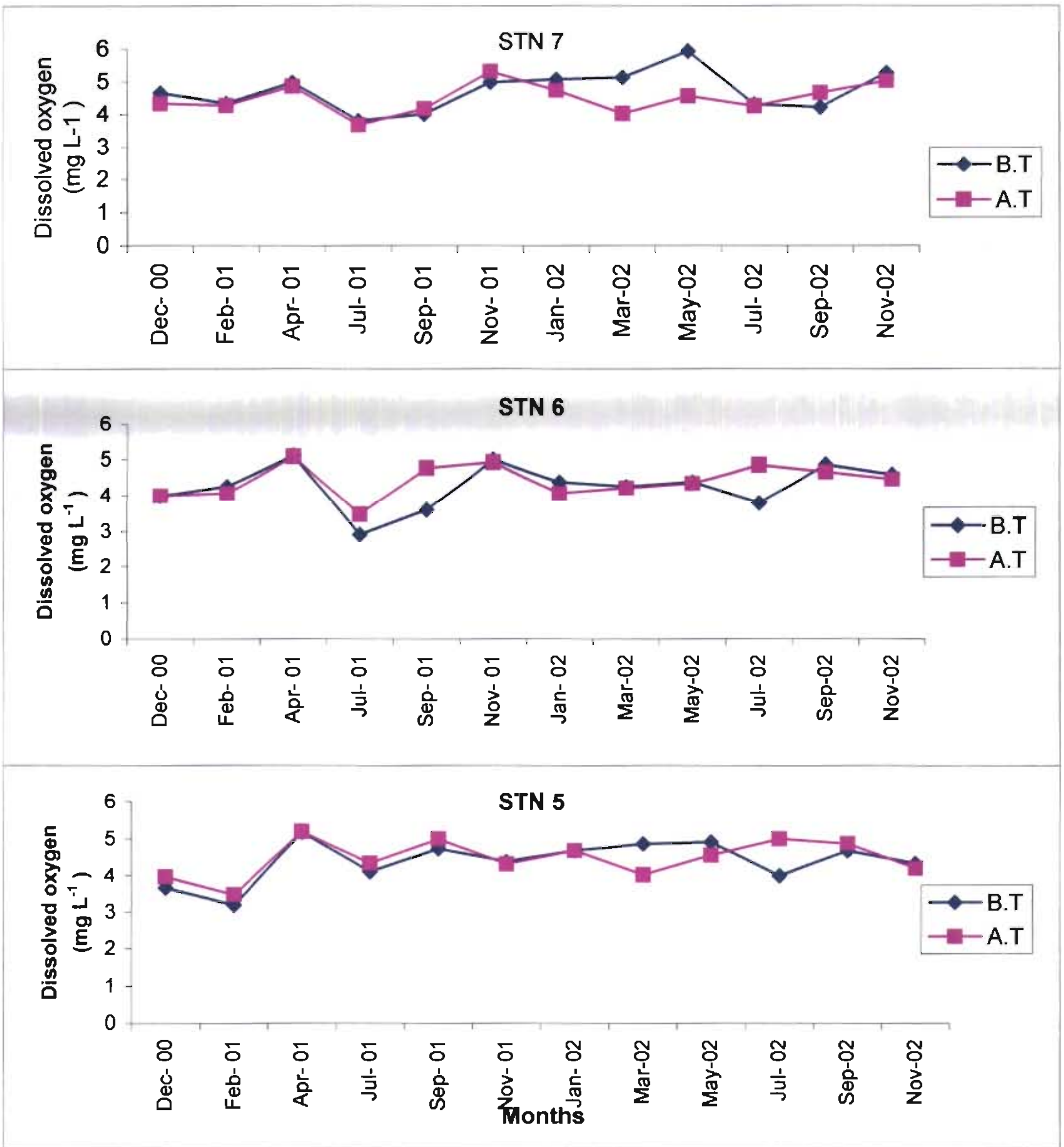


Fig. 3.48a Pattern of variations in dissolved oxygen at ten meter above bottom before and after trawling during Dec.2000 to Nov. 2002

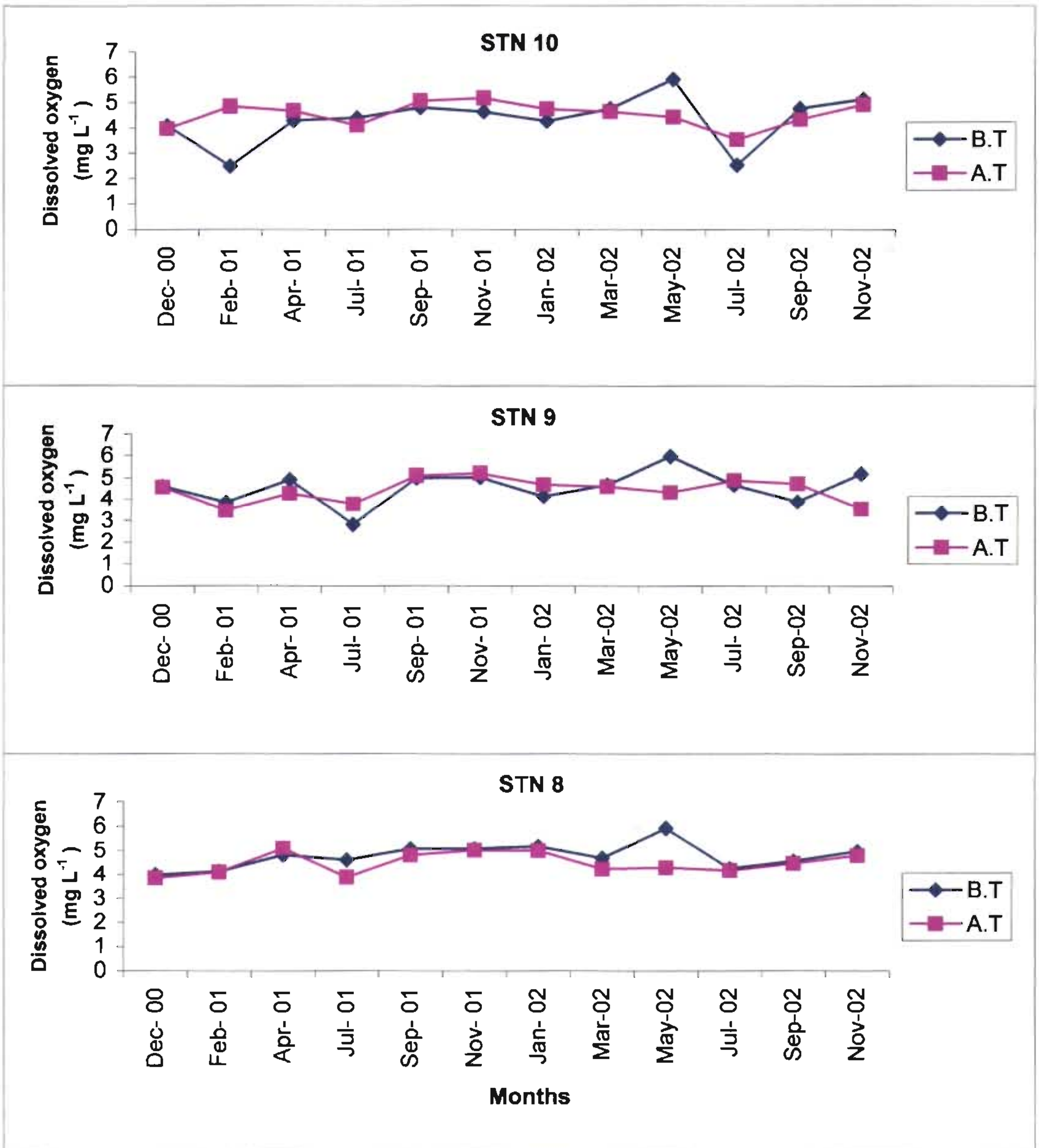


Fig. 3.48b Pattern of variations in dissolved oxygen at ten meter above bottom before and after trawling during Dec.2000 to Nov. 2002

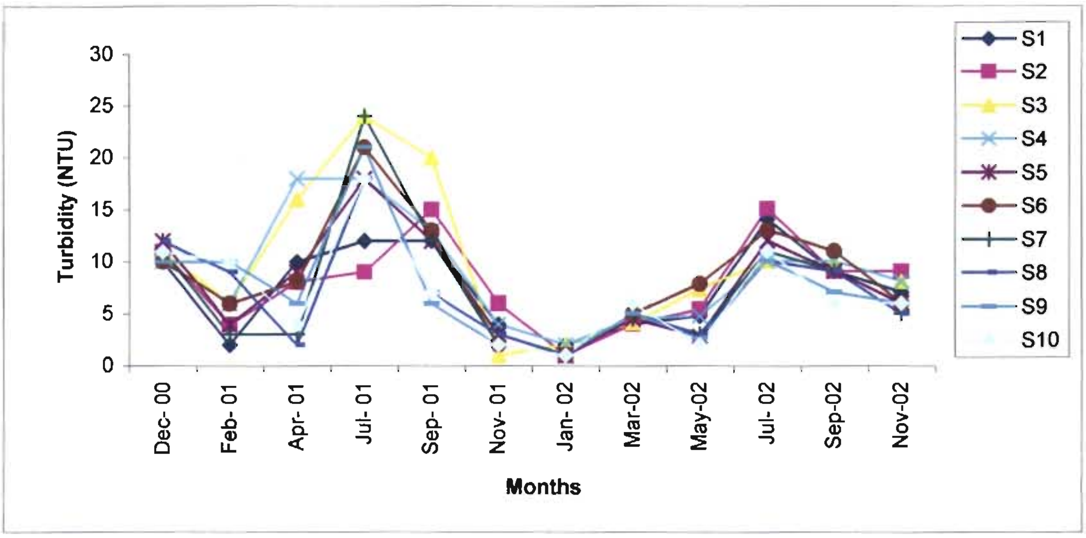


Fig.3.49 Turbidity recorded at surfae before trawling during December 2000 to November 2002

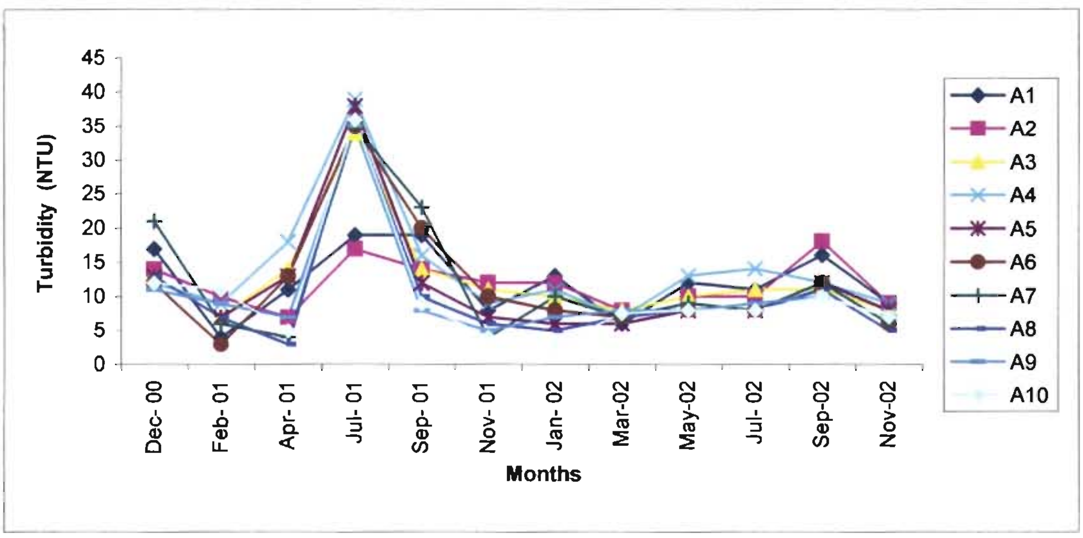


Fig.3.50 Turbidity recorded at surface after trawling during December 2000 to November 2002

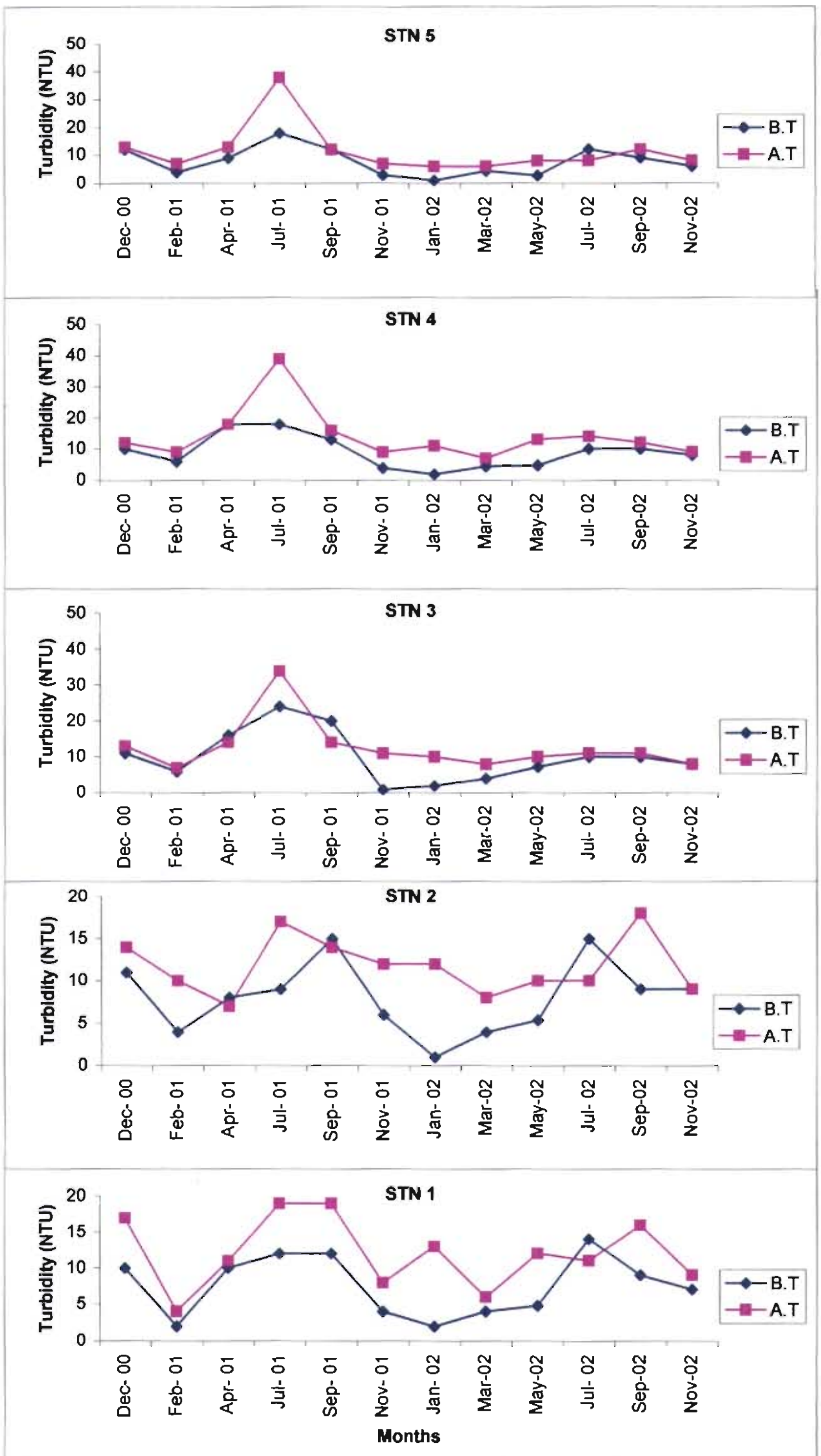


Fig.3.51a Pattern of variations in turbidity at surface before and after trawling duriing December 2000 to November 2002.

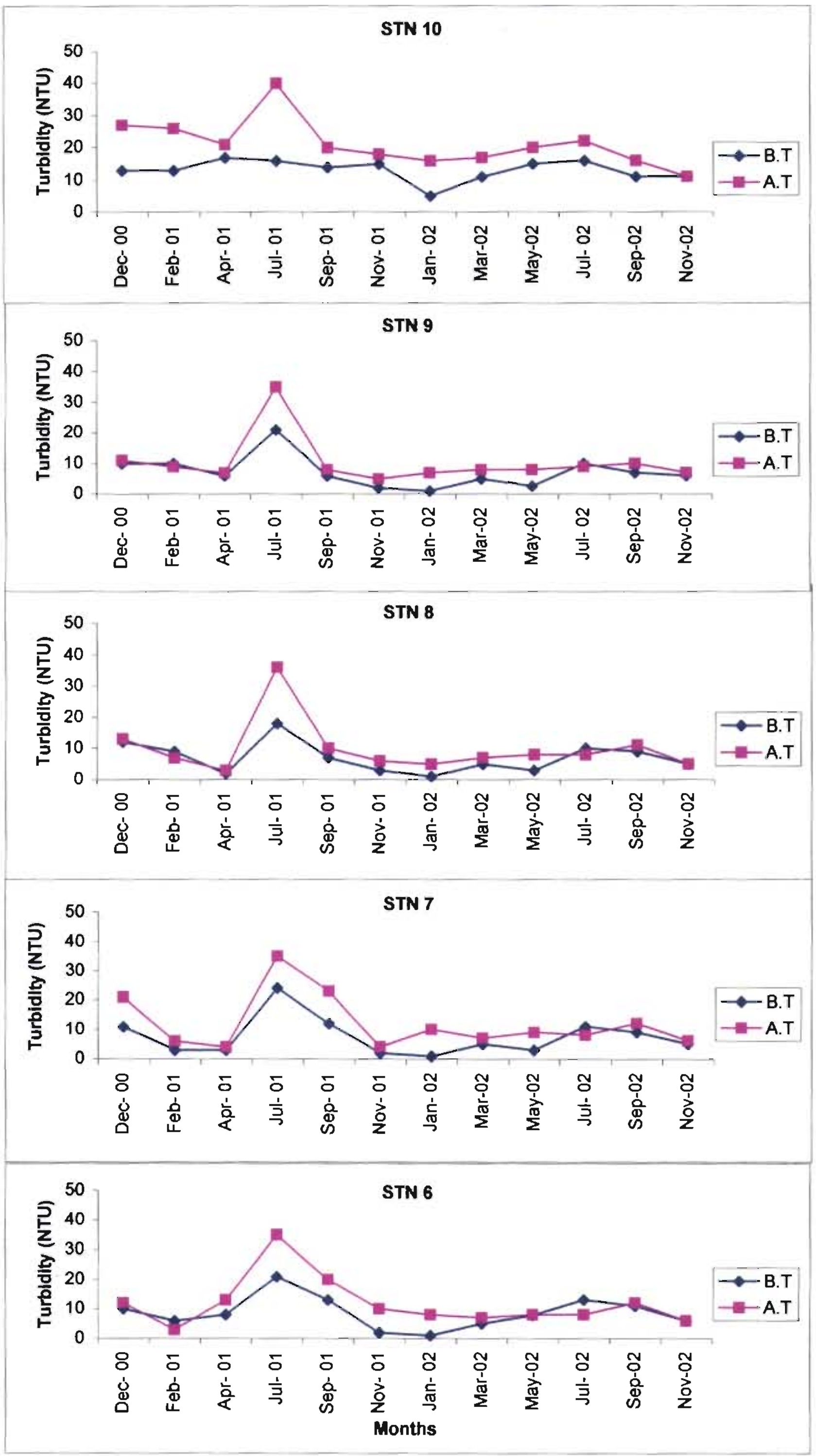


Fig.3.51b Pattern of variations in turbidity at surface before and after trawling during December 2000 to November 2002.

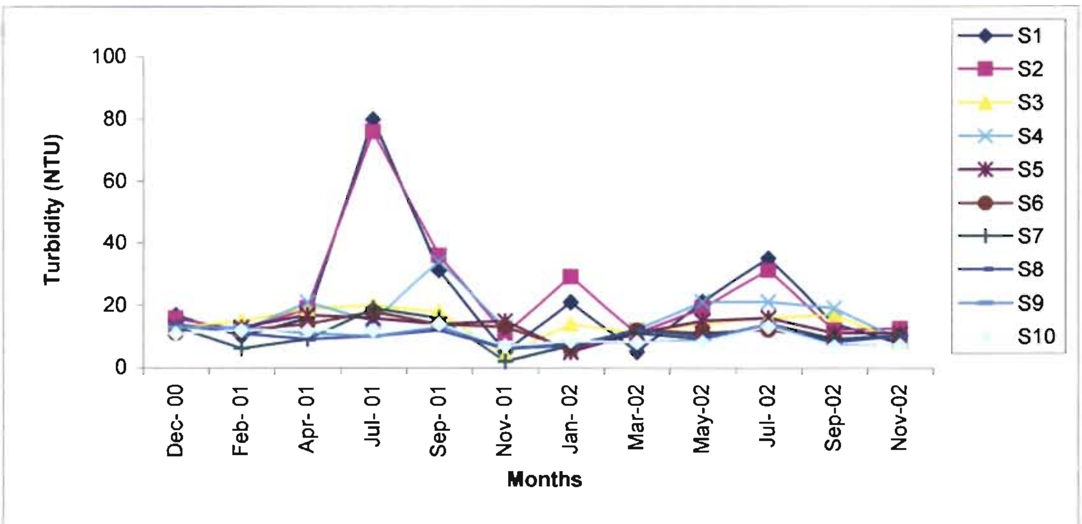


Fig. 3.52 Turbidity recorded at bottom before trawling during December 2000 to November 2002

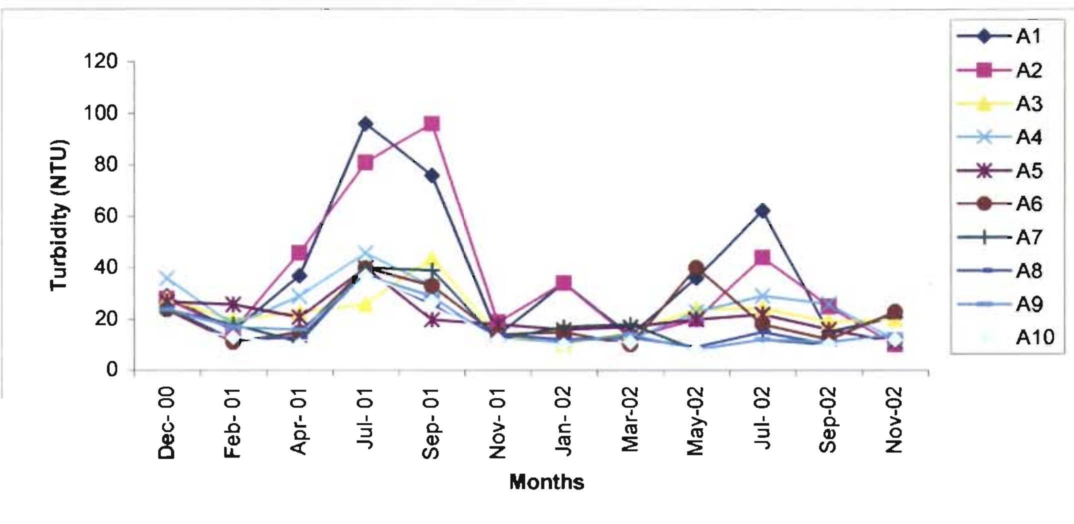


Fig. 3.53 Turbidity recorded at bottom after trawling during December 2000 to November 2002

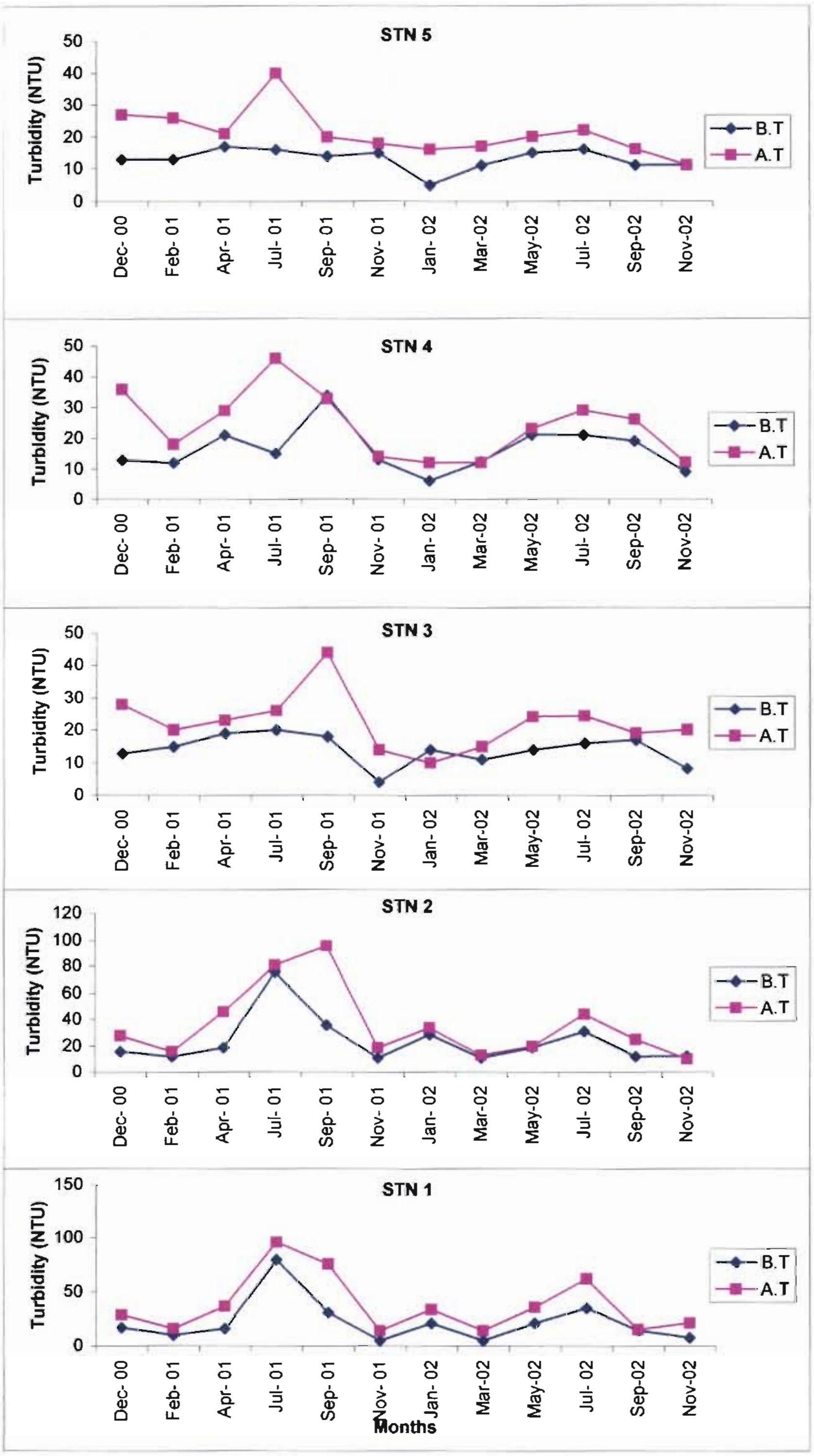


Fig. 3.54a Pattern of variations in turbidity at bottom before and after trawling during December 2000 to November 2002.

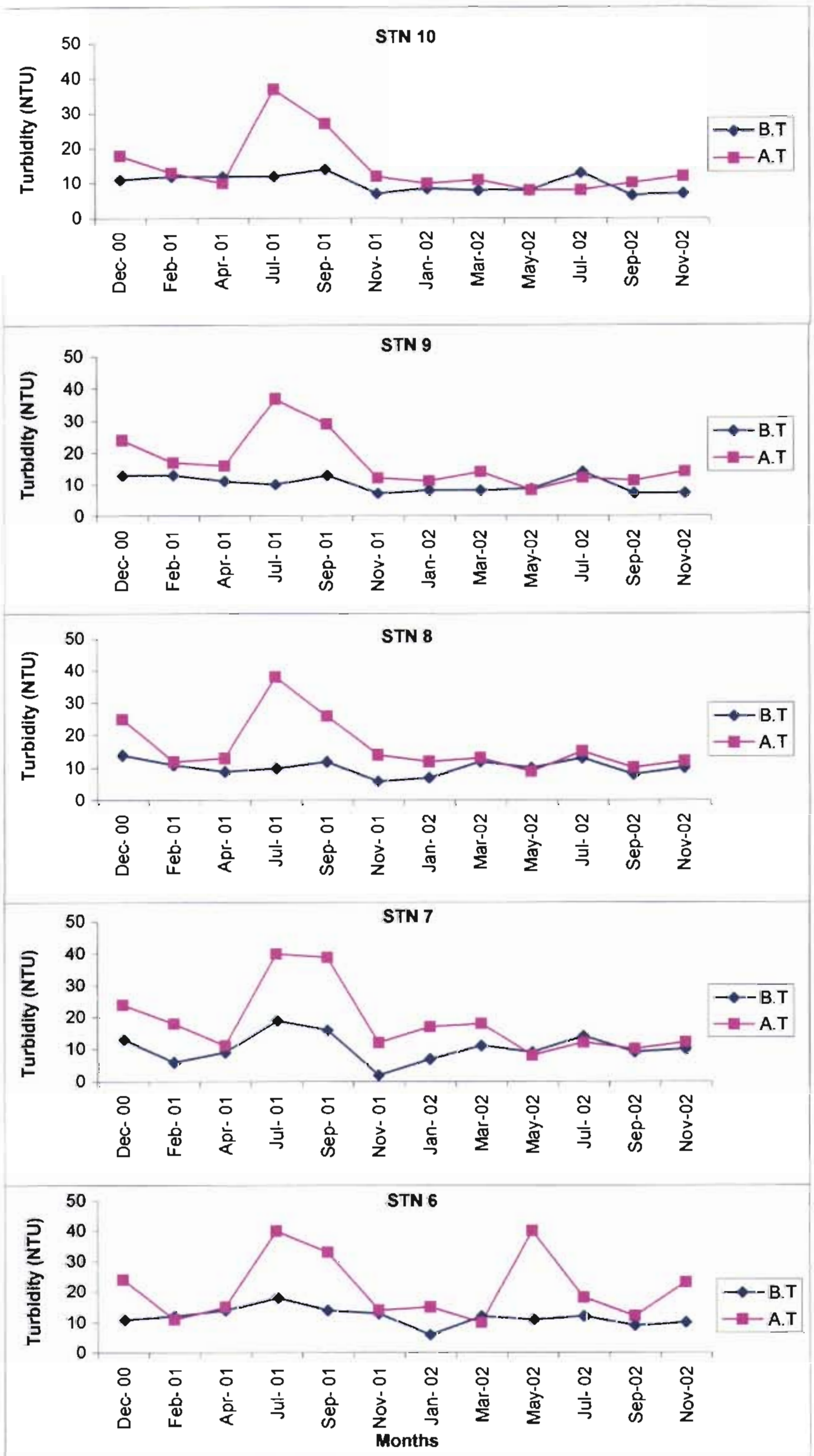


Fig. 3.54 b Pattern of variations in turbidity at bottom before and after trawling during December 2000 to November 2002.

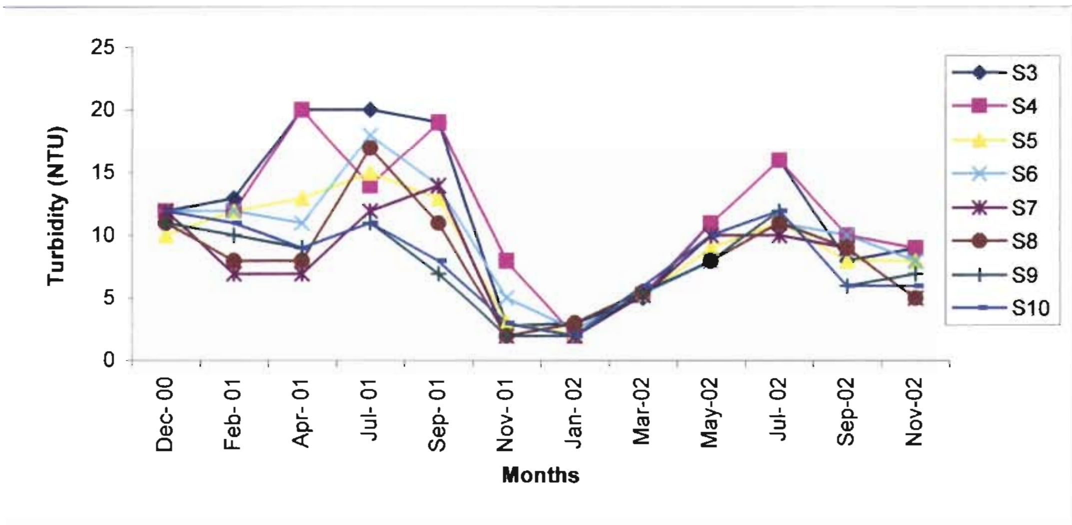


Fig. 3.55 Turbidity recorded at five meter above bottom before trawling during December 2000 to November 2002.

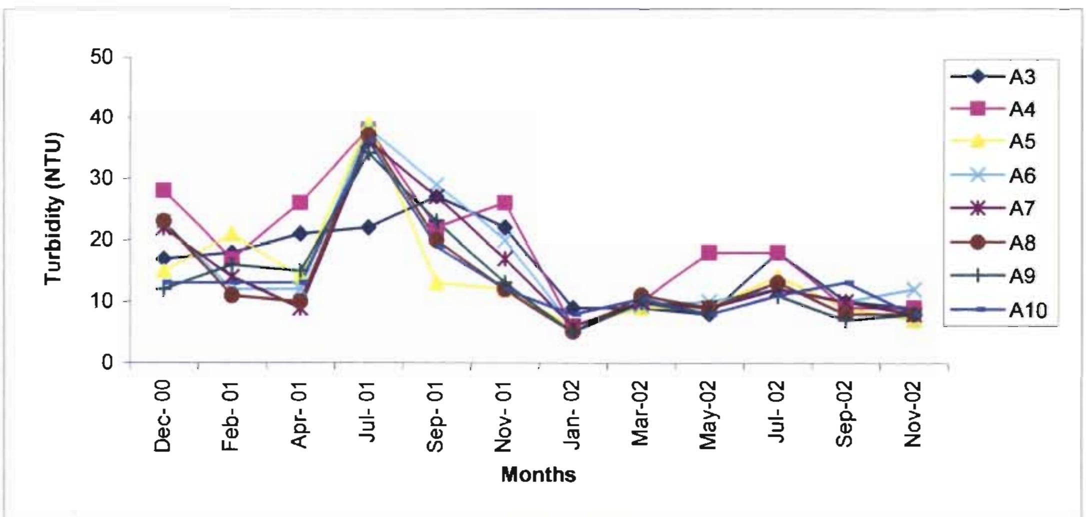


Fig. 3.56 Turbidity recorded at five meter above bottom after trawling during December 2000 to November 2002.

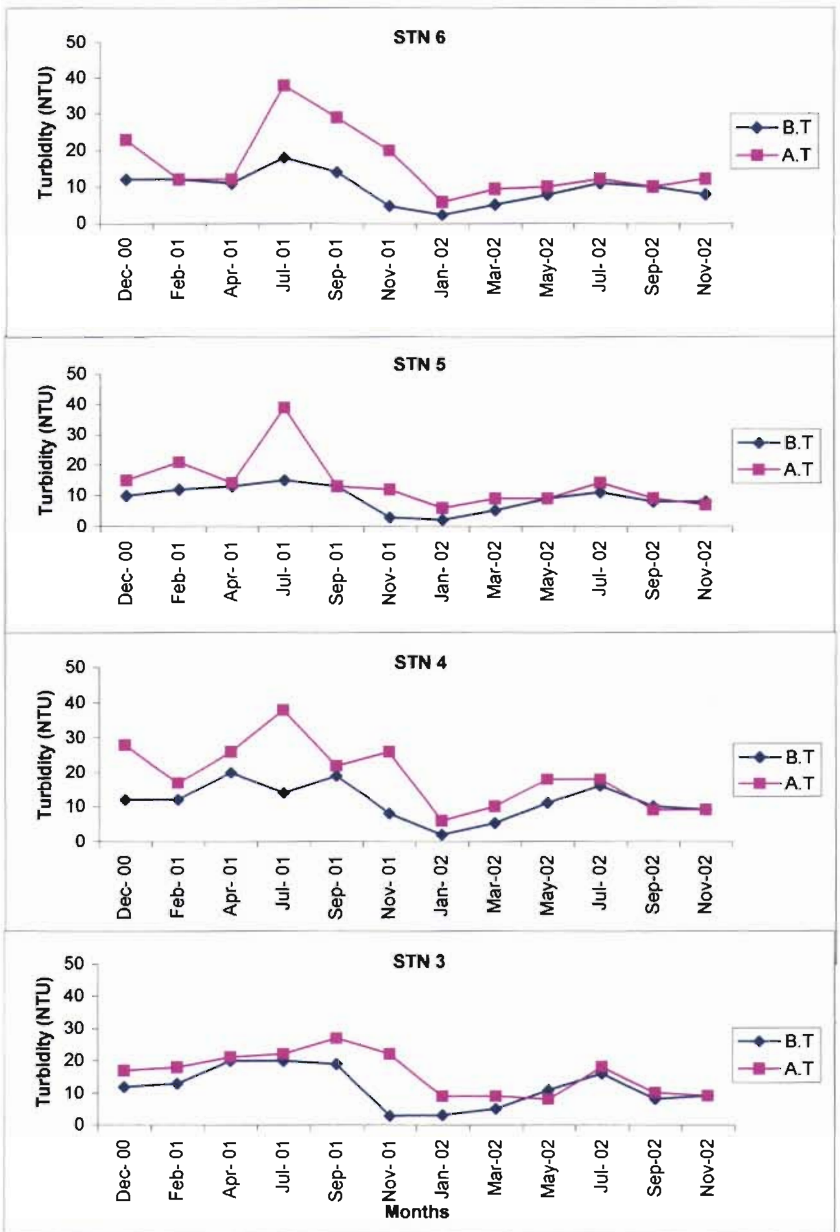


Fig. 3.57 a Pattern of variations in turbidity at five meter above bottom before and after after trawling during December 2000 to November 2002.

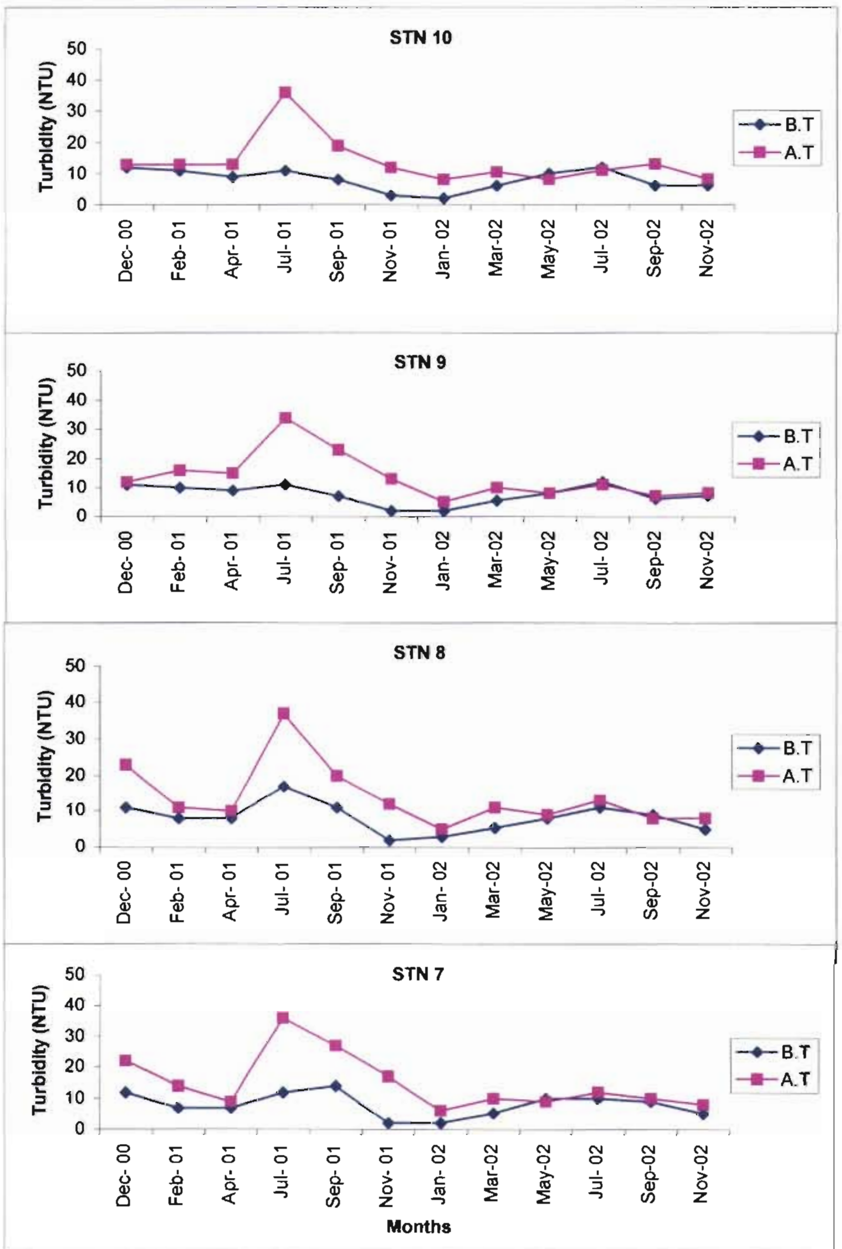


Fig. 3.57b Pattern of variations in turbidity at five meter above bottom before and after trawling during December 2000 to November 2002.

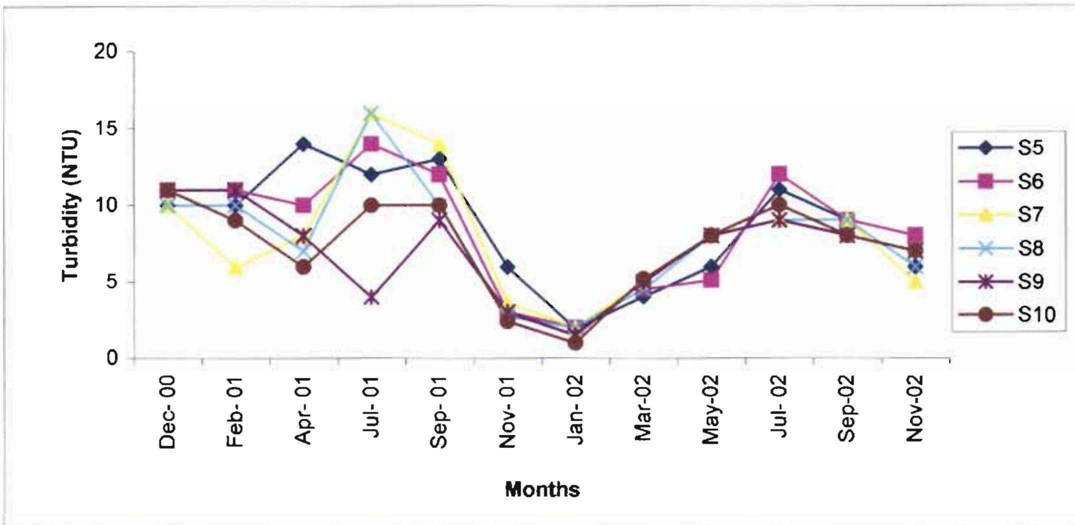


Fig. 3.58 Turbidity recorded at ten meter above bottom before trawling during December 2000 to November 2002.

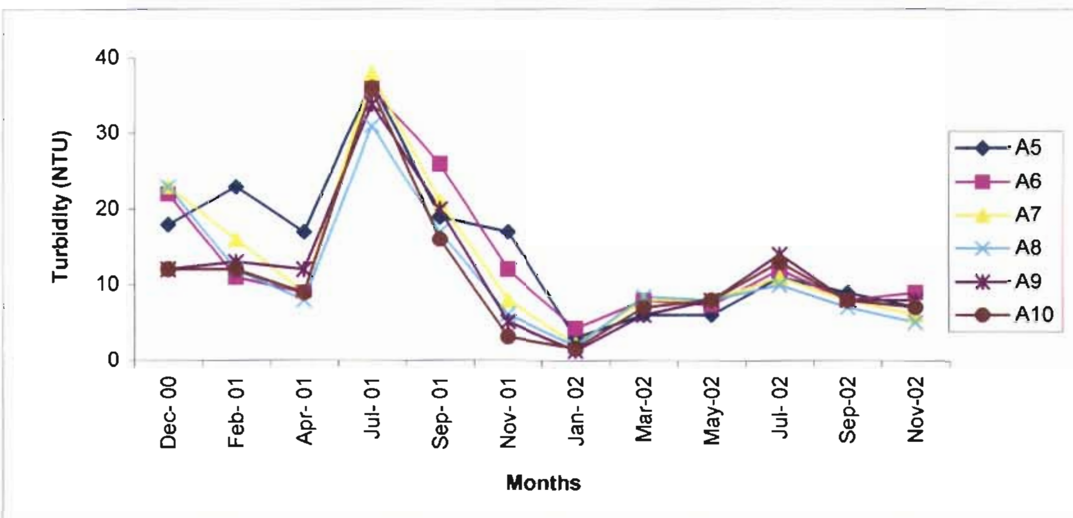


Fig. 3.59 Turbidity recorded at ten meter above bottom after trawling during December 2000 to November 2002.

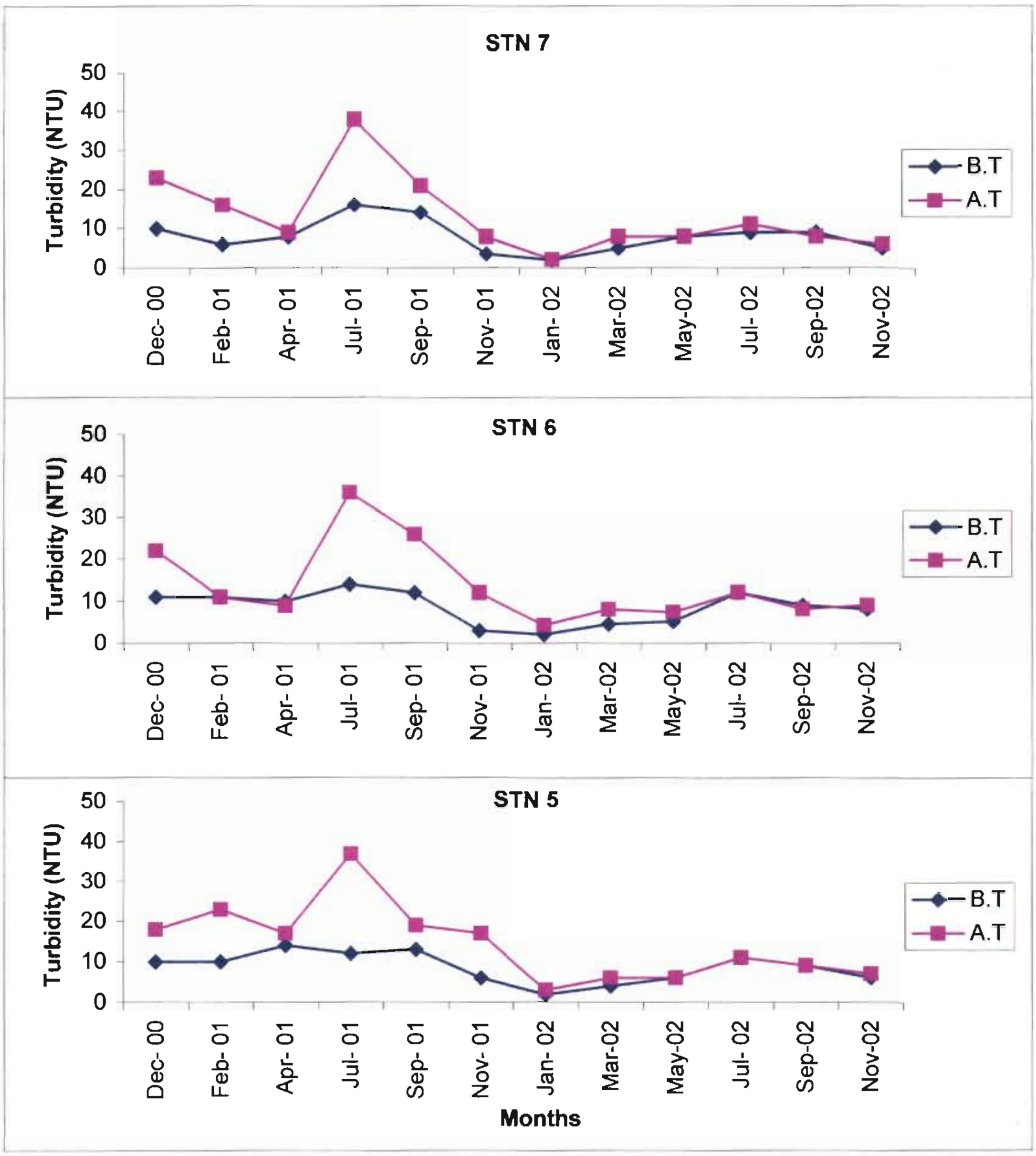


Fig. 3.60a Pattern of variations in turbidity at ten meter above bottom before and after trawling during December 2000 to November 2002.

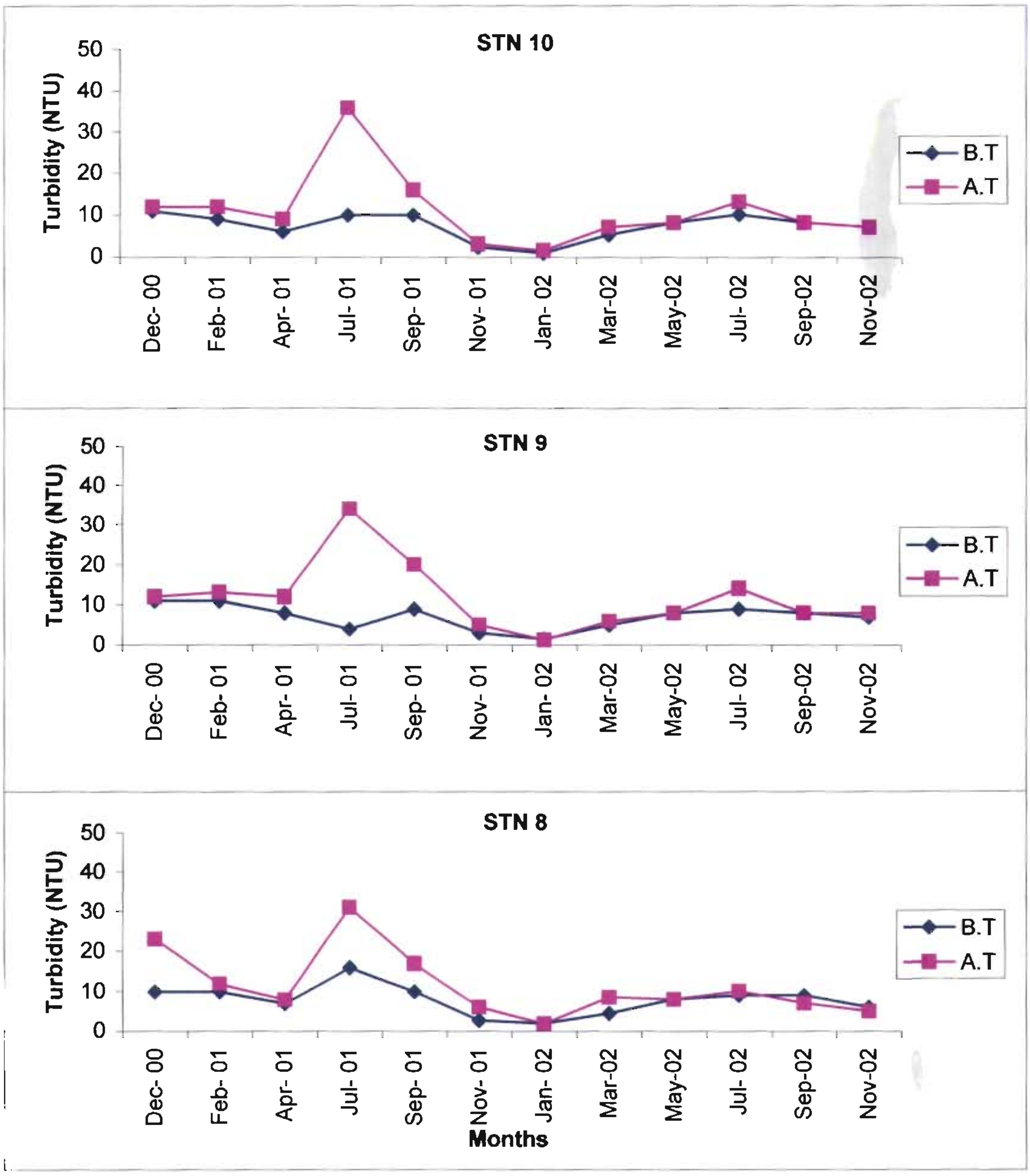


Fig. 3.60b Pattern of variations in turbidity at ten meter above bottom before and after trawling during December 2000 to November 2002.

Table 3.1 Results of the t test conducted in the temperature recorded before and after trawlling

Depth layer	Stations	t	df	Significance
Surface	S1-A1	2.534	11	N.S
	S2-A2	2.342	11	N.S
	S3-A3	0.591	11	N.S
	S4-A4	1.152	11	N.S
	S5-A5	0.607	11	N.S
	S6-A6	0.467	11	N.S
	S7-A7	0.622	11	N.S
	S8-A8	0.578	11	N.S
	S9-A9	0.17	11	N.S
	S10-A10	0.034	11	N.S
Bottom	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
Five meters above bottom	S3-A3	0.964	11	N.S
	S4-A4	0.73	11	N.S
	S5-A5	0.739	11	N.S
	S6-A6	2.174	11	N.S
	S7-A7	1.203	11	N.S
	S8-A8	0.865	11	N.S
	S9-A9	0.833	11	N.S
	S10-A10	0.104	11	N.S
Ten meters above bottom	S5-A5	0.276	11	N.S
	S6-A6	1 146	11	N.S
	S7-A7	1 102	11	N.S
	S8-A8	1.376	11	N.S
	S9-A9	0.727	11	N.S
	S10-A10	0.694	11	N.S

* P< 0.05 N.S. Not significant

Table 3.2 Results of the t test conducted in the salinity recorded before and after trawling

Depth layer	Stations	t	df	Significance
Surface	S1-A1	2.128	11	N.S
	S2-A2	0.534	11	N.S
	S3-A3	1.214	11	N.S
	S4-A4	0.749	11	N.S
	S5-A5	0.306	11	N.S
	S6-A6	1.373	11	N.S
	S7-A7	1.271	11	N.S
	S8-A8	0.815	11	N.S
	S9-A9	0.102	11	N.S
	S10-A10	1.025	11	N.S
Bottom	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
Five meters above bottom	S3-A3	1.058	11	N.S
	S4-A4	0.974	11	N.S
	S5-A5	0.204	11	N.S
	S6-A6	1.006	11	N.S
	S7-A7	1.508	11	N.S
	S8-A8	1.086	11	N.S
	S9-A9	1.012	11	N.S
	S10-A10	0.784	11	N.S
Ten meters above bottom	S5-A5	0.39	11	N.S
	S6-A6	2.268	11	*
	S7-A7	1.526	11	N.S
	S8-A8	1.191	11	N.S
	S9-A9	1.792	11	N.S
	S10-A10	0.908	11	N.S

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

* $P < 0.05$

Table 3.3 Results of the t test conducted in the pH recorded before and after trawlling

Depth layer	Stations	t	df	significance
Surface	S1-A1	0.804	11	N.S
	S2-A2	1	11	N.S
	S3-A3	0.65	11	N.S
	S4-A4	0.601	11	N.S
	S5-A5	0.692	11	N.S
	S6-A6	2.057	11	N.S
	S7-A7	1.449	11	N.S
	S8-A8	1.52	11	N.S
	S9-A9	1.773	11	N.S
	S10-A10	0.22	11	N.S
Bottom	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
Five meters above bottom	S3-A3	0.821	11	N.S
	S4-A4	0.821	11	N.S
	S5-A5	2.421	11	*
	S6-A6	0.692	11	N.S
	S7-A7	1.393	11	N.S
	S8-A8	1.483	11	N.S
	S9-A9	0.411	11	N.S
	S10-A10	2.159	11	N.S
Ten meters above bottom	S5-A5	1.332	11	N.S
	S6-A6	0.897	11	N.S
	S7-A7	0.804	11	N.S
	S8-A8	1.483	11	N.S
	S9-A9	0.243	11	N.S
	S10-A10	0.897	11	N.S

** P< 0.01 N.S Not significant

* P<0.05

Table 3.4 Results of the t test conducted in the dissolved oxygen recorded before and after trawling

Depth layer	Stations	t	df	significance
Surface	S1-A1	0.685	11	N.S
	S2-A2	0.03	11	N.S
	S3-A3	0.763	11	N.S
	S4-A4	0.593	11	N.S
	S5-A5	0.371	11	N.S
	S6-A6	0.787	11	N.S
	S7-A7	0.012	11	N.S
	S8-A8	0.061	11	N.S
	S9-A9	1.512	11	N.S
	S10-A10	0.597	11	N.S
Bottom	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
Five meters above bottom	S3-A3	3.312	11	**
	S4-A4	1.987	11	N.S
	S5-A5	3.689	11	**
	S6-A6	3.557	11	
	S7-A7	2.689	11	
	S8-A8	2.32	11	
	S9-A9	2.546	11	
	S10-A10	2.135	11	*
Ten meters above bottom	S5-A5	0.59	11	N.S
	S6-A6	1.032	11	N.S
	S7-A7	1.517	11	N.S
	S8-A8	2.115	11	*
	S9-A9	0.531	11	N.S
	S10-A10	0.745	11	N.S

** P< 0.01 N.S- Not significant

* P<0.05

Table 3.5 Results of the t test conducted in the turbidity recorded before and after trawlling

Depth layer	Stations	t	df	Significance
Surface	S1-A1	4.077	11	**
	S2-A2	2.726	11	
	S3-A3	1.912	11	N.S
	S4-A4	3.078	11	**
	S5-A5	2.259	11	
	S6-A6	2.096	11	N.S
	S7-A7	3.5	11	**
	S8-A8	1.938	11	N.S
	S9-A9	2.665	11	*
	S10-A10	2.044	11	N.S
Bottom	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
Five meters above bottom	S3-A3	2.666	11	*
	S4-A4	3.3	11	
	S5-A5	2.461	11	
	S6-A6	3.182	11	
	S7-A7	3.378	11	
	S8-A8	3.295	11	
	S9-A9	2.83	11	
	S10-A10	2.744	11	*
Ten meters above bottom	S5-A5	2.694	11	*
	S6-A6	2.507	11	
	S7-A7	2.652	11	
	S8-A8	2.298	11	
	S9-A9	1.921	11	N.S
	S10-A10	1.801	11	N.S

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

* $P<0.05$

Chapter 4

EFFECT OF BOTTOM TRAWLING ON NUTRIENTS

4.1 Introduction

Sea bottom with its rich source of nutrients and minerals fertilizes the seawater and thereby plays a major role in the benthic productivity. Nutrients are essential for life in the seas and the development of all life depends directly or indirectly on the availability of nutrients. In the marine realm, nitrogen, phosphorus, iron and silicate are the most essential elements for the growth of phytoplankton (Rao *et al.*, 1982; Brockman *et al.*, 1990 and Toggweller, 1999). Moreover, nutrients especially nitrite and nitrate have shown much influence on the fishes and other benthic populations along with organic carbon in sediments, salinity and primary production (Bhat and Neelakandan, 1988). Among nutrients, which enhance the productivity in sea, nitrogen and phosphorus are the most important elements (Qasim, 1977). For marine life, the ultimate source of these nutrients is provided by run off from land (Rittenberg *et al.,* 1955; Kamykowski and Zentara 1991). Inputs of nitrogen into the seawater occur mainly through river runoff, atmospheric deposition and nitrogen fixation (Segar and Hariharan, 1989; Naqvi and Jayakumar, 2000) whereas, phosphate, which is almost absent from the atmosphere, comes through river water (Falkowski, 1997; Tyrell, 1999). Vertical distribution of phosphate and nitrate follow the same general trend of lower concentration in the surface waters with increase down the water column (Rao *et al.*, 1982). Concentration of nutrients is enhanced in the sediments due to the dynamic sedimentation process, while diminution of nutrients is observed in the euphotic zone on account of photosynthesis. The nutrient reserves are replenished by the decomposition of organic matter on the surfacial layer of sediments (Naqvi and Jayakumar, 2000; Liang, et *al.*, 2002).

The water movements generated by the action of winds and currents augment the reload of nutrients into the water column. In addition to this, natural calamities like intense upwelling and cyclonic movements also contribute much to the replenishment of the nutrients in the euphotic zone (Banse, 1959; Sharma, 1978; Nair *et al.*, 1989; Madhupratap *et al.*, 1994; Webb and Morris, 1984). Coastal waters are more productive during monsoon season due to the incursion of nutrients from land through land runoff (George, 1953; Jayaraman and Seshappa, 1957; Subramanyan, 1958; Manikoth and Salih, 1974). Southwest coast of India with its rich sources of nutrients and minerals is identified as the most productive area in the Arabian Sea (Banse, 1987; Naqvi *et al.*, 1982). Distribution of nutrients along the west coast of India has been studied by many workers (Jayaraman and Sheshappa, 1957; Subramanyan 1958; Geroge, 1953; Banse, 1968; Sankaranarayanan and Qasim, 1969b; Joseph, 1974a; D'Souza and Sastry, 1975; Sharma, 1978; Naqvi *et al* .,1982; Rivonker *et al.*, 1990; Naqvi and Noronh, 1991).

Upwelling is the major phenomenon in the south and northwest coast of India, which brings the bottom nutrients up to the water column (Banse, 1959, 1968 and 1972; Burkill *et al.*, 1993). South west coast of India witnessed high phosphate and nitrite values in the surface waters during the southwest monsoon (Geroge, 1953; Jayaraman and Sheshappa, 1957; Banse, 1968; Nair *et al.*, 1989) and subsequent heavy primary production in the postmonsoon months (Qasim, 1977; Nair *et al.*, 1989). Though the release of nutrients from the sediment surface by dint of upwelling boost the phytoplankton production in sea, intense upwelling during monsoon months may induce the development of noxious algal blooms, release of lethal gases from sediments and also bring the low oxygen water from bottom to surface (Mantoura *et al.*, 1993). Since seabed is the major supplier of the nutrients to the water column, any disturbance on the sea bottom releases the nutrients into the water along with the other minerals and gases trapped in the sediments (ICES, 1988). In addition to the natural perturbations on the sediment surface, human disturbance on the marine ecosystem also contribute much to the variations to the marine environment.

Fishing is the most widespread human exploitative activity in the marine environment, in which bottom trawling is known as one of the most destructive anthropogenic activity on the sea bottom ecosystem (De Groot 1984; Kaiser and Spencer, 1998; Auster *et al.*, 1996; Schwinghamer *et al.*, 1996). There is a growing concern about the effect of bottom trawling on the marine ecosystem (ICES, 1988). All mobile bottom gears scrape the seabed and inflict heavy damage and disturbance to the bottom structure and organisms (De Groot, 1972; Piet *et al.*, 2000; Jennings and Kaiser, 1998). Dragging of heavy trawl nets/dredges along the sea bottom reduce the organic matter of the top layer of the sediments and also make the surface more coarse which in turn change the natural sediment milieu (Walting *et al.*, 2001; Caddy 1973). Passage of heavy mobile gears such as bottom trawl, beam trawl and dredges over sea bed induce sediment resuspension that result in extensive expulsion of the suspended sediment load in the fishing grounds (Churchill 1989; DeAlteris *et al.*, 1999; Caddy, 1968). Bottom trawling also affects the sea bottom, causing alteration of surface sediments and smothering of seabed topography (Kutti 2002). Studies pointed out that bottom trawling affect the basic nutrient structure of the sea floor (Churchill *et al.*, 1988; Norse and Watling, 1999) in addition to the heavy damage to the benthic organisms. During trawling water column receives organic and inorganic nutrients that may cause significant variations on the nutrient level in the marine ecosystem (Riemann and Hoffmann, 1991). Several studies conducted on the consequence of trawling revealed that bottom trawling induces many direct and indirect changes in the ecosystem (Jones, 1992). In addition to the heavy destruction caused to the fish stocks and benthos by killing and burying them, resuspension of sediment particles, toxic substances and nutrients are suspected to affect the oxygen budget and nutrients levels in the water (Riemann and Hoffmann, 1991). Further, under water observations have revealed that turbulence on the wake of trawl doors often generate clouds of bottom sediments (Korotkow and Martyschewski, 1977). Southwest coast of India is well known for its marine living resources, where trawling, particularly bottom trawling is the most popular fishing method. Though a surfeit of studies have been conducted on the destructive nature of the bottom trawling on sea bottom and its living organisms, no concerted work has been done on the variations of the nutrient level in the marine milieu except few comments on the possible changes of nutrients balance due to bottom trawling. Although Thressiamma *et al.* (1998) made a preliminary study on the effect of dredging on seabed at Cochin harbour, one of the major harbours in the south west coast of India, no authentic study was carried out to bring out the exact changes taking place on the sea bottom due to trawling. Against this background the present study is an attempt to bring out the immediate effect of bottom trawling on nutrients at the sea bottom.

4.2 Material and Methods

The detailed methodology is given in the chapter 2.

4.3 Results

Among nutrients, nitrite-nitrogen and phosphate phosphorus in sea water were analyzed by collecting water samples from surface, bottom, five and ten meters above bottom both before and after trawling at the study area with a view to studying the immediate effect of trawling on these nutrients. Nitrite and phosphate levels showed very prominent seasonal variations throughout the stations with high values during monsoon and low in premonsoon. Vertical distribution of these nutrients clearly indicated the increasing trend down the water column with the surface registering the lowest concentrations. Between these nutrients, phosphate concentration was more in the coastal waters. Bottom trawling experiments conducted at the study area revealed the profound effects of bottom trawling on bottom nutrients as it leads to their release from the seabed along with the sediments clouds raised during trawling.

4.3.1 Nitrite- Nitrogen

4.3.1a Nitrite-Nitrogen at Surface

Nitrite-nitrogen concentrations recorded before and after trawling are depicted in Fig. 4.1 and 2. Similar spatial and temporal distributions have been noticed in the nitrite concentrations registered in the two years. Nitrite-nitrogen at surface ranged from 0.04 - 2.01 μ ML^{-1} in the first year while in the second year it ranged from 0.02 - 1.70 μ ML^{-1} Higher values were noticed in the monsoon months of July and September during the entire period of study and comparatively low values were recorded in premonsoon and postmonsoon periods. Highest value of 2.01 μ ML^{-1} was noticed at station 3 in July 2001 in the first year while the lowest of 0.04 μ ML^{-1} at station 2 in February 2001. In the second year, highest concentration of 1.70 μ ML^{-1} was observed at Station 4 in July 2002 and the lowest (0.02 μ ML^{-1}) at station 10 in November 2002 (Fig.4.1). Significant seasonal variations were noticed in the nitrite concentrations recorded in the entire period of study ($P < 0.01$, Appendix II, Table 1).

After trawling, the nitrite values increased at almost all stations studied (Fig. 4.3 a and b). Nitrite values were significantly varied in the surface waters after trawling ($P < 0.01$, Appendix II, Table 2) with higher values in monsoon and low in postmonsoon and premonsoon periods. Highest nitrite concentration of 2.62 μ ML^{-1} (station 7) and 3.64 μ ML^{-1} (station 6) were recorded in the months of July during the first and second year of the study respectively. The lowest nitrite values recorded in the samples collected after trawling where 0.003 and

0.01 μ ML^{-1} in November 2001 and 2002 at stations 4 and 1 respectively (Fig. 4.2). Wide variations were noticed in the nitrite values collected after trawling when compared to that recorded before trawling (Fig. 4.3 a and b). Average two - fold increase was noticed in the nitrite concentrations in the samples collected after trawling compared to that of before trawling. Among stations, station 9 showed the highest variation where 1.36μ ML^{-1} of nitrite was recorded in February 2001after trawling against 0.07 μ ML^{-1} noticed before trawling. Stations 1 and 8 also showed similar trend in April 2001 with 1.83 and 1.53 μ ML^{-1} recorded after trawling compared to 0.12 and 0.19 μ ML^{-1} before trawling. Likewise, station 10 also showed wide variation in nitrite concentration in July 2001 where nitrite increased to 1.92 μ ML^{-1} after trawling from 0.38 μ ML^{-1} before trawling. Similar trend was noticed in the second year also where, 3.64 μ ML^{-1} was recorded after trawling at station 6 in July against 0.92 μ ML^{-1} before trawling, registering around a three fold increase in nitrite concentration due to bottom trawling. However, the extent of variations in nitrite concentration was higher in the first year when compared to the nitrite values recorded during second year. Even though the nitrite concentrations registered in the surface waters exhibited wide variations due to bottom trawling operations, the variations were not statistically significant while comparing the values recorded both before and after trawling ($P > 0.05$, Table 4.1).

4.3.1b Nitrite-Nitrogen at bottom

Bottom waters showed higher nitrite concentration when compared to that recorded at surface. Annual variations of nitrite showed similar trend with that at surface with high values in monsoon and low in premonsoon and postmonsoon. Highest values of 3.47 and 3.93 µ ML $^{-1}$ were recorded during monsoon months of July 2001 and September 2002 in the samples collected before trawling at stations 1 and 5 respectively while, the lowest values of 0.44 and 0.10 µ ML^{-1} were recorded at stations 10 and 5 in February 2001 and March 2002 (Fig.4.4). Significant seasonal variations were noticed in the samples collected before trawling ($P < 0.01$ Appendix II, Table 3). Near shore waters especially muddy areas below 30m depth showed high nitrite values when compared to higher depths (> 30 m), which were characterized by higher sand content.

Nitrite concentrations measured in the samples collected after trawling also registered higher values in monsoon months. Lower concentration was recorded during premonsoon period and the values ranged between 0.88 – 4.20 and 0.48 - 4.79 µ ML $^{-1}$ in the first and second year of the study respectively. Significant variations were noticed in almost all stations with intense variations during monsoon ($P < 0.01$ Appendix II, Table 4). In the first year, highest value of 4.20 µ ML^{-1} was recorded at station 1 in July 2001 while the lowest of 0.88 µ ML^{-1} was recorded at station 4 in April 2001. Second year also showed a similar trend with highest concentration of 4.79 µ ML^{-1} at station 8 in July 2002 and the lowest (0.48 µ ML^{-1}) at station 3 in March (Fig. 4.5). Bottom waters showed steep increase in the nitrite values after trawling and the extent of variation was extremely high when compared to surface waters (Fig. 4.6 a and b). An abrupt increase was noticed in the nitrite concentrations in the samples collected after trawling and the difference between before and after trawling values were found statistically significant. Highest variation was noticed at station 1 in April 2001 where nitrite values increased substantially to 2.98 µ ML^{-1} on account of bottom trawling from 0.60 µ ML^{-1} recorded before the trawling operations. Around two - fold increase has been noticed at station 8 in September 2002 as it registered a high value of 4.78 µ ML^{-1} after trawling against 2.78 µ ML^{-1} before trawling. Sandy stations (>40 m) also showed remarkable increase in nitrite concentrations due to trawling with almost four-fold increase in the samples collected after trawling with 2.27 and 2.11 µ ML^{-1} at station 9 and 10 in April and February 2001 against 0.63 and 0.45 µ ML^{-1} recorded respectively in the samples collected before trawling (Fig. 4.6 a and b). While comparing the before and after trawling samples, significant changes ($P < 0.05$) were obtained in the samples collected from the bottom waters (Table 4.1).

4.3.1c Nitrite-Nitrogen at five meters above bottom

Nitrite-nitrogen measured at five meters above sea bottom before and after trawling are depicted in the Fig. 4.7 and 4.8. Corresponding to bottom and surface waters, nitrite concentration at five meters above sea bottom also showed clear seasonal variation. Higher values were recorded during monsoon months of the two - year study while premonsoon and postmonsoon periods recorded low values (Fig 4.7). In the initial year, higher values were noticed in July 2001 with highest of 2.02 µ ML^{-1} was registered at station 10 while it was the lowest (0.15 µ ML^{-1}) at station 4 in November. In the second year, the peak value of 2.84 µ ML^{-1} recorded in September 2002 and the lowest (0.04 µ ML^{-1}) was recorded at station 6 in January. Significant seasonal variations were noticed during the period of study (P< 0.01, Appendix II, Table 5) at all the stations. Samples collected after trawling also evinced distinct significant temporal variation during the period of study (P<0.01, Appendix II, Table 6). Nitrite values recorded after trawling ranged from 0.14 - 2.97 and 0.14 - 3.52 μ ML^{-1} respectively in the first and second years. Following the trends noticed in the samples collected before trawling, extreme values were registered in monsoon months with highest of 2.97 μ ML^{-1} at station 3 in September 2001 and 3.52 μ ML^{-1} in the July 2002 whereas lowest values of 0.15 (Station 1) and 0.14 μ ML^{-1} (Station 9) were recorded in November 2001 and December 2002 respectively (Fig.4.8). However, the premonsoon and postmonsoon seasons showed more or less similar values in the inshore regions. Significant (P < 0.01) variations in the nutrient level were noticed while comparing the samples collected before and after trawling at this subsurface layer, which was found analogous to the bottom waters. In the samples collected after trawling, an average two-fold increase observed when compared to that collected before trawling. However, many stations registered showed extreme variations similar to station 6 in January 2002 where nitrite showed an increase to 1.97 μ ML^{-1} after trawling from 0.03 μ ML^{-1} recorded before trawling thus registering a steep increase in nitrite due to bottom trawling (Fig. 4.9 a and b). During the first year, highest variation in nitrite was recorded at station 10 where 2.18 μ ML^{-1} was noticed in the samples collected after trawling against 0.56 μ ML^{-1} before trawling. Approximately two fold increase in nitrite was noticed during September 2001 at station 3 with 2.97 μ ML^{-1} in the samples colleted after trawling against 1.37 μ ML^{-1} that of before trawling. Similarly, at stations 4 and 9 in July and April 2001, high nitrite concentration of 2.96 and 2.08 μ ML^{-1} was registered after trawling against 1.48 and 0.56 μ ML^{-1} recorded before trawling. While comparing the nitrite nitrogen in the samples collected before and after trawling, significant changes ($P < 0.05$) were obtained but the extent of variation was less in contrast to that obtained at bottom waters (Table 4.1).

4.3.1d Nitrite-Nitrogen at ten meters above bottom

Nitrite-nitrogen determined at ten meters above bottom showed more or less similar distribution as noticed at surface and five meters above bottom. The concentration of nitrite observed was slightly lower than that observed at bottom. High nitrite values were recorded during monsoon season followed by postmonsoon and premonsoon ($P<0.01$, Appendix II, Table 7). Nitrite concentration registered before trawling ranged from 0.41 to 2.07 and 0.06 to 1.71 μ ML^{-1} during the first and second years respectively (Fig. 4. 10). Highest nitrite concentration was registered (2.07 μ ML^{-1}) at station 7 during July 2001 and the lowest (0.41 μ ML^{-1}) at station 9 in April 2001. During second year, highest nitrite (1.71 μ ML^{-1}) was recorded at station 5 in September 2002 and the lowest (0.06 μ ML^{-1}) at station 8 in March 2002. The results of the ANOVA showed significant seasonal changes in the nitrite concentrations recorded in the samples collected after trawling ($P<0.01$, Appendix II, Table 8). While comparing the nitrite concentrations in the samples collected before and after trawling, the trend was similar to that of surface, bottom and five meters above bottom. The extent of variation was also tantamount to that observed at five meter above bottom with significant changes ($P < 0.05$, Table 4.1) however, the effect was comparatively lesser when compared to that at bottom. After trawling, nitrite values ranged from 0.01 - 2.34 and 0.13 - 2.37 respectively in the first and second years respectively. While comparing the values recorded during two years, higher values were recorded during monsoon months with highest of 2.34 μ ML^{-1} and 2.37 μ ML^{-1} were measured at station 9 and 5 in July 2001 and September 2002 respectively (Fig. 4.11). Lower values were recorded in premonsoon with the lowest of 0.01 and 0.13 μ ML^{-1} were recorded at station 5 in February 2001 and March 2002 respectively. Highest variation was noticed at station 9 in April 2001 where the nitrite levels showed an increase to 1.8 from 0.41 μ ML^{-1} before trawling (Fig. 4.11). Like wise, station 8 also showed similar trend with 1.53 μ ML^{-1} in the samples collected after trawling when compared to 0.47 μ ML^{-1} in the samples collected before trawling. Similarly, 2.09 μ ML^{-1} was recorded in after trawling samples at station 10 in April 2001 against 1.13 μ ML^{-1} in the samples of before trawling (Fig. 4.12 b). Marked wide variations in nitrite concentrations were also observed in the samples collected during the second year with highest variation at station 9 in July where nitrite values increased to 1.68 μ ML^{-1} after trawling from 0.83 μ ML^{-1} before trawling.

4.3.2 Phosphate phosphorus

4.3.2a Phosphate phosphorus at surface

Seasonal cycle of phosphate phosphorus measured in the samples collected before trawling is depicted in Fig. 4.13. Conspicuous seasonal variations were noticed in the phosphate values with invariably high values in monsoon and low in postmonsoon and premonsoon periods. Phosphate phosphorus recorded in the samples collected before trawling ranged from 0.02 - 3.12 µ ML^{-1} in the first year and that of second year from 0.12 - 3.44 µ ML^{-1} (Fig. 4.13). Highest of 3.12 and 3.44 µ ML^{-1} were recorded at station 3 and 5 respectively in the month of July in both years while the lowest of 0.02 and 0.12 µ ML^{-1} were registered at station 5 and 4 in November 2001 and January 2002 respectively. Uniform spatial distribution of phosphate was noticed in 0 - 50 m depth, however, the seasonal variations were found significant ($P < 0.01$, Appendix II, Table 9) in the study area. Phosphate levels recorded in the water samples collected after trawling showed wide variations when compared to that of before trawling. Similar seasonal variations in phosphate were also recorded in the after trawling samples with high values in monsoon and low in premonsoon and postmonsoon ($P< 0.01$, Appendix II, Table 10). Phosphate levels in the samples collected after trawling ranged from 0.02 - 3.83 µ ML^{-1} in the first year while during the second year it ranged between 0.13 and 3.84 µ ML^{-1} (Fig. 4.14). During the first year, highest value (3.83 µ ML^{-1}) was recorded at station 8 in July 2001 while it was lowest (0.02 µ ML^{-1}) at station 1 in February 2001. In spite of the fact that high phosphate values were recorded in monsoon however, the highest concentration (3.84 µ ML^{-1}) was registered at station 6 in March 2002 during the second year. There was a two-fold increase in the phosphate concentrations were recorded in the samples collected after trawling while comparing to that of before trawling samples. Highest variation was recorded at station 9 in November 2001 where phosphate concentration showed a rise to 3.30 μ ML-1 from 0.06 μ ML^{-1} (Fig.14.15 a and b). Similar variation was noticed at station 10 and 8 in the same month where phosphate values increased to 3.08 and 3.01 μ ML^{-1} in the samples collected after trawling when compared to 0.09 and 0.19 μ ML^{-1} respectively in before trawling samples, thus registering an abrupt increase. Similar trend was noticed in the second year also with the highest elevation at station 6 where the phosphate concentrations increased to 3.84 μ ML^{-1} from 1.19 μ ML^{-1} in March 2002 in the before trawling samples (Fig. 4.15 a and b). Even though there were steep increases in the phosphate phosphorus due to bottom trawling activities, however, only three stations out of ten (4, 7and 10) showed significant variations ($P< 0.05$, Table.2).

4.3.2b Phosphate phosphorus at bottom

Higher phosphate concentrations were recorded at bottom waters when compared to that of surface water. The pattern of variation of phosphate phosphorus in the samples collected before trawling is depicted in the Fig. 4.16. As in the case of surface layer, highest values were recorded during monsoon months while premonsoon and postmonsoon months showed low concentrations. The phosphate concentrations during premonsoon and postmonsoon seasons were steady while there were significant fluctuations during monsoon season ($P<0.01$, Appendix II, Table 11). Phosphate concentrations recorded in the before trawling water samples ranged from 0.47 - 5.83 and 0.21 - 4.93 μ ML^{-1} in the first and second year respectively. Highest values were rerecorded at stations 9 and 4 respectively in July 2001 and 2002 while the lowest was recorded at stations 2 and 10 in November 2001 and

January 2002 respectively in the samples collected before trawling (Fig. 4.16). the concentration of phosphate in the samples collected after trawling also followed the similar pattern of seasonal variations with high values in monsoon and comparatively low values in premonsoon and postmonsoon period. Samples collected after trawling showed steep increase in the phosphate phosphorus content. ANOVA showed significant changes even in the samples collected after trawling as noticed in the samples collected before trawling ($P < 0.01$, Appendix II, Table 12). Values recorded in the after trawling samples ranged from 0.39 - 7.76 and 0.54 - 6.23 μ ML^{-1} in the initial and final year. Highest values of 7.76 and 6.23 μ ML^{-1} were registered at station 4 and 6 in July 2001 and 2002 respectively while the lowest of 0.39 and 0.54 μ ML^{-1} were recorded at stations 2 and 10 in February and January in the years 2001 and 2002. (Fig. 4.17). 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. Station 9 also showed similar trend in phosphate levels where it rose to 4.75 μ ML^{-1} after trawling in February 2001 from 1.25 μ ML^{-1} recorded before trawling. Stations 1 and 8 were showed almost similar changes with increased phosphate concentrations of 3.96 and 4 μ ML^{-1} in the samples collected after trawling in February 2001 from 0.65 and 0.91 μ ML^{-1} recorded in the samples collected before trawling. During the second year, highest variation of phosphate concentration was recorded at station 6 in July with 6.23 μ ML^{-1} while it was 3.74 μ ML^{-1} in the samples collected before trawling. Highly significant variation was noticed ($P<0.01$) when phosphate phosphorus concentrations recorded after trawling samples when compared to that of before trawling (Fig. 4.18 a and b, Table 4.2).

4.3.2c Phosphate phosphorus at five meter above bottom

Phosphate phosphorus recorded five meters above bottom before trawling operation is depicted in the Fig. 4.19. These values were higher than that of surface waters however, was comparatively lower than that of the bottom. The phosphate values ranged between 0.03 - 4.86 µ ML^{-1} and 0.18 - 4.87 µ ML^{-1} during 2000-01 and 2001-02 respectively in the samples collected before trawling. Higher values were registered in monsoon as observed at surface and bottom waters, however the values were low during the premonsoon and postmonsoon months. During the first year, highest phosphate values of 4.86 µ ML^{-1} was recorded at station 3 in July 2001 while the lowest of 0.03 µ ML^{-1} was recorded at station 10 in February 2001. During the second year, highest of 4.87 µ ML^{-1} was noticed at station 3 in July 2002 and the minimum at 0.18 µ ML^{-1} was recorded at station 3 in January 2002 (Fig. 4.19). Significant seasonal variations were noticed in the samples collected before trawling ($P<0.01$, Appendix II, Table 13). Similarly, significant seasonal variation was observed in the samples collected after trawling ($P<0.01$, Appendix II, Table 14). Phosphate phosphorus levels recorded after trawling showed extreme variations when compared to that of samples collected before trawling and ranged between 0.03 and 6.98 µ ML^{-1} in the first year and 0.28 and 5.2 µ ML^{-1} in the second year (Fig. 4.20). Highest value of 6.98 µ ML^{-1} was recorded at station 4 in July 2001 and the lowest (0.03 µ ML^{-1}) at station 10 in February 2001. During the second year, the highest value of 5.21 µ ML-1 was registered at station 3 in July and the lowest of 0.28 µ ML^{-1} was recorded at station 3 in January (Fig. 4.20). Significant seasonal variation was observed in the phosphate concentrations measured after trawling ($P < 0.01$). Wide variations were noticed in the phosphate concentrations recorded in the samples collected both before and after trawling ($P<0.01$, Table. 4.2). Highest variation was observed at station 4 in April 2001 where steep increase was observed with 2.98 µ ML^{-1} registered in the samples collected after trawling against 0.12µ ML^{-1} before trawling. Stations 7 and 8 in December 2000 and September 2001 also showed around 3 fold increase in the after trawling samples where 4.38 and 5.38 µ ML^{-1} were recorded compared to 1.25 and 2.68 µ ML^{-1} respectively in the samples collected before trawling (Fig. 4.21 a and b).

4.3.2d Phosphate phosphorus at ten meters above bottom

Phosphate phosphorus levels recorded at ten meters above bottom before and after trawling are depicted in the figure 4.22 and 4.23 respectively. Similar to that of surface conditions, bottom and five meters above bottom, phosphate phosphorus recorded at ten meters above bottom before and after trawling showed significant seasonal variation ($P< 0.01$, Appendix II, Table 15 & 16). Higher values were recorded during monsoon season while in the postmonsoon and premonsoon values were almost steady. In the samples collected before trawling, phosphate phosphorus ranged from 0.04 - 3.98 µ ML^{-1} in the initial year, the highest values (3.98 µ ML^{-1}) being registered at station 9 in July 2001 and the lowest (0.04 µ ML^{-1}) at station 9 in April 2001 (Fig. 4.22). In the second year, phosphate phosphorus showed wide range between 0.31and 4.51 μ ML^{-1} (Fig. 4.23). The highest value was recorded at station 5 in July 2002 and the lowest at station 8 in January 2002. Phosphate phosphorus was found augmented in the samples collected after trawling, but the extent of increase was low when compared to that at five meter above bottom and bottom waters but more than that recorded at surface waters. The values recorded in the samples collected after trawling ranged from 0.32 - 4.06 and 0.14 - 4.9 μ $ML\text{-}^{-1}$ in the first and second years respectively. Highest values of 4.06 and 4.9 μ ML^{-1} were obtained after trawling at stations 5 and 8 during July 2001 and 2002. The lowest values of the two years (0.32 and 0.14 μ ML^{-1}) were recorded at stations 5 and 6 in April and January in the year 2001 and 2002 respectively. Significant variations were obtained in almost all stations studied and the highest increase was noticed at station 9 in February 2001 where 2.76 μ ML^{-1} was obtained after trawling against 0.09 μ ML^{-1} in the samples collected before trawling. Similarly during November 2002 highest value of 3.71 μ ML^{-1} recorded after trawling against 1.35 μML^{-1} in the before trawling samples showing about three fold increase of phosphate due to the trawling activities (Fig. 4.24 a and b) at station 6. Significant variations were observed while comparing the phosphate phosphorus obtained in the samples collected before and after trawling ($P< 0.05$, Table 2).

4.4 Discussion

Nutrients are essential to life in the sea and among them nitrogen and phosphorus are the most important elements (Tyrrell, 1999 and Naqvi and

Jayakumar, 2000). Nutrients regulate biological processes by limiting or enhancing organic productivity in almost all types of aquatic environments (Redfield *et al.*, 1963). The distribution of nitrite-nitrogen and phosphate phosphorus observed in the present study strongly agrees to the previous studies conducted in the Kerala waters (Damodaran, 1973; De Sousa *et al.*, 1996). Distinct seasonal variations were noticed with high nitrite and phosphate concentrations in the monsoon period in which highest values were recorded in t July. Postmonsoon and premonsoon periods showed comparatively lower values when compared with monsoon season. Subramanyan (1958) recorded high nitrite and phosphate during southwest monsoon in Kerala coast. Earlier studies conducted along the east and west coast of India clearly showed the high nutrient concentrations during the monsoon months (Jayaraman and Seshappa, 1957; George, 1950; Qasim, 1977; Nair *et al.*, 1989; Madhupratap *et al.*, 1996; Burkill *et al.*, 1993). Naqvi *et al.* (1982) stated that nitrite concentrations observed in the Arabian Sea was significantly higher than those reported from eastern tropical north Pacific. The depletion of nutrients in the closing stages of postmonsoon period can be attributed to the planktonic productivity as reported by Sankaranarayanan and Qasim (1969). The apparent seasonal variation observed in nitrite and phosphate in the present study corroborate with the above findings.

Damodaran (1973) recorded the surface phosphate phosphorus in the range 0.03 - 3.37 µ ML-1 and between 0.03 and 5.39 µ ML-1 at the bottom. In the present study, the surface and bottom phosphate concentrations ranged between 0.02   3.44 and 0.04   5.83 µ ML-1 respectively which strongly corroborate to his findings. Nitrite-nitrogen recorded at surface and bottom waters showed lesser values than that of phosphate phosphorus recorded at the study area, ranging from 0.01   3.9 µ ML-1 in the samples collected before trawling which also agrees to the earlier findings of Rivonker *et al.* (1990) and Lakshmanan *et al.* (1987). The Arabian Sea is characterized by several unique seasonal and spatial variations in terms of physical and chemical features (Ramiah *et al* .,1996). High nutrients obtained in monsoon months may be due to the high influx of nutrient rich land run - off and upwelling (Jayaraman and Sheshappa, 1957, Banse, 1959, Madhupratap *et al.*, 1996, Webb and Morris, 1984). Rittenberg *et al.* (1955) opined that in marine condition, the major source of nutrients is the run - off from terrestrial environs. High phosphate and nitrite concentrations observed in the near shore waters in the present study also agree to this.

Nitrite-nitrogen is the intermediate product of nitrification/ denitrification and the concentration of nitrite is more in the sediments where the decomposition of the organic matter takes place (Sen Gupta and Naqvi, 1984; Naqvi, 1991; Kamykowski and Zentara, 1991). Phosphate phosphorus is also found in rich quantities in the finer sediments with abundant inorganic matter where the degeneration of organic matter releases the phosphate (Windom, 1976; Rao *et al.,* 1978). Water movements due to winds and currents transport the nutrients to the surface from the bottom (Sen Gupta *et al.*, 1979; Shetye *et al.*, 1991). Besides the winds and currents, upwelling also takes the lion's share to transfer the nutrients to surface waters (Banse, 1959). High nutrient concentration has been reported in southwest coast of India due to upwelling (Banse, 1959; Qasim, 1977; Muraleedharan and Kumar, 1996). De Sousa and Sastry (1975) reported high phosphate values in the Arabian Sea during southwest monsoon period and also registered a high phosphate concentration at surface in upwelled area. Joseph (1974a) recorded high nitrite-nitrogen during monsoon at the near shore waters off Cochin. In the present study, the high nutrients (nitrite- nitrogen and phosphate phosphorus) observed during monsoon months particularly at the near shore depths reveal that monsoon has a marked influence in the distribution of nutrients in the coastal waters. Nutrients showed an increasing trend from surface to bottom and the highest values were observed at bottom (Rao *et al.*, 1982). Nitrite and phosphate concentrations recorded in the present study also strengthened the above concept.

Nitrite-nitrogen and phosphate phosphorus recorded in the samples collected after trawling was conspicuously high when compared with that of samples collected before trawling. This may be due to the release of nutrients trapped in the bottom soil due to passage of heavy otter boards and nets. During dragging along the bottom, the churning action of otter boards and heavy trawl net rise the sediments into the water column along with nutrients and minerals (de Groot, 1984). Caddy (1973) also reported the rise of sediments clouds due to trawling. Bottom trawling and dredging have marked impacts on the substratum, the physical disturbance due to the direct contact with the fishing gear and the turbulent resuspension of surface sediments (Jennings and Kaiser, 1998). Gislason (1995) stated that the bottom trawling cause physical disturbance and resuspension of sediments as well as increase the exchange of nutrients and pollutants between the sediment and the water column. The high concentration of nutrients observed in the present study, immediately after trawling also points to the same fact. Highly significant variations were noticed in the bottom waters when compared to that recorded at surface in the case of nitrite and phosphate. The gradation in the nutrient levels with high nutrients at the bottom waters compared to surface, five and ten meters above bottom also reinforce the concept that the sea floor is the rich source of these nutrients as reported by De Sousa and Singbal (1986). The nitrite has showed average two – three fold increase in the after trawling samples; especially at bottom waters whereas phosphate recorded average four fold increase in values at bottom. The noticeable variations in the phosphate concentrations recorded after trawling than that of nitrites also strengthen the views that the phosphate content is more at the sea bottom than nitrite especially in the coastal waters (Qasim 1977). Thressiama *et al.* (1998) observed an increasing trend in nutrients at bottom waters due to dredging at Cochin harbour and this finding is also comparable with the present results. They also reported a two – three fold increase in the phosphate phosphorus and nitrite concentrations immediately after the dredging at the Cochin port and this shows strong agreement with the present findings. German researchers noted significant remobilization of nutrients from pore water as a result of disturbance to surface sediment layers (ICES, 1989). Reimann and Hoffmann (1991) also noticed the three - fold increase in nutrients during trawling. Rasheed (1997) noticed an increase of nutrients in the surface waters due to the dredging activities in the Cochin port. The results of the present study also highlights the heavy transport of the nutrients into the water column due to bottom trawling.

Bottom trawling directly affect physical properties of sea floor by increasing turbulence and by altering grain size distribution, sediment porosity and chemical exchange process (McConnaughey *et al.,* 2000). Various observations have revealed that turbulence in the wake of trawl doors and big nets often generate large and highly turbid clouds of suspended sediments (Korotkow and Martyschewski, 1977; Main and Sangster, 1981; Wardle, 1983 Churchill, 1989). Nutrients carried to the sea by the rivers are involved in the role of the principal agent for maintaining the fertility of the ocean (Emery *et al.*, 1955). The high nutrient release in to the water column can be considered as a positive effect of trawling as the high nutrients may increase the productivity of the water and the high nutrients obtained in the monsoon season strongly corroborate to this studies. But the negative effect of trawling is more chronic as it releases lethal gases like ammonia and hydrogen sulphides, which inflict heavy damage to the living organisms (Riemann and Hoffman, 1991). Subramanian and Sarma (1965) recorded high primary productivity in the coastal waters during southwest monsoon. The release of nutrients from the sediment to the water column due to upwelling during monsoon increases the productivity (Banse, 1959; Madhupradap *et al.*, 1996). Upwelling waters off southern Arabian waters found to have nitrite concentrations higher by three orders of magnitude (Mantoura *et al.*, 1993; Reid, 1962). In the present study it could also be noticed that bottom trawling could impart heavy perturbations on the sea bottom so as to release average three to four fold increase of nutrients almost similar to the upwelling effects reported earlier. Smith and Codispoti (1980) had observed high concentration of nutrients along the coast off Somali due to the consequence of extensive upwelling in the region associated with the strong southwest winds blowing along the coast. Increase in nutrients in surface layers due to upwelling result in the increased productivity (Nair *et al*, 1989; De Sousa *et al.*, 1996). Nutrients, which comes to the water surface, has a major role in the productivity of the water. Qasim (1977) recorded high productivity in monsoon and postmonsoon months in the Indian Ocean. Moreover, Ramiah *et al.* (1996) noticed low primary productivity during March – May periods in the Arabian waters and intermonsoon periods also registered lower nutrient concentrations (Smith *et al.*, 1991a). Though the nutrient enrichment observed in the present study at the euphotic zone may give rise to the heavy productivity (Sharma 1978), the pollutants and lethal gases which was also likely to rise to the surface along with the nutrients may produce lethal and noxious algal blooms and that may leads to the massive fish kills as reported by Messiah *et al.* (1991). Demaison and Moore (1980) reported high phytoplankton blooms at the upwelling areas. Bottom trawling causes abnormally high nutrients levels in the ocean by stirring up the sediments and this could increase noxious phytoplankton production notorious for the mass fish kills and shift the balance of plankton populations which would in turn could shift the balance of the fish and other marine life that feed on them as reported by Collie (2000a & b); Gordon *et al.* (1998); Rogers *et al.*, (1998). Naqvi *et al.*, (1998) reported heavy fish kills due the lethal red booms in the coastal waters off Kerala during the monsoon period. Morrison *et al.* (1998) noticed the high algal production at the coastal upwelling zone due to the heavy nutrients concentrations.

Moreover, the heavy turbid clouds arising during the bottom trawling may reduce the transparency of the water which hinder the penetrations of light into the water and in turn, results in the low production at the surface waters as reported by Newcombe and Mc Donald (1991). In the present study a rise of heavy turbid sediments plumes during experimental trawling could also be seen. Nutrients are taken up by the phytoplankton in large amount for their growth (Nair, 1990). The excessive organic production at the surface waters due to the abnormal rise in nutrient concentrations due to monsoon and upwelling reduce the oxygen content in the water column (Mantoura *et al.*, 1993; Banse, 1959). The overenrichment of water with nutrients and the resultant enhancement of growth and decay of aquatic vegetation would lead to the depletion of oxygen (Ryther and Dustan, 1971). Results of the bottom trawling conducted in the present study revealed the depletion of dissolved oxygen concentrations in the water especially at the bottom waters. Moreover, the heavy organic production in the monsoon and postmonsoon season have also reported drastic decline in the oxygen content (De Sousa and Singbal, 1986). It can therefore be inferred that the trawling operations in the monsoon and postmonsoon months would be more deleterious as it causes the abnormal nutrient rise in addition to the heavy rains and upwelling phenomenon prevalent during this season, depletion of oxygen due to sediment clouds and also due to the possible high organic productivity due the discharge of high nutrients to the surface waters during monsoon. While examining the ecological consequence of dredging carried out by Riemann and Hoffmann (1991) who reported the depletion of dissolved oxygen in dredged and trawled areas and also noticed around three fold increase in the surface nutrients. Messiah *et al.* (1991) opined the possible effect of a sudden release of nutrients or contaminants from sediments due to trawling. Studies along the southwest coast of India revealed that the bulk of the pelagic fish populations consisting of oil sardine, mackerel and whitebait avoided temporarily areas of intense upwelling activity because of low oxygen concentration (Pillai, 1993). Heavy nutrients observed in the bottom waters and few meters above sea bottom in the present study reveals the significant disturbance taking place at the sea bottom due to trawling. So it is apparent that bottom trawling reduces the water quality by increasing internal nutrient loads, oxygen consumption and possibly by heavy lethal phytoplankton production as opined by Riemann and Hoffmann (1991). In summer, when the nutrients are low at bottom the sediment mixing takes place due to the trawling activities and this may disturbs the nutrient regime. In conclusion, the incessant operation of bottom trawlers in the coastal waters may create an unfavorable environment in the marine ecosystem by way of abrupt changes in the nutrients level in the water and also by creating a turbid and cloudy low oxygen area in the water,

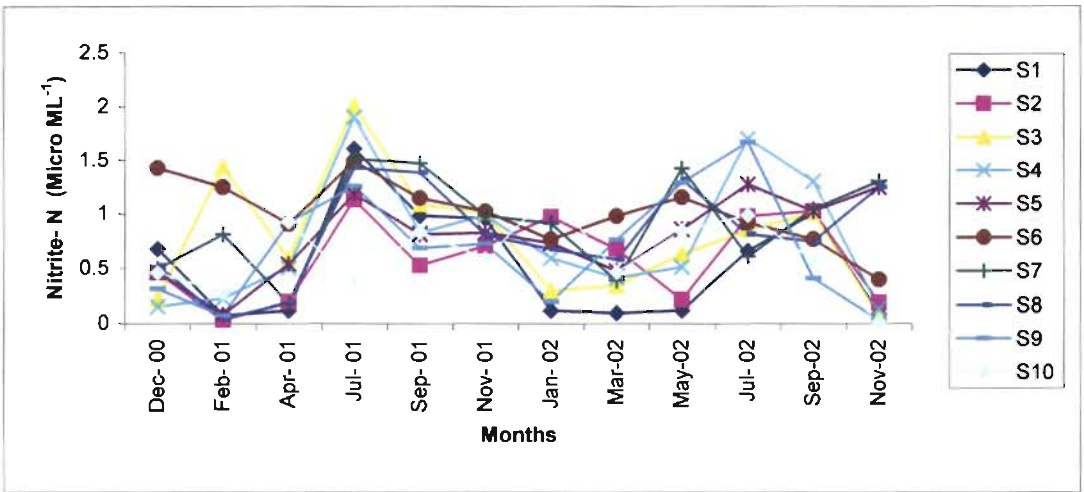


Fig. 4.1 Nitrite nitrogen at surface before trawling during Dec-2000 to Nov-2002

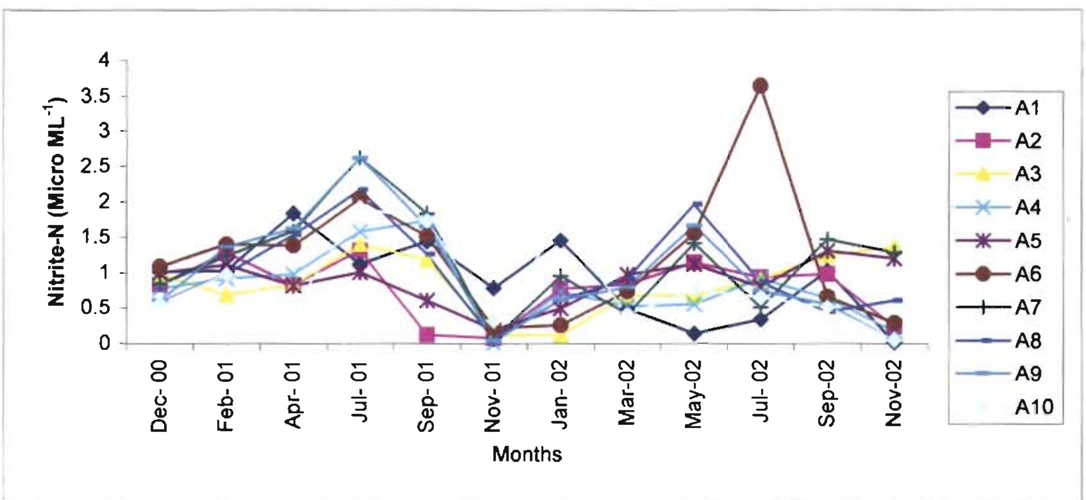


Fig. 4.2 Nitrite nitrogen at surface after trawling during Dec-2000 to Nov-2002

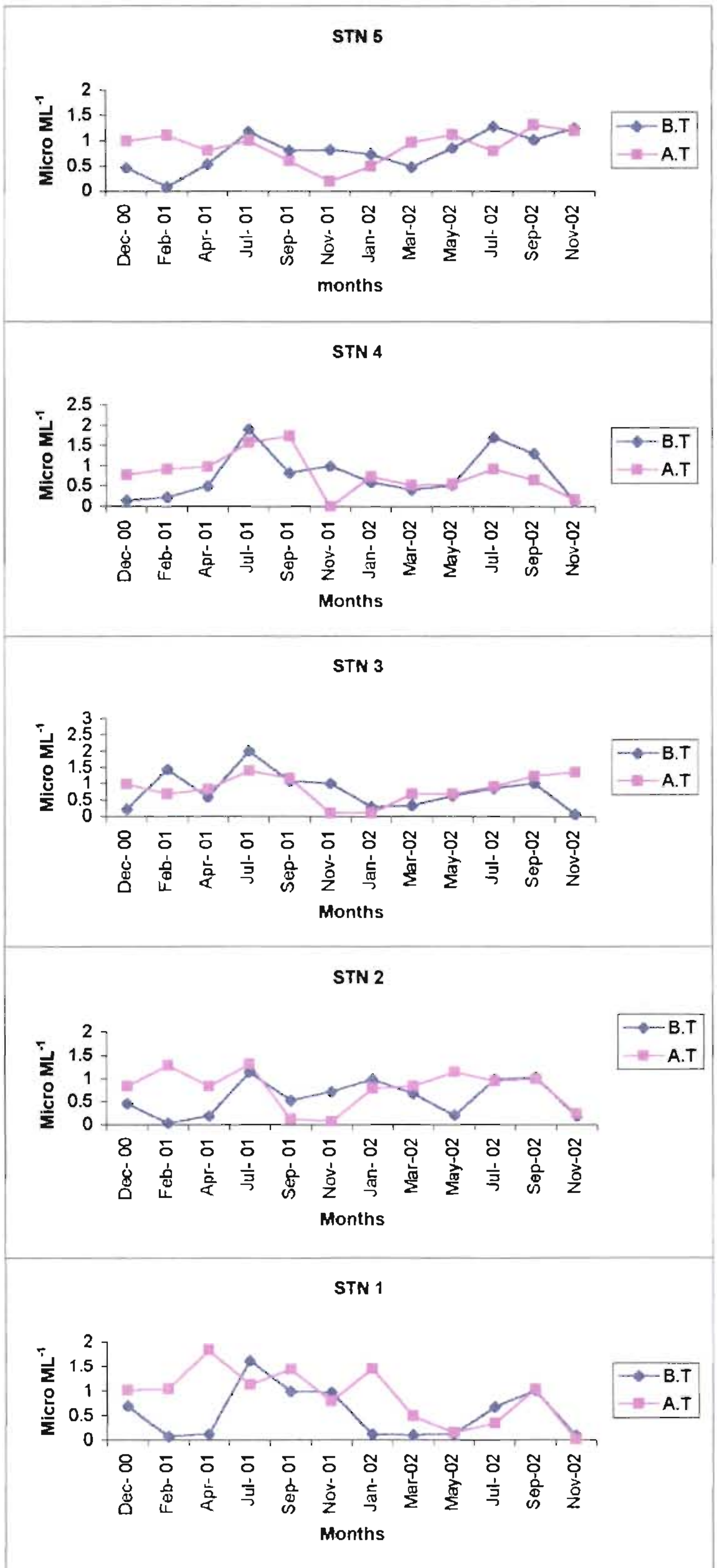


Fig. 4.3a Pattern of variations in nitrite nitrogen at surface before and after trawling during Dec-2000 to Nov-2002.

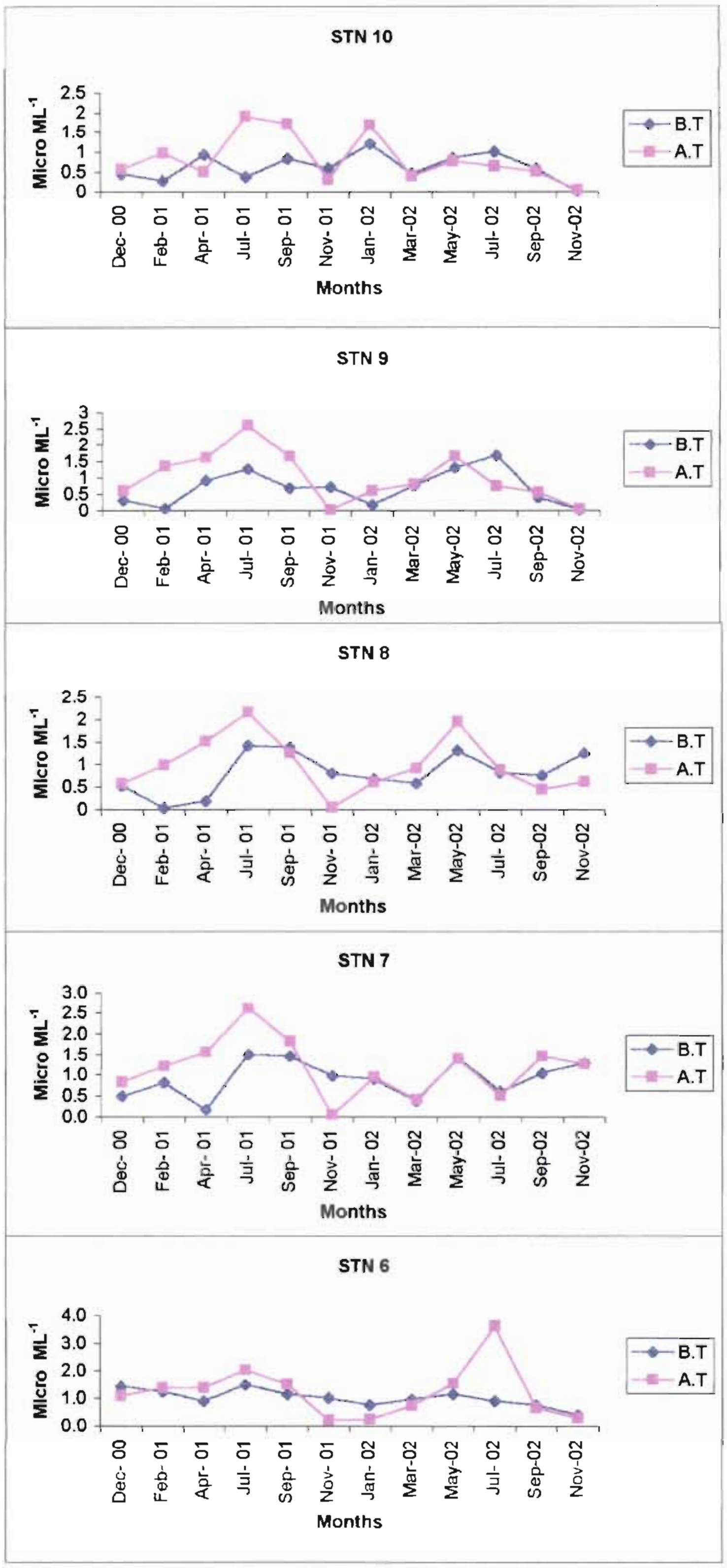


Fig.4.3b Pattern of variations in nitrite nitrogen at surface before and after trawling during Dec-2000 to Nov-2002

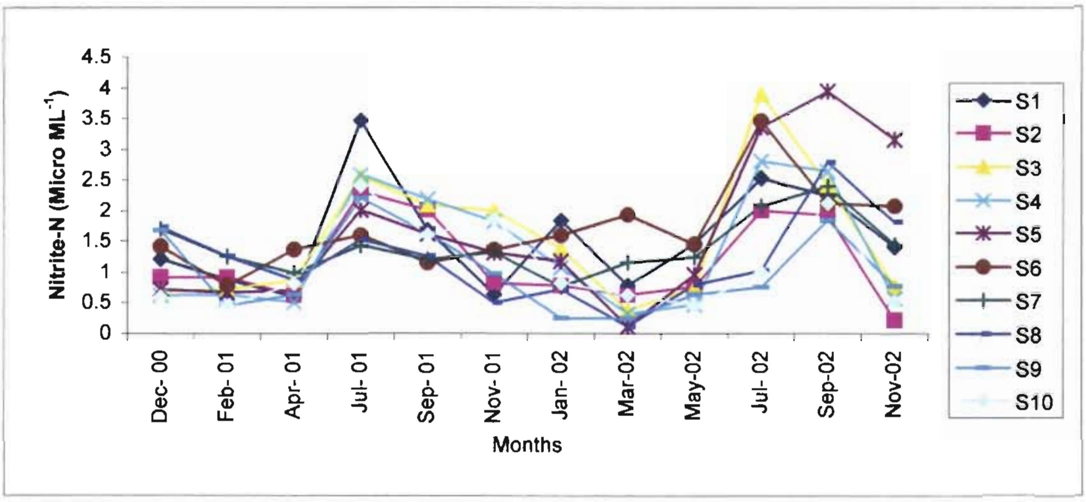


Fig. 4.4 Nitrite nitrogen at bottom before trawling during Dec-2000 to Nov 2002

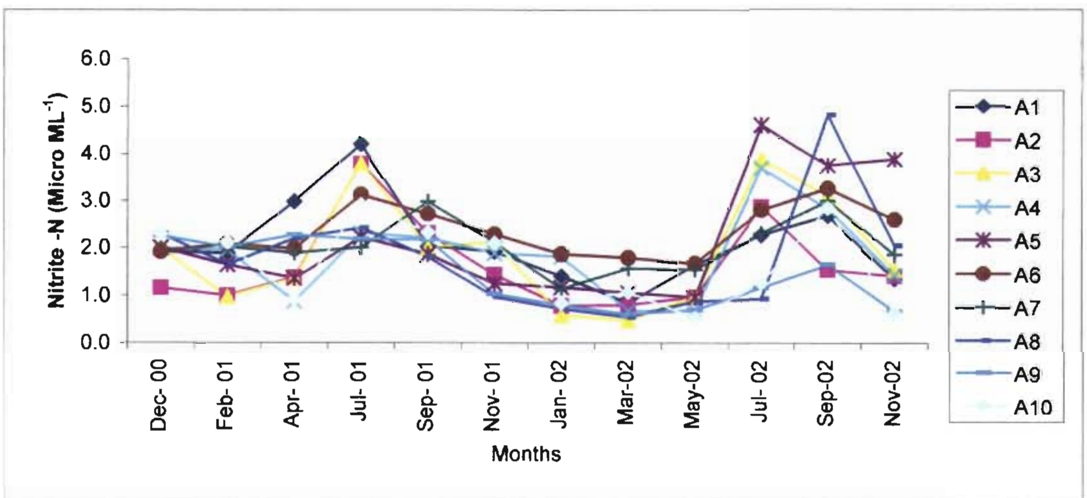


Fig. 4.5 Nitrite nitrogen at bottom after trawling during Dec.2000 to Nov. 2002

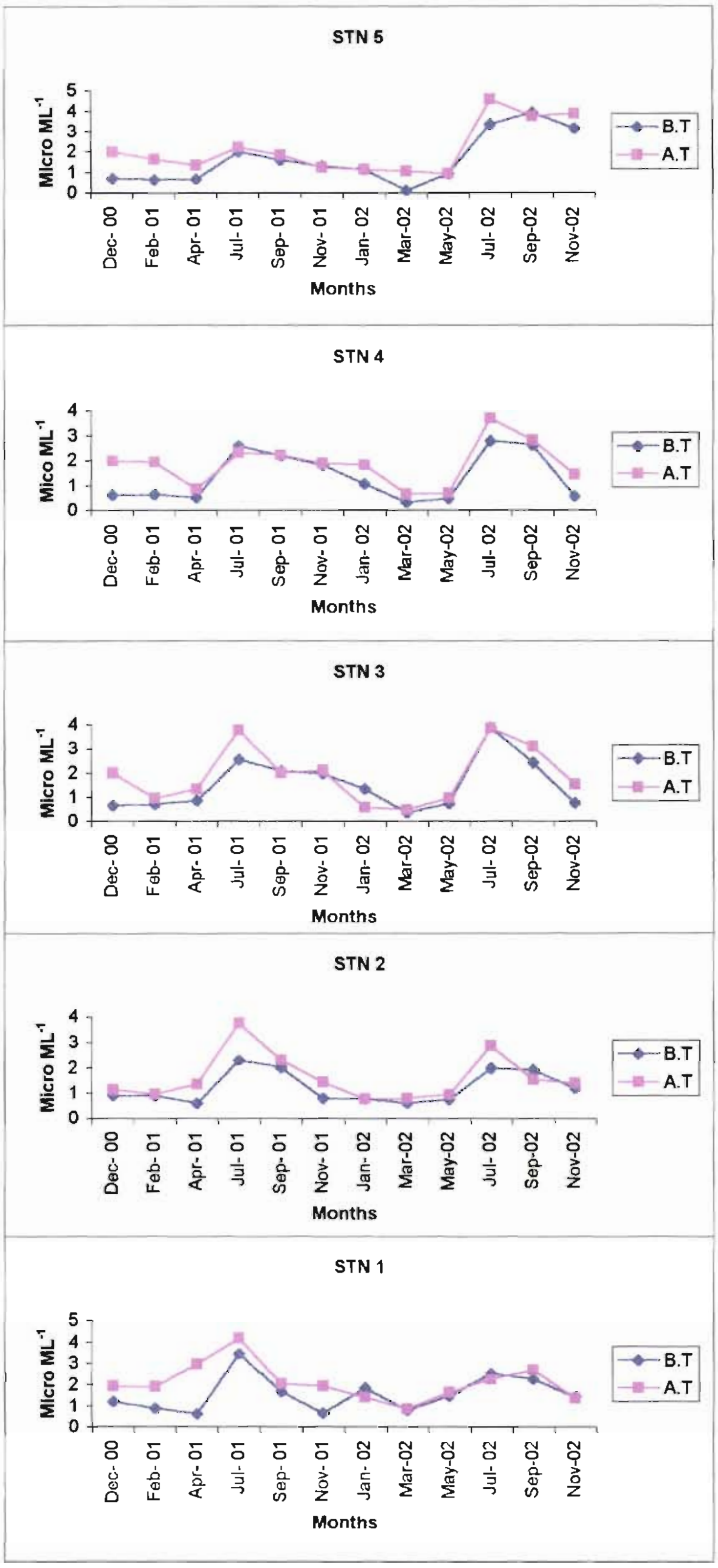


Fig. 4. 6a Pattern of variations in nitrite nitrogen at bottom before and after trawling during Dec-2000 to Nov-2002

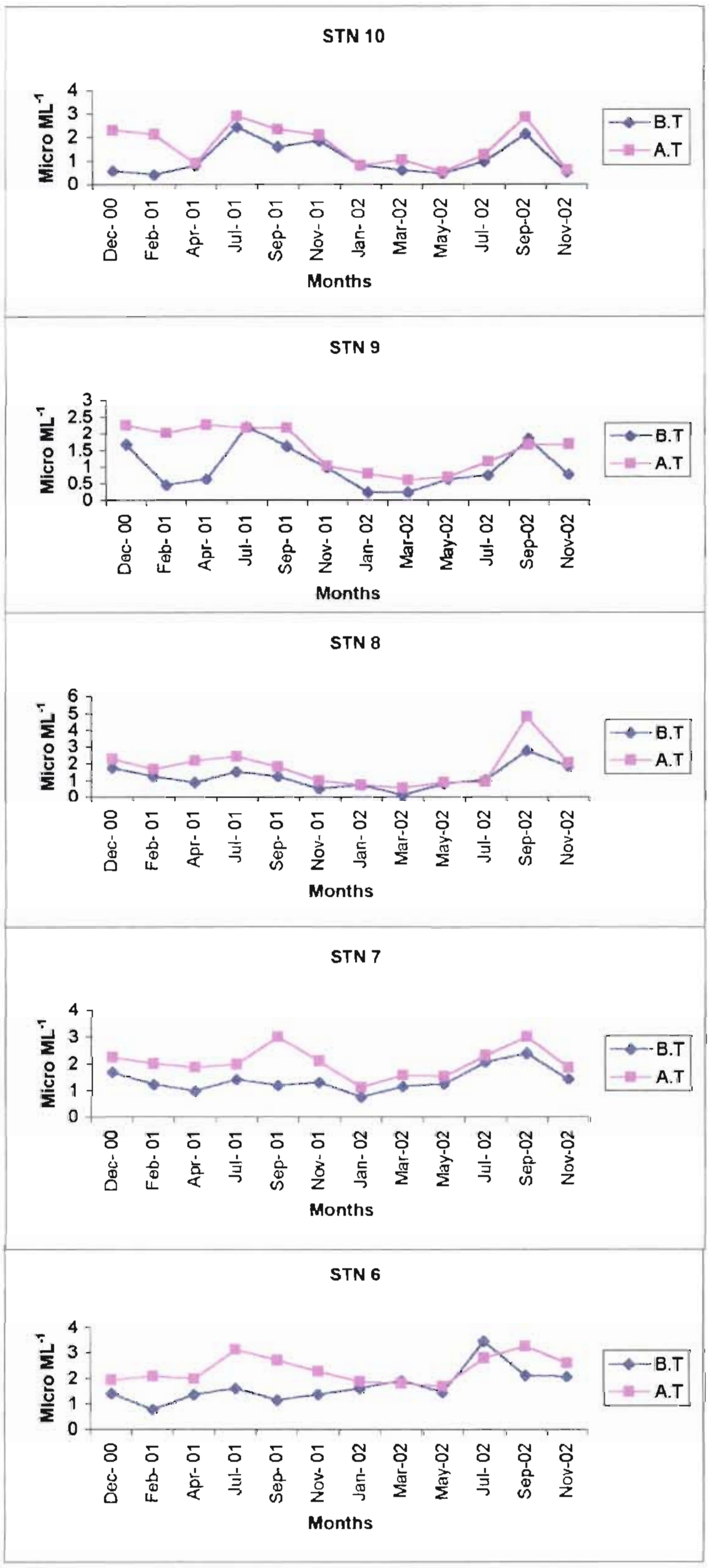


Fig. 4.6 b Pattern of variations in nitrite nitrogen at bottom before and after trawling during Dec-2000 to Nov-2002

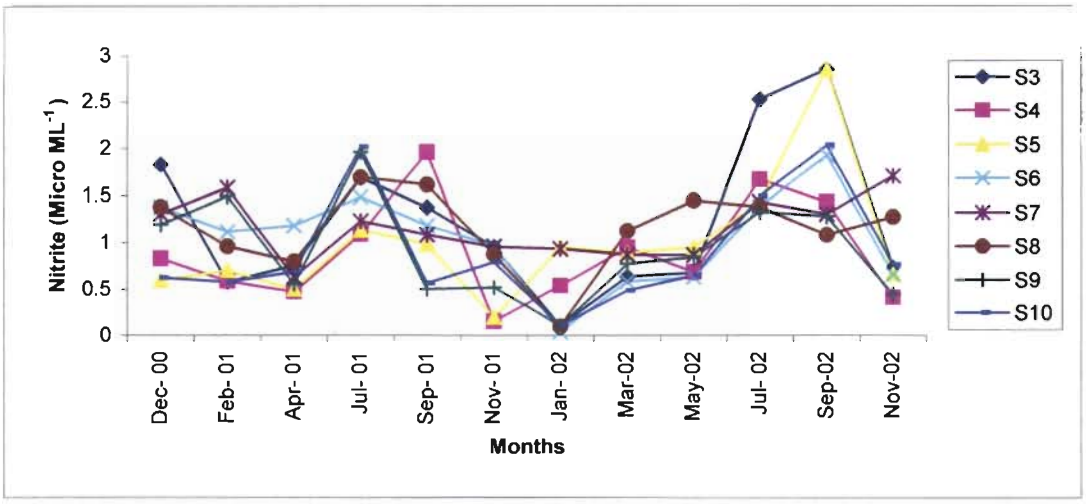


Fig. 4.7 Nitrite nitrogen at five meters above bottom before trawling during Dec-2000 to Nov 2002

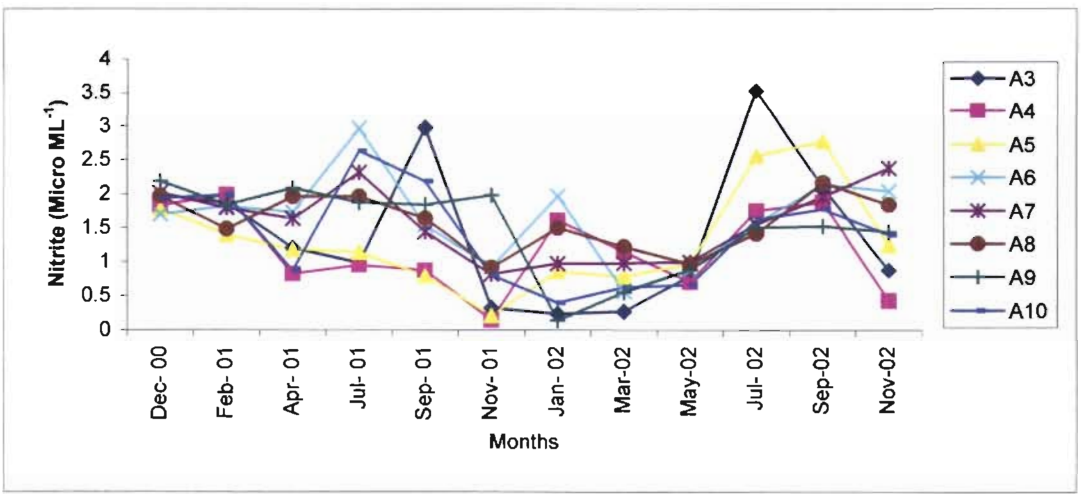


Fig. 4.8 Nitrite nitrogen at five metrs above bottom after trawling during Dec-2000 to Nov-2002

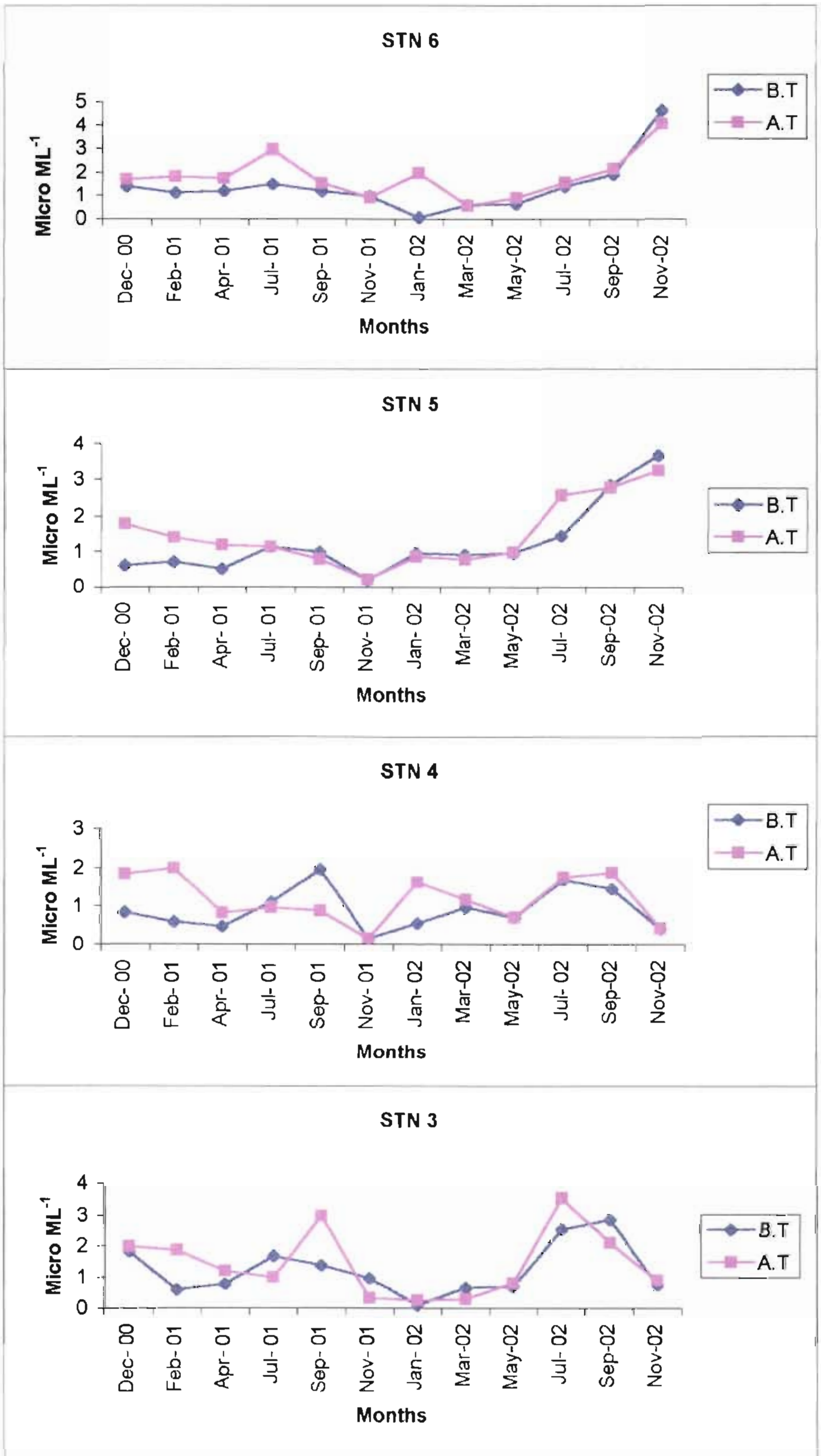


Fig. 4.9a Pattern of variations in nitrite nitrogen at five meters above bottom before and after trawling during Dec-2000 to Nov-2002

Fig. 4.9b Pattern of variations in nitrite nitrogen at five meters above bottom before and after trawling during Dec-2000 to Nov-2002

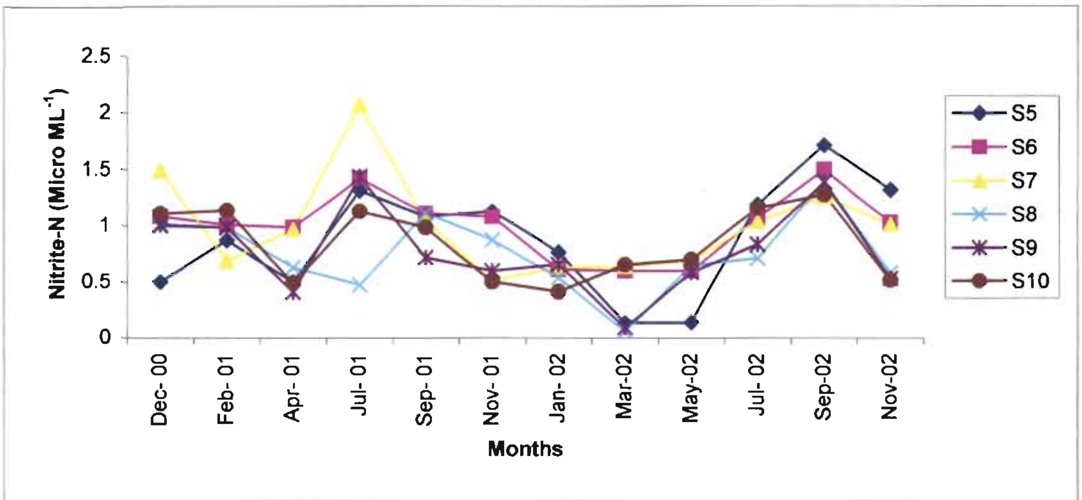


Fig. 4.10 Nitrite nitrogen at ten meters above bottom before trawling during Dec-2000 to Nov-2002

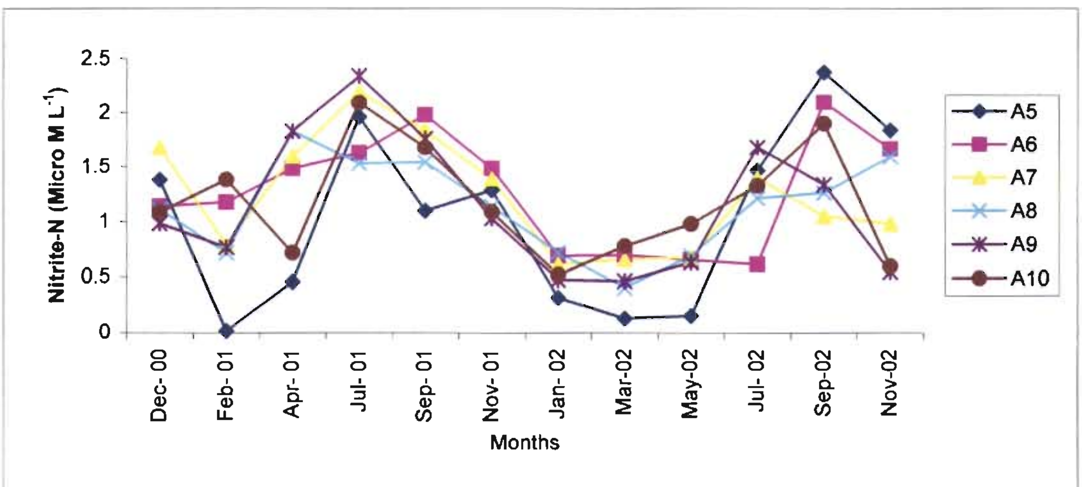


Fig. 4.11 Nitrite nitrogen at ten meters above bottom after trawling during Dec-2000 to Nov-2002

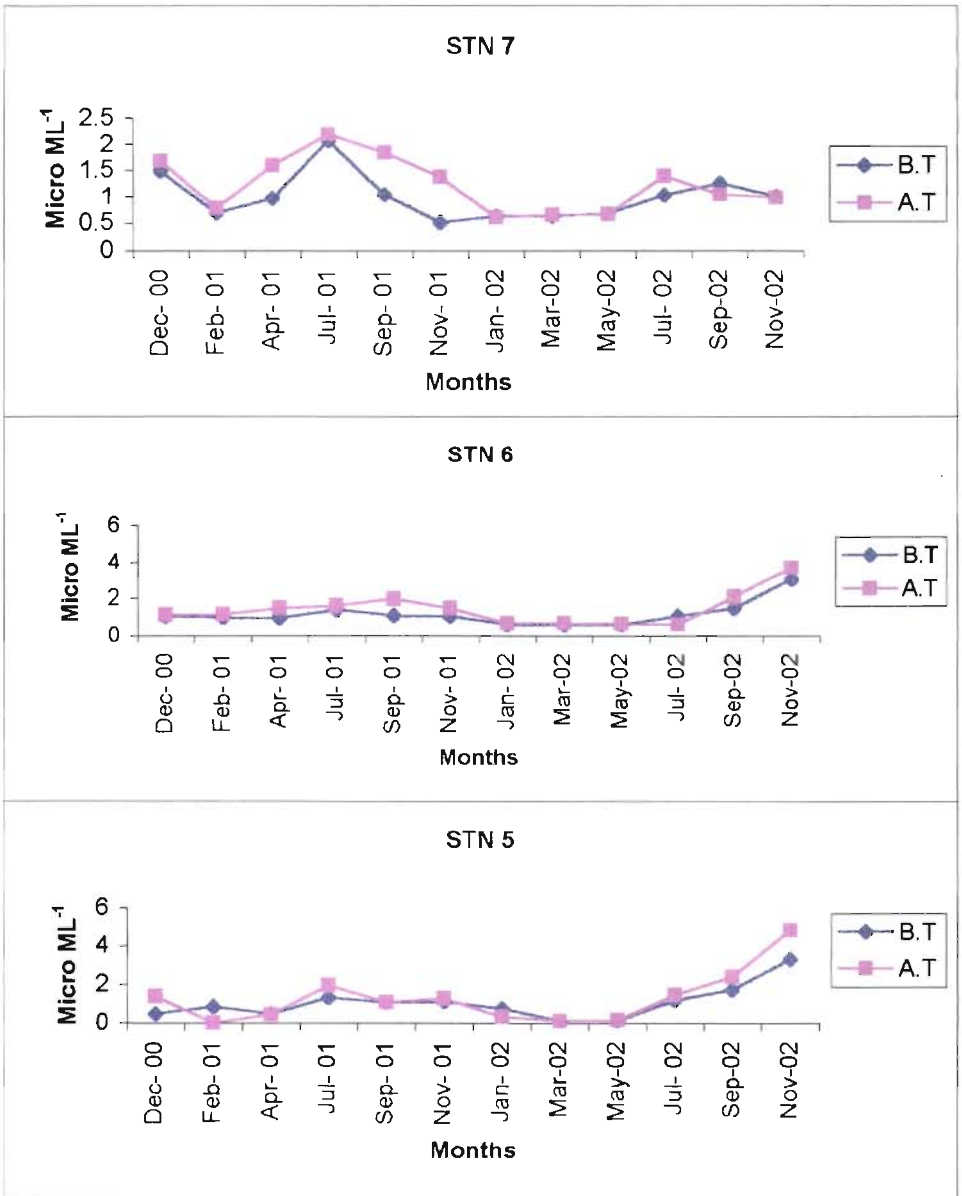


Fig. 4.12a. Pattern of variations in nitrite nitrogen at ten meters above bottom before and after trawling during Dec-2000 to Nov-2002.

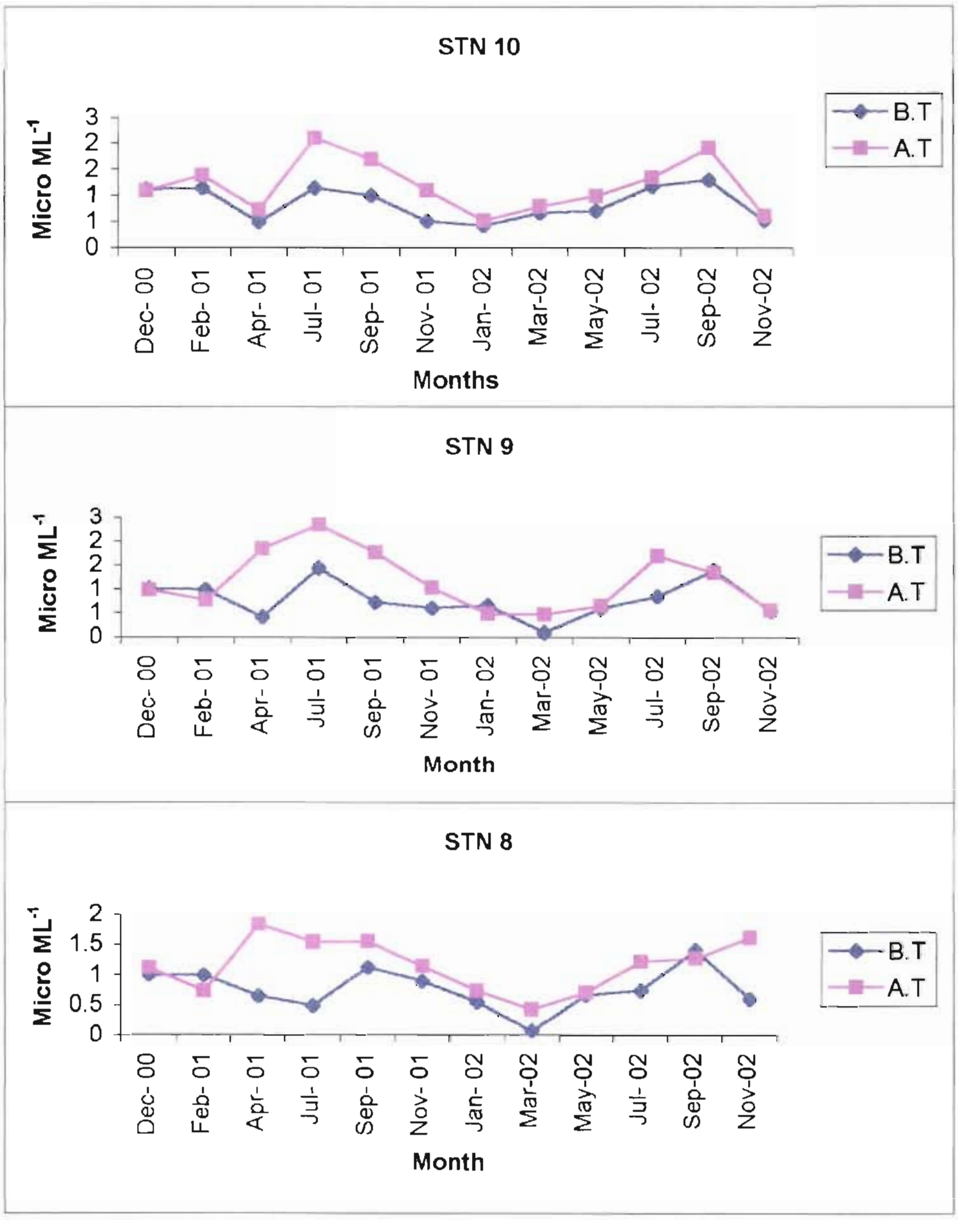


Fig. 4.12 b. Pattern of variations in nitrite nitrogen at ten meters above bottom before and after trawling during Dec-2000 to Nov-2002.

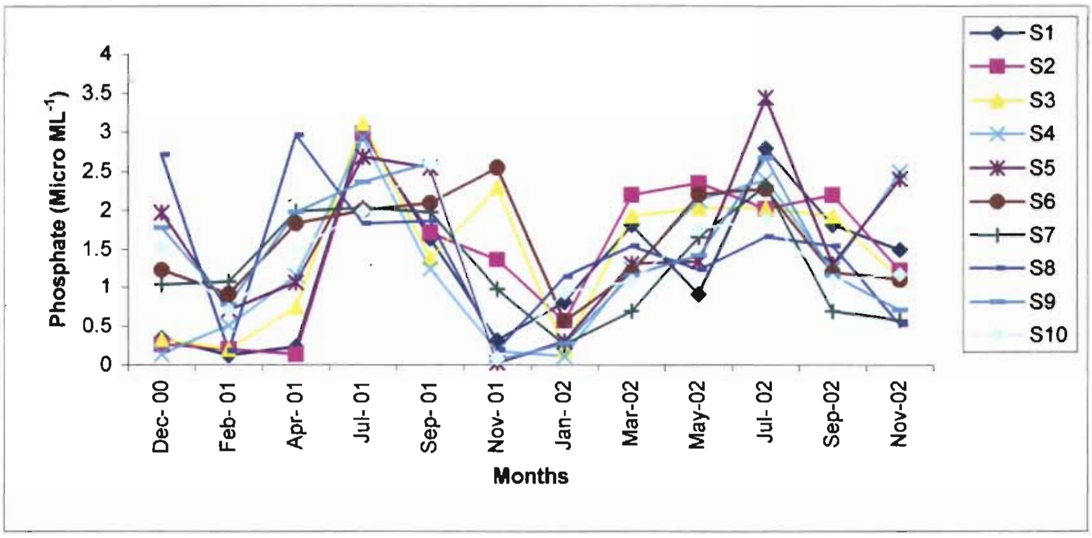


Fig. 4.13 Phosphate - phosphorus at surface before trawling during Dec.2000 to Nov.2002

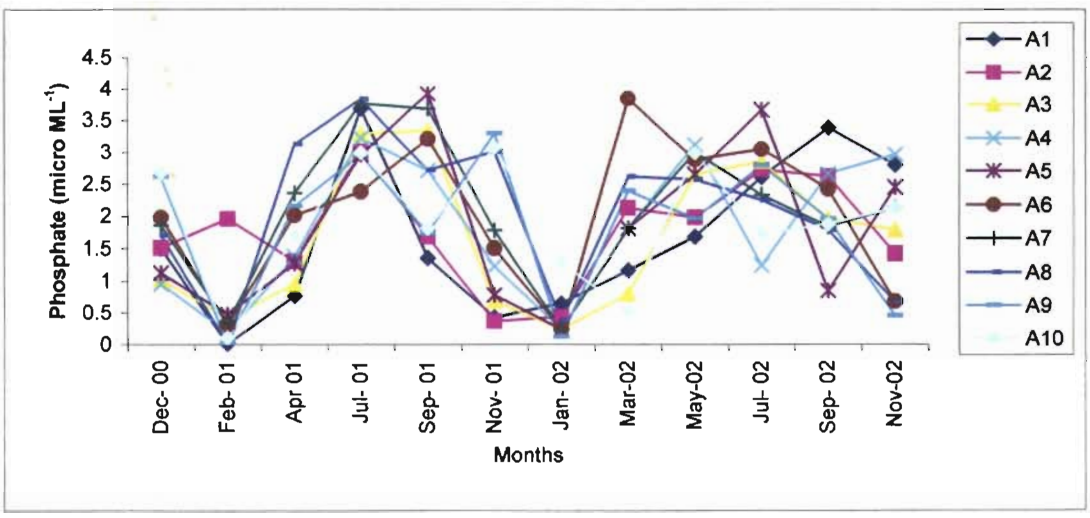


Fig. 4.14 Phosphate - phosphorus at surface after trawling during Dec.2000 to Nov.2002

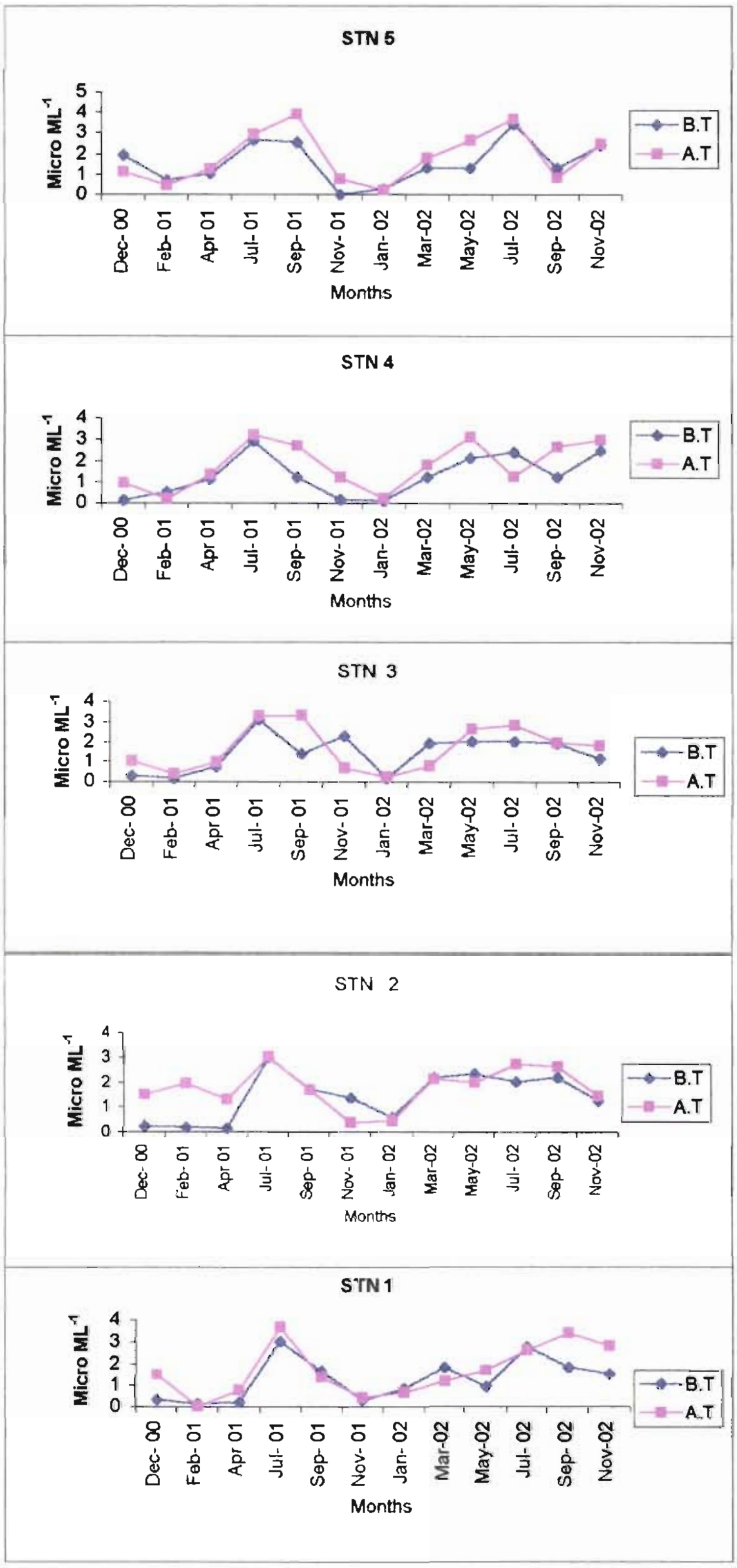


Fig. 4.15a Pattern of variations in phosphte - phosphorus at surface before and after trawling during Dec-2000 to Nov-2002.

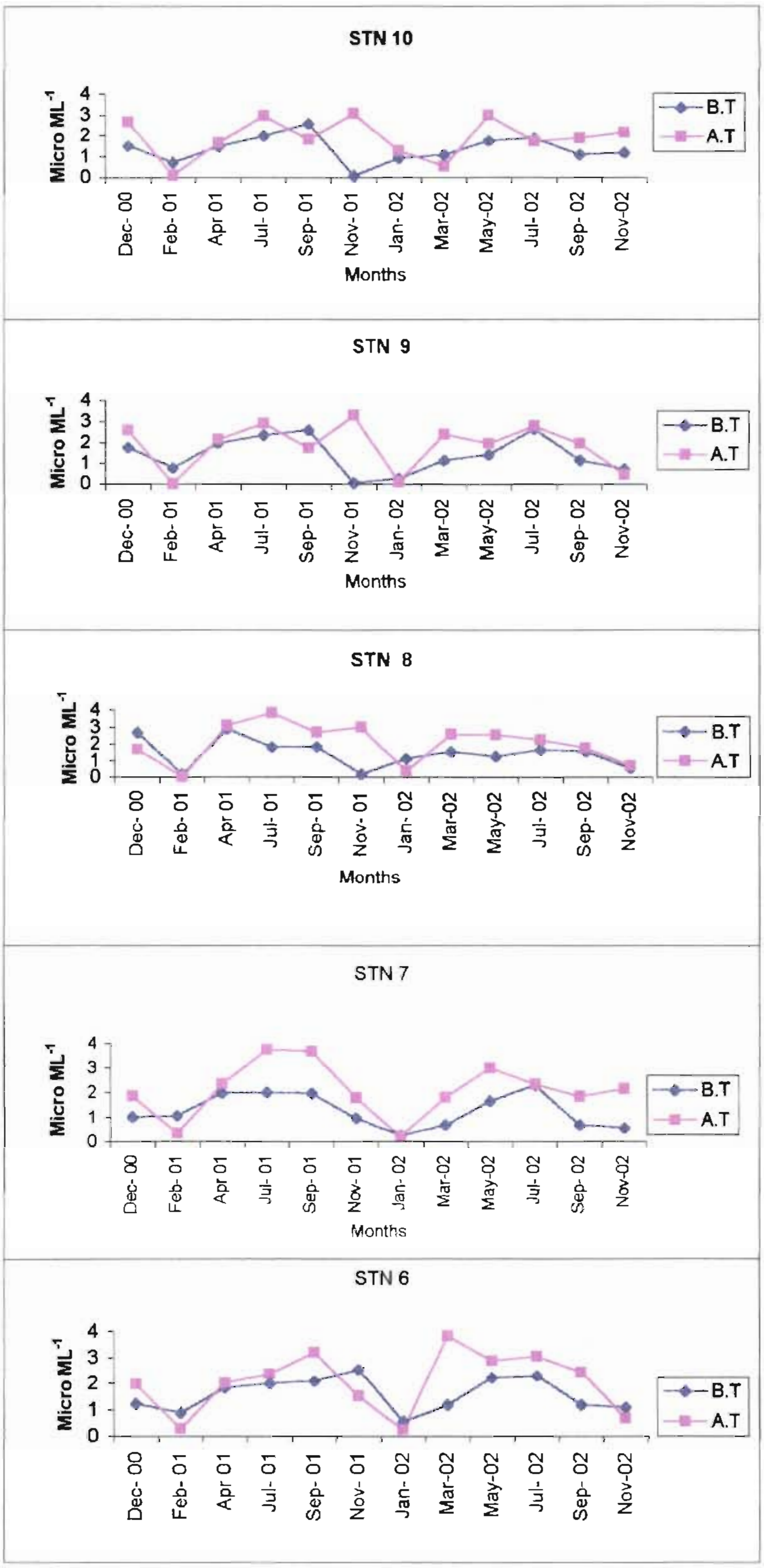


Fig. 4.15b Pattern of variations in phosphate - phosphorus at surface before and after trawling during Dec.2000 to Nov.2002.

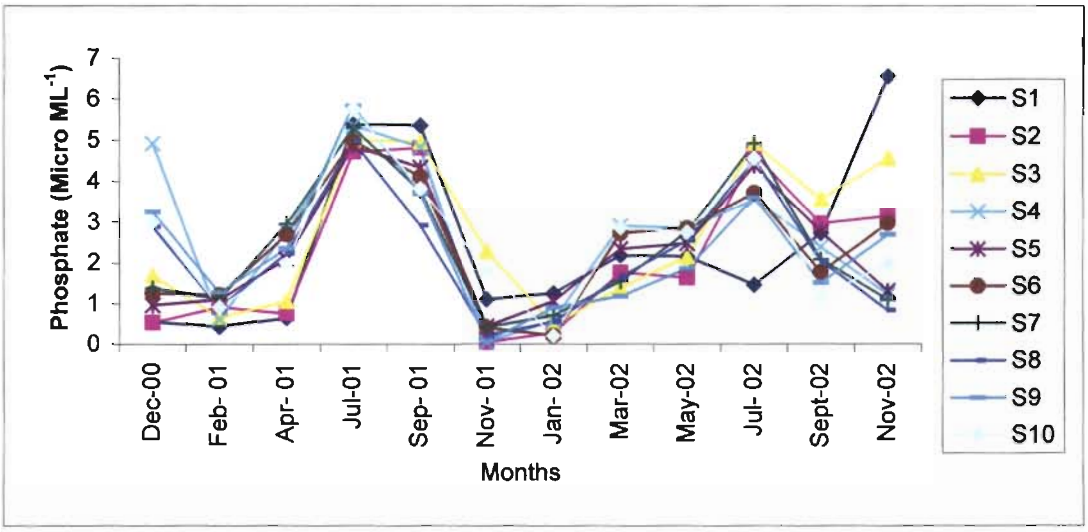


Fig. 4.16 Phosphate - phosphorus at bottom before trawling during Dec.2000 to Nov. 2002.

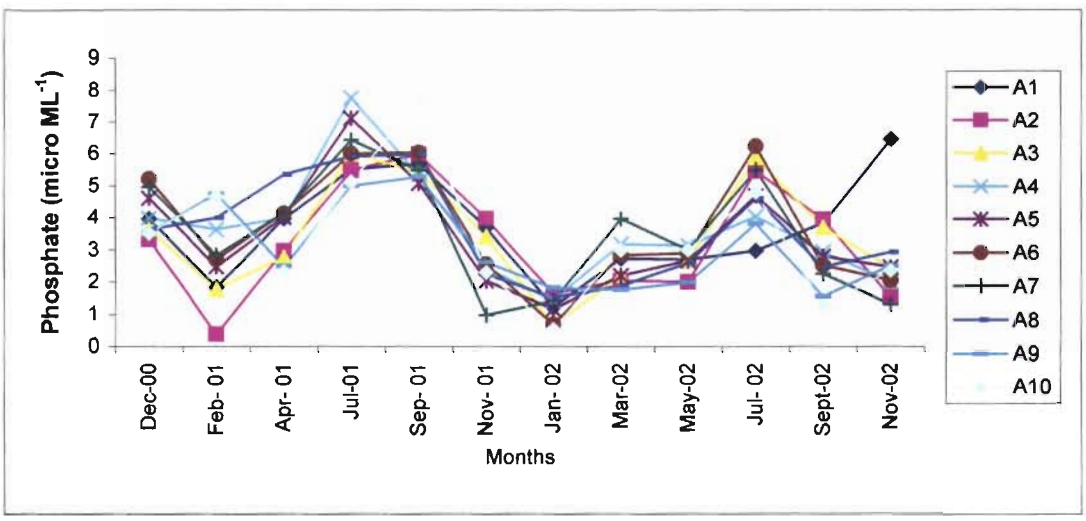


Fig. 4.17 Phosphate - phosphorus at bottom after trawling during Dec. 2000 to Nov. 2002

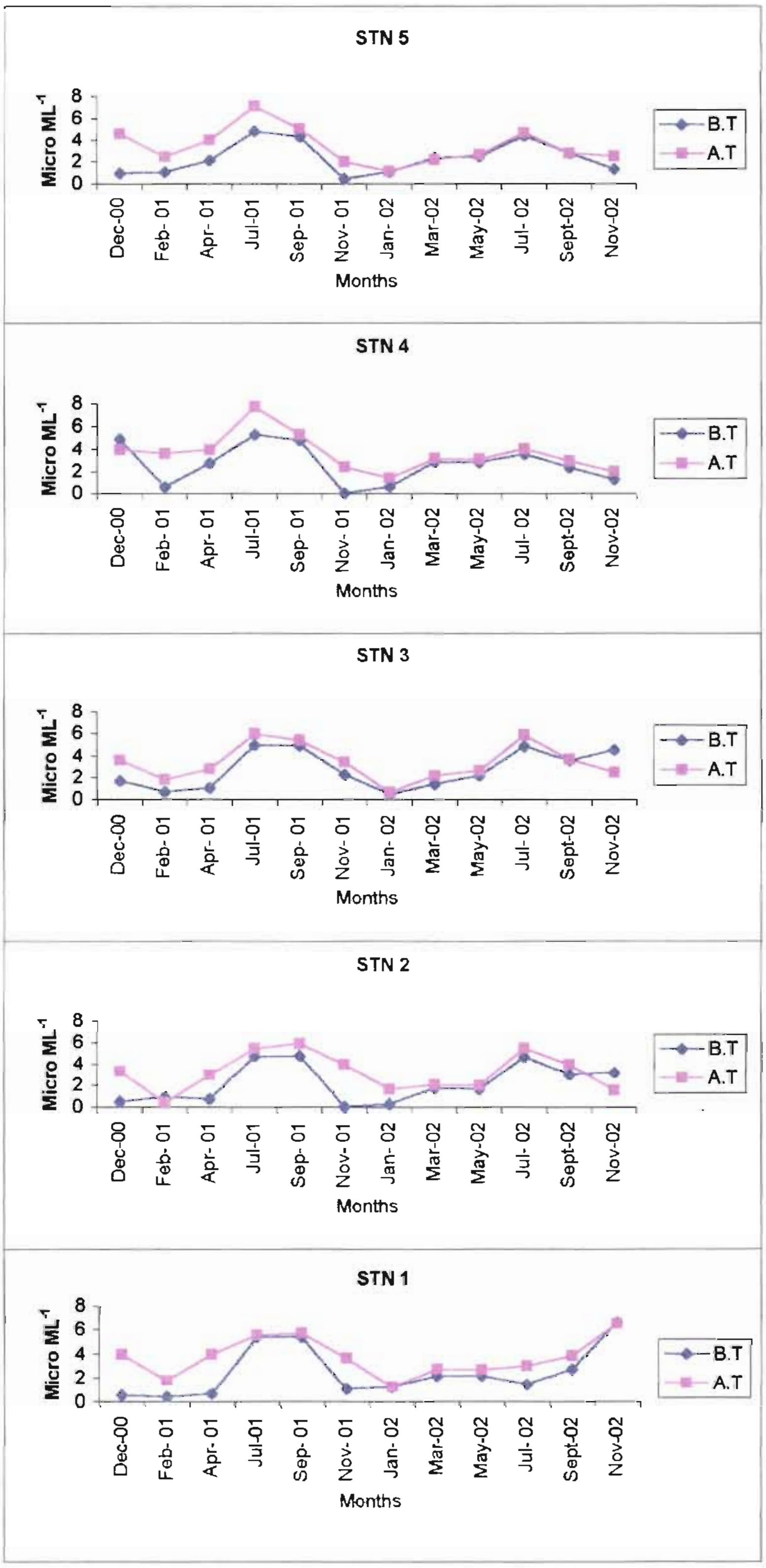


Fig. 4.18a Pattern of variations in phosphate - phosphorus at bottom before and after trawling duriing Dec.2000 to Nov. 2002.

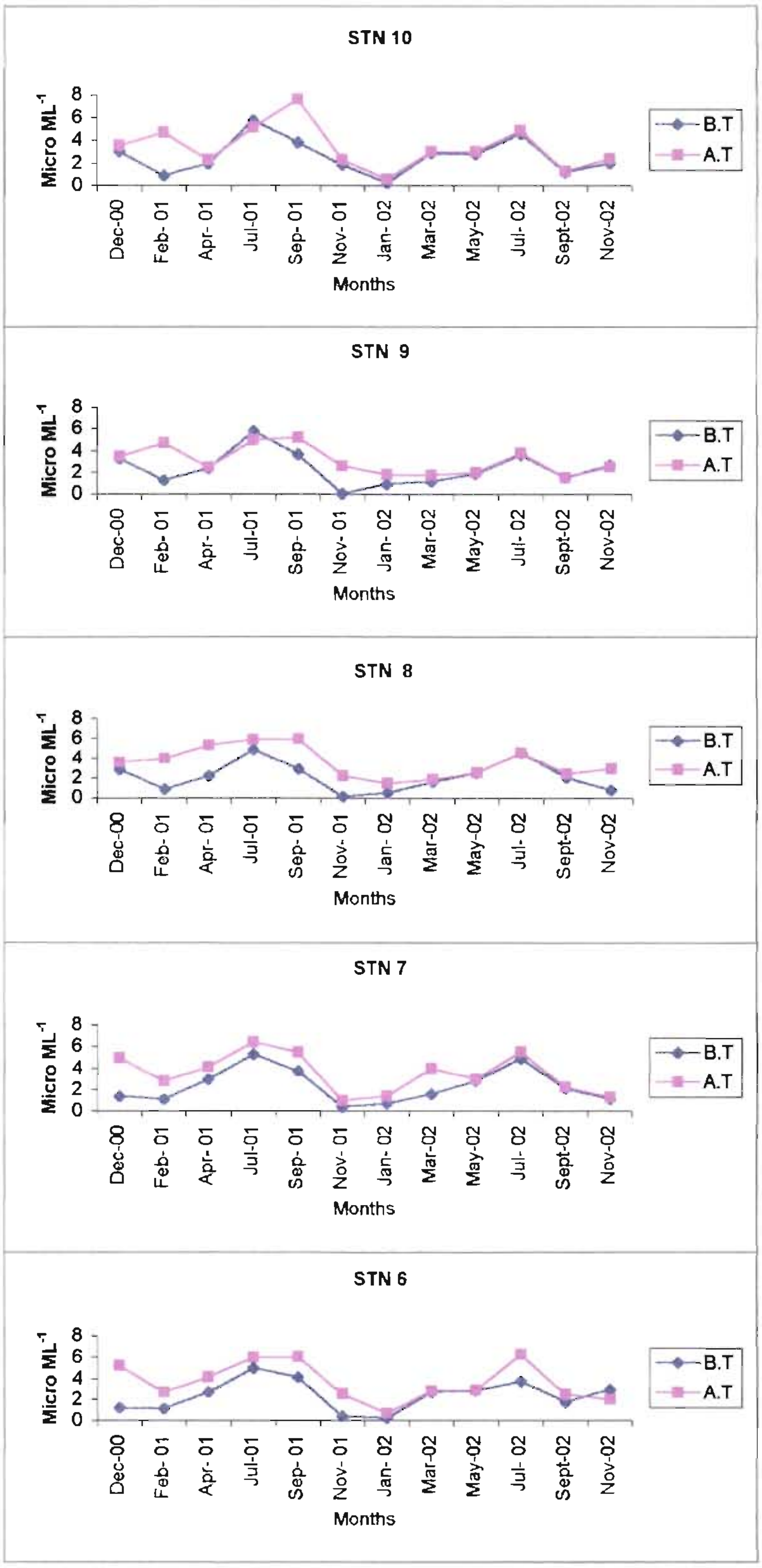


Fig. 4.18b Pattern of variations in phosphate phosphorus at bottom before and after trawling during Dec.2000 to Nov. 2002.

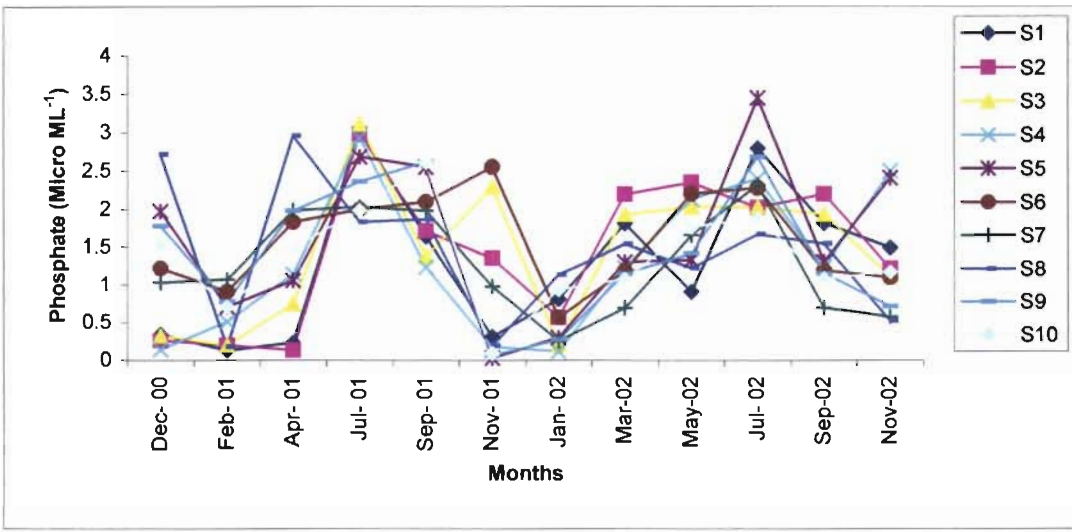


Fig. 4.19 Phosphate - phosphorus at five meters above bottom before trawling during Dec.2000 to Nov.2002

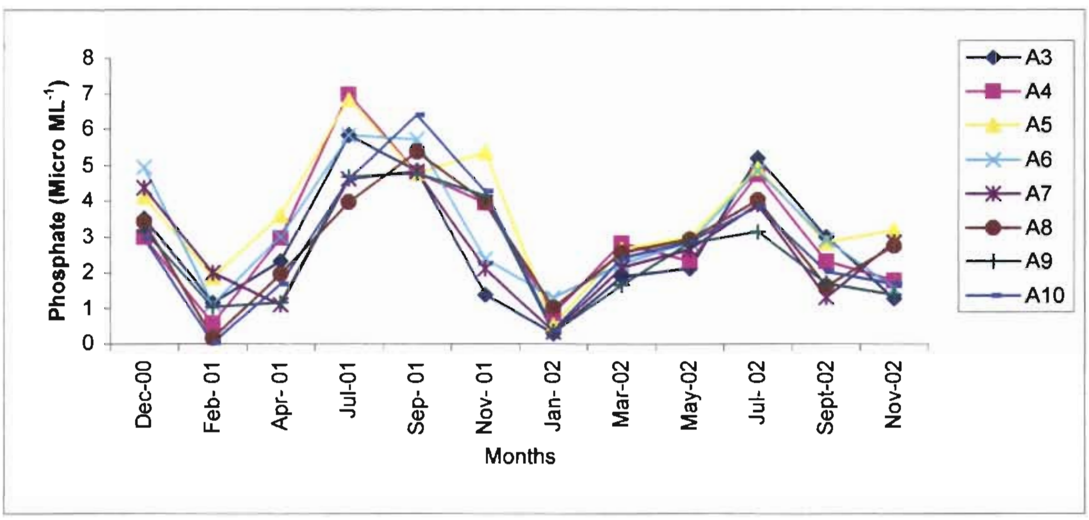


Fig. 4.20 Phosphate - phosphorus at five meters above bottom after trawling during Dec.2000 to Nov. 2002

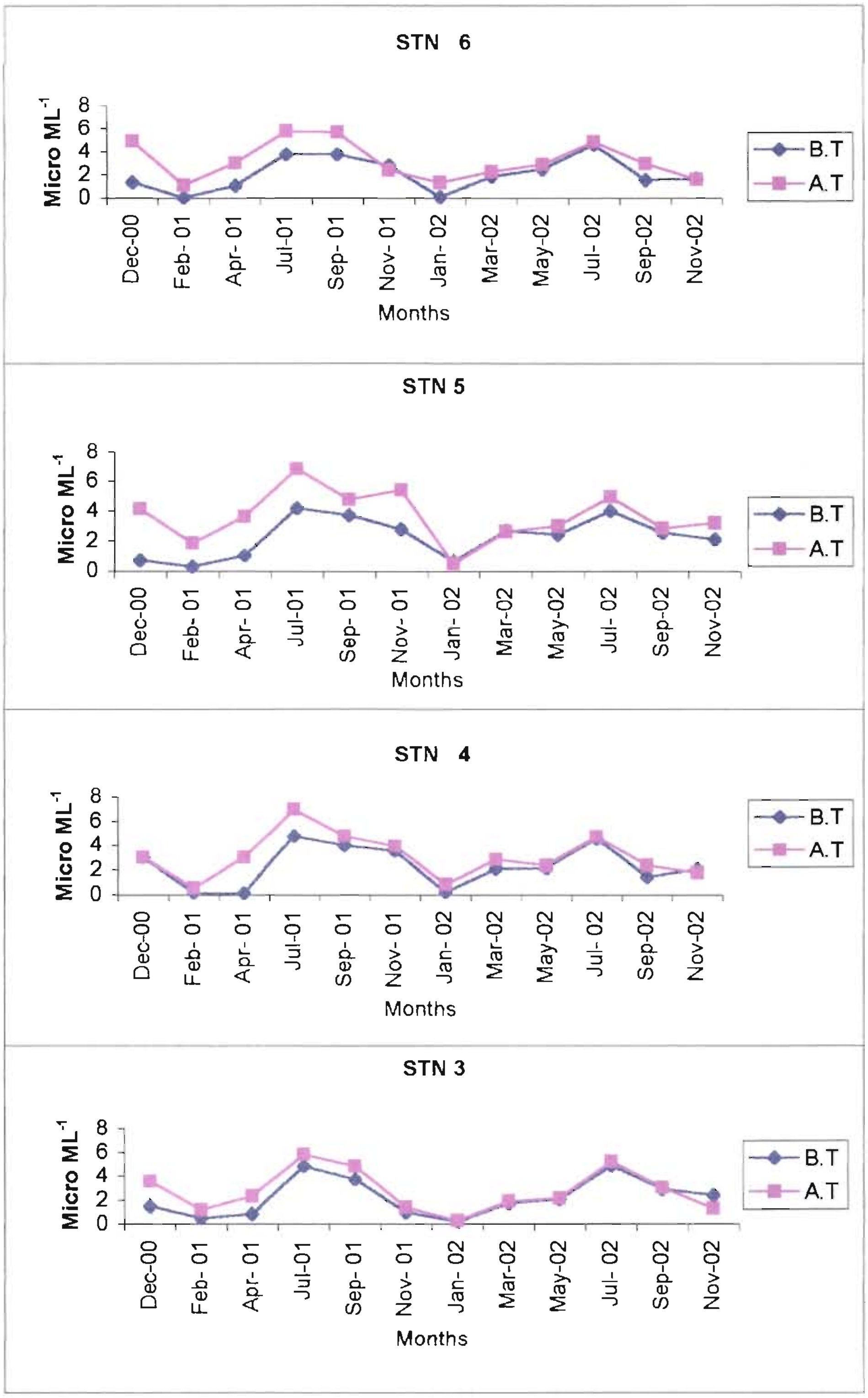


Fig. 4.21a. Pattern of variations in phosphate - phosphorus at five meters above bottom before and after trawling during Dec.2000 to Nov.2002.

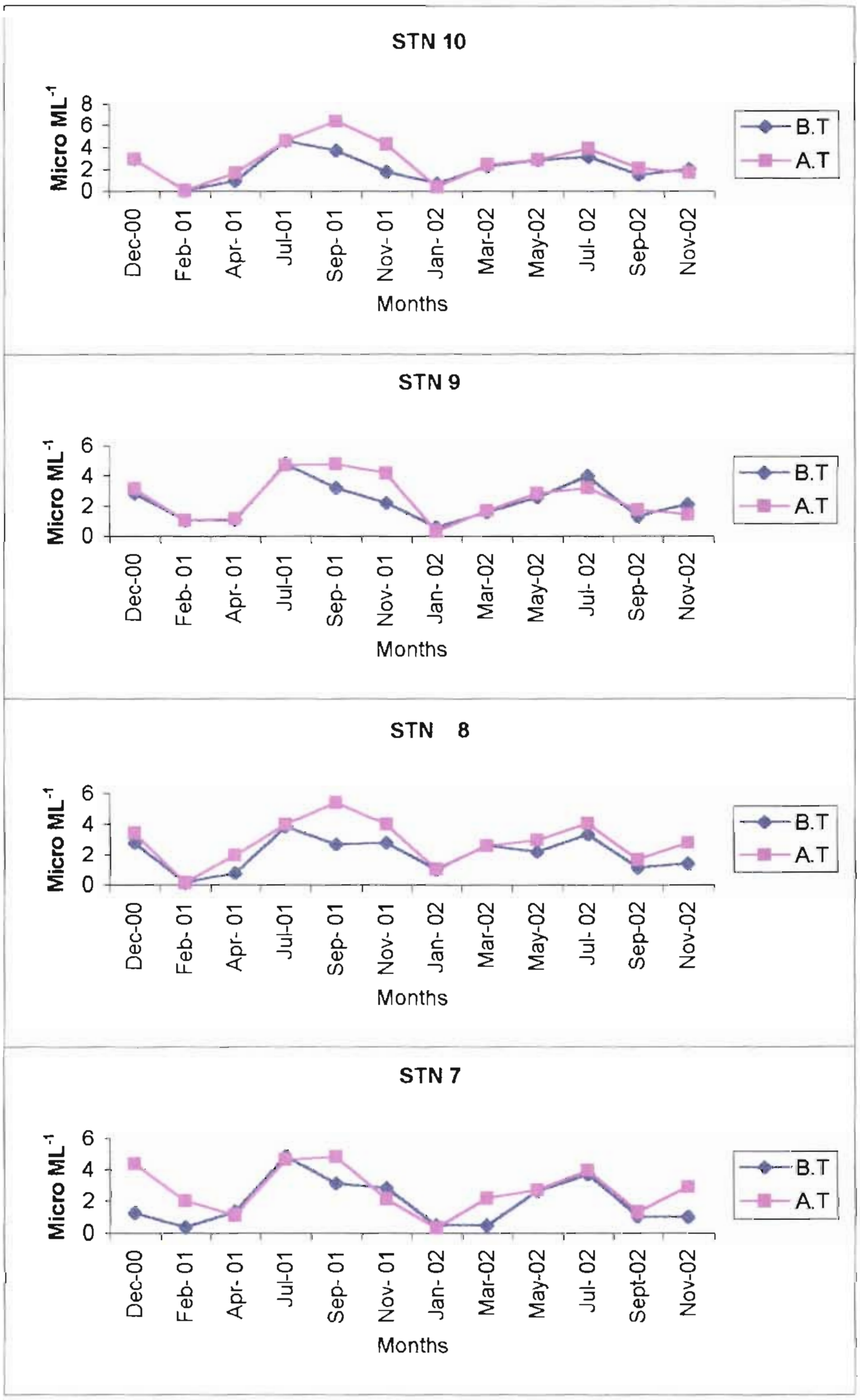


Fig. 4.21b. Pattern of variations in phosphate - phosphorus at five meters above bottom before and after trawling during Dec.2000 to Nov.2002.

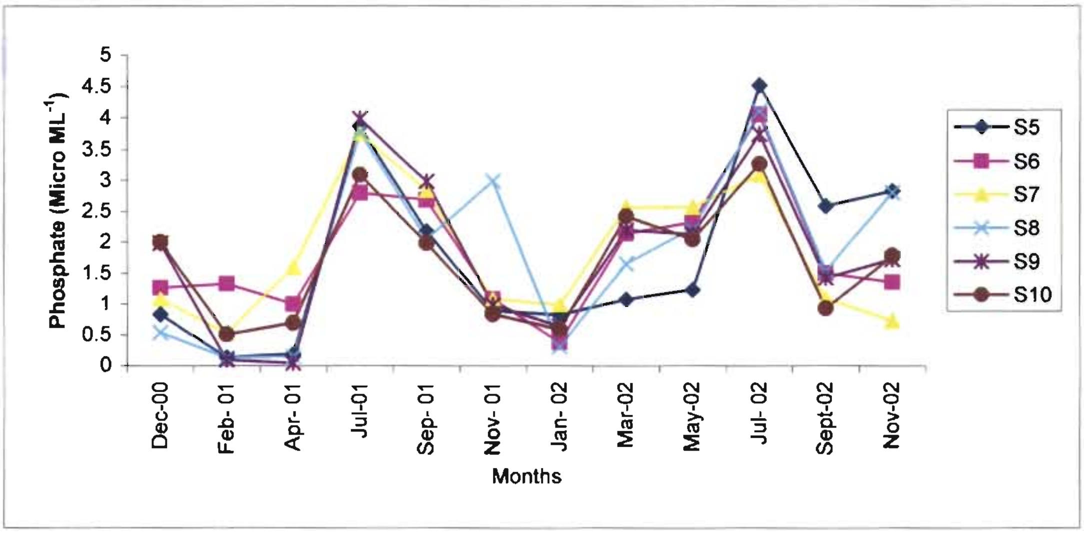


Fig. 4.22. Phosphate - phosphorus at ten meters above bottom before trawling during Dec.2000 to Nov.2002.

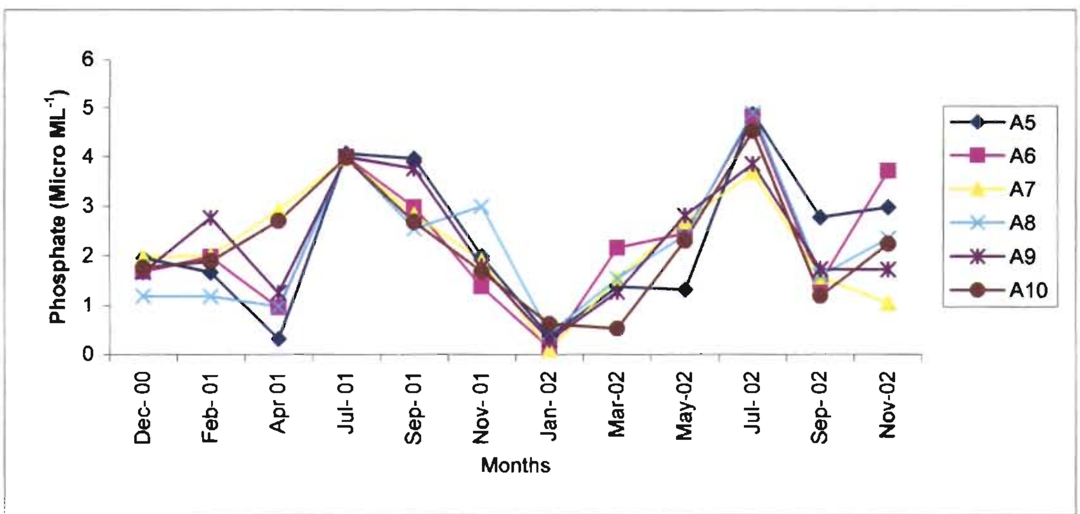


Fig. 4.23. Phosphate - phosphorus at ten meters above bottom after trawling during Dec.2000 to Nov. 2002

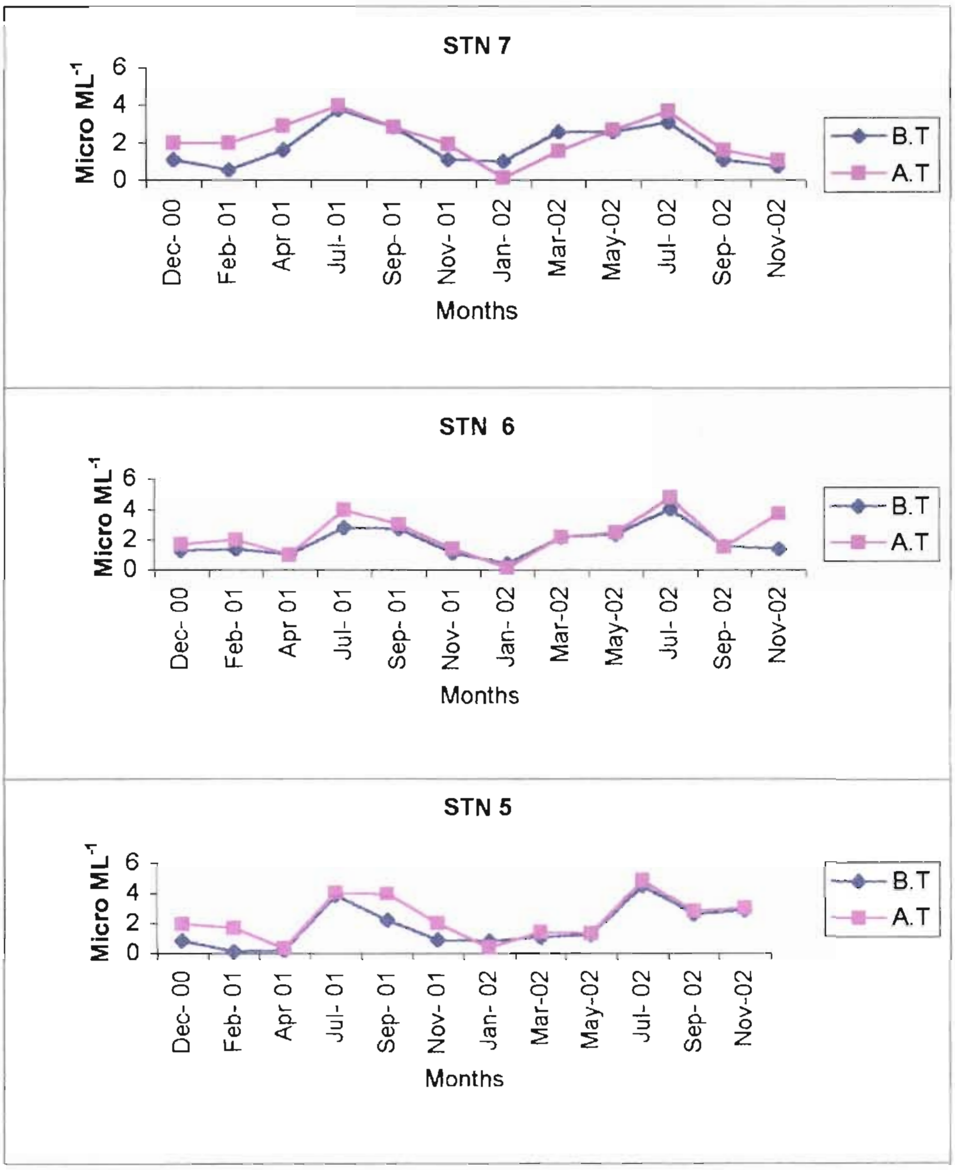


Fig. 4.24a. Pattern of variations in phosphate - phosphorus at ten meters above bottom before and after trawling during Dec.2000 to Nov.2002.

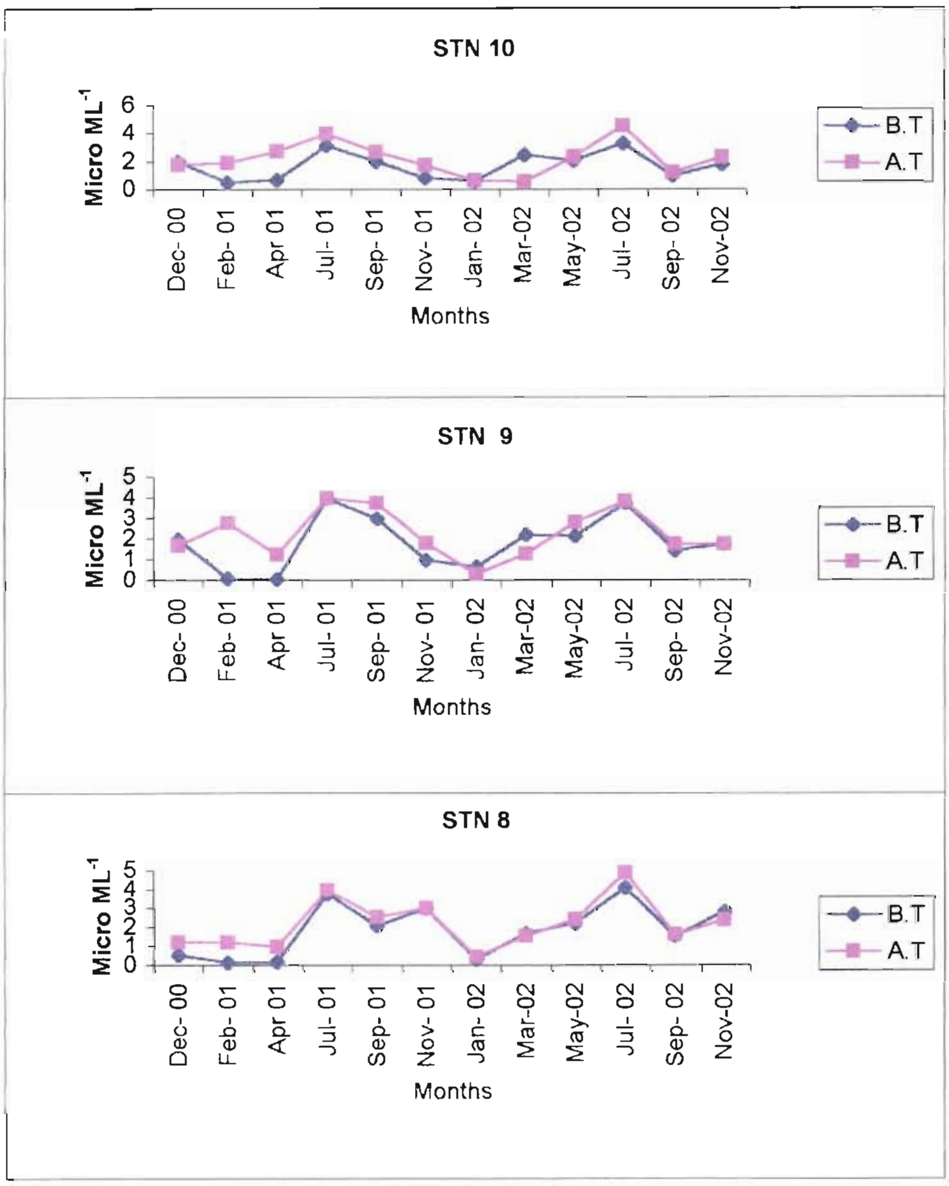


Fig. 4.24b. Pattern of variations in phosphate - phosphorus at ten meters above bottom before and after trawling during Dec.2000 to Nov.2002.

Table 4.1 Results of the *t* test on comparing the nitrite-nitrogen recorded before and after trawlling

Depth layer	Stations	t	df	P - value
Surface	S1-A1	1.774	11	N.S
	S2-A2	1.195	11	N.S
	S3-A3	0.279	11	N.S
	S4-A4	0.122	11	N.S
	S5-A5	0.653	11	N.S
	S6-A6	0.814	11	N.S
	S7-A7	1.485	11	N.S
	S8-A8	1.004	11	N.S
	S9-A9	1.64	11	N.S
	S10-A10	1.248	11	N S
Bottom	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	**
Five meters above bottom	S3-A3	0.897	11	N.S
	S4-A4	1.469	11	N.S
	S5-A5	1.505	11	N.S
	S6-A6	2.258	11	*
	S7-A7	3.566	11	**
	S8-A8	2.738	11	
	S9-A9	3.027	11	
	S10-A10	2.815	11	*
Ten meters above bottom	S5-A5	1.294	11	N.S
	S6-A6	2.625	11	*
	S7-A7	2.35	11	
	S8-A8	2.892	11	
	S9-A9	2.435	11	
	S10-A10	3.882	11	

N.S - Not significant

* - P< 0.05 ** - P< 0.01

Table 4.2 Results of the *t* test on comparing the phosphate - phosphorus recorded before and after trawlling

Depth layer	Stations	t	df	P- value
Surface	S1-A1	1.94	11	N.S
	S2-A2	1.49	11	N.S
	S3-A3	0.869	11	N.S
	S4-A4	2.337	11	*
	S5-A5	1.372	11	N.S
	S6-A6	1.577	11	N.S
	S7-A7	3.703	11	**
	S8-A8	1.935	11	N.S
	S9-A9	1.479	11	N.S
	S10-A10	1.81	11	N.S
Bottom	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
Five meters above bottom	S3-A3	2.319	11	*
	S4-A4	2.857	11	
	S5-A5	4.094	11	**
	S6-A6	3.584	11	**
	S7-A7	2.259	11	
	S8-A8	3.406	11	
	S9-A9	1.021	11	N.S
	S10-A10	2.004	11	*
Ten meters above bottom	S5-A5	2.795	11	*
	S6-A6	2.364	11	
	S7-A7	1.648	11	N.S
	S8-A8	2.524	11	*
	S9-A9	1.572	11	N.S
	S10-A10	1.766	11	N.S

N.S - Not significant

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

Chapter 5

EFFECT OF BOTTOM TRAWLING ON CHLOROPHYLL

5.1 Introduction

Microalgae constitute the major groups of primary producers of any aquatic ecosystem. Quantification of these tiny plant materials is important for the direct estimation of primary productivity in the aquatic systems and also to estimate the fishery potential indirectly. Primary producers of the marine ecosystems are highly dependent on the photosynthetic pigments for the production of organic food for their growth as well as the growth and development of the secondary producers in the ecosystem. Oceans comprises 71% of the Earth's surface and the marine phytoplankters clearly play a significant role in the global biogeochemical cycling of carbon, nitrogen, phosphate silicate and many other elements (Kilham and Hecky, 1988). Productivity is always high in the coastal waters on account of the accumulation of nutrients from the river runoff and terrigenous deposits. Primary producers act as the most important component in the aquatic food web since they are the only organisms capable of producing organic materials with the help of photosynthetic pigments embedded in them.

Arabian sea is the most productive area of the world ocean with the high rate of primary production and the quantum of standing crop by and large comparatively higher than the average values recorded from the other areas of world oceans (D'souza and Sastry, 1975). Many studies have revealed that the phytoplankton production increased during monsoon and post monsoon months due to the input of large amount of nutrients (Segar and Hariharan, 1989). Upwelling also contributes nutrients to the surface waters resulting in the high productivity in the Indian ocean (Qasim, 1977). High productivity in the surface waters contributes to the organic rich sedimentary deposits on the continental shelves and slopes (Demaison and Moore, 1980), which sustain diverse flora and fauna. Chlorophyll content of the sediments also influences the benthic productivity (Heip *et al.*, 1992). Organic production in marine ecosystems is truly connected to the environmental parameters and the variations on the physico-chemical parameters will definitely affect the organic production in water (Triantafyllou *et al.*, 2000). Besides the natural variations, anthropogenic activities also seem to inflict heavy variations on the environmental parameters in the marine milieu affecting the marine productivity severely (Watling and Norse, 1998).

Fishing is the most widespread anthropogenic activity in the marine environment, which causes several direct and indirect impacts on the marine ecosystem (De Groot, 1984). 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, Jennings *et al.*, 2001b), infaunal communities such as bivalves, polychaetes (Thrush *et al.*, 1995; Ramsay *et al.*, 1998; Kaiser *et al.*, 1999; Kutti, 2002) and causing heavy resuspension of sediments. Resuspension of sediments causes several harmful effects in the water column by changing the structure of microbial communities, increasing the water turbidity, decreasing the dissolved oxygen content in the water, increasing the exchange of nutrients and pollutants between sediment and the water column (Messiah *et al.*, 1991; Riemann and Hoffmann, 1991;

Churchill *et al.*, 1994; Watling and Norse, 1998). It has been pointed out that the disturbance on the sea bottom would reduce the primary production due to the removal of microalgae present on the sediments surface (Cahoon *et al.*, 1990, 1993; Cahoon and Cooke, 1992). The release of microalgae into the water column may take place while scraping the sediment surface by the nets and otter boards during bottom trawling. In the Arabian Sea, Southwest coast of India is well known for its surface production compared to other coasts. This region is highly vulnerable to heavy trawling pressure especially at the inshore waters. Though many studies were conducted on the biological parameters of Southwest coast of India (Sankaranarayan and Qasim, 1969b; Gopinathan, 1972; Joseph, 1974b; Manikoth and Salih, 1974; Balachandran *et al.*, 1989) no concerted attempt has been carried out to analyze the possible effect of bottom trawling on the productivity. This study attempts to measure the variations in chlorophyll pigment concentrations due to bottom trawling.

5.2 Materials and methods

Materials and methods used in the study is explained under chapter 2.5 in detail

5.3 Results

Effect of bottom trawling on chlorophyll pigments was studied by analyzing the chlorophyll pigment concentrations at surface and bottom waters during before and after trawling operations. Among the three chlorophyll pigments, chlorophyll *a* was found more both at surface and bottom followed by chlorophyll *c* while the chlorophyll *b* was recorded in meager concentrations.

Chlorophyll pigment concentrations were found to increase after trawling operations, however these variations were statistically insignificant.

5.3.1Variations on Chlorophyll a

5.3.1a Chlorophyll *a* at surface

Chlorophyll *a* concentration registered at surface waters are given in Fig. 5.1. Chlorophyll at surface ranged from 0.1- 12.96 µg L^{-1} where the highest value (12.96 µg L^{-1}) recorded at station 8 in July 2002 and the lowest (0.1 µg L^{-1}) at station 6 during May 2002. Chlorophyll *a* concentration showed significant ($P< 0.01$, Appendix III, Table 1) seasonal variations with peak during monsoon period while it was lowest during premonsoon. During post monsoon season moderate chlorophyll concentrations were recorded. Chlorophyll *a* concentration was found elevated in the water samples collected after trawling (Fig. 5.2), which ranged between 0.21 – 15.13 µg L^{-1} Highest value (15.13 µg L^{-1}) was recorded at station 1 in July 2002 while it was lowest (0.21 µg L^{-1}) at station 5 during May 2002. Chlorophyll *a* recorded in the after trawling samples also manifested distinct seasonal changes ($P< 0.01$ Appendix III, Table 2) similar to those recorded in the samples collected before trawling, with high values in monsoon followed by postmonsoon and the premonsoon. In the after trawling samples, the Chlorophyll *a* concentration showed higher values compared to that before trawling (Fig. 5.3 a and b). Highest variation was recorded at station 1 where elevated chlorophyll *a* value (7.93 µg L^{-1}) was recorded after trawling against 2.83 µg L^{-1} recorded before trawling showing a three-fold increase in the samples collected after trawling (Fig. 5.3 a). Similar changes were also recorded at station 5 where chlorophyll *a* concentration of 7.71 µg L^{-1} was registered in the samples collected after trawling against 2.71 µg L^{-1} before trawling (Fig. 5.3 a). Though ostensible variations were noticed in the chlorophyll *a* concentrations recorded in the samples collected after trawling when compared to that of before trawling, no significant variations could be observed in the *t* test analysis (P>0.01, Table 5.1).

5.3.1b Chlorophyll *a* at bottom

Chlorophyll *a* concentration showed high values at bottom when compared to that of surface waters. Distribution of chlorophyll *a* pigments at bottom waters analysed from the samples collected before trawling is given in Fig.5.4. ANOVA showed significant temporal and seasonal variations in the chlorophyll *a* concentration recorded at bottom waters (P< 0.01, Appendix III, Table 3). High chlorophyll *a* concentrations were noticed during monsoon and postmonsoon periods while it was lowest during premonsoon. Chlorophyll *a* values recorded in the samples collected before trawling ranged between 0.22 and 23.5 µg L^{-1} where the highest value (23.5 µg L^{-1}) was recorded at station 1 in July 2002 while it was lowest (0.22 µg L^{-1}) at station 9 during January 2002 (Fig 5.4). Chlorophyll *a* values recorded in the water samples collected after trawling ranged between 0.17 and 29.6 µg L^{-1} with slight increase in the concentration when compared to that recorded in the samples collected before trawling (Fig 5.5). Highest value (29.6 µg L^{-1}) was recorded at station 1 during July 2002 while it was lowest (0.17 µg L^{-1}) at station 7 during May 2002. Significant temporal and seasonal variations were also noticed in the samples collected after trawling with high values during monsoon and post monsoon seasons while premonsoon showed lower concentrations ($P < 0.01$, Appendix III, Table 4). When the chlorophyll *a* values recorded in the samples collected before and after trawling operations were compared, the highest variation was noticed at station 6 during November 2002 where a four-fold increase was noticed after trawling (1.12 to 5.19 $\mu g\ L^{-1}$) (Fig 5.6 b). Wide variations were also noticed at station 2 during September 2002 when chlorophyll *a* concentration was increased to 18.16 $\mu g\ L^{-1}$ after trawling from 7.67 $\mu g\ L^{-1}$ recorded before trawling (Fig 5.6 a). Similarly, station 4 during July 2002 recorded around two-fold increase in the chlorophyll *a* concentration with 19.51 $\mu g\ L^{-1}$ recorded after trawling against 10.62 $\mu g\ L^{-1}$ recorded in the before trawling samples. However, comparison of before and after trawling samples did not reveal any significant variations in the chlorophyll *a* concentrations at bottom waters ($P > 0.01$, Table 5.1).

5.3.2a Chlorophyll *b* at surface

Chlorophyll *b* recorded in surface water samples collected before trawling is depicted in Fig. 5.7. Chlorophyll *b* values were much lower when compared to chlorophyll *a* concentration, in the samples collected before trawling at surface. Chlorophyll *b* concentrations ranged from 0.01 to 1.05 $\mu g\ L^{-1}$ in the samples collected before trawling (Fig. 5. 7) where the highest (1.05 $\mu g\ L^{-1}$) was recorded at station 7 in May 2002 and the lowest (0.01 $\mu g\ L^{-1}$) noticed at station 8 during the same period. However, no significant seasonal variations were noticed ($P > 0.01$, Appendix III, Table 5) in the chlorophyll *b* values recorded at surface with peak values in monsoon period followed by post monsoon and premonsoon. Chlorophyll *b* in the water samples collected after trawling experiments showed wide variations from that recorded before trawling, showing an average two-fold increase after trawling. Chlorophyll *b* recorded after trawling ranged between 0.005 and 1.48 μg L^{-1} (Fig. 5.8). The highest value (1.48 μg L^{-1}) was recorded at station 9 during September 2002 while the lowest (0.005 μg L^{-1}) was observed at station 5 during July 2002 (Fig 5.8). The maximum variation in chlorophyll *b* concentration before and after trawling was registered at station 4 during May 2002 when 0.57 μg L^{-1} was recorded after trawling against 0.0034 μg L^{-1} before trawling (Fig 5.9 a). Wide variation was also noticed at station 7 during July 2002 with chlorophyll *b* values of 0.97 μg L^{-1} after trawling against 0.02 before trawling (Fig. 5.9 b). Similarly chlorophyll *b* value was found to increase to 0.59 μg L^{-1} in the samples collected after trawling from 0.06 μg L^{-1} before trawling at station 2 during May 2002. Even though surface waters showed variations in the chlorophyll *b* concentrations recorded after trawling when compared to that before trawling, no significant variation was noticed ($P > 0.01$, Table 5.2, Appendix III, Table 6).

5.3.2b Chlorophyll *b* at bottom waters

Chlorophyll *b* pigment concentrations recorded at bottom waters in the samples collected before trawling is given in Fig. 5. 10. Compared to surface waters, bottom waters showed higher concentration of chlorophyll *b* in the samples collected before trawling. Chlorophyll *b* concentration registered at the bottom water samples collected before trawling ranged from 0.009 – 1.44 μg L^{-1}

where the highest value (1.44 μg L^{-1}) was recorded at station 9 during September 2002 and the lowest (0.009 μg L^{-1}) at station 2 during July 2002. Samples collected after trawling ranged between 0.002 - 2.47 μg L^{-1} where the highest value (2.47 μg L^{-1}) was registered at station 10 during September 2002 and the lowest (0.002 μg L^{-1}) at station 9 during July 2002 (Fig. 5.11). No significant seasonal variations were observed in the samples collected before and after trawling (P>0.05, Appendix III, Table 7 & 8). Around two-fold increase was noticed in the chlorophyll *b* values recorded after trawling, compared to the samples collected before trawling experiments. Highest variation was noticed at station 2 during January 2002 where chlorophyll *b* concentration of 1.24 μg L^{-1} was recorded after trawling against 0.009 μg L^{-1} before trawling (Fig. 5.12 a). A wide change was also noticed at station 4 during September 2002 where chlorophyll *b* concentration was raised to 0.97 μg L^{-1} after trawling from 0.02 μg L^{-1} before trawling. Similarly, station 10 also showed a steep increase in chlorophyll *b* concentration with 2.4 μg L^{-1} recorded after trawling against 0.09 μg L^{-1} before trawling (Fig. 5.12 b). Nevertheless the variations were insignificant in the chlorophyll *b* concentrations in the water samples collected before and after trawling operations when statically analysed (P> 0.01, Table 5.2).

5.3.3a Chlorophyll *c* at surface waters

Chlorophyll *c* recorded in the surface water before trawling experiments is given in Fig. 5.13. Chlorophyll *c* concentrations were higher when compared to that of chlorophyll *b* but lesser than that of chlorophyll *a*. Chlorophyll *c* also showed seasonal variations with significantly high values during monsoon and postmonsoon periods, while premonsoon showed the least ($P < 0.01$ Appendix III, Table 9). Before trawling, chlorophyll *c* concentration in samples ranged between 0.009 and 2.86 µg L^{-1} where the highest value (2.86 µg L^{-1}) was registered during July 2002 at station 1 and the lowest (0.009 µg L^{-1}) during September 2002 at station 8. Samples collected after trawling experiments ranged from 0.02 - 2.9 µg L^{-1} where the highest (2.9 µg L^{-1}) was recorded in July 2002 at station 1 and the lowest during November 2002 at station 10 (Fig 5. 14). Average two-fold increase was noticed when chlorophyll *c* concentration before trawling was compared against that of after trawling. Highest variation was noticed at station 7 during January 2002 where chlorophyll *c* concentration of 0.11 µg L^{-1} recorded before trawling while it was 1.56 µg L^{-1} after trawling (Fig. 5.15 b). Distinct variation was also noticed at station 4 during November 2002 when an increased chlorophyll *c* concentration level of 1.0 µg L^{-1} was obtained after trawling from 0.08 µg L^{-1} before trawling (Fig. 5. 15 a). However, the variations of chlorophyll *c* concentrations of the samples collected before and after trawling experiments are insignificant ($P > 0.01$, Table 5.3, Appendix III, Table 10).

5.3.3b Chlorophyll *c* at bottom waters

Chlorophyll *c* concentrations recorded at bottom waters in the samples collected before trawling is depicted in Fig. 5.16. Chlorophyll *c* pigments recorded at bottom waters were in the range 0.01 – 4.75 µg L^{-1} showing higher values when compared to that of surface. The highest concentration (4.75 µg L

^{1}) was recorded from station 1 during July 2002 while the lowest was during November 2002 at station 6 (Fig. 5.16). No significant temporal and seasonal variations were noticed in the chlorophyll *c* concentration recorded before trawling (P> 0.01, Appendix III, Table 11). Peak values were registered during monsoon season, followed by post monsoon and premonsoon. Stations nearer to the shore (1 - 6) showed higher chlorophyll values than that recorded at stations 7 – 10. Chlorophyll *c* concentrations registered after trawling experiments ranged from 0.05 to 3.32 µg L^{-1} where the highest value (3.32 µg L^{-1}) was noticed at station 4 during July 2002 and the lowest (0.05 µg L^{-1}) at station 7 during September 2002 (Fig. 5.17). Chlorophyll *c* concentrations recorded at bottom waters also showed around two-fold increase after trawling when compared to that in the samples collected before trawling. Highest variation was noticed at station 3 during May 2002 where chlorophyll *c* concentration increased to 3.11 µg L^{-1} after trawling from 0.03 µg L^{-1} before trawling (Fig. 5.18 a). Wide variation was also discernible at station 8 where chlorophyll *c* concentration increased after trawling to 2.04 µg L^{-1} from 0.7 µg L^{-1} before trawling. However variations between before and after trawling were found statistically insignificant (P> 0.01, Table 5.3, Appendix III, Table 12).

5.4 Discussion

The chlorophyll pigments in the water play an essential role in the primary productivity of water. Among the three major chlorophyll pigments, chlorophyll *a* and *c* were high at surface and bottom water samples, compared to chlorophyll *b*. The results obtained in the present study revealed that the chlorophyll *a* was the most dominant pigment followed by chlorophyll *c* while the quantity of chlorophyll *b* was scarce in the coastal waters. According to Morris (1967) chlorophyll *a* and *c* are most abundant in almost all algal groups and the results of the present study also corroborate to this. The chlorophyll pigments were shown almost similar concentrations both at surface and bottom waters which would manifest that they are distributed almost uniformly in the inshore waters (0 50 m depth). Balachandran (2001) also reported more or less similar concentrations of chlorophyll pigments from the Cochin waters.

The growth and development of phytoplankton population depends on several environmental factors, which are variable in according to seasons and regions (El-Gindy and Dorgham, 1992). Nutrients especially nitrogen and phosphate has strong influence on regulating the phytoplankton productivity (Sen Gupta *et al.*, 1975). In the present study, chlorophyll pigments were found in high levels during monsoon and postmonsoon periods while during premonsoon periods it was the lowest concentrations in the all the stations studied. Seasonal studies carried out in the Indian waters brought out the influence of southwest and northwest monsoon on the primary productivity. D' Souza and Sastry (1975) reported high primary production during postmonsoon periods while the lowest primary production was reported during May in the Arabian Sea (Smith *et al.*, 1991a). The high productivity reported in the monsoon and postmonsoon periods was due to the accumulation of enormous amount of nutrients and minerals in the coastal waters from the river discharge (Subramanyan and Sarma, 1965). The high chlorophyll pigment concentration obtained in the monsoon and postmonsoon months in the present observation also points to the intense productivity during these periods. Nair and Balchand (1992) observed high chlorophyll *a* concentration during southwest monsoon period. The high chlorophyll concentrations obtained in the monsoon and post monsoon periods in the present observation also agreed to the view that the seasonal variations had genuine influence on the growth and development of the phytoplankton in the marine environment.

Bottom trawling bring out intense perturbation on the sea bottom by killing and destroying the benthic organisms and also causes perceptible changes to the bottom sediment structure (Thrush *et al.*, 1995; Tuck *et al.*, 1998). Trawling causes scrapping of sediment surface generating heavy sediment plumes several meters high in the water column (Churchill, 1989; Messaih, *et al.*, 1991). The sediment cloud formed during dragging increase the water turbidity and eventually decreases the light penetration in water. Euphotic zone is the most productive region in the marine environment (Subramanyan and Sarma, 1965). The proper light penetration is obstructed in the turbid waters, which may lead to the poor primary productivity, impaired growth of bottom vegetation and other benthic fauna as reported by Morgan *et al.* (1983) and Newcombe and Mac Donald (1991). Caddy (1973) observed the loss of visibility in the trawled / dredged grounds of Gulf of St. Lawrence due to the rise of sediment clouds. Any hindrance to the penetration of light in the turbid waters, which is identified as the major impact of bottom trawling, will definitely affect the coastal water productivity as reported by Mayer *et al.* (1991).

The surface of marine sediments is an important site of benthic production. The dispersion of sediment surface due to the scraping action of bottom trawls may reduce the productivity at sea bottom (Gislason, 1995; Schwinghamer *et al.*, 1996; Collie *et al.*, 1997). In the present study, the increase in chlorophyll pigments in the water samples collected after trawling indicated the disturbance of benthic algal groups during trawling. The release of benthic microalgae will unquestionably reduce the benthic primary productivity. Brylinski *et al.* (1994) demonstrated that the biomass of benthic diatoms (measured as chlorophyll *a*) was significantly less in trawl door furrows on a muddy substratum in shallow water. Similarly, Guillen *et al.* (1994) observed a reduction in primary productivity due to the loss of meadows on the sea bottom, the major source of primary production, during bottom trawling. Resuspension of buried organic material by trawlers increases oxygen demand in the water column in areas where dissolved oxygen is already limiting which significantly affects the growth of plankton and nekton (Watling *et al.*, 2001). Thus the release of chlorophyll pigments from the sediment surface during bottom trawling may eventually reduce benthic productivity.

Towed fishing gear such as bottom and beam trawls will physically disturb the seabed presumably changing the characteristics of the upper part of sediment leading to alterations in microbial communities (Gislason, 1995). Shallow water acts as the major site for primary productivity due to the easy penetration of light and immense source of nutrients and minerals. 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 (Riemann and Hoffmann, 1991; Jones, 1992). Cahoon *et al.* (1993) reported the reduction in primary production by benthic microalgae after a disturbance in relatively shallow depths (below 40 m). In the present study, the high chlorophyll pigments recorded in the after trawling water samples also indicate that bottom disturbance paved the way for the dispersion of microalgae which may give result in the reduction in benthic primary productivity. Rasheed *et al.* (2000) also noticed high chlorophyll values in the dredged bottom waters due to the transport of microflora from sediments to the water column due to dredging.

The major primary producers on the sea bottom are the microphytobenthos, which form an important component of all shallow water ecosystems where enough light reaches the sediment surface (Cahoon, 1999). They alter sediment properties forming a mat or crust on the sediment surface (Miller *et al.*, 1996). Bottom trawling causes flattening of the sediment surface and leveling of sediment mounds on the sea bottom (Smith *et al.*, 2000). Muddy bottom sediments are characterized by very small mineral grains bound loosely with organic material and associated microorganisms (Watling and Norse, 1998). Bottom trawls equipped with otter boards scraps the sediment surface which may result in the in the removal of micro phytobenthos from the sediment surface. The microphytobenthos help to stabilize the sediment surface against resuspension by secreting mucilaginous films (Holland *et al.*, 1974; Delegado *et al.*, 1991) and the removal of these organisms may affect the stability of sediments. Patterson (1989) noted that the diatoms protect the underlying sediments from erosion as it forms a brownish mucous mat or carpet over the sediments. Moreover, the removal of microphytobenthos from the sediment surface due to trawling may affect the growth of macro, meio and other micro benthos since microphytobenthos act as a major food resource of these organisms (Blanchard, 1990; Montagna, 1995). The smaller benthos 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), any disturbance or destruction of the smaller microphytobenthos may affect the benthic ecosystem.

Important consequences of trawling are the reduction in habitat complexity that accompanies the removal of sessile epifauna and the alteration of physical structure such as rocks and cobbles (Korotkow and Martyschewski, 1977; Berghahn, 1990; Bergman and Hup, 1992; Kaiser and Spencer, 1994; Thrush, *et al.*, 1995; Collie *et al.*, 1997). Trawling destroys the tubiforms, which have important role in maintaining the structure and oxygenation of muddy sediment habitats (Reise, 1981). Tubes formed in the sea bottom harbour these microphytobenthos and the removal of these tubes during trawling operations indirectly affects the growth of the microphytobenthos. The high concentration of chlorophyll pigments noticed in the after trawling samples particularly at the bottom waters also indicates the release of microphytobenthos from the sediments during trawling. Intense release of these photosynthetic pigments from the sediments undoubtedly affects the benthic primary productivity and subsequently the growth of the benthic organisms, which feed on them.

In the present study, chlorophyll pigment concentrations were found increased in the surface and bottom water samples collected after trawling. Though significant variations could not be observed when the samples collected before and after trawling were compared, the wide fluctuations observed in the chlorophyll pigment concentration after trawling postulates serious changes in these pigments during bottom trawling. The present study clearly demonstrates the results of immediate effects of bottom trawling on the chlorophyll. The release of chlorophyll pigments from the surface sediments noticed in the present study revealed that incessant trawling operations may pave the way for tremendous increase in the chlorophyll pigments in water and subsequently result in the decrease of benthic microflora at the sediments. The sediment microflora is the major primary producer of the benthic realm. If the intensity of the trawling operation is intense, it would eventually lead to the loss of these organisms and indirectly decrease benthic productivity henceforth.

Arabian sea is the most productive part of the world ocean, the role of the primary productivity and the quantum of standing crop are by and large comparatively higher than the average values encountered in the world oceans (D' Souza and Sastry, 1975; Qasim, 1977). In the Arabian Sea, the highest primary production is observed in the southwest coast of India due to the availability of enormous nutrients and minerals and the special climate prevailing in this region (Subramanyan and Sarma, 1965; Ryther and Menzel, 1965).

Southwest and Northwest monsoon have a major role in the increase in primary productivity in the southwest coast of India as it paves the way for the augmentation of nutrient resources in the coastal waters through the heavy river discharge during monsoon (Banse, 1959; Nair and Balchand, 1992). In addition to the heavy monsoon regime prevailing in these regions, intense upwelling also brings nutrients and minerals to the surface facilitating heavy primary production (Banse, 1959; Kumar and Prasad, 1996; Madhupratap *et al.*, 1996). Many studies conducted on the productivity along southwest coast of India revealed that natural variations on the physico –chemical parameters have major role in the variation of the primary productivity at marine environment (Kasturirangan, 1957; Qasim, 1977; Radhakrishna *et al.*, 1978). In addition to these natural variations, anthropogenic activities in marine milieu also affect the primary productivity. Trawling, the major anthropogenic activity at sea brings about severe changes to the physico-chemical parameters, which may give rise to wide changes in the productivity (Riemann and Hoffmann, 1991). The heavy disturbance on the seabed by dint of intense trawling operations gives rise to the loss of benthic microflora from the sediment surface. Resuspension of sediments results in the loss of benthic microflora, which play a significant role in the benthic primary productivity (Cahoon *et al.*, 1993). The increase of chlorophyll pigments in the present study also demonstrates the release of these photosynthetic pigments during trawling. Thus it can be postulated that the heavy loss of these microorganisms, may lead to the decline of primary productivity at sea bottom, which lead to the decrease of food resources for other benthic organisms in the higher trophic level in the benthic ecosystem.

Primary productivity sustains the higher trophic levels in the marine ecosystem, as it is the only source of energy. It had been estimated that 8 % of the world aquatic primary production is required to sustain the fisheries (Pauly and Christensen, 1995). The marine ecosystem is dominated by a microbial food web with nutrients being recycled through small phytoplanktonic, zooplanktonic groups and bacteria along with detritus resulting in strong coupling between pelagic and benthic systems (Dounas and Koutsoubas, 1996; Koutsoubas *et al.*, 2000). The disturbance on the sediments may break this food web and may lead to the total destruction of the ecosystem. Trawling disturbance on the sediments had resulted in the increase of nutrients (Chapter 5) in the bottom waters due to the release of nutrients from the sediment surface (Messiah *et al.*, 1991; Riemann and Hoffmann, 1991; Churchill *et al.*, 1994). Though the release of nutrients increase the phytoplankton population in the water column (Reddy *et al.*, 1979; Segar and Hariharan, 1989), an excessive nutrient supply would negatively affect the benthic fauna and flora as reported by Gray (1992). Heip (1995) observed the decrease of phytoplankton production due the high amount of nutrients in the marine environment. Benthic organisms such as fishes and other marine invertebrates are destroyed by way of intense trawling operations especially in the coastal waters. Besides this direct loss of benthic organisms, the removal of microalgae from the top layer of the sediments during bottom trawling also indirectly reduces the benthic productivity.

The increase of chlorophyll pigments observed in the present study is a tangible proof of the release of micro phytobenthos from the sediments. So it can well be inferred that the bottom trawling in the coastal waters by all means destroy the entire benthic ecosystem by its destructive nature of operations on the sea bottom and the increase of bottom trawling fleet and their inordinate trawling operations by all means pose a threat to the marine ecosystems.

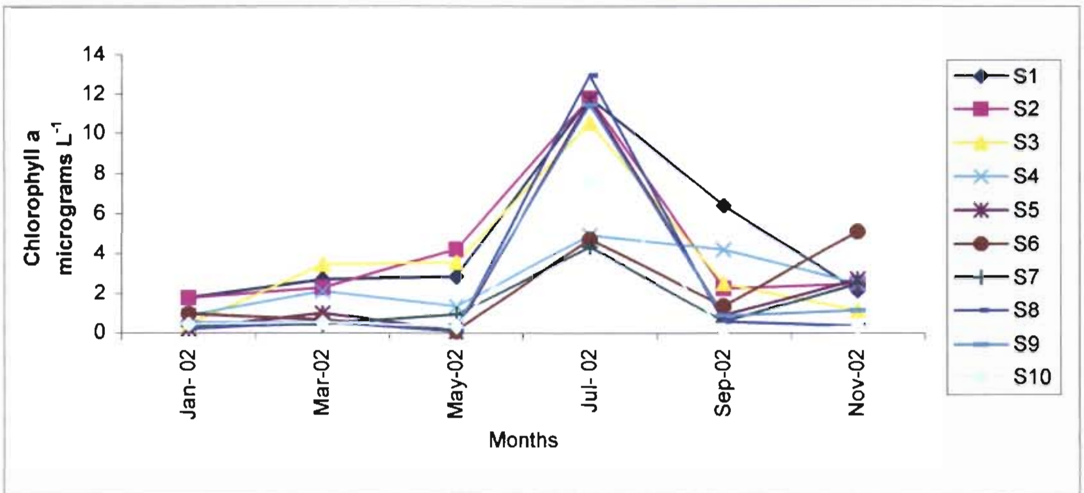


Fig. 5.1. Concentration of chlorophyll *a* at surface waters before trawling during Jan. 2002 to Nov. 2002

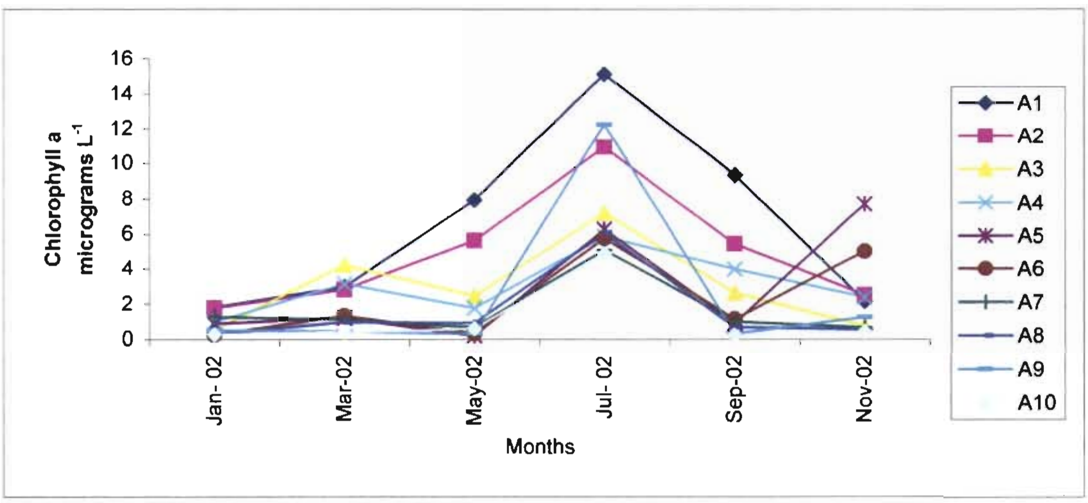


Fig. 5.2. Concentration of chlorophyll *a* at surface waters after trawling during Jan.2002 to Nov.2002.

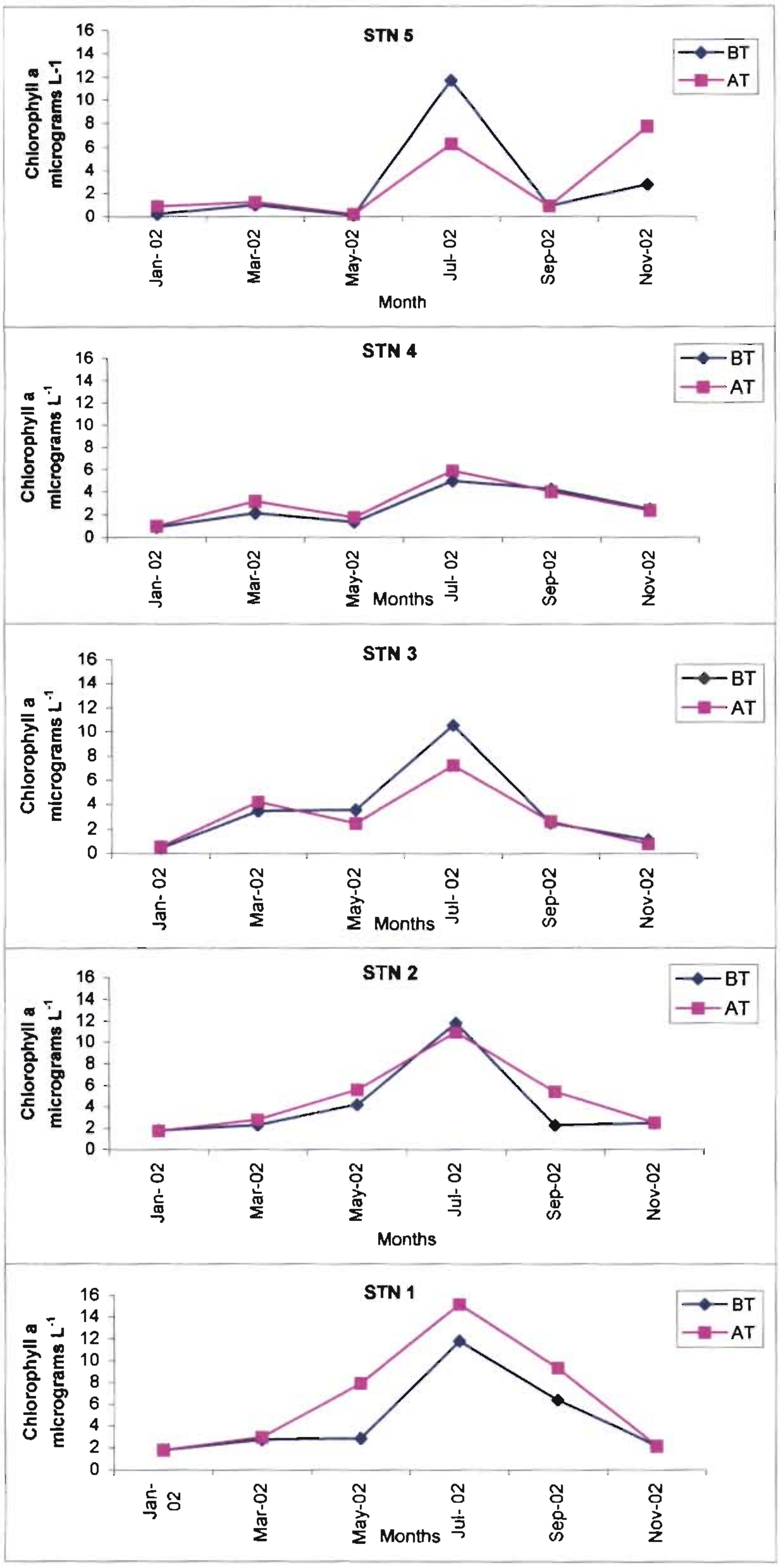


Fig. 5.3a. Pattern of variation of chloropyll *a* at surface before and after trawling during Jan.2002 to Nov.2002.

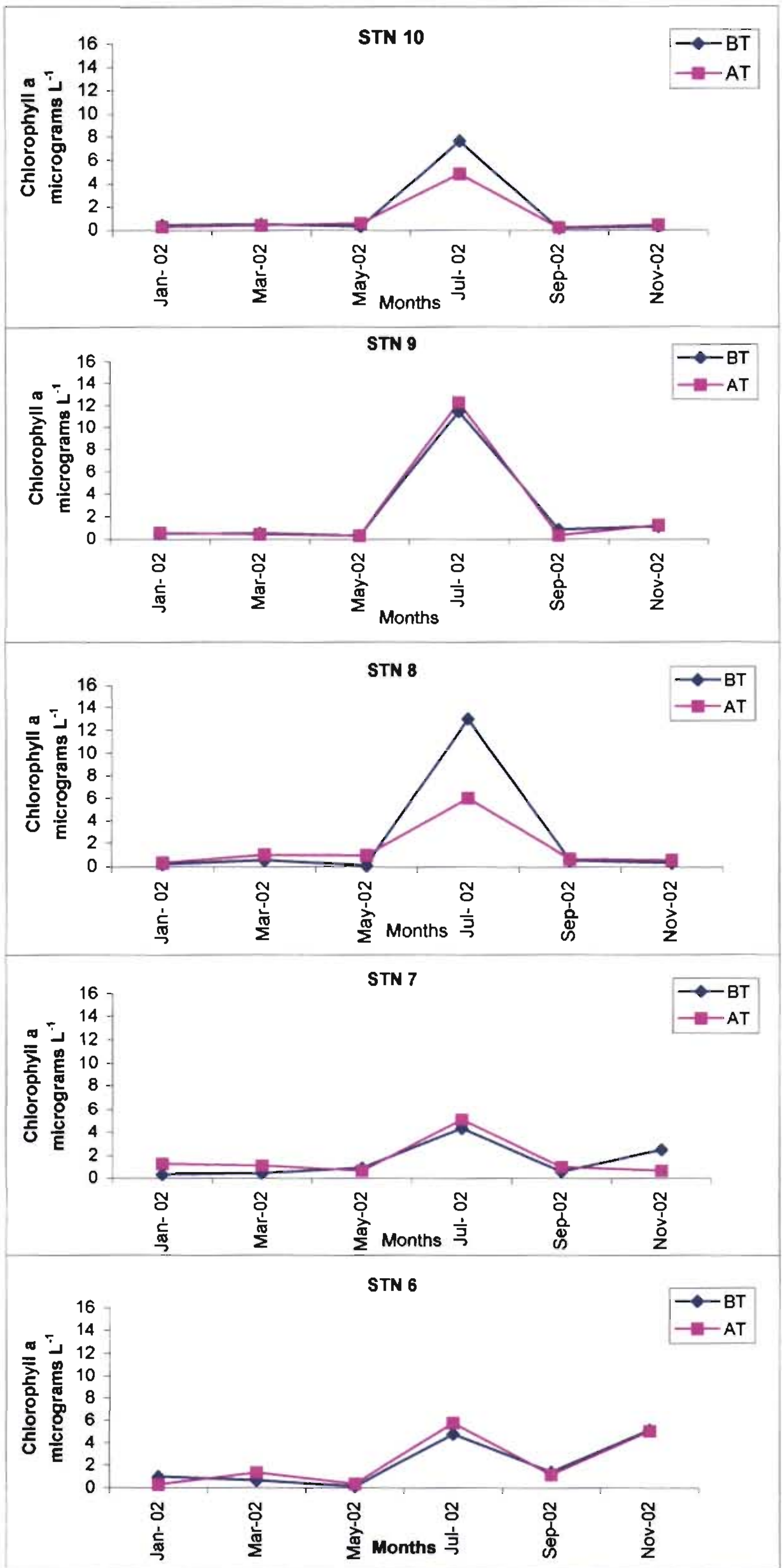


Fig. 5.3b. Pattern of variation of chlorophyll a at surface before and after trawling duimg Jan. 2002 to Nov. 2002.

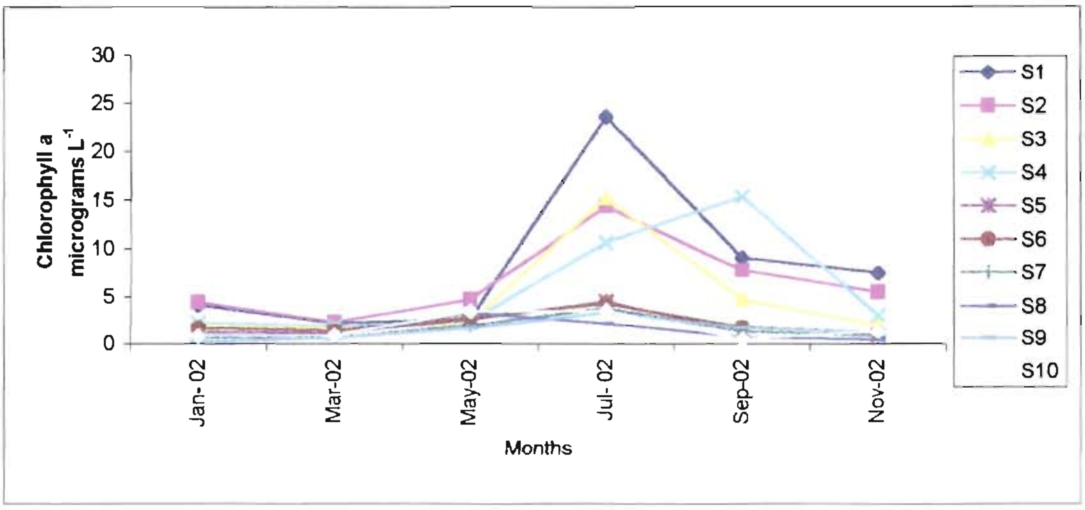


Fig. 5.4. Concentration of chlorophyll *a* at bottom waters before trawling during Jan. 2002 to Nov. 2002

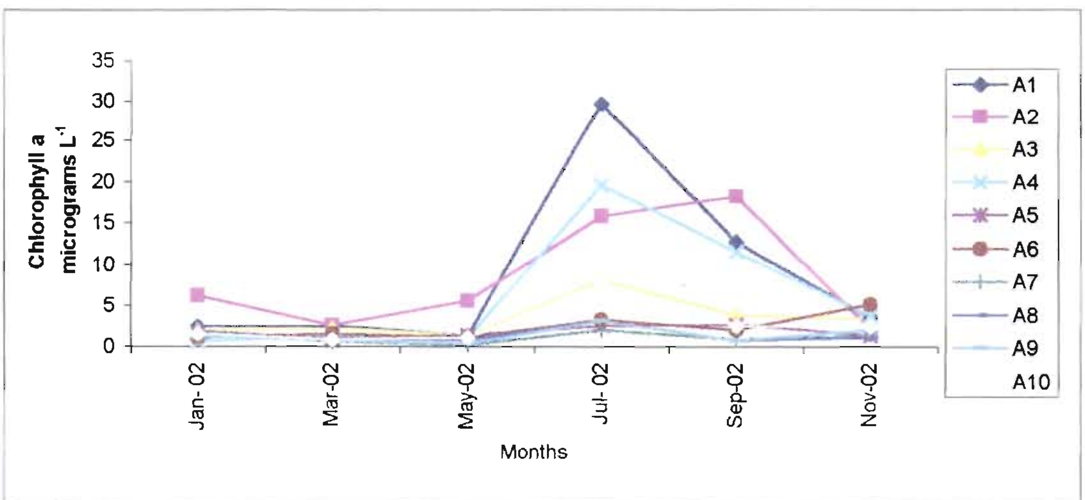


Fig. 5.5. Concentration of chlorophyll *a* at bottom waters after trawling during Jan.2002 to Nov. 2002

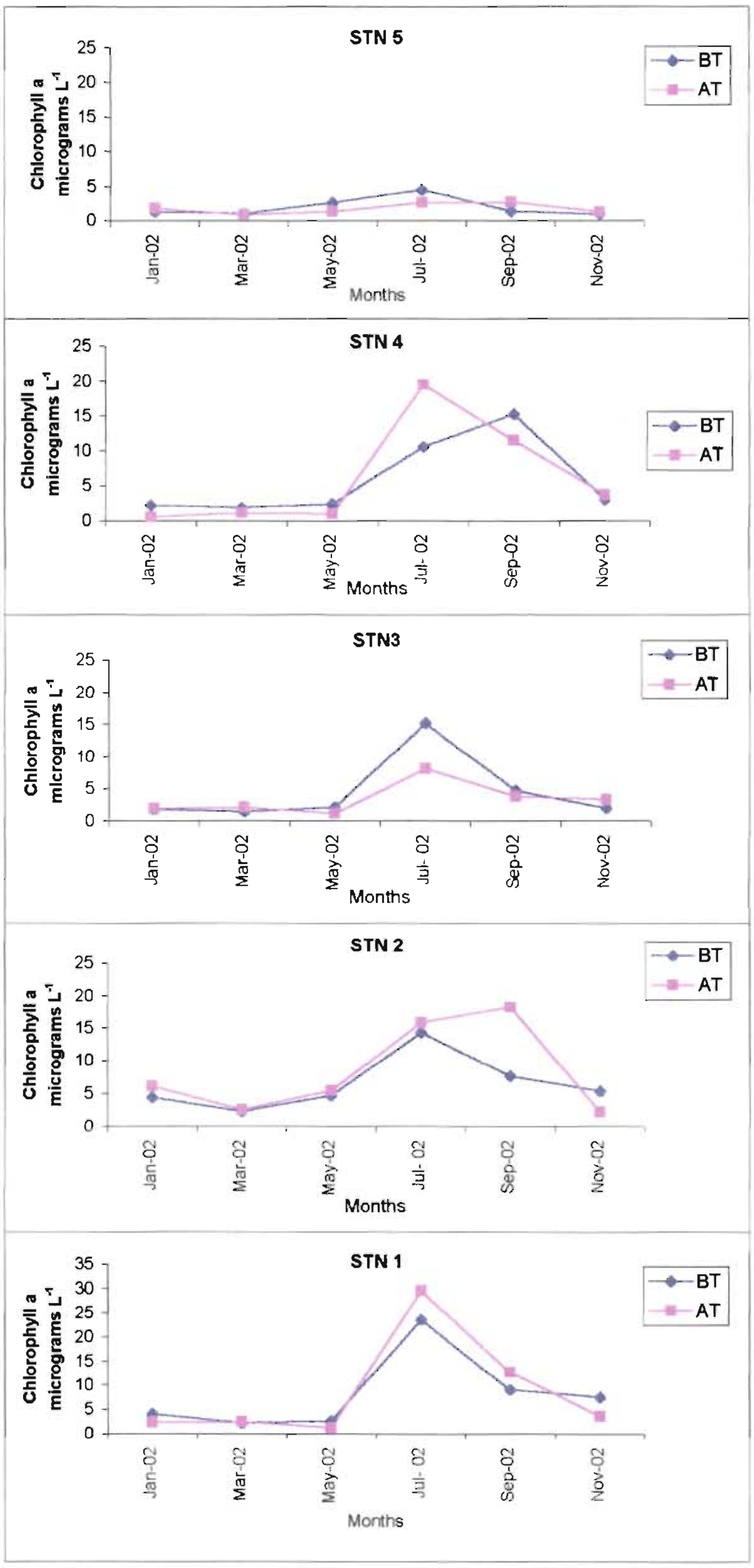


Fig. 5.6a. Pattern of variation of chlorophyll *a* at bottom before and after trawling duirng Jan.2002 to Nov.2002.

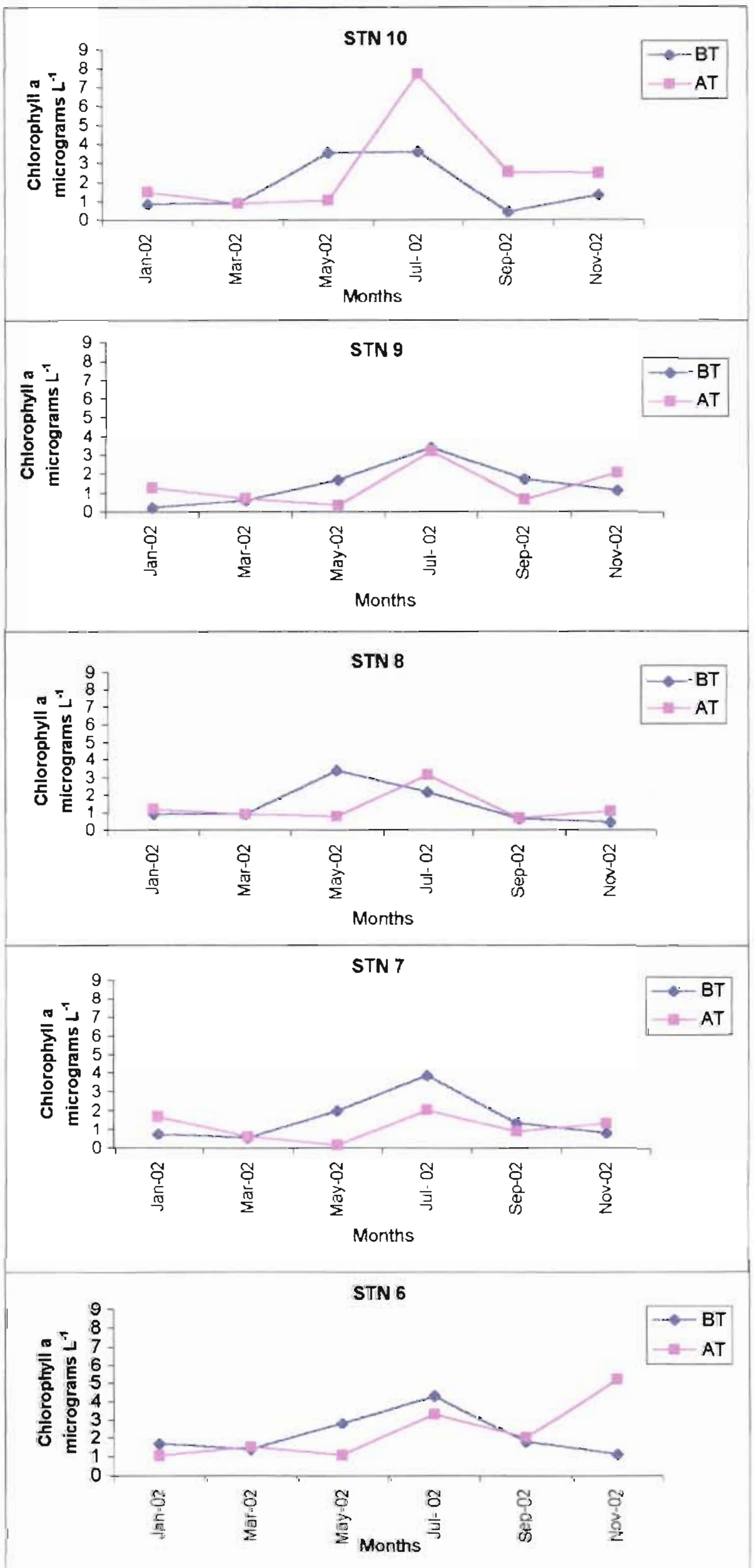


Fig. 5.6b. Pattern of variation of chloropyll *a* at bottom before and after trawling duirng Jan. 2002 to Nov. 2002.

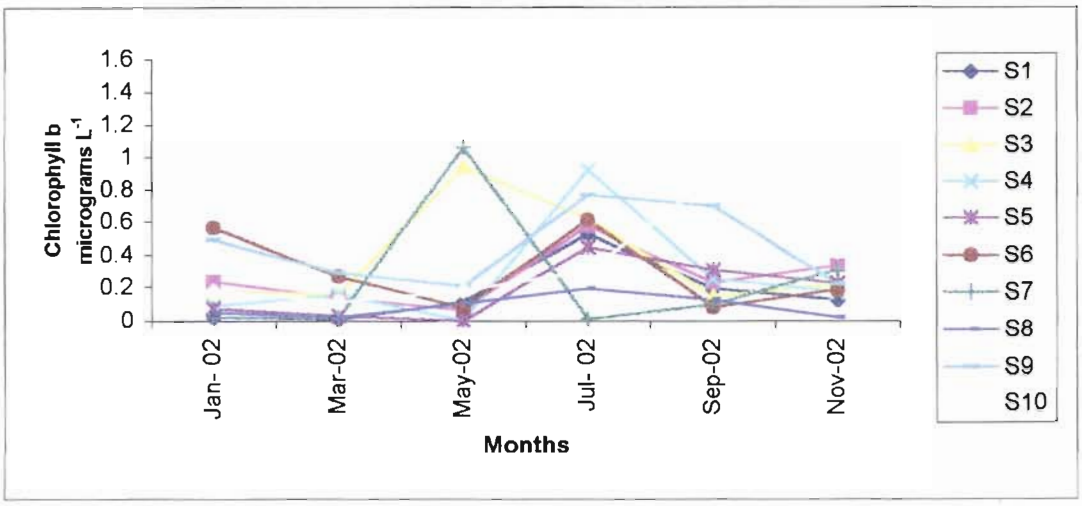


Fig. 5.7. Pattern of variation in chlorophyll b at surface before trawling during Jan. 2002 to Nov. 2002

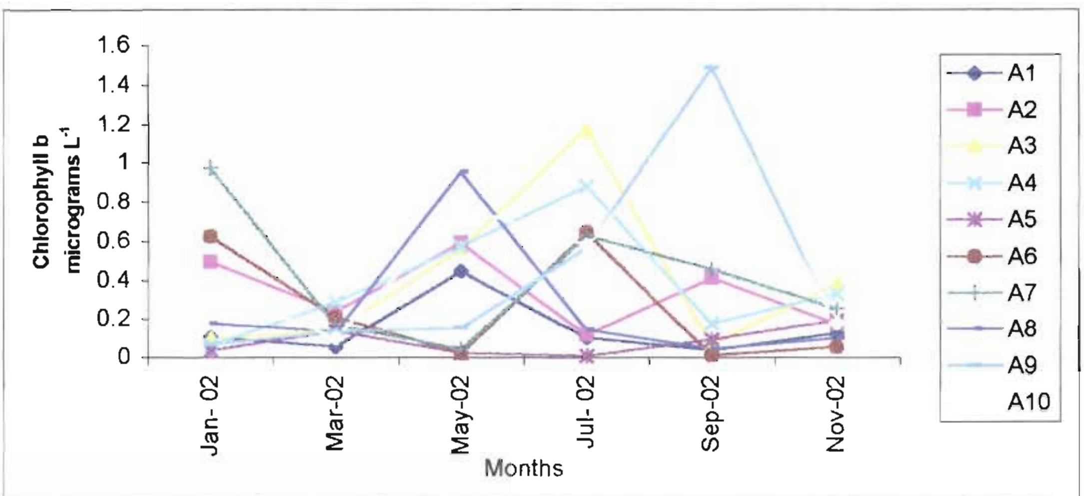


Fig. 5.8. Pattern of variation in chlorophyll b at surface after trawling during Jan. 2002 to Nov. 2002

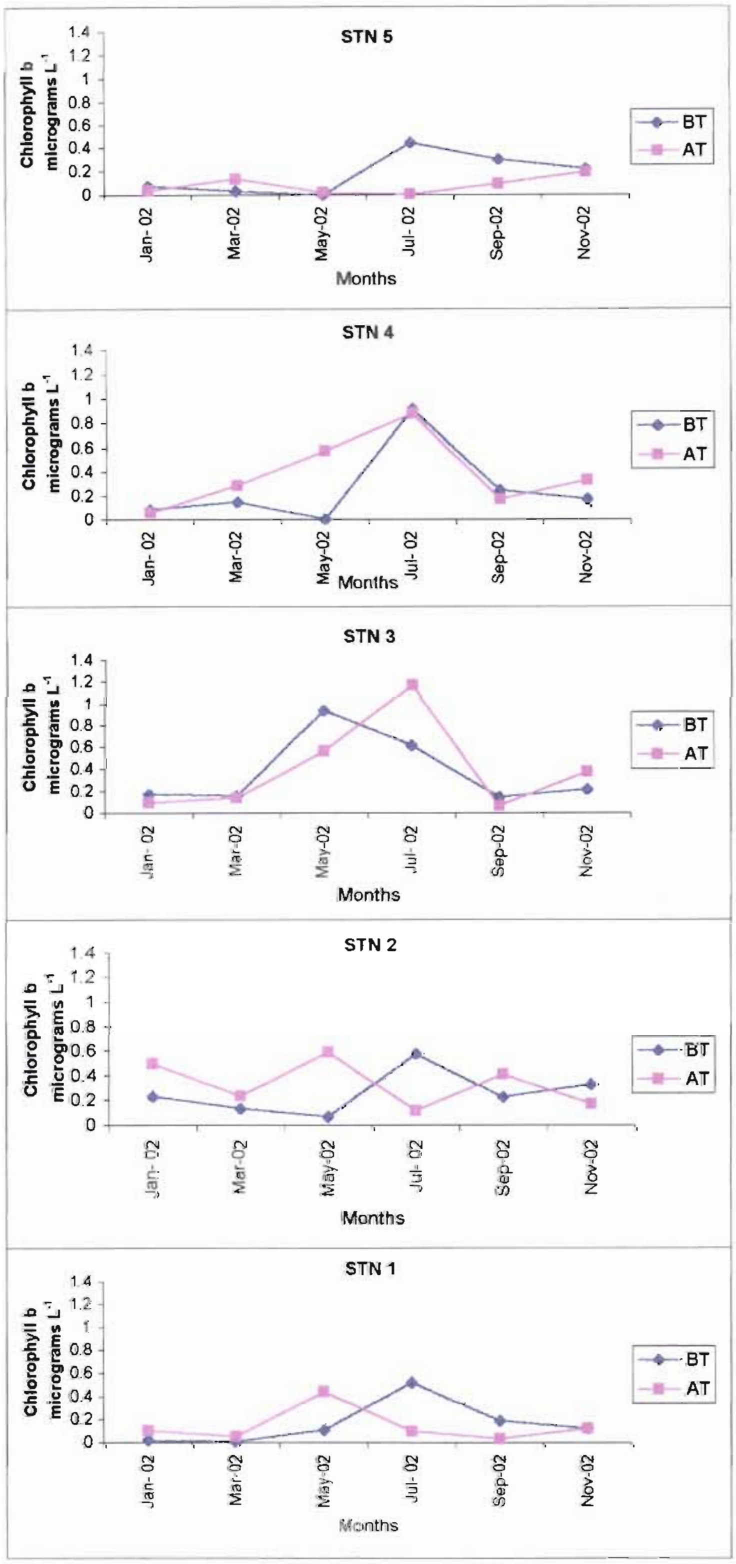


Fig. 5.9a. Pattern of variation of chlorophyll *b* at surface before and after trawling during Jan.2002 to Nov. 2002.

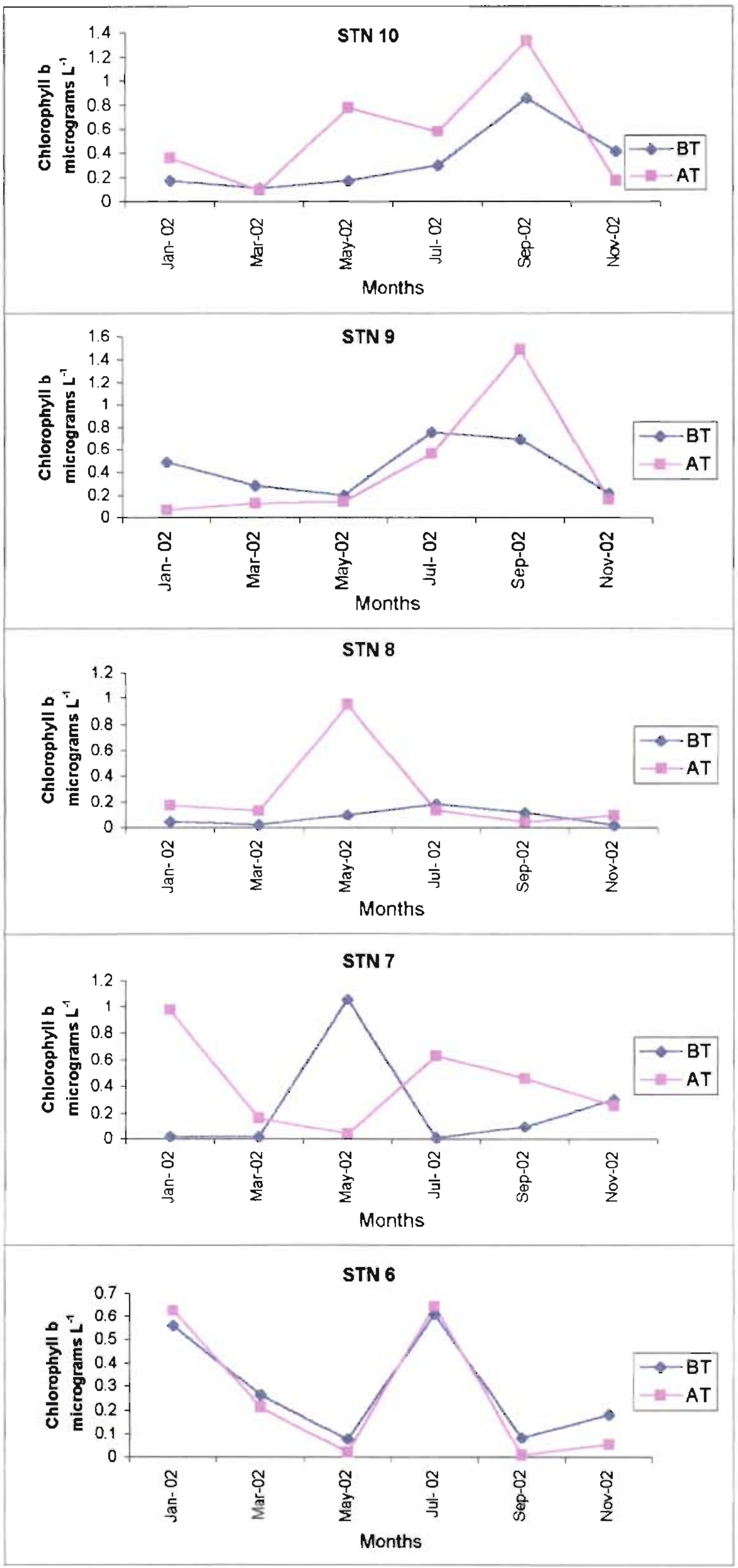


Fig. 5.9b. Pattern of variation of chlorophyll *b* at surface before and after trawling duirng Jan. 2002 to Nov. 2002.

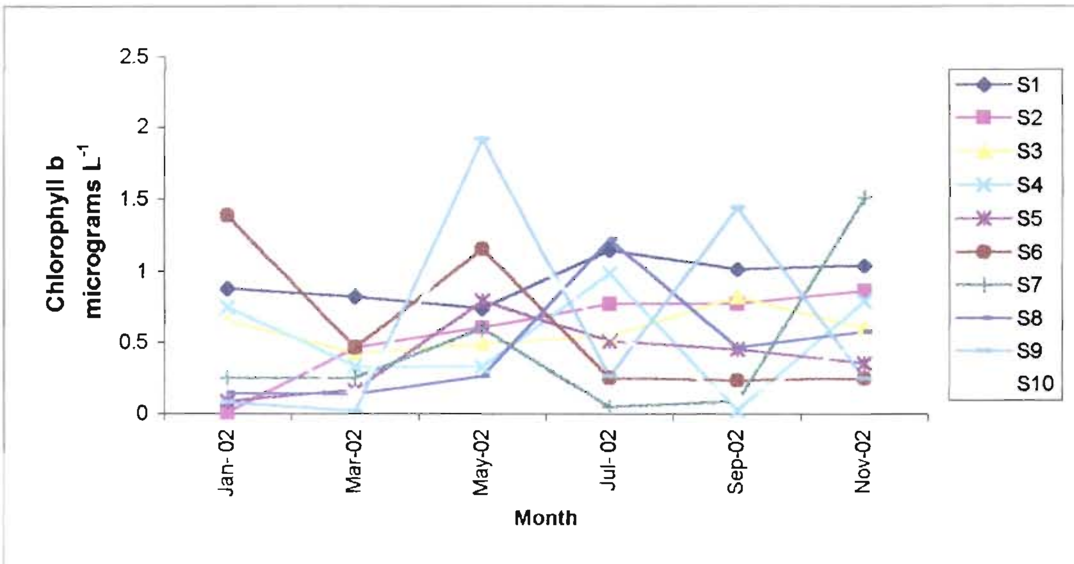


Fig. 5.10. Pattern of variation in chlorophyll *b* at bottom before trawling during Jan. 2002 to Nov. 2002

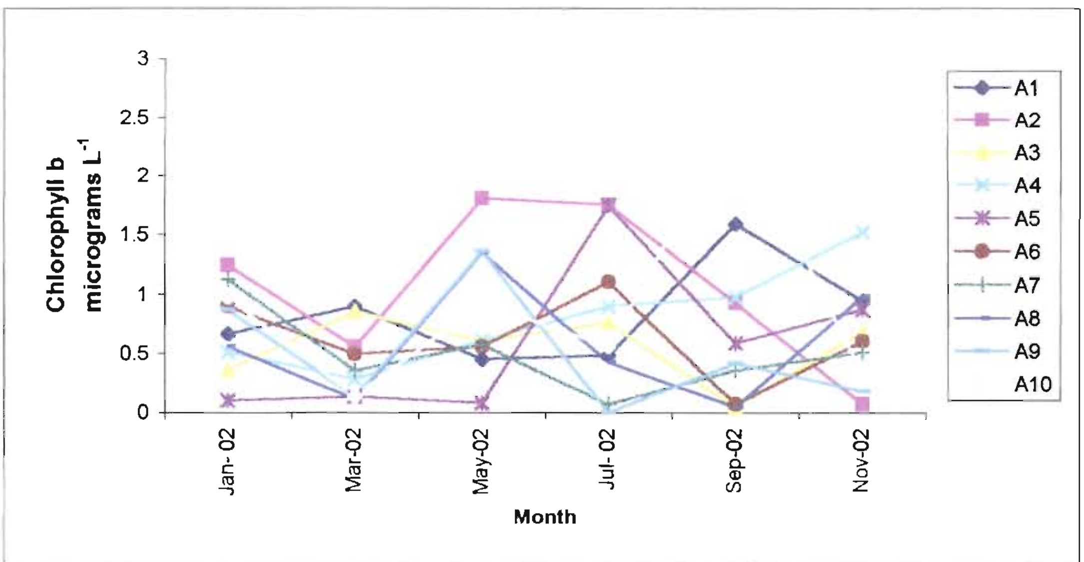


Fig. 5.11. Pattern of variation in chlorophyll *b* at bottom after trawling during Jan. 2002 to Nov. 2002 .

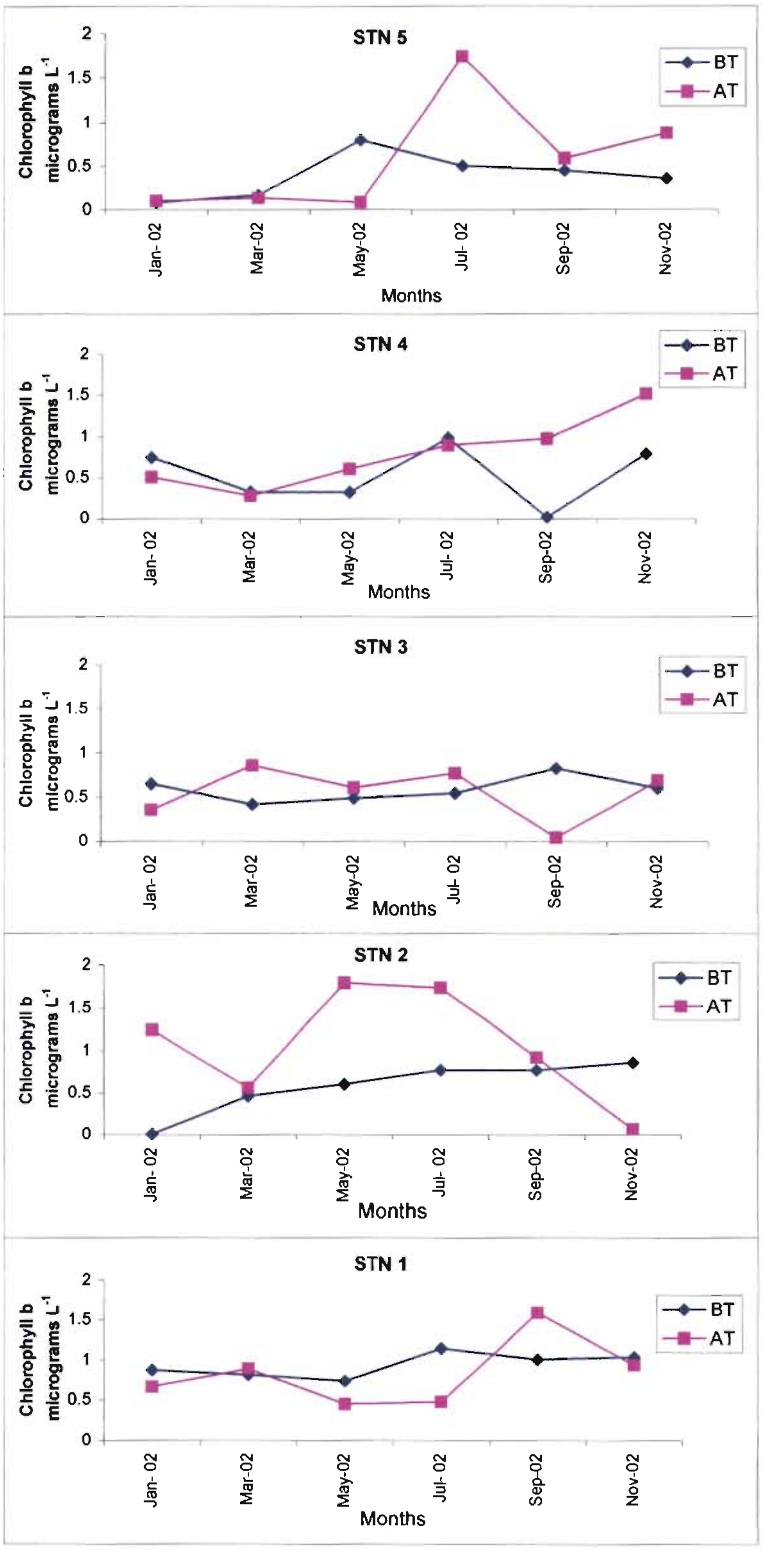


Fig. 5.12a. Pattern of variation of chlorophyll *b* at bottom before and after trawling during Jan. 2002 to Nov. 2002

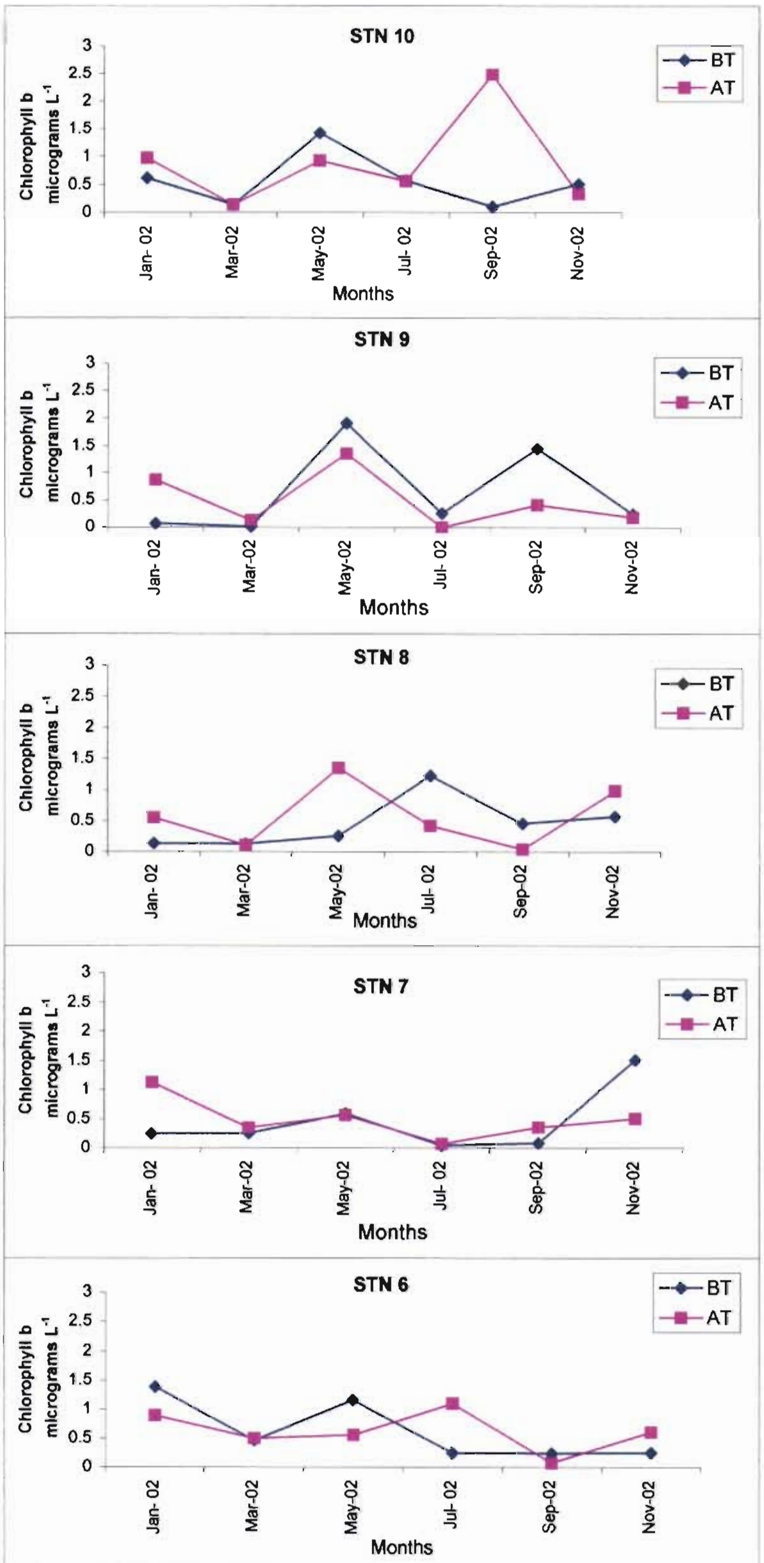


Fig. 5.12b. Pattern of variation of chlorophyll *b* at bottom before and after trawling during Jan. 2002 to Nov. 2002

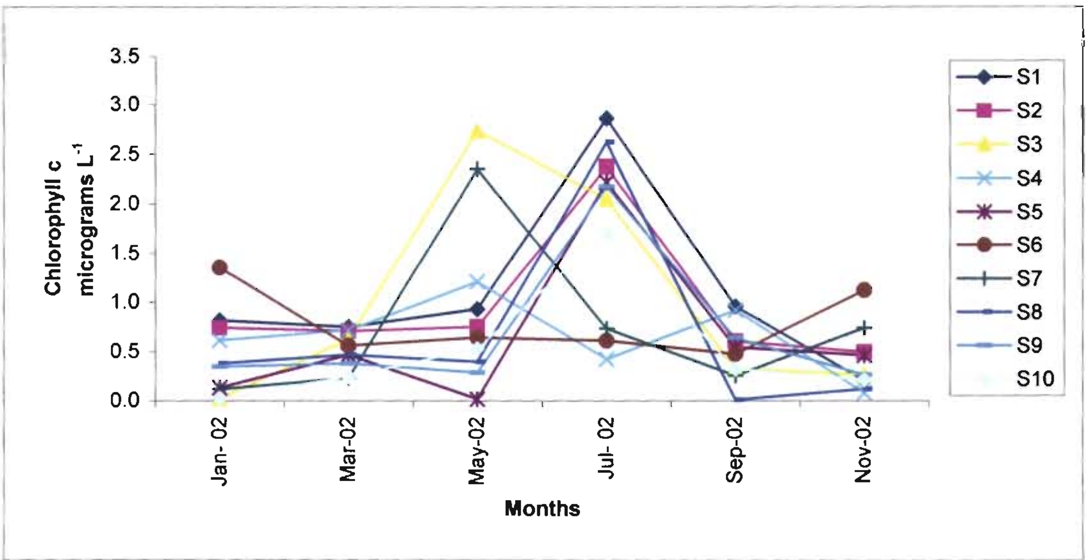


Fig. 5.13. Pattern of variation in chlorophyll *c* at surface before trawling during Jan. 2002 to Nov. 2002 .

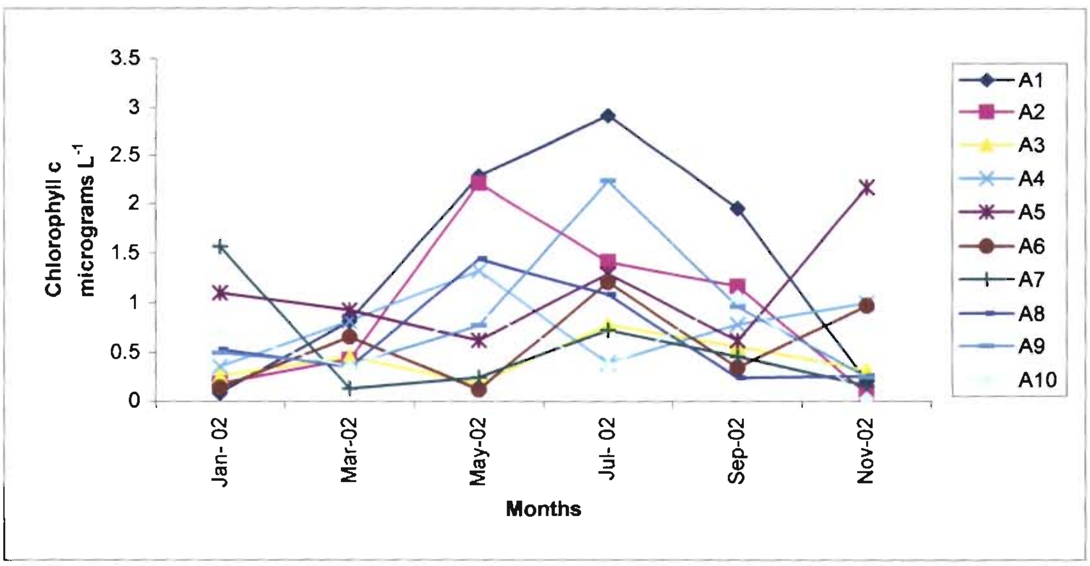


Fig. 5.14. Pattern of variation in chlorophyll *c* at surface after trawling during Jan. 2002 to Nov. 2002 .

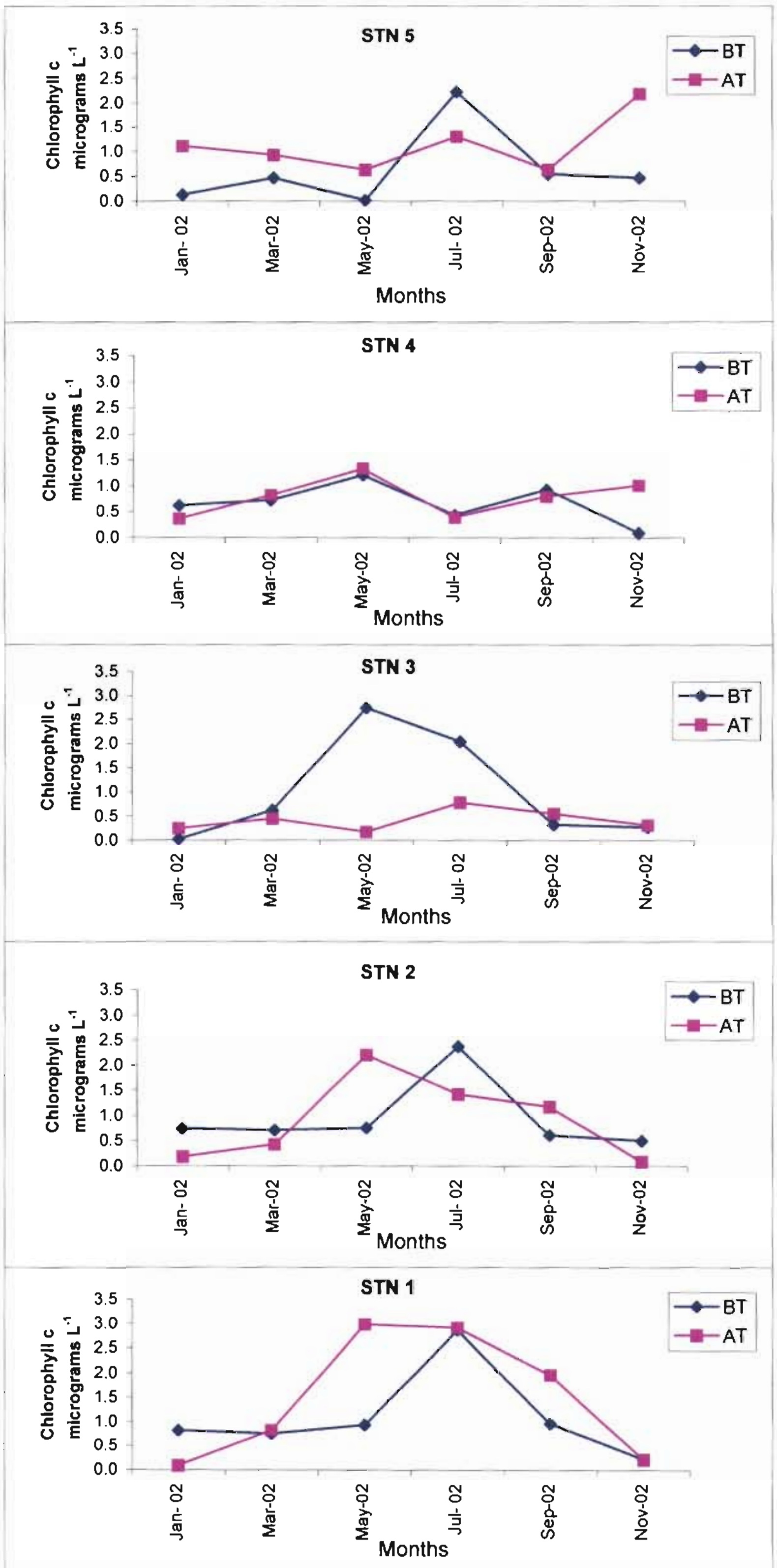


Fig. 5.15a. Pattern of variation of chlorophyll *c* at surface before and after trawling during Jan. 2002 to Nov. 2002.

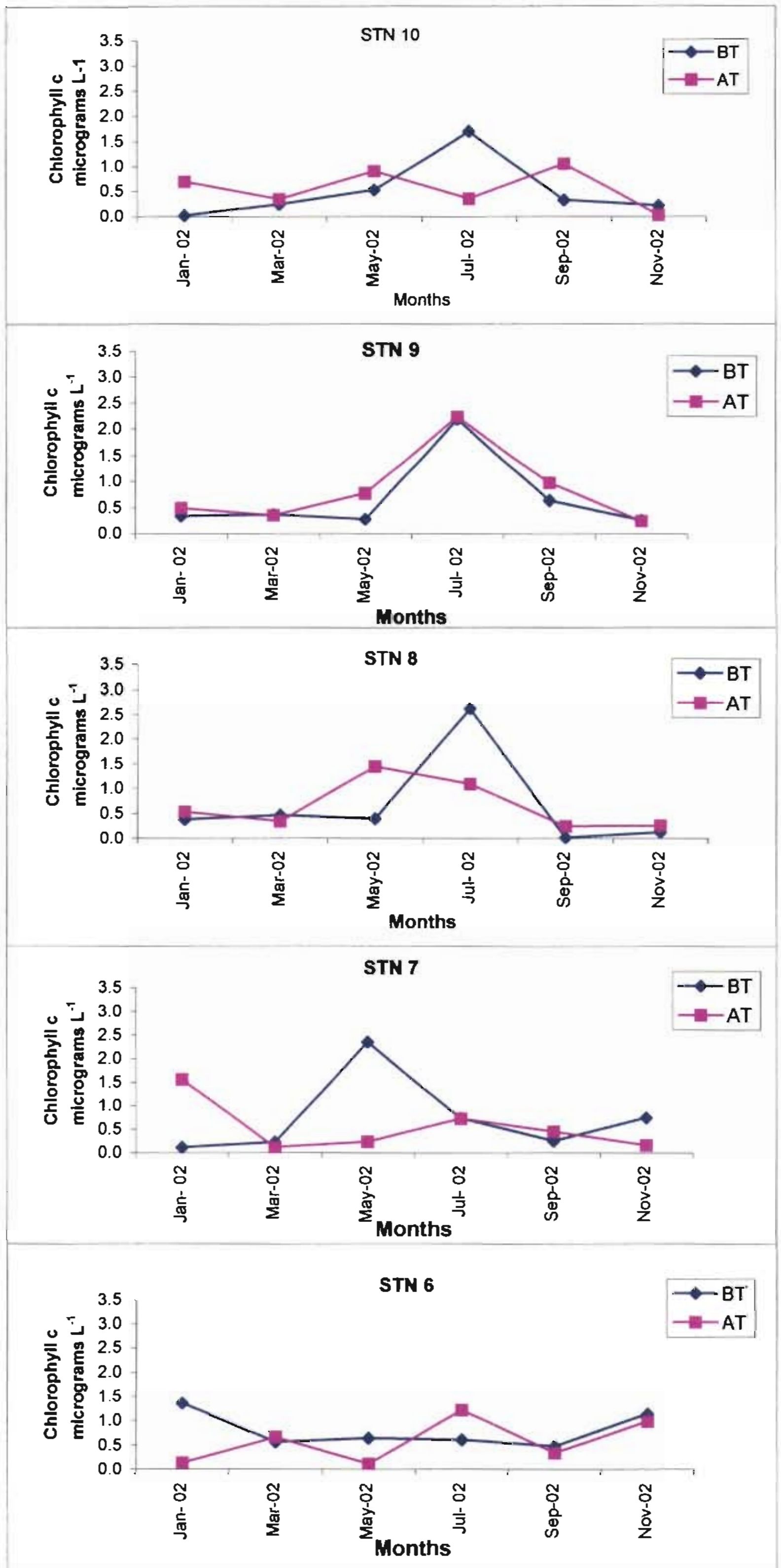


Fig. 5.15b. Pattern of variation of chlorophyll *c* at surface before and after trawling during Jan. 2002 to Nov. 2002.

Table 5.1 Results of the t test on comparing the chlorophyll *a* recorded before and after trawling

Depth layer	Stations	t	df	P -Value
Surface	S1-A1	2.2	5	N.S
	S2-A2	1.215	5	N.S
	S3-A3	1.053	5	N S
	S4-A4	1.633	5	N.S
	S5-A5	0.076	5	N.S
	S6-A6	0.614	5	N.S
	S7-A7	0.294	5	N.S
	S8-A8	0.714	5	N.S
	S9-A9	0.343	5	N.S
	S10-A10	0.88	5	N.S
Bottom	S1-A1	0.337	5	N.S
	S2-A2	1.046	5	N.S
	S3-A3	0.92	5	N.S
	S4-A4	0.188	5	N.S
	S5-A5	0.398	5	N.S
	S6-A6	0.205	5	N.S
	S7-A7	0.895	5	N.S
	S8-A8	0.206	5	N.S
	S9-A9	0.203	5	N.S
	S10-A10	1.018	5	N.S

N.S - Not significant

Table 5.2 Results of the t test on comparing the chlorophyll *b* recorded before and after trawlling

Depth layer	Stations	t	df	P -Value
Surface	S1-A1	0.19	5	N.S
	S2-A2	0.553	5	N.S
	S3-A3	0.219	5	N.S
	S4-A4	1.219	5	N.S
	S5-A5	1.23	5	N.S
	S6-A6	1.193	5	N.S
	S7-A7	0.609	5	N.S
	S8-A8	1.235	5	N.S
	S9-A9	0.081	5	N.S
	S10-A10	1.7	5	N.S
Bottom	S1-A1	0.61	5	N.S
	S2-A2	1.461	5	N.S
	S3-A3	0.2	5	N.S
	S4-A4	1.345	5	N.S
	S5-A5	0.736	5	N.S
	S6-A6	0.007	5	N.S
	S7-A7	0.164	5	N.S
	S8-A8	0.406	5	N.S
	S9-A9	0.659	5	N.S
	S10-A10	0.81	5	N.S

N.S - Not significant

Table 5.3 Results of the t test on comparing the chlorophyll *c* recorded before and after trawlling				
Depth layer	**Stations**	**t**	**df**	**P -Value**
Surface	S1-A1	1.051	5	N.S
	S2-A2	0.093	5	N.S
	S3-A3	1.275	5	N.S
	S4-A4	0.682	5	N.S
	S5-A5	1.334	5	N.S
	S6-A6	0.886	5	N.S
	S7-A7	0.408	5	N.S
	S8-A8	0.043	5	N.S
	S9-A9	1.981	5	N.S
	S10-A10	0.188	5	N.S
Bottom	S1-A1	1.271	5	N.S
	S2-A2	0.798	5	N.S
	S3-A3	0.151	5	N.S
	S4-A4	2.726	5	N.S
	S5-A5	0.702	5	N.S
	S6-A6	0.66	5	N.S
	S7-A7	1.157	5	N.S
	S8-A8	1.594	5	N.S
	S9-A9	1.246	5	N.S
	S10-A10	0.793	5	N.S

N.S - Not significant

Chapter 6

IMPACT OF BOTTOM TRAWLING ON SEDIMENTS

6.1 Introduction

Seabed plays an important role in the marine ecosystem as it provides shelter to the bottom dwelling organisms and augments the productivity by fertilizing the overlying seawater. Disturbance on the sea bottom may alter the benthic ecosystem and these changes ultimately may lead to the destruction and devastation of entire benthic populations (Gislason, 1995). Fishing has a great role in bringing about the changes in the marine ecosystem by way of removal of the fish and benthic communities thereby causing harmful environmental effects (Dayton *et al.*, 1995a; Auster and Langton, 1999). Among the various fishing practices that prevail in the world fisheries sector, bottom trawling/ dredging are the most destructive fishing methods (De Groot, 1984). Trawls and dredges have marked impacts on the substratum and many workers who studied the effect of bottom trawling and dredging on the sediment (Dare, 1974; Ganz, 1980; Main and Sangster, 1981; De Groot, 1984; Messiah *et al.*, 1991; Auster *et al.*, 1996; Schwinghamer *et al.*, 1996) clearly explained that bottom trawling is the most destructive and unscientific gear which inflicts drastic alterations on sea bed.

Seabed disturbance by commercial fishing gear has emerged as a major concern over the last few decades (Churchill *et al.*, 1988). Physical disturbance of the substratum results from direct contact with the fishing gear and the turbulent resuspension of surface sediments (Caddy, 1973, Jennings and Kaiser, 1998). Trawl net operating at sea bottom penetrates deep into the sediments and disperses the sediments during dragging. 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 (De Groot, 1984; Redant, 1987; Jennings and Kaiser, 1998). The effect may persist for few hours in shallow waters with strong currents / tides and for decades in the deep sea (Jennings and Kaiser, 1998).

For centuries, fishermen had been using various kinds of mobile gear to exploit bottom dwelling finfish and shellfish (Von Brandt, 1984). Mobile fishing gear types include otter trawls, beam trawls, mussel and scallop rakes and clam dredges of which otter trawl is the most notorious gear for causing profound variations on the physical properties of surfacial sediments, bringing about chemical exchange between sediments and water and altering the composition of benthic communities (Messiah *et al.*, 1991; Riemann and Hoffmann, 1991; Jones, 1992). Due to the sudden spurt in the fishing sector, larger and heavier trawl nets have been introduced in the marine environments to forage more depths (Van Beek *et al.*, 1990). More over, huge returns from this fishing resulted in an inordinate proliferation of this gear and currently most of the continental shelf waters are overburdened by it (Norse, 1993).

The parts of the trawl that leave the most distinctive mark on the seabed are the otter boards. Single otter board track range in width from approximately 0 to 2 m and their depth can vary from 1 - 30 cm (Churchill, 1989; Krost *et al.*, 1990; De Groot and Lindeboom, 1994; Black and Parry, 1999). Sediment type is one of the more important factors; in sandy sediments there is low penetration of otter boards (1 - 5 cm) (Churchill, 1989) due to high mechanical resistance of the sediments and the rapid restoration by the currents and waves. Consequently, on sandy sea bottom, the tracks are short lived where as in muddy bottom the tracks will be deeper and last longer, even for years together (Caddy, 1973; Werner *et al.*, 1976; Krost *et al.*, 1990; Schwinghamer *et al.*, 1998a). Otter trawl tracks are detectable for over two months in more stable muddy sediments (De Groot and Lindeboom, 1994).

High-resolution video images of sediment surface before and after otter trawling indicate that trawling reduces the overall surface roughness of seabed (Schwinghamer *et al.*, 1996) although trawl door may leave depressions. Passage of trawl nets remove the organic rich surface sediment layer and mixes this nutrient rich food resource of many benthic organisms into the subsurface water column (Mayer *et al.*, 1991). These changes can be considered as the indirect changes of bottom trawling in addition to the direct changes by way of reduction and destruction of fish populations and those of other marine organisms (Hall, 1994). Passage of heavy bottom trawl equipped with heavy otter boards and tickler chains cause depression of sediments, removal of rocky shelter, sediment mounts as well as erected life such as coral and polychaetes (Auster *et al.*, 1996; Fonteyne, 2000).

The passage of trawl can be responsible for disturbing and relayering of the sediment, causing a change in grain size and thereby affecting the chemical composition (Smith *et al.*, 2000). Heavy sediment clouds have been reported in the trawled grounds during trawling operations (Butman and Noble, 1979), which could spread to 50m width and heights of 10 metres (Churchill, 1989). The heavy ploughing of sediments during trawling may also give rise to the release of excessive amount of lethal gases such as methane, hydrogen sulphide, ammonia along with the sediment clouds (Watling and Norse, 1998), resulting in the death of marine organisms, especially eggs and young ones. High levels of turbidity and sedimentation have been reported to be preventing settlement of benthic larvae, thus affecting recolonization after disturbance (Galtsoff, 1964; Stevens, 1987).

In the wake of large-scale commercial exploitation of prawn resources, the demand for more efficient trawl gear increased considerably in the Indian waters, which resulted in the introduction of otter trawls in early 60's. The end of 70's saw otter trawling as the most popular fishing method (John, 1996). A series of studies were conducted in Indian waters on aspects related to design and efficiency of operation of trawl nets (Kurian *et* al., 1964; Nair, 1969; Kartha *et al.*, 1977; Pillai *et al.*, 1978,1985; Kunjipalu *et al.*, 1979, Mahalatkar *et al.*, 1982; Rao and Gerorge, 1983; Narayanappa *et al*, 1985), on improving the performance of otter boards (Takyama and Kayama, 1959; Sathyanarayana and Mukundan, 1963; Mukundan *et al.*, 1967; Despande *et* al., 1970; Sathayanaraya *et al.*, 1978). Even though wide attention has been given to the ecosystem changes due to bottom trawling internationally (Churchil, 1989, Messiah *et al.*, 1991; Churchill *et al.*, 1994; Watling and Norse, 1998; Norse and Watling, 1999), no resolute attempt has been carried out in Indian waters to study the effect of bottom trawling on sediments. The present study is carried out as a pioneer attempt in Indian coastal waters to understand the immediate effect of bottom trawling on the sediments.

6.2 Materials and Methods

The materials and methods are explained under chapter 2.5.

6.3 Results

Immediate effect of bottom trawling on sediment has been studied by analyzing the variations in the sediment pattern and organic matter present in the sediment samples collected both before and after trawling experiments. The results of the study revealed that the sediment pattern and organic matter varied considerably due to the trawling activity in the coastal waters especially at the nearshore waters.

In the samples collected before trawling, sediments at stations 1- 6 were clayey silt/ silty clay. Stations 1, 2 and 3 were clayey silt in nature while stations 4, 5 and 6 showed a higher clay content, turning to a silty clay texture. Sediment samples collected at stations 6 -10 before trawling showed higher sand content where stations 7 and 8 were silty sand in nature and stations 9 and 10 showed clayey sand and sandy texture respectively with a mixture of clay and silt in almost equal proportions (Fig 6.1). In the samples collected after trawling, 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 the 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 (Fig. 6.2). 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.

6.3.1Variations in sand

Percentage distribution of sand fractions obtained before trawling is given in Fig. 6.3 a and b. The sand fractions ranged between 0.17- 94 % and 0.04 – 97.25 % in the first and second years of study respectively. Significant variation was noticed in the sand fractions obtained at different stations ($P < 0.01$, Appendix IV, Table 1) with lowest values at stations below 40 m depth when compared to those located above 40 m depth. Sand content was more in the stations 9 and 10 at the 40 - 50 m depth zone and ranged from 22.17 to 97.25 % with an average of 75 % during the entire period of study. Stations 7 and 8 (30-40m depth) were also dominated by comparatively higher sand content when compared to the stations located below 30 m depth (Stations 1-6). In the samples collected before trawling, the highest percentage of sand (94%) was recorded from station 9 in April 2001 while the lowest (0.17 %) was observed at station 1 in November 2001 in the first year. During the second year, the highest percentage of sand (97%) was recorded at station 10 in November 2002 while it was lowest (0.08 %) at station 1 in the same month (Fig. 6.3 a and b). Comparatively lower sand percentage was recorded during July with significant reduction ranging from 3.1- 43 % and 0.14 - 89 % in the first and second years (P< 0.01, Appendix IV, Table 1) respectively.

After trawling the sand proportion was found increased in almost all stations with predominant increase in the near shore stations. During the first year, the sand content ranged between 0.4 – 96 % in the sediment samples collected after trawling with the highest (96 %) was observed at station 10 in April 2001 while the lowest (0.4 %) was recorded at station 3 in February 2001 (Fig. 6.4 a and b). During the second year, in the after trawling samples, the percentage of sand varied from 0.15 – 97.4 % where the highest sand content was recorded at station 9 in September 2002 and the lowest (0.15 %) at station 5 in July 2002. Significant variation was also noticed among different stations and seasons studied (P< 0.01, Appendix IV, Table 2). Sand content in the samples colleted after trawling increased by an average of two-fold in sediment samples, compared to that obtained before trawling (Fig 6.5 a and b). The highly significant variations was noticed at station 5 in September 2001 where sand fraction increased to 29.7 % after trawling from 1.35 % before trawling, thus registering 22-fold increase due to the impact of bottom trawling. Similarly, station 4 also showed 20-fold increased after trawling with 10.4 % of sand was recorded against 0.52 % before trawling (Fig 6.5 a and b). Even though wide variations were noticed among different stations, significant variation was noticed only at stations 1, 2, 9 and 10 (Table 6.1).

6.3.2 Variations in silt

Percentage distribution of silt fraction of sediment collected before and after trawling is given in Fig 6.6 a & b and Fig 6.7 a & b respectively. 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 and 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 obtained at station 8 in January 2002 (Fig. 6.6 a and b). Silt fractions of all months and stations showed significant variations ($P<0.01$ Appendix IV, Table 3). Highest silt proportions were noticed during monsoon and post monsoon periods while premonsoon showed the lowest. Among different stations, near shore stations (1-6), which were located 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 (Fig. 6.7a and b). Significant variation was also noticed in the samples collected after trawling in all months and stations studied ($P<0.01$, Appendix IV, 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. During the first year the highest value (86.12 %) was registered at station 2 in February 2001 while it was lowest (1 %) was at station 8 in September 2001 whereas in the second year, the highest values

(53.15 %) were observed at station 2 in January 2002 and the lowest (1.3 %) at station 8 in March 2002 (Fig 6.7 a and b). 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. 6.8 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 6.1).

6.3.3 Variations in clay

Percentage distribution of clay fraction obtained before and after trawling is given in Fig. 6. 9 a & b and 6.10 a & b respectively. Near shore stations showed high percentage of clay, particularly at stations 1-6 (Fig. 6.9 a and b). Clay fraction measured in the sediment samples collected before trawling ranged between 6.17 and 59.58 % during first year 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 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 IV, Table 5). Monsoon and postmonsoon 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 particularly at the near shore stations which are located below 30 m depth (Fig. 6.10 a and b). Percentage of clay obtained in the samples collected after trawling ranged between 1.05 – 55.3 % and 1.03 – 66.72 % in the first and second years respectively. During the first year, the highest (55.3 %) clay proportion was recorded at station 7 during July 2001 while the lowest was recorded at station 9 in December 2000. Whereas in the second year the highest values were registered at station 6 in May 2002 and the lowest at stations 9 and 10 in September 2002 (Fig. 6.10 a and b). ANOVA showed significant variations in the clay fractions obtained at different stations ($P < 0.01$, Appendix IV, Table 6). While comparing the values recorded before trawling, the clay fraction of the samples collected after trawling showed an apparent reduction. 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 showing a 100 times decline due to bottom trawling (Fig. 6.11 a & b). 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 was observed while comparing both before and after trawling samples collected at six stations such as 1, 2, 4, 5, and 9 and 10. It appears that trawling making significant alteration on the sea bottom sediment texture (Table 6.1).

6.3.4 Variations in organic matter

Organic matter present in the sediments samples were analysed both before and after trawling operations in order to bring out likely changes in the organic load on the seabed during bottom trawling. Organic matter analysed from the sediments samples collected before trawling is given in the Fig. 6.12. Significant variation was noticed in the organic matter obtained in different seasons and depths (P< 0.01, Appendix IV, Table 7). Highest values were noticed in the postmonsoon months and the lowest in premonsoon while the monsoon months showed the moderate values. Moreover, among the different stations studied near shore stations (stations 1-6) showed higher values (Fig. 6.12). During the first year, the organic matter recorded before trawling ranged from 0.26 –7.76 %, where the highest percentage was recorded at station 3 in November 2001 and the lowest at station 9 in April 2001. During the second year, the organic matter ranged from 0.22 – 7 13 % in the samples collected before trawling. Highest value (7 13 %) was observed at station 5 in November 2002 while it was lowest (0.22%) at station 9 in September 2002.

In the samples collected after trawling, organic matter was found decreasing in almost all stations (Fig 6.13). ANOVA showed significant variations in the organic matter obtained at different stations and seasons studied (P< 0.01, Appendix IV, Table 8). The percentage distribution of organic matter recorded after trawling ranged between 0.13 – 5.02 % and 0.87 – 6.87 % in the first and second year respectively (Fig. 6.13). Highest organic matter (5.02) was recorded at station 2 in November 2001 in the first year while it was lowest (0.13%) at station 10 in April 2001. During the second year, the peak (6.87 %) was registered at station 8 in May 2002 and the lowest (0.87%) at station 10 in November 2002. In the samples collected after trawling, a reduction in the organic matter was noticed with highest variations at the near shore stations (Fig. 6.14 a & b). Reduction in the percentage of organic matter was most drastic at station 4 in July 2001 where the organic matter was reduced to 0.77 % after trawling from 4.49 % recorded before trawling showing 6 times reduction after trawling (Fig. 6.14 a & b). The peak reduction in organic matter during the second year was at station 8 where 6.44 % of organic matter recorded before trawling declined to 2.24 % after trawling, thus showing a reduction to the tune of 3 %. Around two-fold reduction was noticed on an average in the all stations. However, the variation was not statistically significant in stations ($P < 0.05$) except at stations 1 and 2 where a conspicuous decrease in organic matter was noticed ($P < 0.05$).

6.3.5 Grain size variations of all fractions

Variations in the standard deviation, skewness and kurtosis analysed in the sediments samples collected before and after trawling are given in Table 6.2. Sediment ranged from poorly sorted to very poorly sorted at the stations 1-8 in the samples collected before trawling. At the stations 9 and 10, sediments were moderately sorted to very poorly sorted (Table 6.2). After trawling, stations 1-10 showed the similar type of sediments ranging from poorly sorted to very poorly sorted except at stations 3 and 9. At station 3, sediments were very poorly sorted while at station 9, it ranged from moderately sorted to very poorly sorted

(Table 6.2). Skewness of sediments showed that the stations 1 - 6 fall in the category of very fine skewed to very coarse skewed in the samples collected before trawling whereas at stations 7 and 8, the values ranged from very fine skewed to fine skewed. Similarly, at stations 9 and 10 also showed slight variations and fell between very fine skewed to near –symmetrical.

In the samples collected after trawling, similar skewness was recorded at all the stations (Table 6.2). Kurtosis values showed that the stations 1 - 6 ranged from very platykurtic to platykurtic in the samples collected before trawling while station 7 and 8 varied between mesokurtic to extremely leptokurtic. Stations 9 and 10 fall under the category of leptokurtic to extremely leptokurtic. Sediment samples collected after trawling experiments did not show much variations between stations 1 to 10 where stations 1   6 showed the kurtosis values ranged between very platykurtic to platykurtic while stations 7 10 belonged to the category of mesokurtic to extremely leptokurtic (Tab le 6.2).

6.4 Discussion

The results of the natural sediment structure computed from the study area before trawling were corroborated to the earlier reports (Bhosle *et al.*, 1978; Hashimi *et al.*, 1978; Nair *et al.*, 1978). In the present study, the distribution of sediments were in the silty clay/ clayey silt range up to the 30 m depth and silty/ clayey sand between 30-40 m however, it turned into sandy above 40 metres depth. The high percentage of clay and silt may be due to the discharge of fine sediments from Vembanad lake as reported by Hashimi *et al.* (1981). Seasonal variations of organic matter reported in the present study also agree with the previous studies (Nair and Balchand, 1992). The high organic matter observed during the postmonsoon and monsoon months are due to the heavy river runoff and surface productivity as reported by Subrahmanyan and Sarma (1965) and Bhattathiri and Devassi (1979). High productivity in the surface waters gives rise to organic rich sedimentary deposits on the underlying continental shelves and slopes (Demaison and Moore, 1980). The high quantities of organic matter obtained in the present study also agree to the above observations. Organic matter is trapped predominantly by clays and to a lesser degree by fine silts, coarse silt and sands and the maximum organic matter is to be expected in sediments with maximum clay (Russel, 1950; Sanders, 1956). The rich organic matter obtained from the near shore stations of the study site where muddy sediment dominated also agrees with the earlier reports (Damodaran, 1973; Hridayanathan, 1981) from the central Kerala coast.

The results of the present study suggest that the bottom trawling causes severe damage to the upper sediment layers. Sediments are dispersed off into the subsurface water column due to the scrapping of heavy otter boards and nets (Messiah *et al.*, 1991). In the present observation, sand and silt fractions were found to be increasing in the trawled grounds after trawling. This may be due to the quicker settlement of the heavier sand and silt particles when compared to the lighter clay particles. The latter on the other hand, showed drastic decline at the trawled grounds. It can be surmised that clay fractions being lighter, gets removed from the sediment due to the dispersion along with the current created in the wake of passage of nets. The predominance in silt proportion after trawling at the stations 1 – 6, where sand proportion was minimal, clearly depict the loss of clay content during trawling. Moreover, wide changes occurred in the percentage distribution of sediments at stations 4, 5 and 6 where the pattern of sediment changed from silty clay to clayey silt after trawling, manifesting a severe loss of clay fraction during trawling. Similarly, drastic change over in sediment structure was noticed at the stations 9 and 10 where the loss of clay fractions paved the way for the dominance of silt and sand fractions, manifesting the ostensible loss of clay due to bottom trawling.

Bottom trawling has proved to be most destructive fishing method in the world by its far-reaching consequences (Graham, 1955; De Groot, 1984). Bottom trawling causes direct and indirect changes to the marine ecosystem of which scraping and dispersion of the sediment is considered as the obvious direct effect (De Groot, 1984; Redant, 1987; Riemann and Hoffmann, 1991).

In the present study, disturbance of the sediment layers were most pronounced in the muddy areas where the natural clay fractions were lost due to the churning action of the bottom trawl net. Significant variations observed at the near shore stations also revealed that bottom trawling brings about predominant alterations in muddy areas where the light clay fractions are suspended in the water column for a longer time when compared to sand particles. The increased sand, silt concentrations and subsequent decrease in clay content in the samples collected after trawling are attributed to resuspension as opined by Shelton and Rolfe (1972); Caddy (1973) and Langton and Robinson (1990). Rasheed and Balchand (2000) while studying dredging impacts in Cochin harbour, Southwest coast of India, reported the presence of higher amount of sand in dredged areas. Gislason (1995) reported that apart from creating mortality and discards, towed gears in contact with the seabed would disturb it physically and cause resuspension of fine particles and relocation of stones and boulders. The results of the present study also agree with these findings. During trawling the topmost layer of the sediments will be raised up to the water column and the settlement of the dispersed sediments will require a long period of time to attain the pre trawl state. The settlement of the heavier particles and the loss of the fine clay will undoubtedly be responsible for the turning the grounds into a more sand filled one. The increase in sand fractions in the experiment indicated that the export of the resuspended fine particles resulted in a coarsening of the sediments thereby changing the natural sediment structure as reported by Langton and Robinson, 1990.

Bottom trawl can change sediment grain size distribution or characteristics, suspended load and the magnitude of sediment transport processes (Churchill, 1989; Riemann and Hoffmann, 1991; Dyekjaer *et al.*, 1995; Pilskaln *et al.*, 1998). Rapid resettling of the heavier particles also has a major role in the coarsening of sediments, with the finer fraction remaining suspended for some time. The incessant perturbations on the substratum may leave the seabed in an altered condition (Eleftheriou and Robertson, 1992; Black and Parry, 1994) with permanent sediment clouds in the water column as noticed by Schwinghamer *et al.* (1996) and Currie and Parry (1996).

In the present study, it could be established that the disturbance on the sea bottom by way of scraping and resuspension of sediments pave the way for the change in natural sediment structure due to increase in the percentage of heavier sand particles. Nevertheless, pulverization of the sediments could not be observed when further analysis of the particle size were conducted by way of Standard deviation, Skewness and Kurtosis. Grain size analysis before and immediately after trawling showed no change in the particle size of the sediments although distinct increase in the sand fraction was observed at the trawled grounds. Clear changes were recorded after trawling in the upper 6 cm of sediments during visual inspection (Caddy, 1973; Eleftheriou and Robertson, 1992; Pranovi and Giovanardi, 1994; Kaiser and Spencer, 1996a; Tuck *et al.*, 1998). Schwinghamer *et al.* (1998a) and Gordon *et al.*(1998) also 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. In the present study, glaring variations were noticed in the percentage distribution of sediments at the study area immediately after trawling operations and this would manifest the possibility of longer-term impacts on sediment texture especially when the trawling operations are chronic.

Smith *et al.* (2000) opined that the passage of the trawl could be responsible for disturbing and relayering 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). On the contrary, in the present study, no change in grain size was observed during detailed fraction analysis, but relayering of the sediments observed after trawling, which strongly corroborate to the above results. It was inferred from the present study that there are drastic variations on the percentage distribution of sediments due to dispersion and relayering during bottom trawling. Bergman and Hup (1992) observed that tickler chain penetrate hard sandy substrate to a depth of at least 6 cm during beam trawling. Otter trawling causes flat tracks on the sediments and the track are visible even after many years (Smith *et al.*, 2000). The increase in turbidity observed in the present study indicated that the extent of impact on the muddy sediments was more severe when compared to that on sandy or silty sediments. This observation agrees to the findings of Fonteyne (2000) who observed that trawling alters the topography of muddy seabed over a much longer time than a coarse sediment habitat.

In the observations made after trawling, turbidity of water was found increased alarmingly, especially at bottom, which was attributed to the rise of sediments clouds during trawling. The rise of sediment clouds had been observed by video and sonar in the study conducted by Churchill (1989) and Black and Parry (1999). They also noticed the movement of those sediment plumes to other areas along with the underwater currents. In sandy areas however, turbidity was less due to minimal amount of clay. The soft nature of muddy sediments makes them more susceptible to the physical impacts of trawl gear compared with harder and coarse sediments (Ball *et al.*, 2000). Several studies conducted on the effect of trawling revealed that when trawl doors were towed under normal fishing speed, they generated intense turbulent wakes capable of creating turbid clouds of suspended sediments (Korotkow and Martyschewski, 1977; Wardle, 1983; Bohlen and Winnick, 1984). The high turbidity in water has been reported to prevent settlement of benthic larvae thus affecting their recolonization after disturbance (Galtsoft, 1964; Stevens, 1987). Thus, it can be inferred that the bottom trawling activities increase the turbidity of the water column by way of digging up the sediment surface, which in turn adversely affect the existence and survival of the marine organisms especially to the young ones.

In the present study, the dragging of the otter boards and nets were found to create an unfavorable environment for the living organisms especially at the bottom. A series of changes were catalogued as the immediate effect of trawling, such as increase in turbidity, decrease in the dissolved oxygen, abrupt increase in nutrients, and wide variations of epifaunal and infaunal organisms. The increase in turbidity and consequent decrease in the oxygen content in the marine waters due to the bottom trawling activities has 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; Rosenberg, 1977; Rosenberg, 1985; Berghahn, 1990; Gibson and Robb, 1992; Heip *et al.*, 1992; Camphuysen *et al.*, 1993; Waltres and Juanes, 1993; Kaiser *et al.*, 1994; Walting and Norse, 1999; DeAlteris, *et al.*, 1999; Ball *et al.*, 2000). Moreover the ploughing of bottom sediments during bottom trawling releases the nutrients embedded in it and abrupt release of these nutrients as recorded in the present study would cause an unbalanced condition in the water column leading to the formation of unwanted algal blooms posing a threat to the living animals (Riemann and Hoffmann, 1991). Moreover the disturbance on the soft sediments may remobilize contaminants and radio nuclides and also expose the anoxic layer sediment layers as reported by Krost *et al.* (1990); De Groot and Lindeboom, (1994); Jennings *et al.* (2001a). Resuspended sediments may also act as carriers for organic and inorganic pollutants (Mirarchi,1998).

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 (Auster and Langton, 1999; Steele, 2002). Several studies were conducted on the penetration of otter boards in the sediments (Arntz and Weber, 1970; Margetts and Bridger, 1971; Churchill, 1989; Laban and Lindeboom, 1991; Santbrink and Bergmann, 1994; Lindeboom and de Groot, 1998; Giovanardi *et al.*, 1998) which revealed that persistence of trawl marks depend on grain size, current strength and biological activity (Smith *et al.*, 2000). Otter trawl leaves more persistent marks on muddy bottom compared to the sandy bottom (Lindeboom and de Groot, 1998) 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 (Krost *et al.*, 1990; Hall *et al.*, 1990). Though the underwater video tests could not be conducted in this study, the persistent turbidity and reduction in dissolved oxygen can be taken as the tangible proof of greater impact on muddy bottom than sandy areas.

In the present study, the organic matter was found decreased at the trawled grounds, which clearly indicated that the loss of organic resources from the sediment surface during bottom trawling. Sediment surface is a rich source of organic matter, nutrients and minerals (Levinton, 1989; Hall, 1999). The diminution of organic content in the sediment is attributed to the removal and dispersal of the sediment surface layers during bottom trawling. Mayer *et al.* (1991) had showed that heavy chain dredges mix surface organic material with subsurface layers. In the present study, the decrease in organic matter obtained in the after trawling samples also supports with this point. Trawl gear equipped with heavy otter boards, and tickler chain stir up the sediments, which result in the assimilation of organic matter into the water. Resuspension of the sediments at seabed had been reported to be the obvious direct effect of the bottom trawling. The maximum organic matter is found at the sediment surface and the removal of the top layer of sediments by all means reduced the organic load at the sediments. Significant reduction noticed in the 0 –30 m depth also revealed that the extent of variation was more in the near shore stations (below 30 m) where the organic load is more than that of sandy stations (above 30m depth). Mayer *et al.*, (1991) reported that the trawling/ dredging causes loss of organic matter from the surface layer of sediment. In the present study, the reduction of organic matter observed in the samples collected after trawling strongly agrees to the above results. Fader (1991) found that while trawling, the otter boards scour the seabed generating turbulent wakes of sediment and detritus in the water column. The results of the present study also show the destructive nature of bottom trawls causing the suspension of organic matter, and thereby indirectly affect the marine ecosystem in toto.

Bottom trawling causes serious perturbations on the marine ecosystem directly and indirectly (Gislason, 1994, De Groot, 1995; Jennings and Kaiser, 1998). 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; Brown, 1989; Rees and Eleftheriou, 1989; Krost, 1990; Bergman and Santbrink, 2000). The effect of dragging has a strong and immediate impact on the sediment milieu by suspension of fine sediments in to the water column (Caddy, 1968,1973; Korotkow and Martyschewski, 1977; Main and Sangster, 1981, 1983; Wardle, 1983; De Groot, 1984; Churchill, 1989; Fader, 1991; Black and Parry, 1999). The sediments will be turned coarser and the food quality significantly reduced, most likely by export of the fine, low-density fraction due to resuspension. In the present study the variations on the sediment structure after trawling, subsequent increase of turbidity and diminution of dissolved oxygen undoubtedly agree to the fact that the bottom trawling has an undeniable role in the disturbance on the seabed. Besides, the reduction of organic matter recorded in the after trawling samples also strengthens the above results. So it can be understood that the dragging of heavy nets along the sea bottom reduce the organic matter of the top layer of the sediments and also make the surface more coarse which in turn changes the natural sediment milieu as reported by Watling *et al.* (2001). The reduction of organic matter may affect the growth and development of benthic organisms since most of the bottom dwelling organisms depend on the organic deposit on the sea bottom for their food (Levinton, 1989). Deposit feeders obtain nutrition from sedimentary organic matter (Basford *et al.*, 1993). The reduced organic matter levels after trawling may adversely affect the survival of such deposit feeders. The resuspension thus induced results in the reduction of water clarity and dissolved oxygen content and finally the change the species composition of the faunal communities living in the sediment (Pilskaln *et al.*, 1998). Moreover, the variations in the natural sediment structure will also lead to the destruction of natural habitat of benthic organism which live on and in the sediments (Messiah *et al.*, 1991). The animals which live in the muddy areas may be destroyed or forced to leave their natural grounds due to the change in sediments as most of the organism shows a preference for certain grain size. One of the factors governing the abundance and distribution of benthic fauna are sediment characteristics like grain size and silt (Duineveld *et al.*, 1991). The turbid clouds formed due to trawling may result in changes to fish communities, from ones dominated by fish that find food using their eyesight, to those that find food by touch or by sensing it through chemical attraction (Dayton *et al.*, 1995b).

The faunal abundance and diversity may be reduced as a repercussion of the changes in sediment milieu and reduction of organic food particles in the trawled grounds as postulated by Watling and Norse (1998). Heavy destruction of epifaunal and infaunal organisms were also noticed in the present study. Moreover, the scraping and ploughing on the seabed may reduce the roughness of the sea bottom and that results in the reduction of habitat complexity and diversity as reported by Humborstad *et al.* (2002). Many fishes and benthic organisms depend on these complex habitats for protection from predator and for food (Levinton, 1989; Collie *et al.*, 1997). In a nicety, the inordinate proliferation of bottom trawlers in the coastal waters by all means pose a threat to the benthic animals and the existence of the marine ecosystem by way of intense perturbations on it during fishing. The results obtained in the present study clearly depicted the drastic variations on the seabed ecosystem due to bottom trawling. South west coast on India is embellished with immense marine resources and contributes the major share to the total Indian landings. Technological and economic power and have brought unprecedented disturbance to the seabed ecosystem worldwide (Auster, 1998). The inordinate proliferation of the bottom trawlers in the Southwest coast of India and their incessant operations in the resource rich coastal waters undoubtedly alter the benthic ecosystem unless serious measures are taken to control this bottom fishing method. In summary, the incessant operation of bottom trawlers in the marine environment makes a series of immediate changes such as disturb the natural sediment structure by digging up the sediment surface layers, reduce the organic matter present by exporting the organic rich surface layers and converting the grounds to more coarse in nature. The incessant trawling operations would keep the ground always in an altered state, which is quite unfavorable for the growth and development of the marine organisms, leading to the loss of the marine ecosystem.

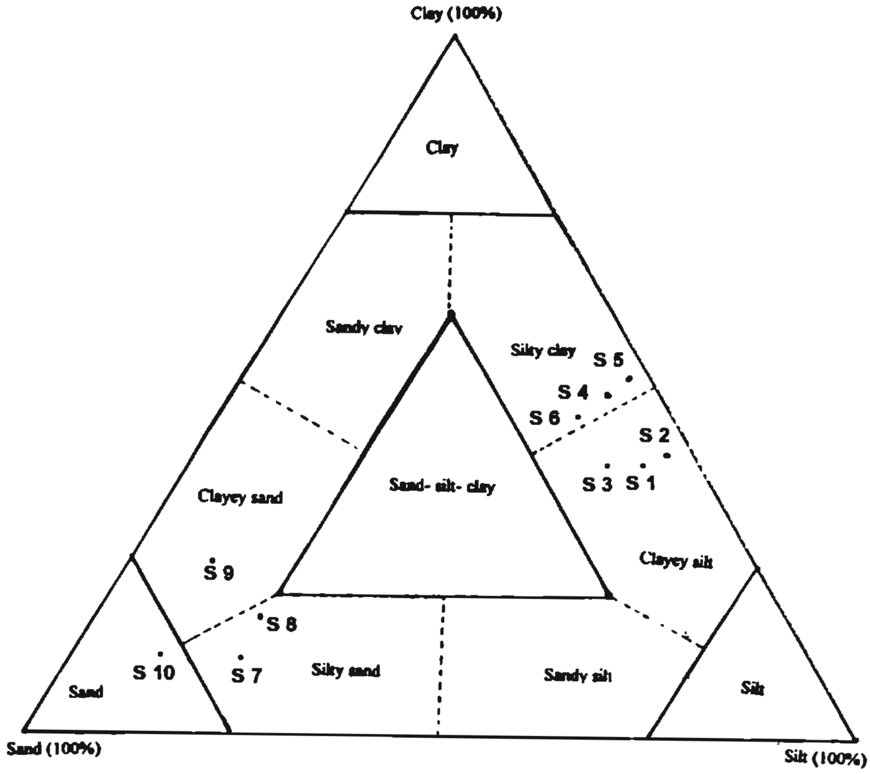


Fig. 6.1 Sediment texture at stations 1 to 10 before trawling

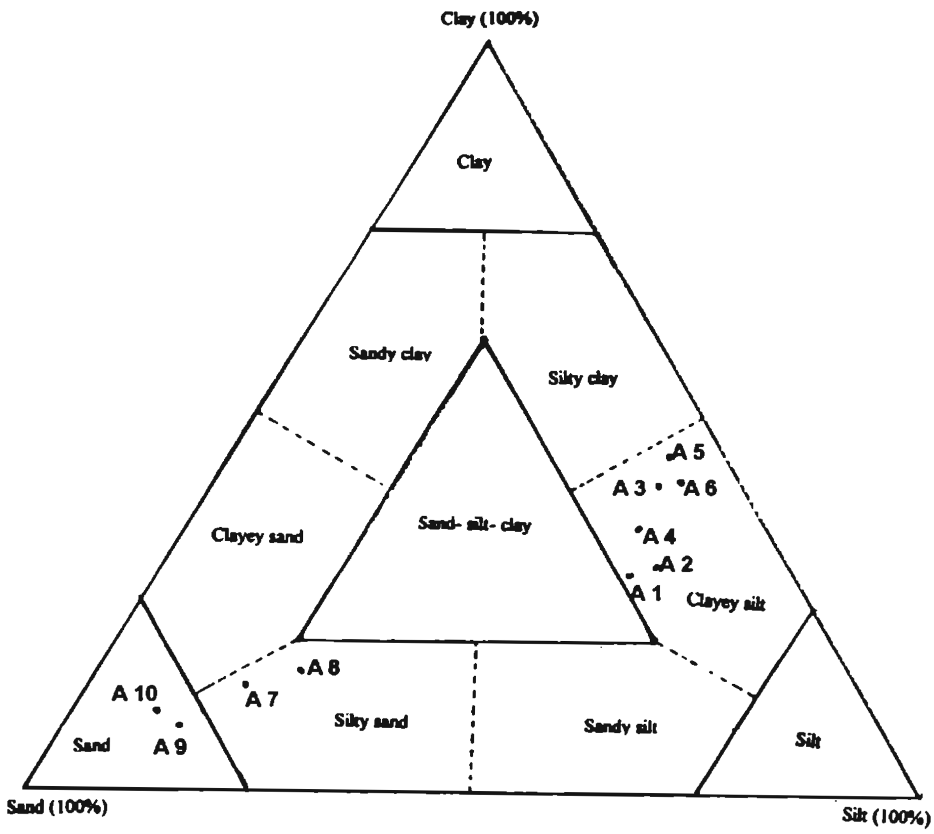


Fig. 6.2 Sediment texture at stations 1 to 10 after trawling

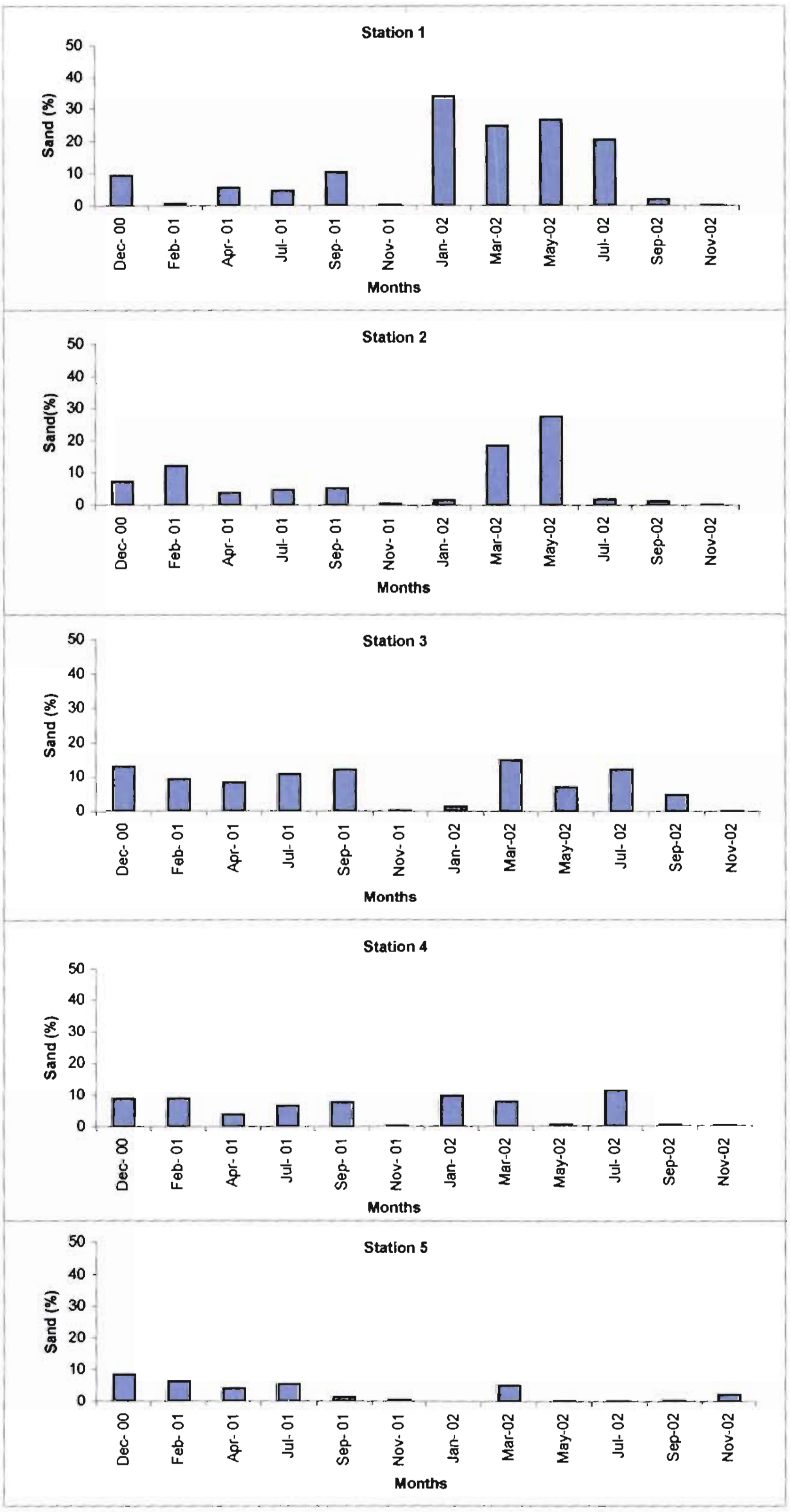


Fig .6.3a Sand fraction recorded before trawling at stations 1 to 5 from Dec. 2000 to Nov. 2002

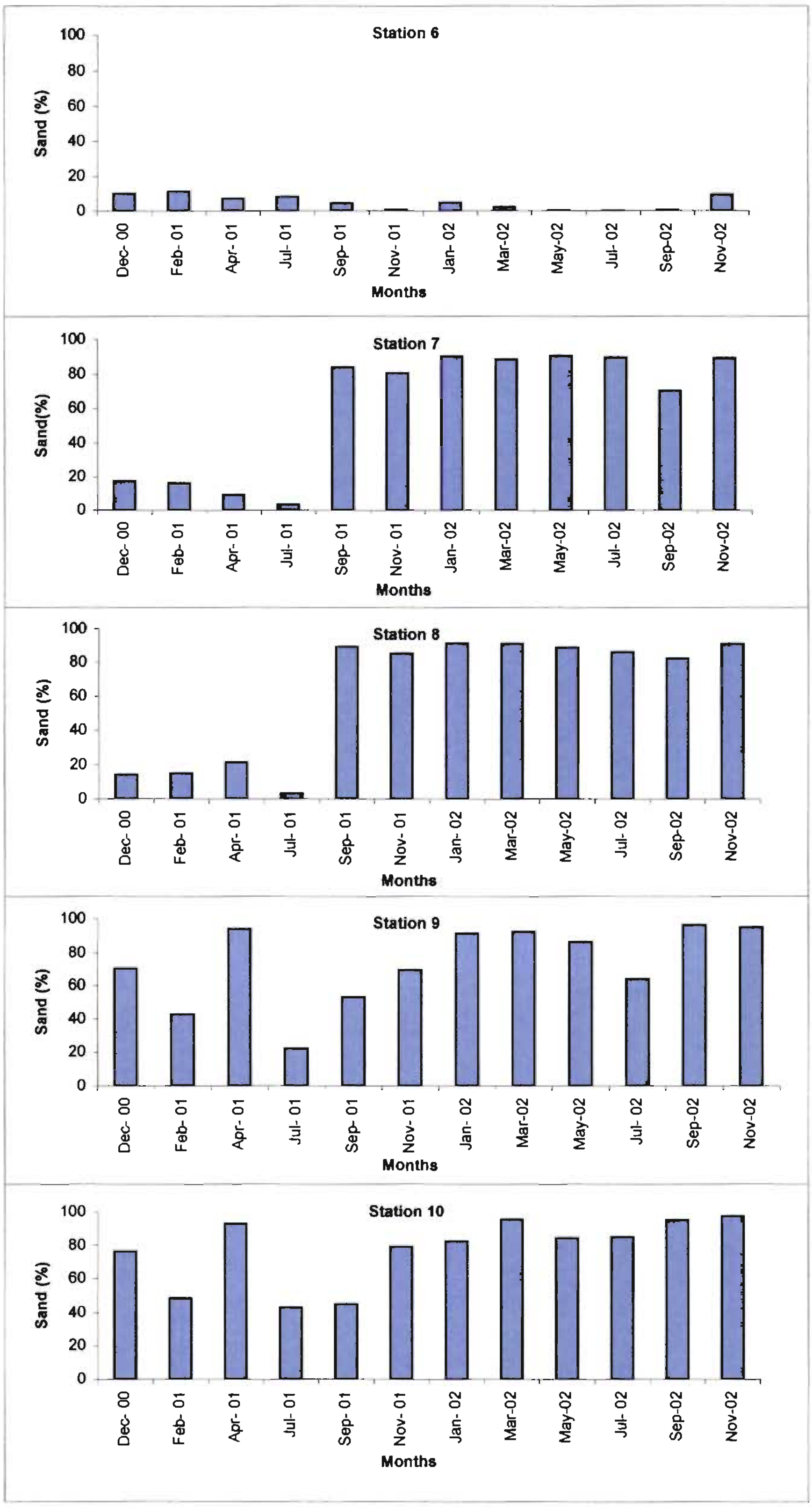


Fig .6.3b Sand fraction recorded before trawling at stations 6 to 10 from December 2000 to November 2002

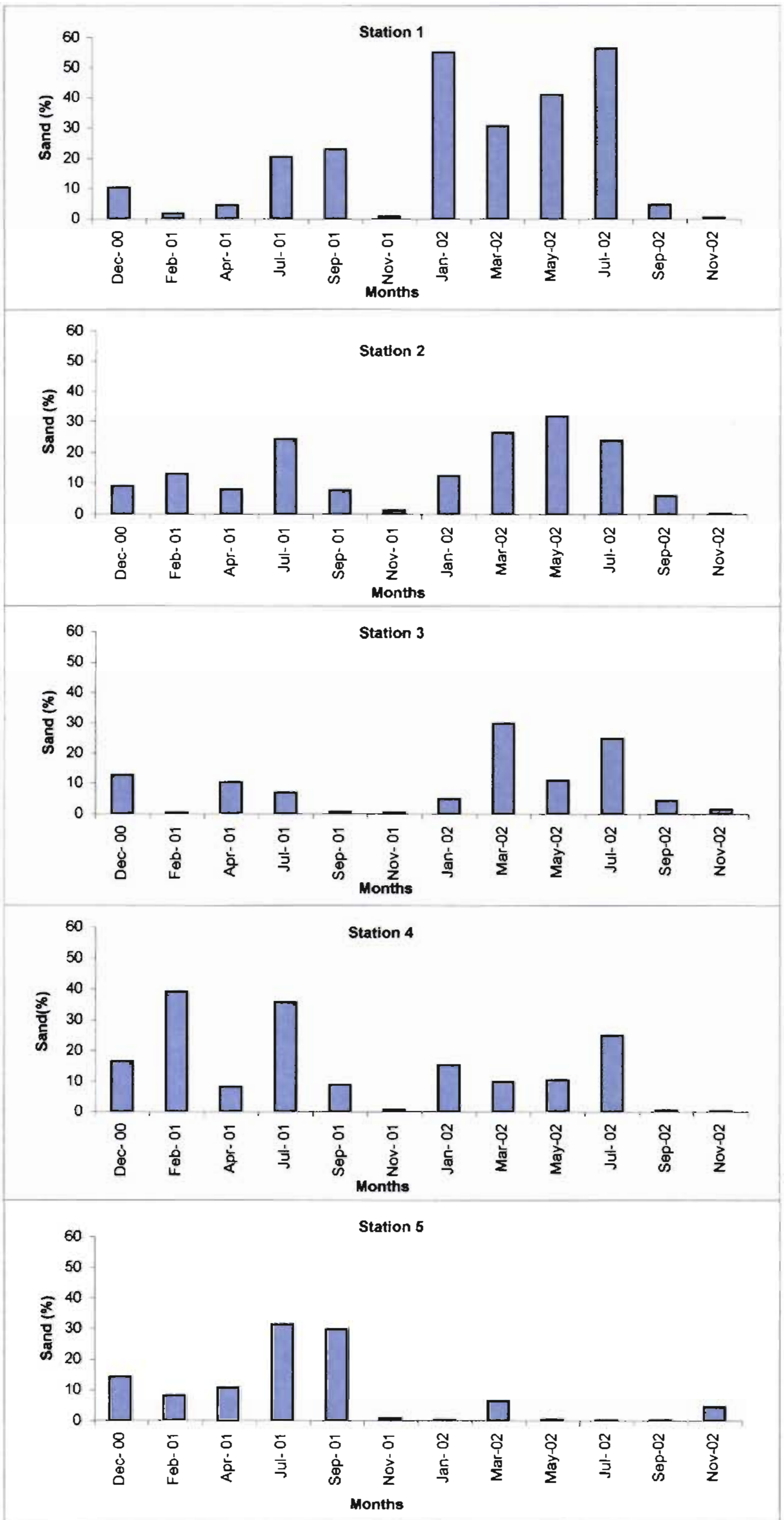


Fig .6.4a. Sand fraction recorded after trawling at stations 1 to 5 from December 2000 to November 2002

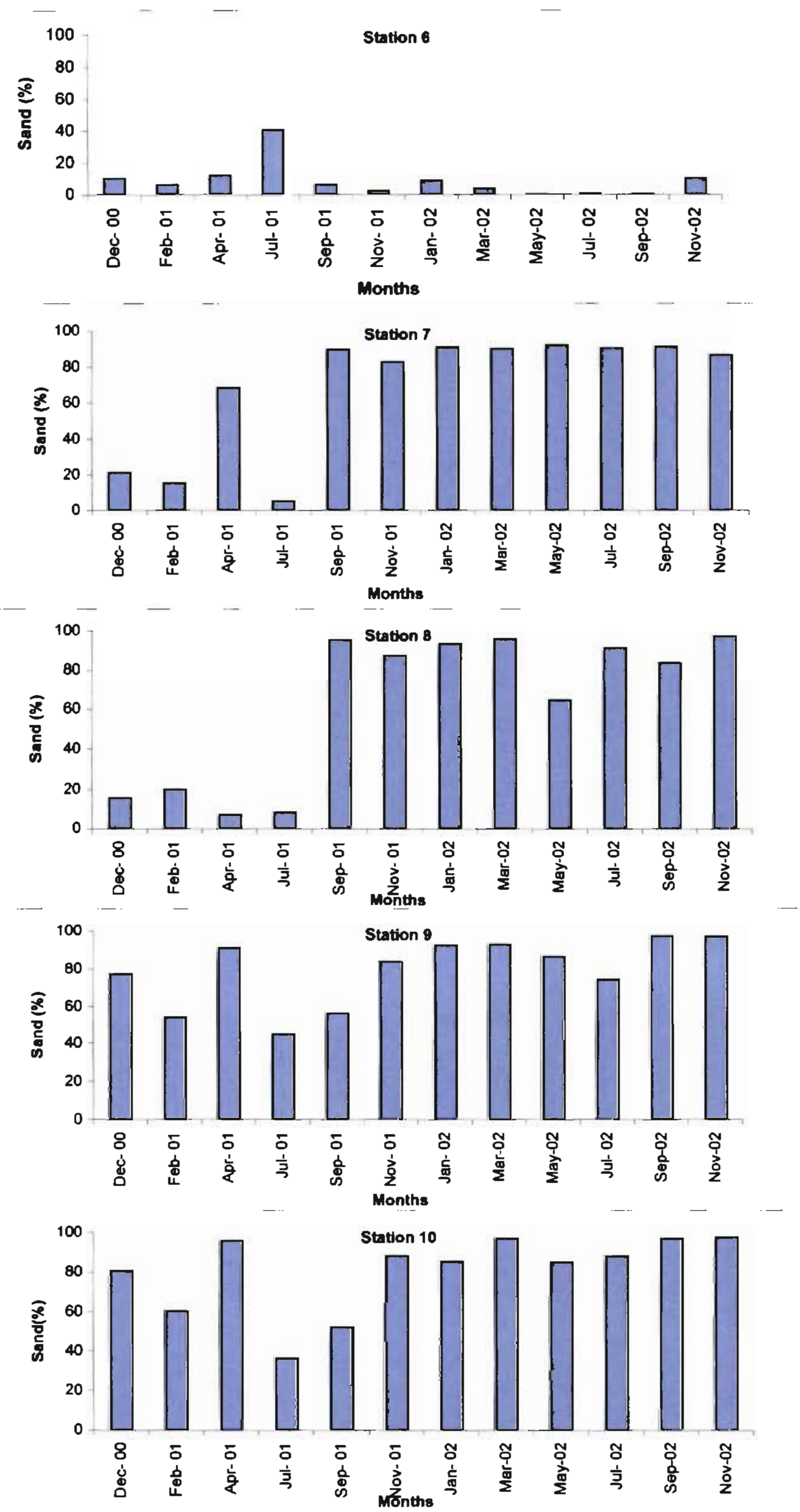


Fig. 6.4b. Sand fraction recorded after trawling at stations 6 to10 from December 2000 to November 2002

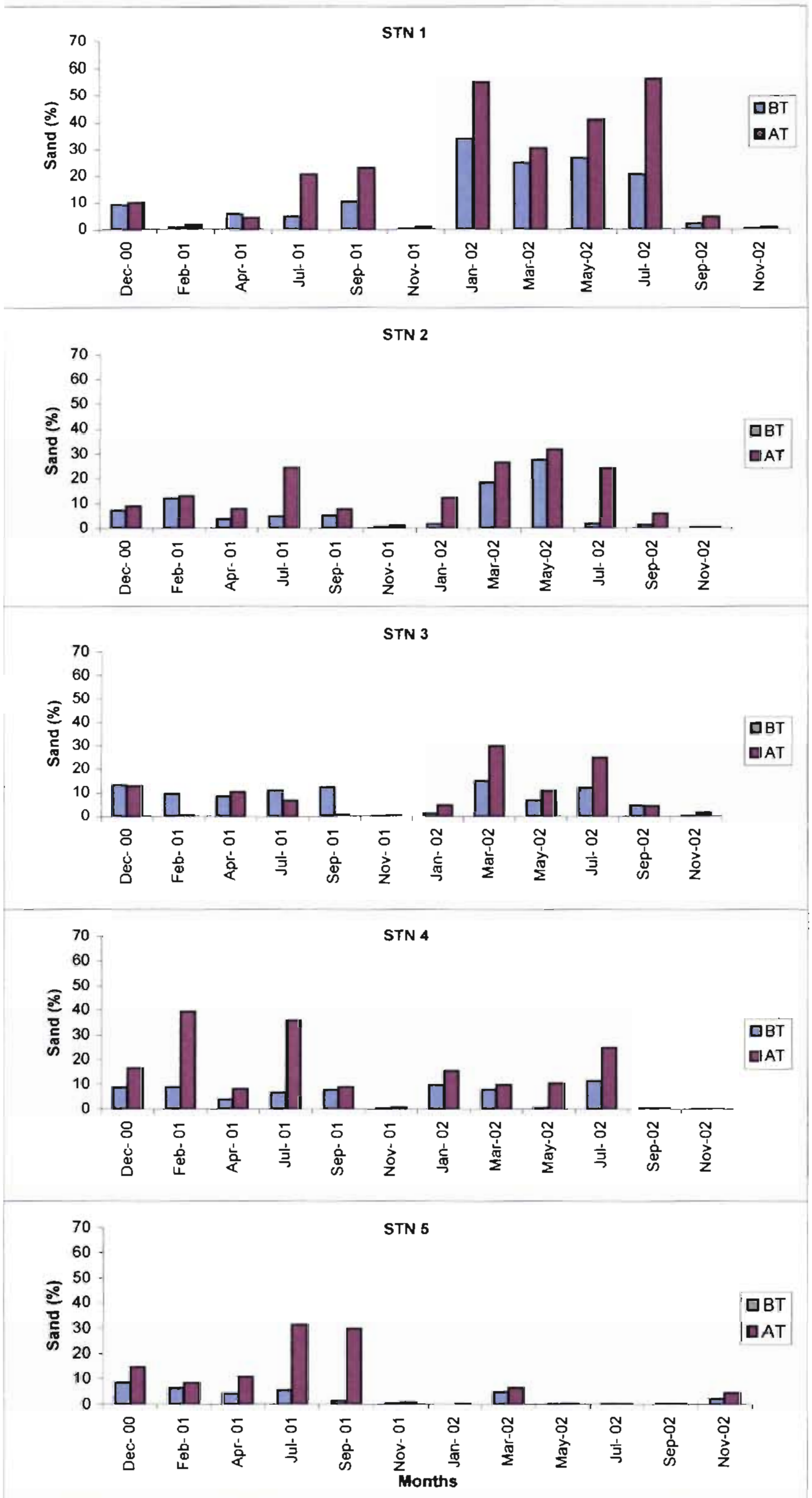


Fig. 6.5a. Comparison of sand content before and after trawling in the study area from December 2000 to November 2002

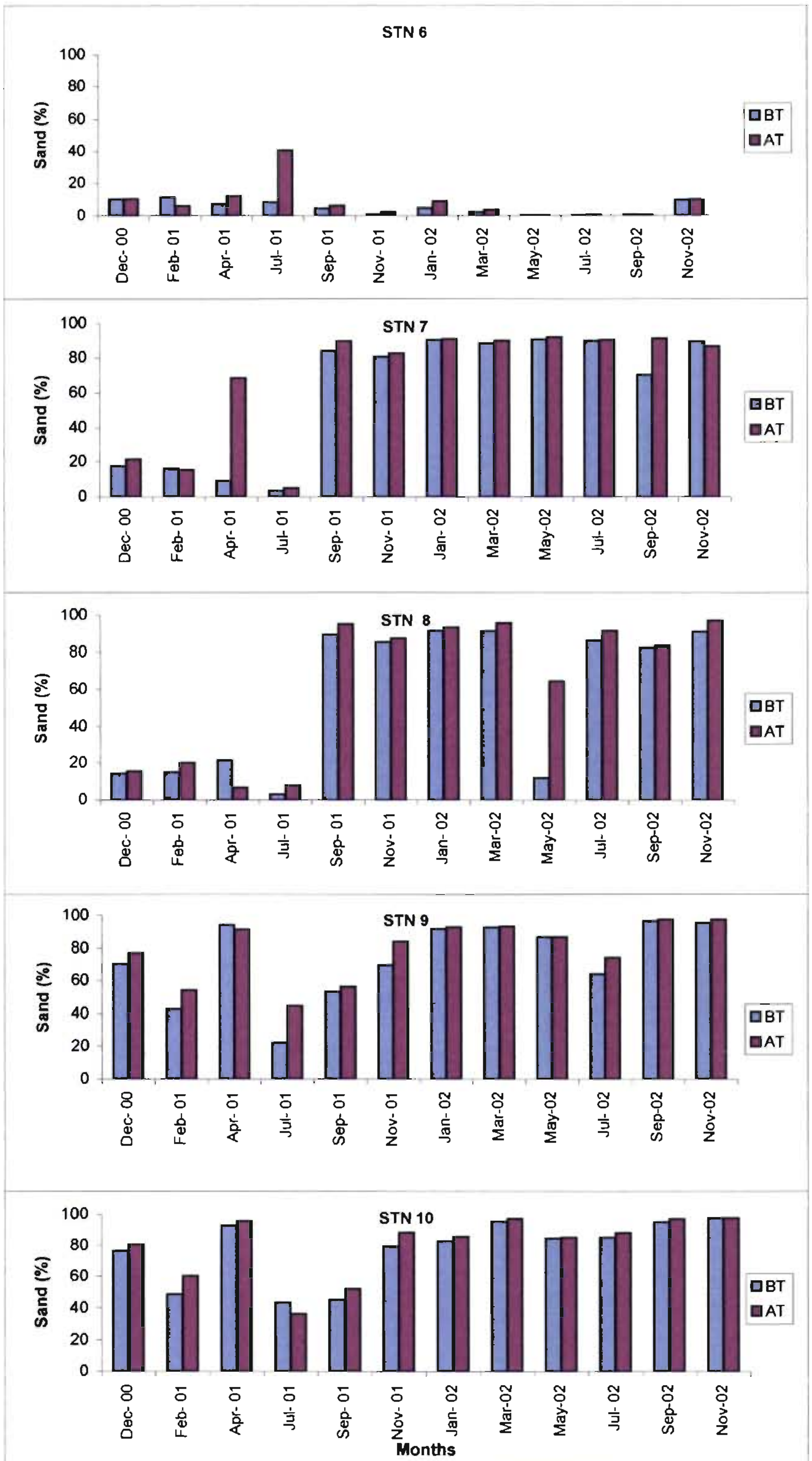


Fig. 6.5b. Comparison of sand content before and after trawling in the study area from December 2000 to November 2002

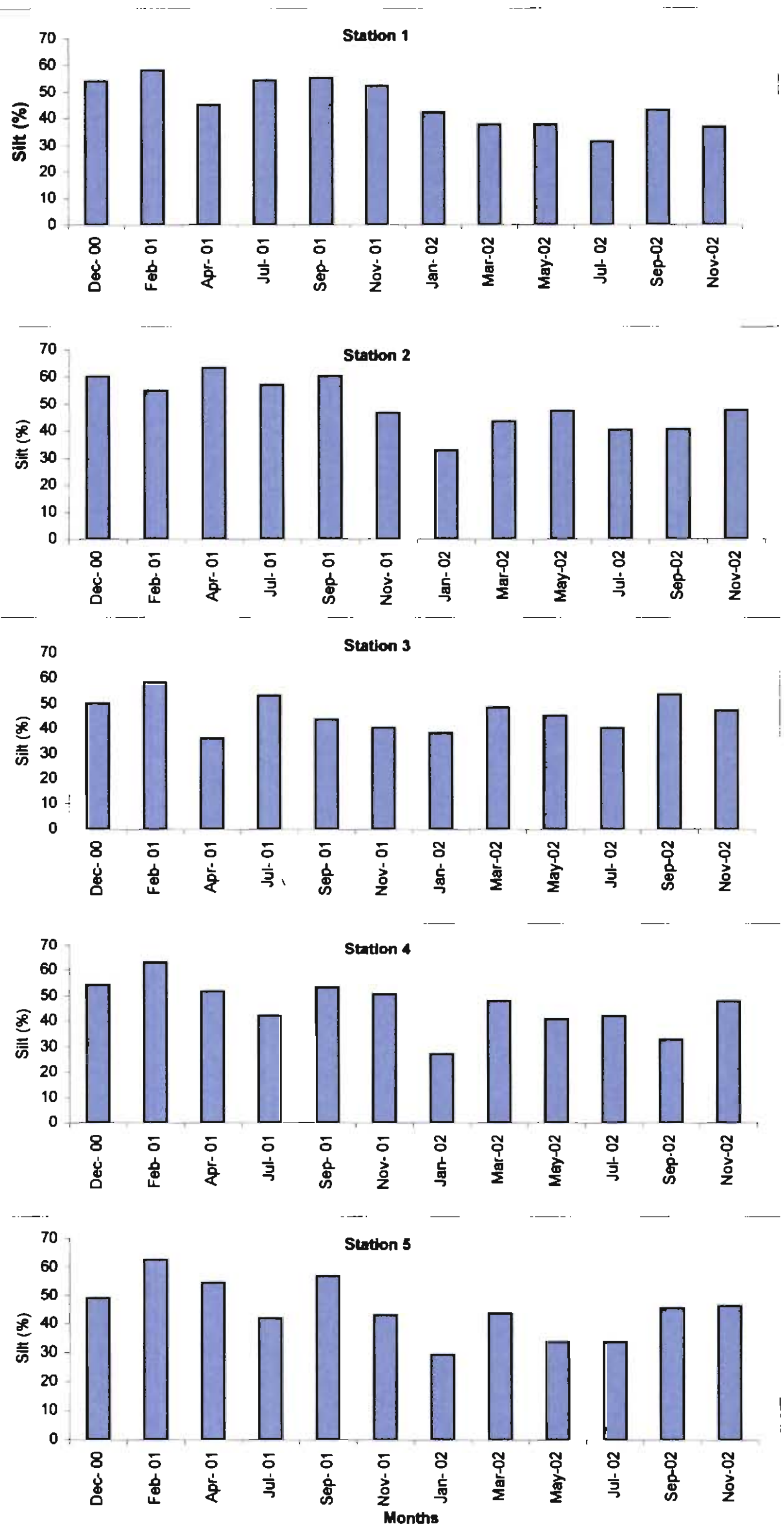


Fig. 6.6a. Silt fraction at stations 1 to 5 recorded before trawling from December 2000 to November 2002

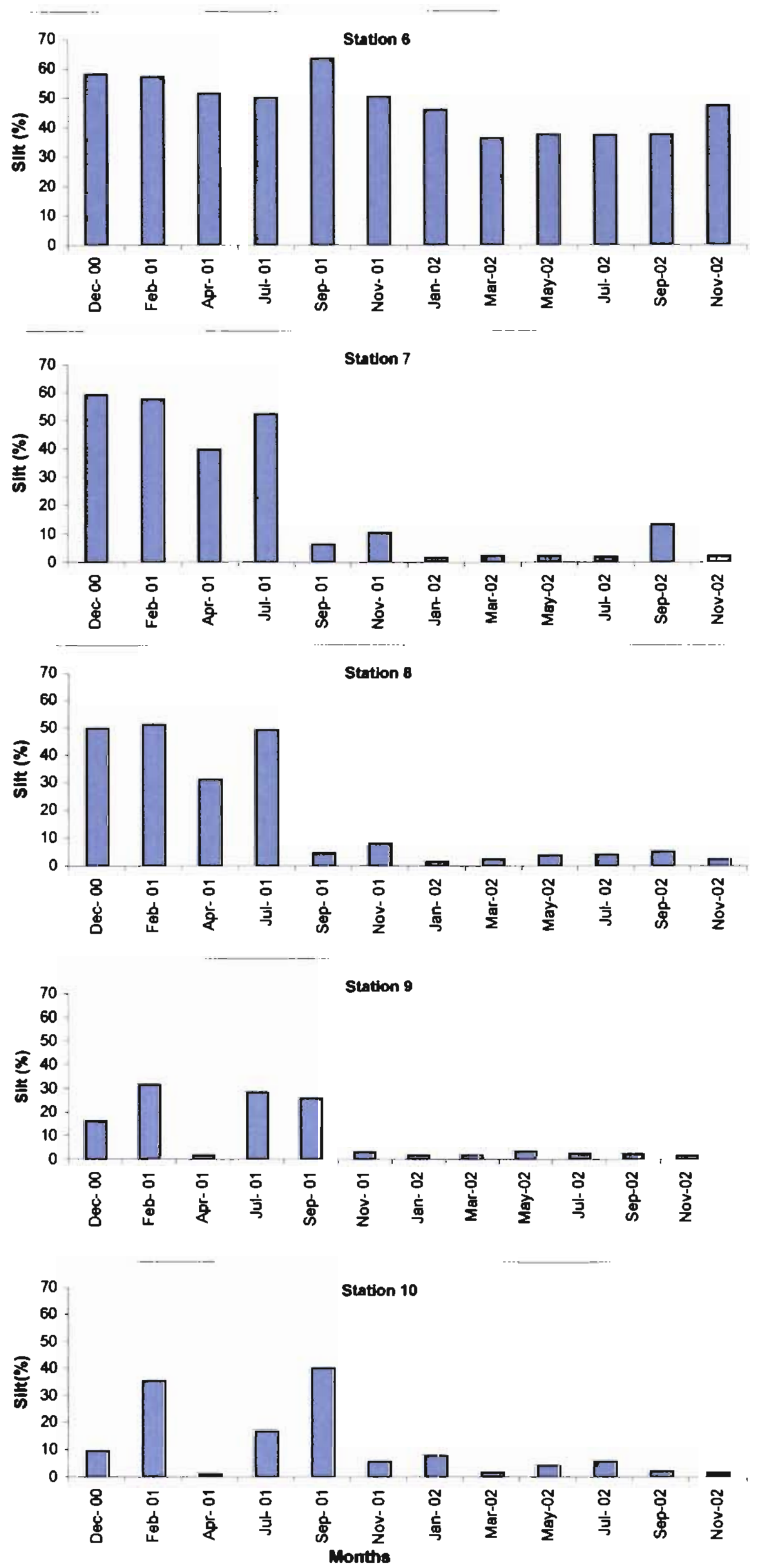


Fig. 6.6b. Silt fraction recorded before trawling at stations 6 to 10 from December 2000 to November 2002

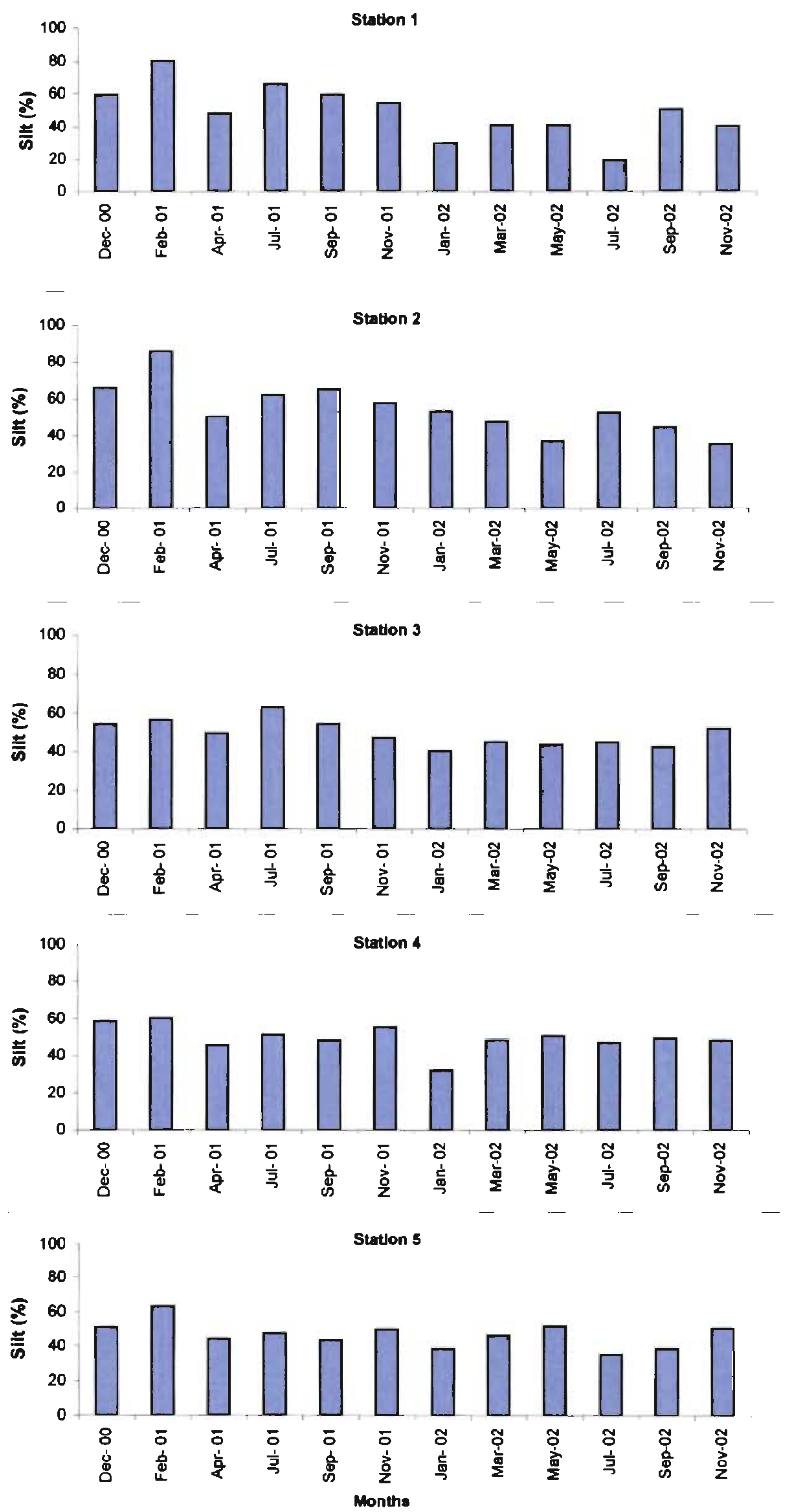


Fig. 6.7a. Silt fraction at stations 1 to 5 recorded after trawling from December 2000 to November 2002

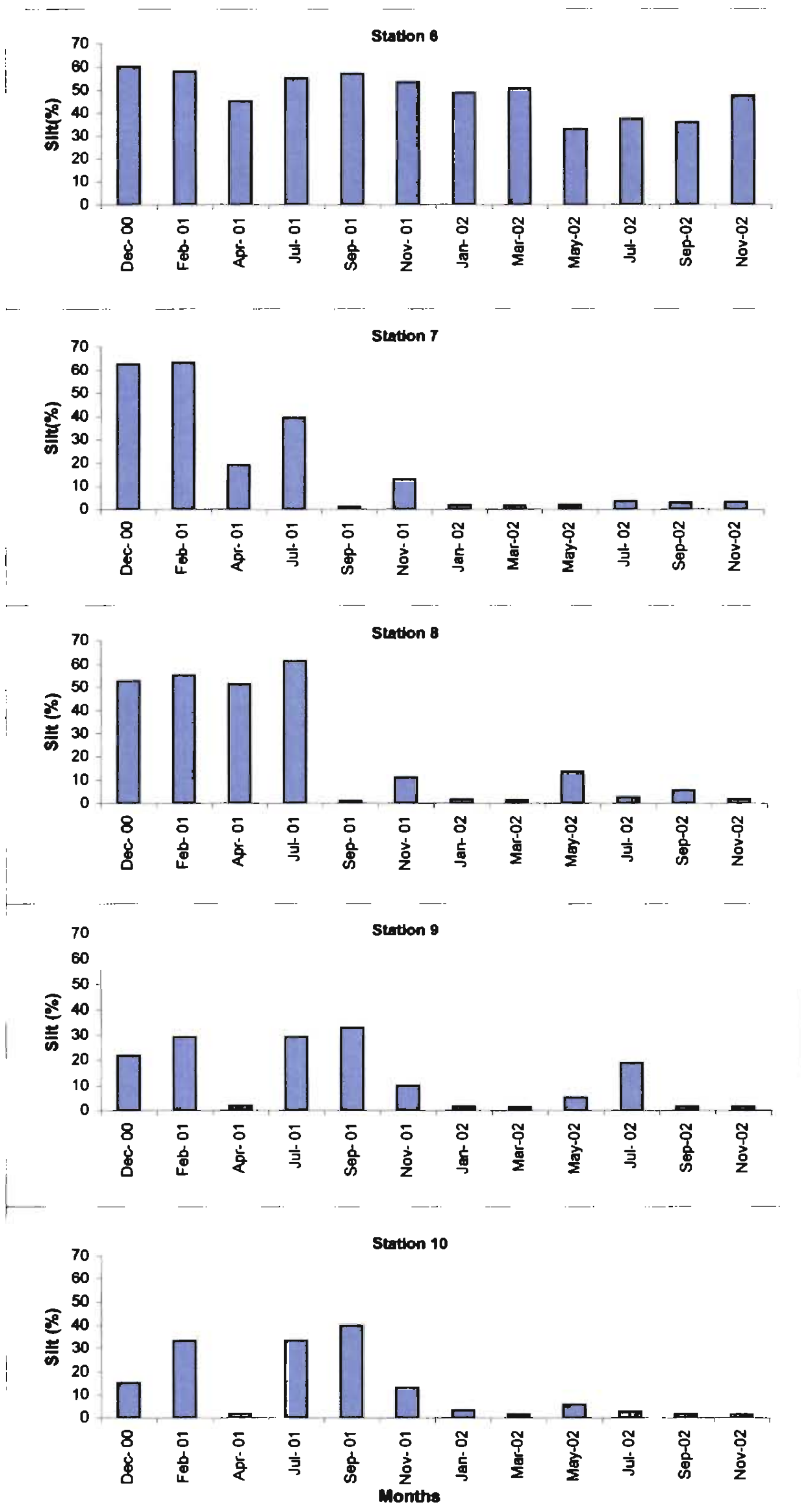


Fig. 6.7b. Silt fraction at stations 6 to 10 recorded after trawling from December 2000 to November 2002

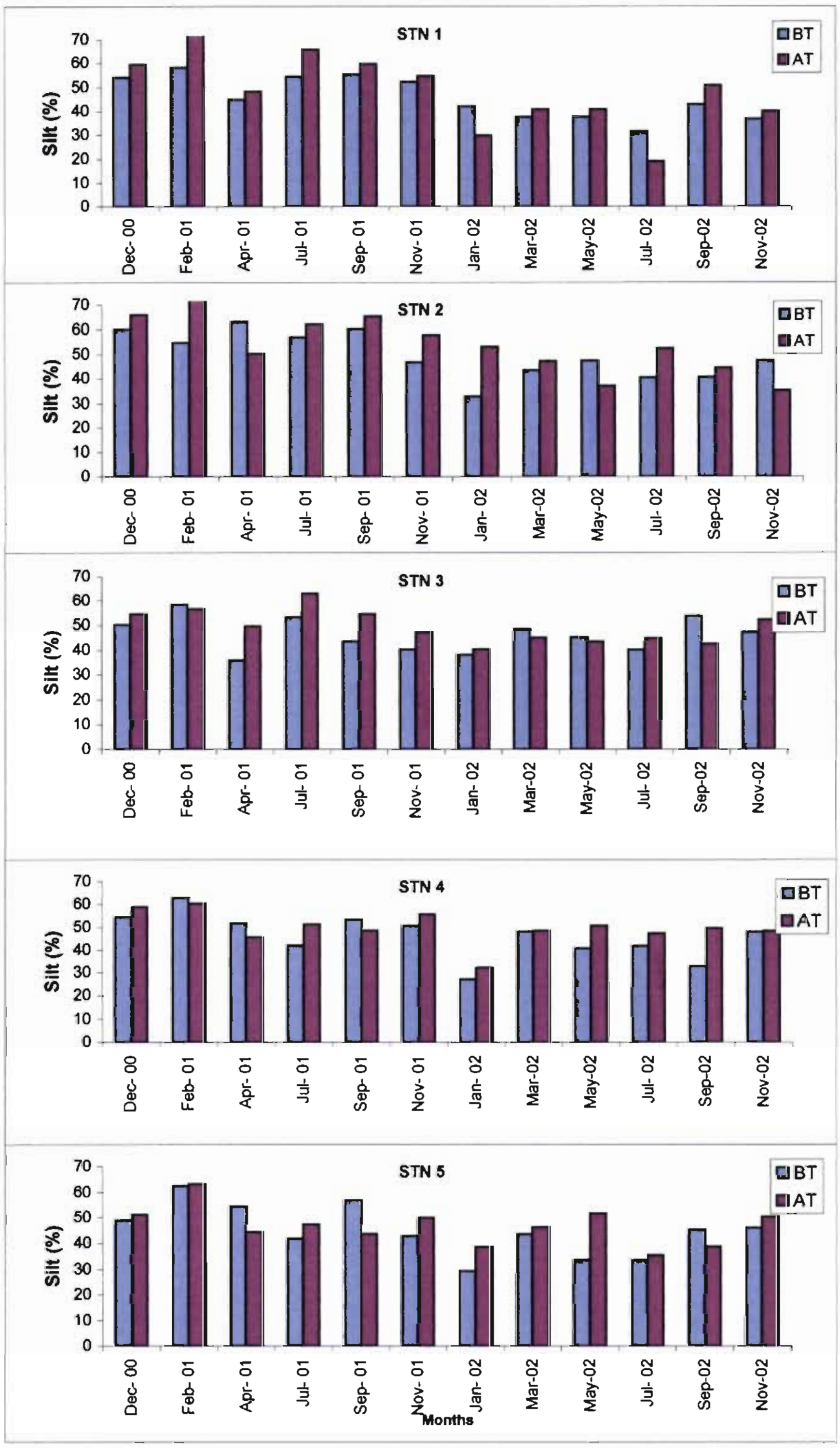


Fig. 6.8a. Comparison of silt content before and after trawling in the study area from December 2000 to November 2002

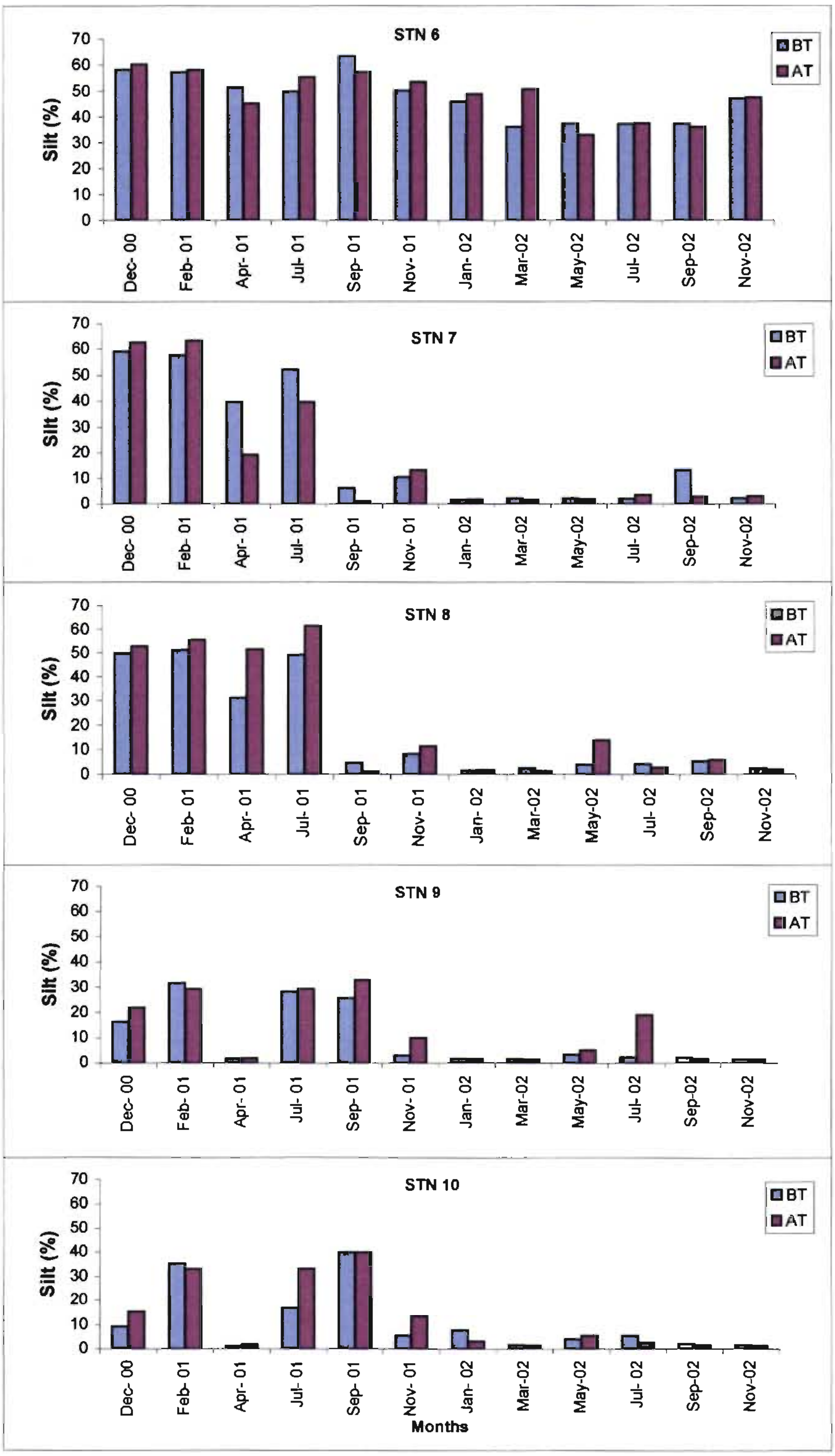


Fig. 6.8b. Comparison of silt content before and after trawling in the study area from December 2000 to November 2002

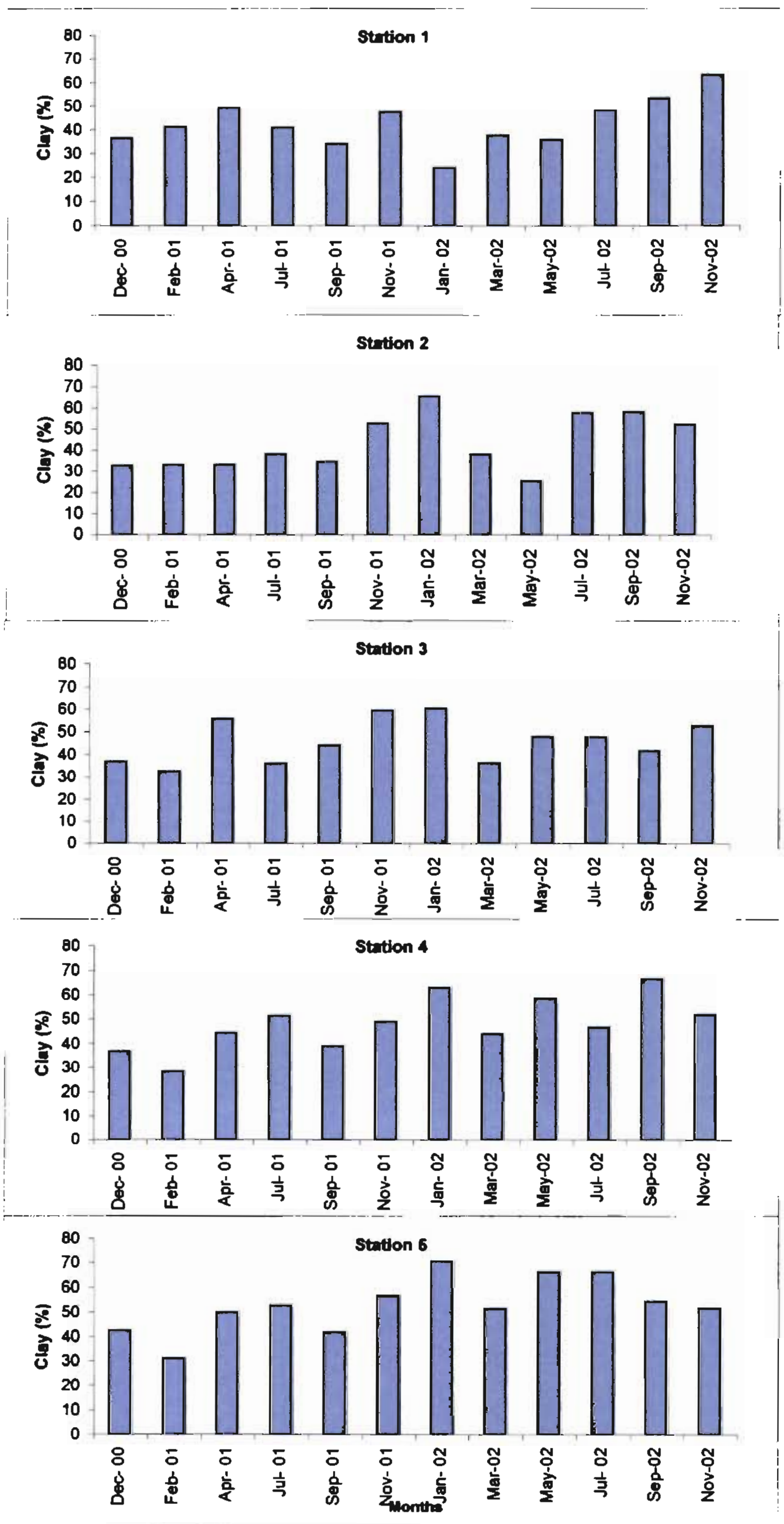


Fig .6.9 a Clay fraction recorded before trawling at stations 1 to 5 from December 2000 to November 2002

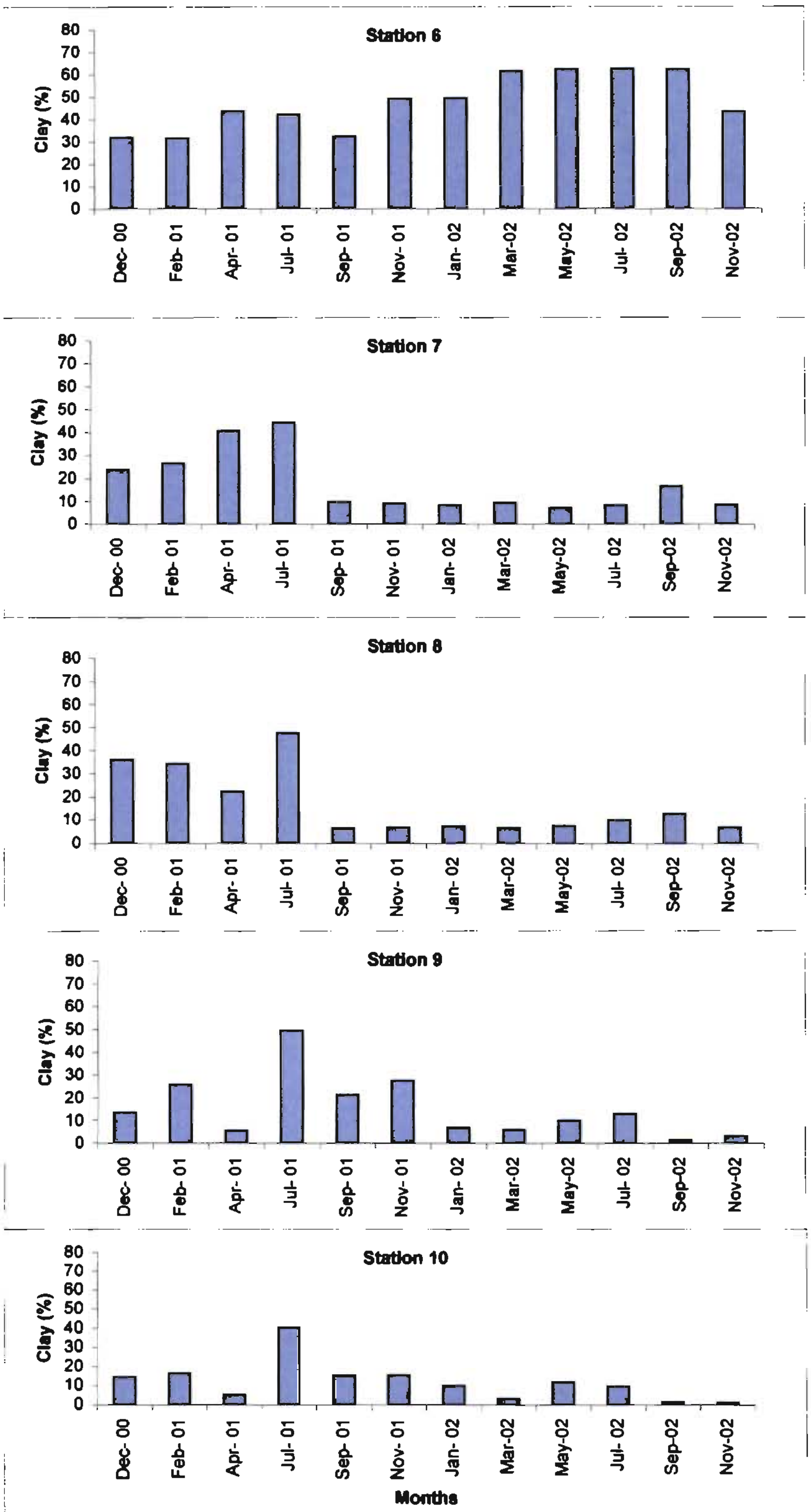


Fig .6.9b. Clay fraction recorded before trawling at stations 6 to 10 from December 2000 to November 2002

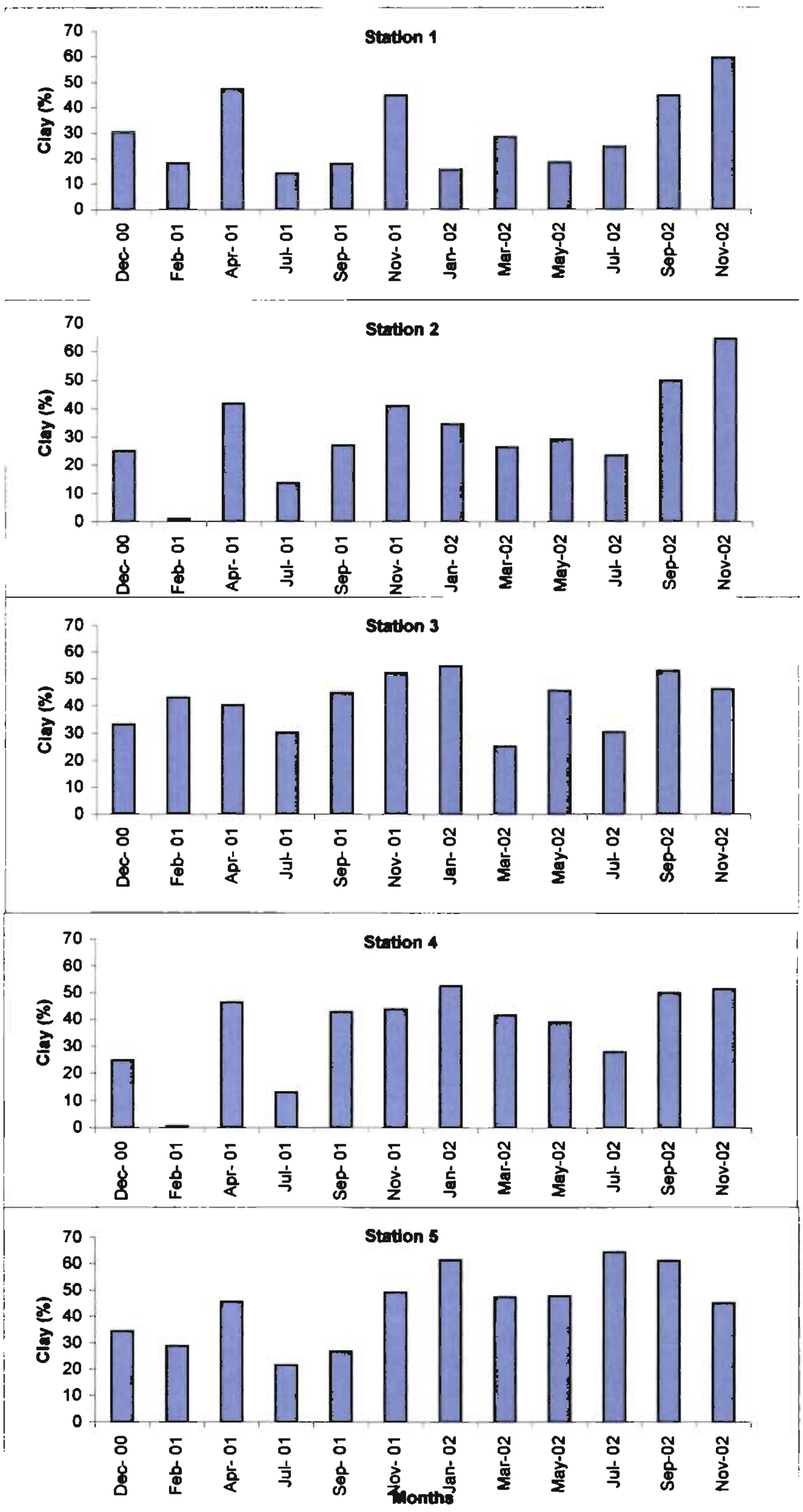


Fig .6.10a Clay fraction recorded after trawling at stations 1 to 5 from December 2000 to November 2002

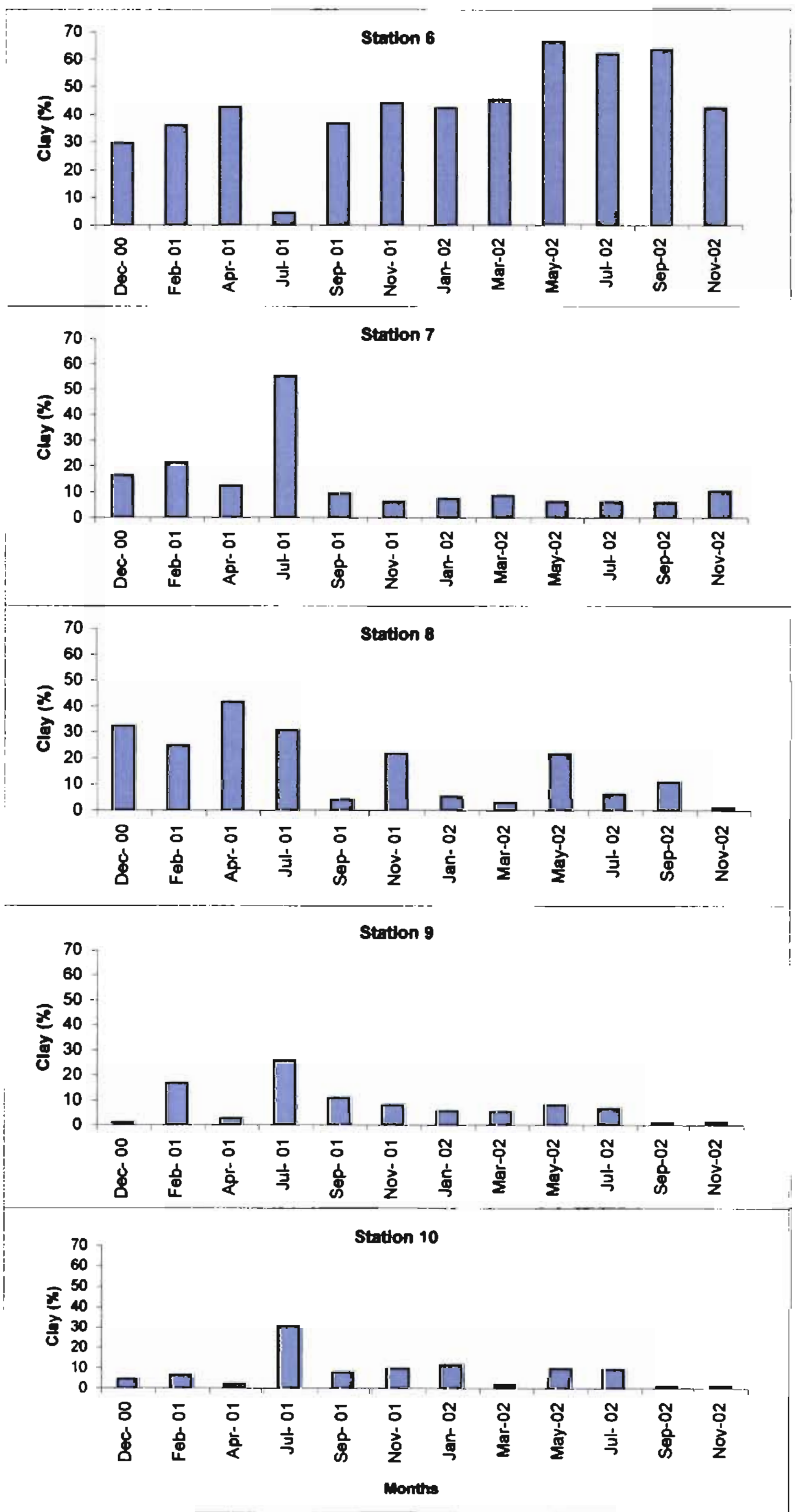


Fig. 6.10b Clay fraction recorded after trawling at stations 6 to 10 from December 2000 to November 2002

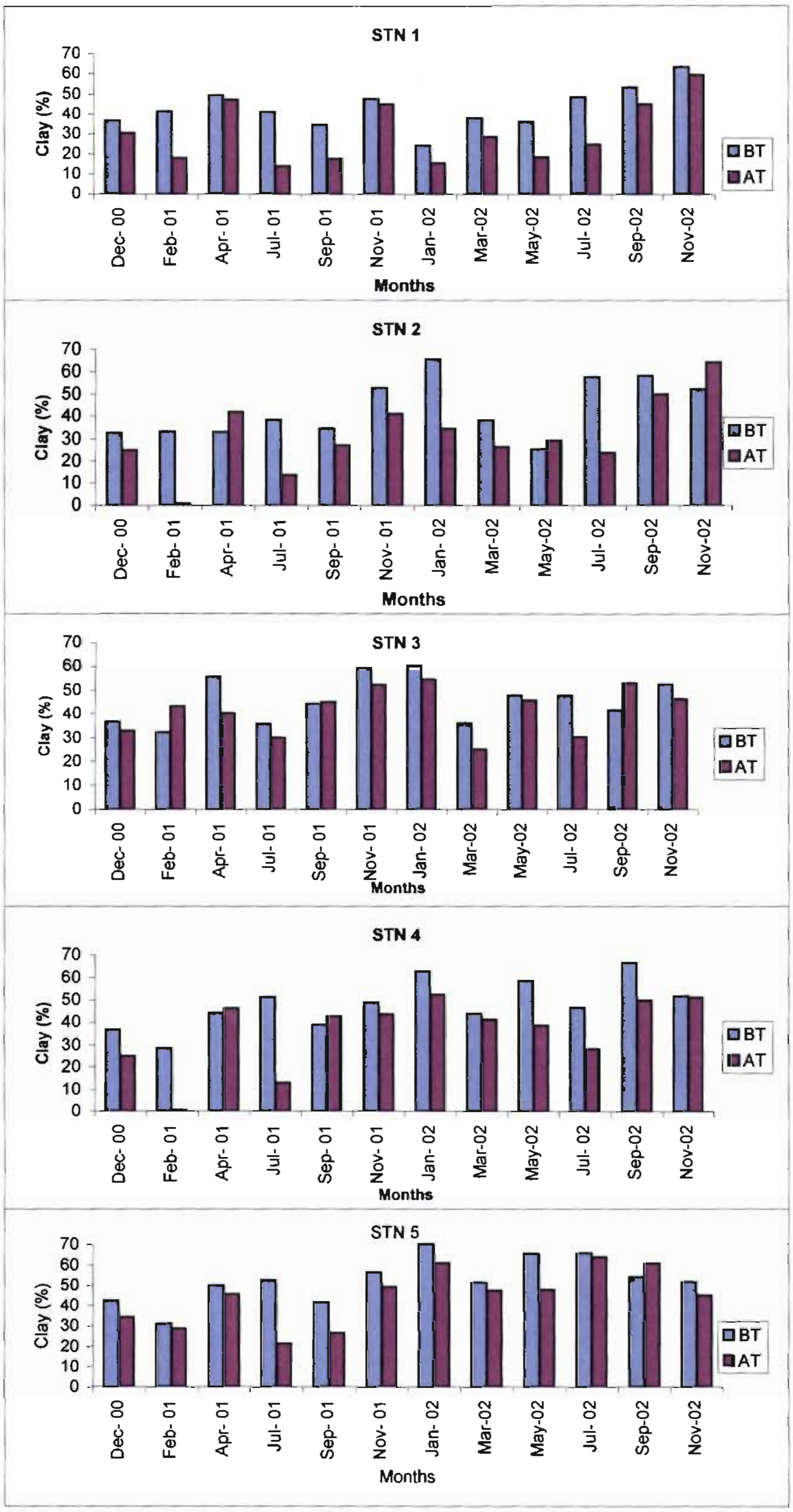


Fig. 6.11a Comparison of clay content before and after trawling in the study area from December 2000 to November 2002

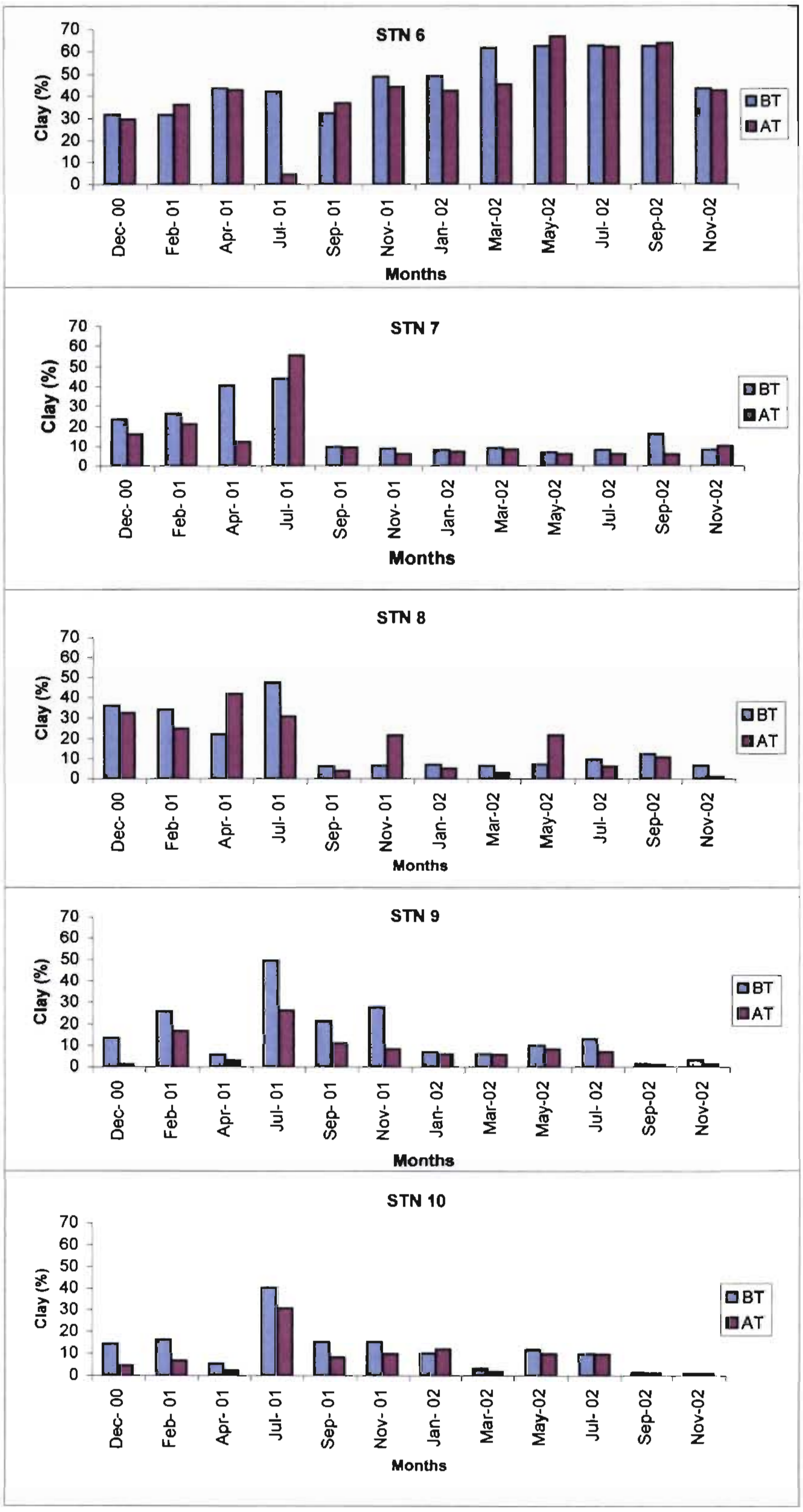


Fig. 6.11b Comparison of clay content before and after trawling in the study area from December 2000 to November 2002

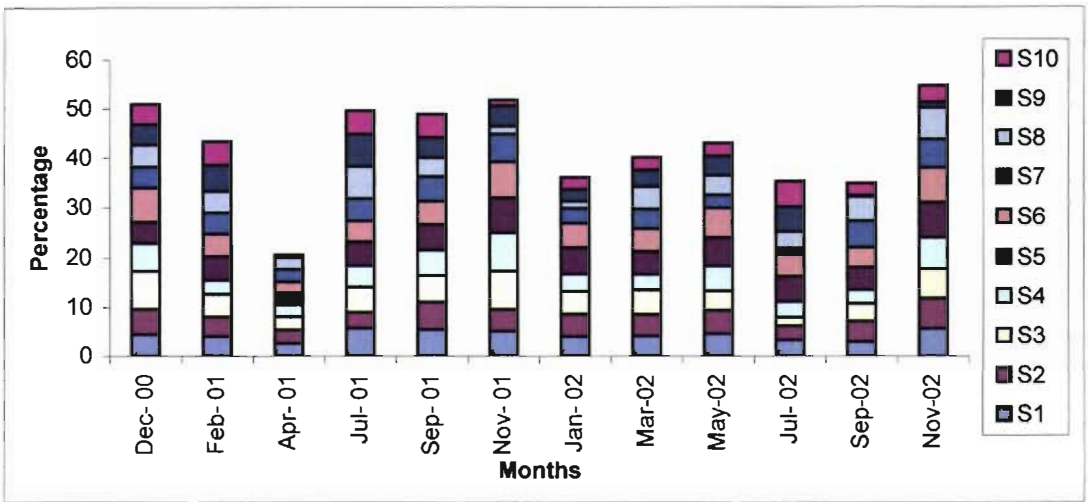


Fig. 6. 12 Organic matter recorded before trawling at stations 1 to 10 during December 2000 to November 2002

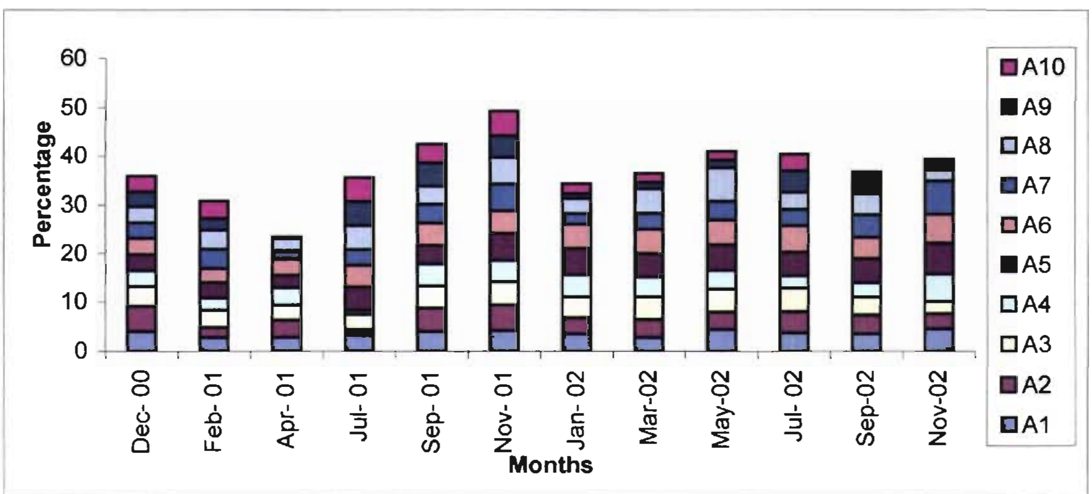


Fig. 6.13 Pattern of sediment organic matter after trawling at stations 1 to 10 from December 2000 to November 2002

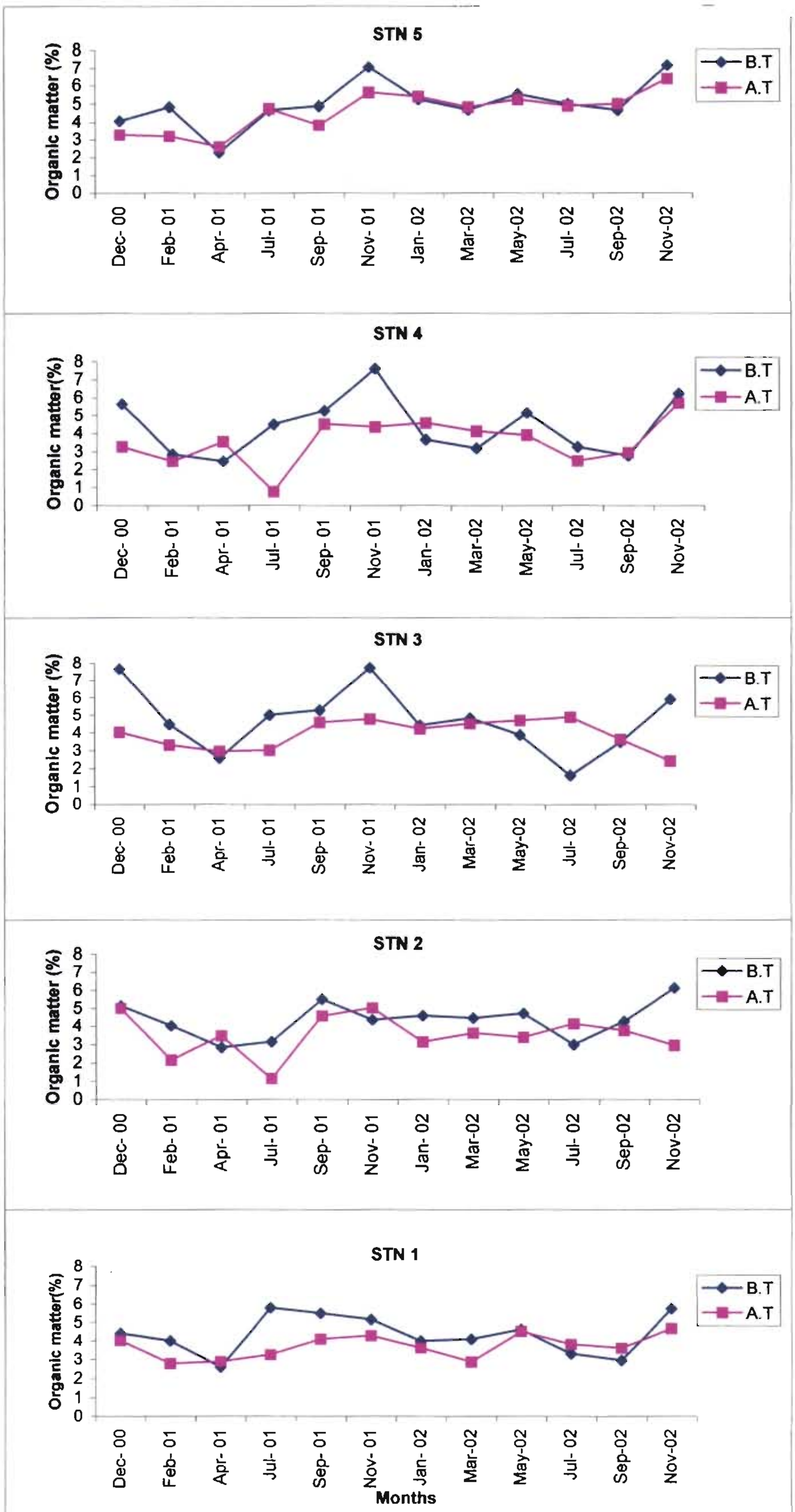


Fig. 6.14a Comparison of sediment organic matter before and after trawling at stations 1 to 5 during December 2000 to November 2002 .

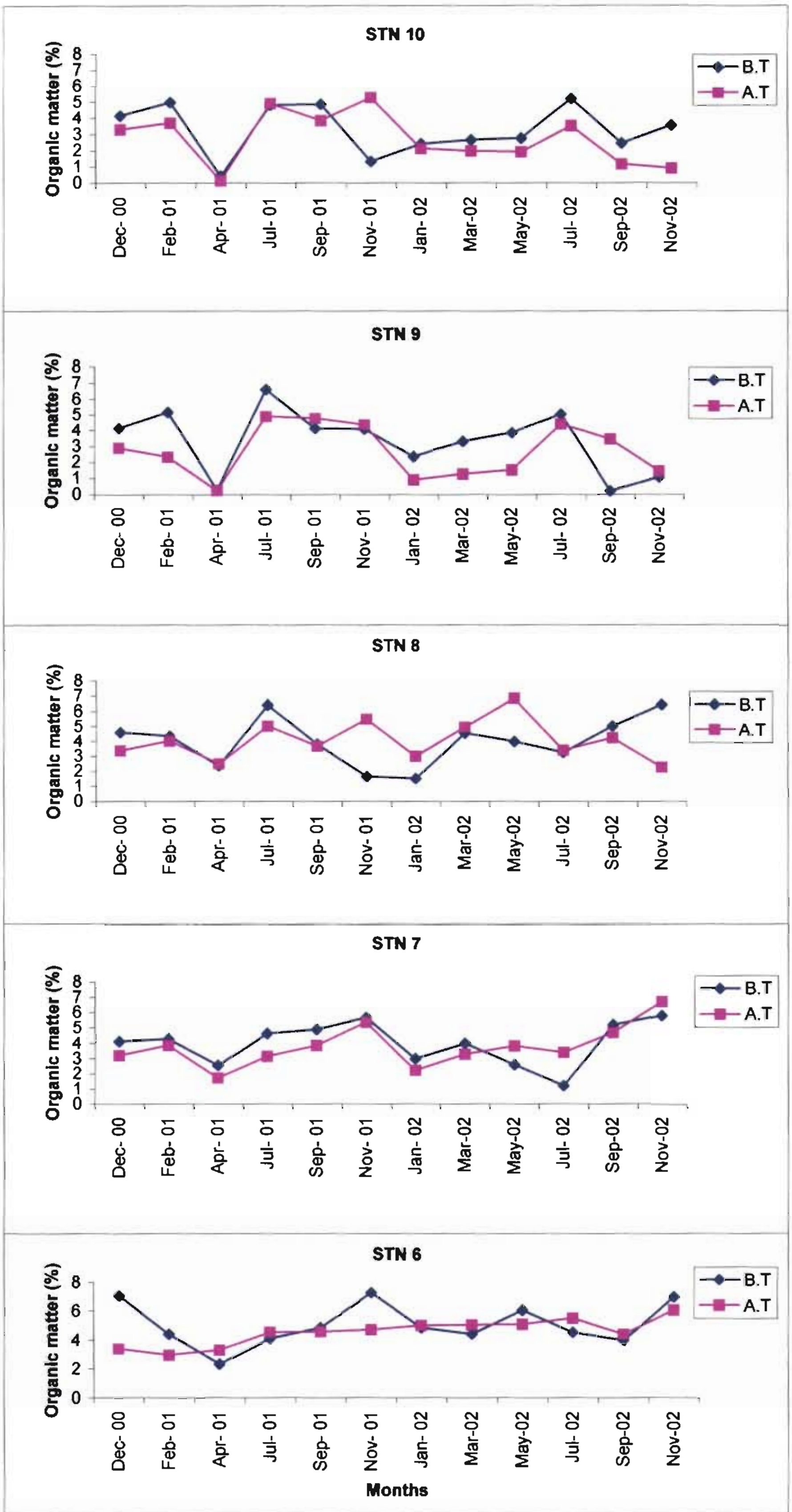


Fig. 6.14b Comparison of sediment organic matter before and after trawling at stations 6 to 10 during December 2000 to November 2002

Table 6.1 Results of the t test on comparing the sediment fractions and Organic matter recorded before and after trawlling

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	N.S
	S4-A4	1.806	11	N.S
	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

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

Table. 6.2 Results of the grains size analysis of the sediments

St.No	Standard deviation		Skewness		Kurtosis	
	Before Trawling	**After Trawling**	**Before Trawling**	**After Trawling**	**Before Trawling**	**After Trawling**
1	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Very fine skewed to Coarse-skewed	Very fine skewed to Near symmetrical	Very platykurtic to Platykurtic	Very platykurtic to very Leptokurtic
2	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Very fine skewed to Very coarse-skewed	Very fine skewed to Very coarse-skewed	Very platykurtic to Platykurtic	Very platykurtic to Platykurtic
3	Poorly sorted to Very poorly sorted	Very poorly sorted	Near-symmetrical to Very coarse skewed	Fine skewed to Very coarse skewed	Very platykurtic to Platykurtic	Very platykurtic to Platykurtic
4	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Fine -skewed to Very coarse-skewed	Very fine skewed to Very coarse skewed	Very platykurtic to Platykurtic	Very platykurtic to Platykurtic
5	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Coarse skewed to Very coarse - skewed	Near symmetrical to Very coarse skewed	Platykurtic	Very platykurtic to Platykurtic
6	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	coarse skewed to Very coarse skewed	Near symmetrical to Very coarse skewed	Very platykurtic to Platykurtic	Very platykurtic to Platykurtic
7	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Very fine skewed to Fine skewed	Very fine skewed to Fine skewed	Mesokurtic to Extremely leptokurtic	Very leptokurtic to Extremely leptokurtic
8	Poorly sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Very fine skewed to Fine skewed	Very fine skewed to Near symmetrical	Very leptokurtic to Extremely leptokurtic	Platykurtic to Extremely leptokurtic
9	Moderately sorted to Very poorly sorted	Moderately sorted to Very poorly sorted	Very fine skewed to Near symmetrical	Very fine skewed to Fine skewed	Leptokurtic to Extremely leptokurtic	Mesokurtic to Extremely leptokurtic
10	Moderately sorted to Very poorly sorted	Poorly sorted to Very poorly sorted	Very fine skewed to Near symmetrical	Very fine skewed to Fine skewed	Leptokurtic to Very leptokurtic	Very platykurtic to Extremely leptokurtic

Chapter 7

EFFECT OF BOTTOM TRAWLING ON EPIBENTHOS

7.1 Introduction

Trawling in general and bottom trawling in particular are the mainstreams of human interventions involved in the exploitation of seafood resources all over the world. Such activities are among the most disruptive and widespread human induced physical disturbances to seabed communities and has become a global environmental concern. A vast number of studies have concentrated on the ecological effects of fishing (Jennings and Kaiser, 1998; Hall, 1999; Moore and Jennings, 2000). The trawl gears used in the bottom trawlers scrape the sea bottom capturing organisms or species, both of economically important and unimportant groups. The ubiquitous use of tickler chains by bottom trawlers for maximizing the catch are gaining importance in the recent past. The species, which do not fetch any price otherwise, termed as "discards" are simply thrown back to the sea or brought to the harbours to fetch very minimal price.

The global commercial fishery has been conservatively estimated to generate 27 million tonnes per year of discards and by-catch organisms that are returned to the sea for various reasons, of which the highest rates of discarding have been attributed to shrimp/ prawn trawl fisheries with an estimate of 9.5 million tonnes per year (Alverson *et al.*, 1994). Fish are discarded due to a number of reasons (Clucas, 1997), such as the wrong species, wrong size, wrong sex, damaged fishes, poisonous nature, rapid spoilage, lack of storage space onboard, high grading, prohibited species, caught using prohibited gears, etc. Recent studies have demonstrated that fishing gears towed across the sea bottom scuffing it may lead to perturbation of benthic fauna and habitats (De

Groot 1984; Messiah *et al.,* 1991; Jones 1992; Dayton *et al.,* 1995a; Jennings and Kaiser 1998; Auster and Langton 1999). The incessant operation of bottom trawlers along the sea bottom resulted in disproportionate destruction non-target groups along with juveniles/ sub adults of heterogeneous species of commercially important shell fishes and finfishes and a wide spectrum of benthic organisms, most of which have low or currently no edible·and economic value but perform a vital role in the food web of all exploitable resources (Menon, 1996). This post harvest loss in capture fisheries and habitat alteration and diversity degradation as a consequence of excessive bottom trawling is a matter of grave concern to most of the developed and developing countries and therefore, a lot of effort has been made to recover and utilize the by-catch. Many studies are also being conducted to resolve the by-catch loss in the bottom fishing. The discards may not be important from the economic point of view but their removal from the ecosystem may bring about both direct and indirect effects. The direct effects include damages sustained by organisms coming in contact with the trawl gear and mortality of a significant percentage of discards hauled up (Graham, 1955; Bridger, 1970; Houghton *et al.,* 1971; Margetts and Bridger, 1971; De Groot, 1973; Fonds, 1994). Among the indirect effects, which are not looked in to quite often, exposure to predation (Holme, 1983; Brown, 1989; Rees and Eleftheriou, 1989; Krost, 1990; Langton and Robinson, 1990; Bergman and Hup, 1992; Brylinski *et al.* 1994; Kaiser and Spencer, 1996b; Ramsay *et al.*, 1996, 1998), reduction in benthic abundance, diversity and habitat complexity (Pope and Knights, 1982; ICES, 1992; Thrush *et* *al.,* 1995; Currie and Parry 1996; Greenstreet and Hall, 1996; Kaiser and Spencer 1996a; Rijnsdorp *et al.*, 1996; Collie *et al* 1997; Tuck *et al.*,1998) are most notable. Among the discarded component a considerable amount of organisms fall in the epifaunal category. Epifauna are defined as those animals living on, protruding from, anchored in, or attached to the substratum. Fishing has significant direct and indirect effects on the habitat, diversity and productivity of communities. One of the most likely direct effects of towed gears on seabed communities will involve changes in the relative abundance of predators and/or their prey, and the reduction in abundance of vulnerable species. The size structure of the fish assemblages will also be strongly affected by fishing pressures (Rice and Gislason, 1996; Rijnsdorp et al., 1998). Many of the scientists in this field are now assessing 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 (Ehrlich and Wilson, 1991; Walker, 1992; Huston, 1994; Lawton 1994; Tilman and Downing, 1994; Naeem *et al.*, 1994,1995; Johnson *et al.*, 1996; Kunin and Lawtom, 1996; Vane-Wright, 1996).

Currently, 90% of the global fish catch comes form the coastal ocean (Moore 1999) and among the various fishing methods bottom trawling is the most dominant, widely employed for the capture of benthic resources (De Groot, 1984). The mechanized bottom trawling became widespread all along the trawlable grounds of Indian waters by the end of 1960s and established as the most dominant fishing techniques to exploit the benthic resources. The southwest coast of India especially the coastal waters of Kerala is the most productive area in the subcontinent and the state has been in the forefront in marine fish production (Kurup 2001b). Though the coastline of Kerala is one tenth of the coastline of India, the state occupies the foremost position in the marine fish production of the country, accounting for more than 30% of the marine fish production (Thomas, 2000). The fisheries production increased from 2.2 lakh tonnes in 1983 to 5.62 lakh tonnes in 2001 (Kurup 2001a). The coastal waters of Kerala have rich and varied fishery resources, which are subjected to heavy exploitation by a number of fishing gears. Mechanized bottom trawlers along Kerala state have a numerical strength of 4900 (Kurup 2001a) against the permissible number of 1145 (Anon 1989), and outnumber all the other types of fishing methods. Apart from the target groups the trawl catch is composed of a variety of demersal fish species, which are destined to be discarded due to various reasons given above. So far no serious attempt has been made in India to establish the quality and quantity of the enormous post harvest loss of benthos. Quantitative information on discarding has a great importance in relating to the energy flow of the marine ecosystem. The lack of quantitative data set of discards in the southwest coast of India makes it difficult to evaluate the effect of trawling on the epibenthos in this region. The present study, therefore attempts to quantify the epifaunal discards along the coastal waters of Kerala.

7.2 Materials and methods

Materials and method used for in the study is illustrated under in the chapter 2.

7.3 Results

Effects of bottom trawling on epibenthos were analysed by estimating the quantity of epibenthos discarded from the trawl catches by participating in onboard trips in the commercial bottom trawlers along the Kerala coasts as well as conducting experimental trawling operations along Cochin - Munambam area (Plate 7 1- 7.4). Discards obtained during the study period encompass 7 species of finfishes, 23 species of gastropods, 6 species of soles, 14 species of crabs including 3 commercially important ones, 4 species of shrimps in the stage of advanced post larva and juvenile, 1 species of stomatopod, and 3 species of echinoderms. The discards quantified from the Kerala coast during the years 2000 - 01 and 2001 02 were to the tune of 2.62 and 2.25 lakh tonnes respectively.

7.3.1Groupwise composition of Epifaunal discards

Month wise contribution of the target and discards in the year 2000-01 and 2001-02 along in the Kerala coast are depicted year wise in Fig 7 1 and 7.2 respectively. The quantity of epibenthos discarded was 1.68 and 1.31 lakh tonnes in the period 2000-01 and 2001-02 respectively (Fig.7.3). Month wise contribution of the epifauna to the total discards observed in the two years period are given in Fig 7.4 and 7.5. The species composition of the epibenthos discards revealed that crabs were the dominant in both the years (Fig.7.6 and

7.7). During 2000 - 01 the share of crabs was 39.59% followed by stomatopods (39.22%) and gastropods (12.73%). The share of the shrimps, finfishes and soles were to the tune of 3.30, 2.91 and 1.67% respectively. In comparison, in the year 2001-02, an increase in the percentage composition of crabs (46.79 %) followed by gastropods (13.14%), finfishes (5.94 %) and a decrease in that of stomatopods (25.83%) were noticed.

7.3.2 Temporal variation in quantity of Epifaunal discards

The highest quantity of discards during the first year of study was recorded in January with 27072 tonnes. The dominant groups recorded during this period were crabs (13361 tonnes) with preponderance of the species *Charybdis granulis* (9696 tonnes). On the contrary, during the second year, highest discards were recorded in April (21514 tonnes) during when stomatopods showed dominance (10940 tonnes). Discards were minimum during early post monsoon months in both the years (Fig. 7. 8).

7.3.3 Groupwise temporal variation of epifaunal discards

The stomatopods were dominated by viz *Oratosquilla nepa.* During the first year, 66002 tonnes of stomatopods were discarded back in to the sea, however, the quantity caught and discarded during the second year showed around 50% decrease (34015 tonnes). Maximum discards during the first year were recorded in February (11510 tonnes). The quantity of this group even reached up to 300-400 kg/ haul with a CPUE of 88.5 kg/ hr. During the second year, high quantity of stomatopods as discards was registered during April 2001 with 10939 tonnes. Subsequently, a decreasing trend in its abundance was observed till March 2002. However, this species was not found in September 2001. In the two-year study, the lowest quantity of discards of this species was recorded in October 2000 with 370 tonnes (Fig. 7 9).

A total of 128247 tonnes of crabs, of both edible and non- edible species were discarded back to the sea. The quantity of crabs discards during the first and second years was 66637 and 61610 tonnes respectively. During first year (2000-01) highest quantity of crab discards was observed in August 2000 (19144 tonnes), among them the most predominant species was the swarming crab *Charybdis smithii* which accounted for 54.67 % of the total discarded non-edible crabs. *C.smithii* was found all along the coast with highest abundance off Cochin region at the depths of 70-180 m. During the second year also, the trend was similar with 17343 tonnes of crabs were recorded in August and the predominance of C. *smithii* was noteworthy. Lowest quantities of crabs were discarded during November in both the years (Fig. 7 10). Highest quantities of epifaunal finfishes discarded in 2000-01 were in September (958 tonnes) where the species *Rogadius asper* dominated with 760 tonnes. In 2001-02, maximum quantitiy of epifaual finfishes with 1957 tonnes was recorded in October 2001 and the highest share was contributed by *Rogadius asper* (1512 tonnes). The lowest quantity of discards was registered in May during both the years (Fig. 7 11).

Soles, which are having commercial importance, were discarded largely because of their smaller size. The quantity of soles discarded in the first and second years was 2802 and 2984 tonnes respectively. Highest quantity of soles was discarded during the first year in May 2000 (678 tonnes) wherein Cynoglossus *macrostomus* (590 tonnes) appeared as the most predominant species. During second year, maximum discards of soles were registered in February 2002 (603 tonnes) with the dominance *Cynoglossus macrostomus* (261 tonnes). Lowest quantities of sole fish discards were encountered in November during both the years. Interestingly discards were nil during December 2001 (Fig. 7.12).

Discarding of juvenile shrimps from bottom trawling is another matter of grave concern. It was observed that a total of 5587 and 5662 tonnes of juvenile shrimps were discarded back into sea during 2000-01 and 2001-02 respectively. Highest quantity of shrirnp juveniles was observed in May during the first and second years with 1591 and 2813 tonnes respectively (Fig. 7 13). Among the shrimp juvenile discards, *Parapenaeopsis stylifera* appeared as the dominant species during both the years registering 1177 and 2238 tonnes respectively. Discards of this category were negligible or practically nil during the late post monsoon and early pre-monsoon periods.

Gastropods, which appeared as another important group in the discards, were mostly discarded into the sea due to their unpalatibility. Gastropods constituted only 12% (21419 tonnes) of the total epifaunal discards in the first year, interestingly, in the second year, even though the quantity discarded was lesser (17,303 tonnes) when compared to the first year, its percentage contribution to the total epifaunal discards showed an increase to 25.83% (Fig. 714). Highest quantity of gastropods was discarded during September 2000

(3757 tonnes) with *Tibia matala* as the dominant species (831 tonnes), followed by *Babylonia spp* (1165 tonnes) and *Murex spp.* (442 tonnes). Gastropods were found least in the discarded fraction in December 2000 (252 tonnes).

During second year, highest gastropod in the discards was observed in February 2001 with 3471 tonnes. The dominant species were *Murex spp* (2458 tonnes), *Babylonia spirata* (636 tonnes) and *Harpa spp.* (276 tonnes). Lowest quantity of gastropod was discarded in December 2001 (470 tonnes, Fig. 7 14)

Echinoderms also registered in the discards with a 998 and 2288 tonnes during 2000-01 and 2001-02 respectively. The peak quantity in this group in the discards was observed during May 2000 (226 tonnes) in the first year and 1388 tonnes in April 2001 during second year. These groups were found absent during August 2000, January 2001, February 2001, August 2001 and December 2001. The lowest quantity of this group in the discards was observed in November 2001 (13.31 tonnes, Fig. 7.15).

7.3.4 Seasonal variation in epifaunal discards

Finfishes in discards did not show much seasonal variations in both the years. However crabs were found to be discarded in large quantities during the monsoon season and this was attributed the emergence of swarming crab *Charybdis smithii* during these periods along the southwest coast of India (Plate 7.5). In 2000-01, quantity of crabs (30719 tonnes) discarded was much higher during the monsoon season than the pre monsoon (18344 tonnes) and post monsoon (17574 tonnes) seasons (Fig.7 16). Although a similar trend was observed in the year 2001-02, however, the quantity registered in the monsoon

(37535 tonnes) was relatively high whereas a reduction was observed during premonsoon (13125 tonnes) and post monsoon seasons (10948 tonnes) (Fig. 7 17). With regard to other groups such as soles, shrimps, gastropods, stomatopods and echinoderms, the quantity discarded in the pre monsoon season was much higher when compared to monsoon and postmonsoon months.

7.3.5 Species Composition of Epifaunal discards groups

Among the finfishes *Rogadius asper* appeared as the most dominant species in the discards in both the years contributing to 42.63% in the first year and 51.69% in the second year. During the first year, of the finfish group, the share of *Muraenesox spp*, *Platycephalus spp*, *Conger cinereus* and *Parapercepsis nebulosa* were in the tune of 23.51, 20.93, 7.96 and 4.96% respectively (Fig. 7 18). On the contrary, during the second year, there was a reduction in percentages of *Muraenesox spp* (7.21%) and *Conger cinereus* (5.75%), however, an increase was observed in respect of *Platycephalus spp* (27.47%), and *Parapercepsis nebulosa* (7.89%) (Fig. 7 19).

Crabs were dominated by the species *Charybdis granulis* (45.72%) and *Charybdis smithii* (33.19%) during the first year (Fig.7.20). On the contrary, during the second year *Charybdis smithii* (44.18%) showed dominance among the discards followed by *Charybdis granulis* (34.83%) and *Callapa lophos* (10.67%) (Fig.7.21). Interestingly, the edible component in this category formed only 5.22 (2000-01) and 3.33 % (2001-02).

In the case of shrimps, only three species were encountered in the discards during the first year viz *Parapenaeopsis stylifera* (62.79%), *Metapenaeus dobsonii* (36.63%) and *Trachypenaeus spp* (0.58%) (Fig. 7.22). During the second year, the percentage contribution of *Parapenaeopsis stylifera* and *Metapenaeus dobsonii* were in the tune of 64.22 and 33.68% respectively (Fig. 7.23). The share of *Plesionika ensis*, which was absent in the first year, was 2.10%. Interestingly the species *Trachypenaeus* was absent during this period.

The dominant species of soles appeared in the discards during the first year was *Cynoglossus macrostomus*, which accounted for 80% of the discarded soles. The share of the *Pseudorhombus arsius* and *Cynoglossus bilineatus* during this period was 8.04 and 6.08% respectively (Fig. 7.24). During the second year, even though there was the dominance of *Cynoglossis macrostomus*, its percentage showed a reduction (55.17%), on the other hand, *Pseudorhombus arsius* (25.85%) and *Cynoglossus bilineatus* (10.77%) showed their enhanced contributions in the discards (Fig. 7.25).

Among the gastropods discarded, *Babylonia spirata* (19.14%) was the dominant species followed by *Turritella maculata* (18.04%) and *Tibia fusus* (12.98%) with significant contributions from Babylonia zeylanica (8%), Turritella spp (7.96%) and Murex (7.49%) during the first year (Fig. 7.26). On the contrary, during year 2001-02, Murex spp. (26.65%) was the dominant one followed by *Babylonia spirata* (16.89%) and *Tibia fusus* (14.54%) (Fig.7.27).

7.3.6 Temporal variations in CPUE of epifaunal discards

The actual fishing time is defined as the duration of the drag of the net when it is in contact with the sea bottom. The average duration of a tow was 1.4 hrs with 10 minutes each for shooting and retrieval of the net. The highest CPUE during the first and second year was observed in August with 69.9 and 71.75 kg/ hr respectively (Fig.7.28). During this period, crabs especially *Charybdis smithii,* were the dominant species registering 59.28 (2000-01) and 48.62 kg/ hr (2001-02).

7.3.7 CPUE of major groups in epifaunal discards

The CPUE of finfishes during the first and second year of study was highest in September recording 3.61 and 3.51 kg/ hr respectively. *Rogadius asper* was the dominant species during both the years with 3.23 (2000-01) and 3.15 kg/ hr (2001-02). The lowest CPUE was recorded in December with values as low as 0.28 and 0.07 kg/ hr during 2000-01 and 2001-02 respectively (Fig.7.29).

Highest CPUE of crabs was recorded in August in 2000-01 (59.28 kg/ hr) and 2001-02 (48.62 kg/ hr). Post monsoon season registered the lowest CPUE during the preceding and succeeding years. Smaller peaks were observed in September 2000 (21.93 kg/ hr) January 2001 (25.2 kg/ hr), and September 2001 (21.41 kg/ hr) (Fig.7.30). The high CPUE of crabs in January 2001 was accounted by *Charybdis granula* (26.73 kg/ hr).

During 2000-01, highest CPUE of soles was registered in May (2.73 kg/ hr) while it was least during February 2001 (0.12 kg/ hr) whereas, the catch was nil in November 2000. On the contrary, during 2001-02, January 2002 accounted for the highest CPUE of soles (1.7 kg/ hr), however, it was least in February 2002 (0.12 kg/ hr). In both the years CPUE of soles was higher during the premonsoon period in the discards (Fig. 7.31).

As reported in gastropods, highest CPUE was recorded in September with 14.37 kg/ hr during 2000-01 and 13.98 kg/ hr during 2001-02. The least was observed in October during both the years of survey. CPUE of gastropods was almost similar throughout the remaining months (Fig. 7.32).

Highest CPUE of stomatopods was recorded in April during both the years showing 30.14 and 31.03 kg/ hr respectively and the least was observed during late monsoon and postmonsoon seasons (Plate 7.6). CPUE was high during the pre monsoon season of the first year, however, similar trend was not observed during the second year (Fig.7.33).

A trend of higher CPUE of shrimps was recorded during the month of May in both first (6.4 kg/ hr) and second years (7.06 kg/ hr). CPUE was lowest during late postmonsoon, however, the increasing trend observed during the premonsoon period of the first year could not be observed during the second year during when its representation was nil (Fig.7.34).

During the two year periods of the study, the CPUE of echinoderms was found highest during April 2001 with 3.44 kg/ hr. They were absent or negligible during early pre monsoon periods (Fig.7.35).

ANOVA showed significant seasonal variations in the major epifaunal discards such as finfishes, crabs, gastropods (P< 0.01, Appendix V, Table 1-3). However, no significant variations could be observed in the echinoderms discarded during the study period (P>0.01, Appendix V, Table 4). Moreover, no significant variations could be noticed when the CPUE of the above groups of both the first and second years were compared (P> 0.01, Appendix V, Tables 5-8).

7.3.8 Seasonal variation in CPUE of epifaunal discards

The CPUE of epifaunal discards during both the years of observation was highest during the monsoon period registering 42.64 and 41.37 kg/ hr respectively. Crabs were the dominant groups during this period recording on an average 25.6 (2000-01) and 21.3 kg/ hr (2001-02). However, the CPUE was lowest during the post monsoon season of the both the years registering 25.23 kg/ hr in 2000-01 and 15.28 kg/ hr in 2001-02.

7.3.9 Variations in the diversity of major epifaunal discards

Shannon diversity index of the major epifaunal discards such as finfishes, crabs and gastropods were calculated based on the biomass obtained in the two years of the study. Among finfishes diversity (H') ranged between 0.5 – 1.37 in the first year where the highest (1.37) was observed during January 2001 and the lowest (0.5) recorded during August 2000. During the second year, the diversity values ranged from 0.64 to 1.3, with highest (1.3) in January 2002 and the lowest (0.64) in October 2001. An increase in diversity of finfishes was observed during the second year (Fig. 7.36) however, the variation was not statistically significant (P> 0.01, Appendix V, Table 9). In the case of Gastropods, Shannon's diversity ranged between 1.4 - 2.28 during first year where the highest (2.28) was registered in March 2001 and the lowest (1.4) in December 2000. During the second year, diversity (H') values ranged between 0.64 and 2.04 where the highest (2.04) was recorded during June 2001 and the lowest during December 2001. The diversity of gastropods was found decreased during the second year when compared to that of first year (Fig. 7.37). Nevertheless significant variations could not be observed (P> 0.01, Appendix V, Table 10). Shannon's diversity measured in the case of crabs were also showed a decreasing trend in the second year when compared to that of first year (Fig. 7.38). During the first year, the values ranged between 0.37 and 1.49 where the highest (1.49) value was observed during December 2000 and the lowest (0.37) during August 2000. During the second year, the diversity (H') values ranged from 0.35 to 1.13 where the highest (1.13) was registered during June 2001. Though the diversity values showed a distinct reduction decrease in the second year, however, significant variations were not found significant when compared to that of first year (P> 0.01, Appendix V, Table 11).

7.3.10 Quantification of epibenthos during experimental trawling

Experimental trawling was conducted using a hired commercial trawler on a bimonthly basis along the Cochin - Munambam area from December 2000 to November 2002. The study area up to 50 m depth was divided in to five-depth zones viz. 0-10, 11-20, 21-40 and 41- 50 m. A total of two hauls were operated in each depth zone with duration of one hour each.

7.3.11Temporal variation in quantity of epifaunal discards

Month wise contribution of the target and discards for the year 2000-02 obtained in the experimental trawling operations conducted along Cochin-Munambam area. The total quantity of epibenthos discarded during the study period is depicted in Fig. 7.39. The total quantity of epibenthos discarded during 2000-01 and 2001-02 were to the tune of 1103 and 505 kg respectively (Fig 7.40). Highest quantity of discards was recorded in December 2000 during the first year (Fig.7.41) with 456kg where Stomatopods appeared as the dominant group registering 301 kg. During the Second year, highest discard of 179 kg was recorded in November 2002 with crabs as the major group (73 kg) of discards, which is dominated by *Callapa lophos* (28 kg). Lowest discards were registered in February 2001 (121 kg) and March 2002 (51 kg) respectively in first and second years (Fig.7.41). Though experimental trawling was conducted in July during both the years by obtaining special government sanction since there is a ban imposed for bottom trawling, however, no discard was registered during this period.

7.3.12 GroupWise quantity discarded

Of the 1103 kg discarded during the first year, stomatopods were the dominant group (518.7 kg) followed by crabs (284.65 kg) and gastropods (212.96 kg). The share of finfishes (50.99 kg) and Soles (27.62 kg) were glaring, however, shrimps (5.81 kg) and Echinoderms (3 kg) were appeared in negligible quantities (Fig.7.42).

On the contrary, during the second year, the quantity of discards showed a reduction (505 kg) to less than half of the first year. The dominant groups appeared in the discards were gastropods (152.58 kg) followed by crabs (121.97 kg), finfishes (86.90 kg), stomatopods (72.63 kg) and soles (62.67 kg). The contributions of echinoderms and shrimps were 8.22 and 0.13 kg respectively (Fig. 7.43).

7.3.13 GroupWise temporal variation of epifaunal discards

Finfishes were found in large quantities during April 2001 (15.89 kg) in the first year and in January 2002 (46.52 kg) in the second year. *Rogadius asper* (7.81 kg) was the dominant species in the first and while it was *Platycephalus niger* (22.87 kg) in the succeeding year. September accounted for the lowest finfish discards in both the years (Fig. 7.44).

Highest quantities of crabs were found discarded during September 2001 (115.2 kg) and November 2002 (73.42 kg) during 2000-01 and 2001-02 respectively. Among the dominant species, Charybdis *granulis* accounted for 111 kg during 2000-01 while *Callapa lophos* landed with 28.18 kg during 2001-02 (Fig. 7.45).

Soles, another major group of discards were recorded highest in April 2001 during the first year (8.66 kg) and in January 2002 (27.6 kg) during the second year. *Cynoglossis macrostomus* (6.71 kg) was the dominant species in the first year while *Pseudorhombus arsius* (14.87 kg) dominated in the second year (Fig.7.46).

In the case of shrimps, highest quantities were recorded during April 2001 with 3.8 kg during first year. Barring the negligible amount in March 2002, during the second year, this category was totally absent in the discards (Fig. 7.47).

Highest quantity of stomatopods was recorded in December 2000 during the first year with 301.8 kg. During the second year, the quantity of stomatopods discarded was generally low in all the months with January 2002 recording the highest (31.13 kg) (Fig. 7.48).

Echinoderm discards were very minimal and were noticed only during November 2001 (2 kg) and April 2001 (1 kg) in the first year Discards of this category were highest during November 2002 (5.7 kg) in the second year (Fig. 7 49).

7.3.14 Species Composition of Epifaunal discard groups

Stomatopods in the discarded fraction was represented by a single species viz *Oratosquilla nepa*.

Of the 7 species of epifaunal finfish encountered in the discards during the first year, *Platycephalus niger* (23.16 %) and *Rogardius asper* (23.16 %) were found dominant. The share of *Muraenesox bagio* (12.36 %), *Conger cinereus* (11.77%) and *Parapercepsis nebulosa* (11.02%) were noticeable (Fig. 7.50). Interestingly, during the second year, only three species such as

Rogadius asper (44.32 %), *Platycephalus niger* (39.19 %), and *Parapercepsis nebulosa* (16.48%) were recorded in the discards (Fig. 7.51).

Among the crabs, during first year *Charybdis granulis* (64.75%) showed dominance together with *Callapa lophos* (7.55%) and *Doclea gracilipes* (6.67%) (Fig. 7.52). On the contrary, during the second year, *C. lophos* (26.56%) appeared as the dominant species followed by *C. granulis* (20.44%), *Charybdis variegata* (14.32%), *Phyllyra coralicola* (10.21%) and *Doclea gracilipes* (10.17%) (Fig. 7.53). The share of the edible components during the first and second years was 6.18 and 6.86 % respectively.

Cynoglossus macrostomus was the dominant species among the sole discarded during the first year with a contribution of 55.43%. *Pseudorhombus arsius* was the second most dominant species during this period with 28.64 % (Fig. 7.54). However during the second year *P. arsius* (54.44%) showed its dominance followed by *C. macrostomus* (40.77%) (Fig. 7.55).

Among gastropods, there was the dominance of *Babylonia* spirata (27.28%), followed by *Tibia maculata* (19.11%), *Turritella spp* (13.52%) and *Tibia fusus* (11.22%) (Fig. 7.56). During the second year too, *Babylonia spirata* (43.19%) appeared as the most dominant species with significant contributions also from *Harpa spp* (26.20%), *Tibia fucus* (9.12%) and *Tibia maculata* (8.20%) (Fig. 7.57).

Of the total quantity of shrimps discarded, 58.35% was constituted by *Parapenaeopis stylifera* and the rest by *Metapenaeus dobsonii* (41.65%) (Fig. 7

58). During the second year, very meager quantity of shrimps was discarded and comprised of single species, *Parapenaeopsis stylifera* (0.13 kg).

7.3.15 CPUE of Epifaunal discard groups

While comparing the temporal variation of the total quantity discarded as part of the experimental trawling, highest CPUE was recorded in November during the first (23.33 kg/ hr) and second years (17.87 kg/ hr)(Fig.7.59). Stomatopods (10.56 kg/ hr) was the dominant group during the first year while crabs (7.34 kg/ hr) occupied the major share during the second.

CPUE of finfishes was highest (1.55 kg/ hr) in April 2001 during the first year and in January 2002 (4.22 kg/ hr) during the second (Fig.7.60). The dominant species was reported by *Rogadius asper* (0.76 kg/ hr) and *Parapercepsis niger* (2.07 kg/ hr) during the first and second years respectively.

Highest CPUE of crabs was recorded in September 2001 (7.2 kg/ hr) during the first year. The corresponding figure for the second year was recorded in November 2002 (7.34 kg/ hr) (Fig. 7.61). *Charybdis granulis* (6.93 kg/ hr) was the predominant species in the first year while *Callapa lophos* dominated in the second year (2.81 kg/ hr).

The quantity of soles discarded in the first year was low when compared to second year (Fig. 7.62). Highest CPUE of 0.85 kg/ hr was recorded in April 2001 during first year and 2.5 kg/ hr in January 2002 during the second. *Cynoglossus macrostomus* (0.65 kg/ hr) and *Pseudorhombus arsius* (1.35 kg/ hr) were the dominant species during the preceding and succeeding years respectively.

Highest CPUE of stomatopod (14.57 kg/ hr) was recorded in December during first year (Fig. 7.63). However during the second year the quantity recorded was very low, the highest CPUE was recorded in January 2002 (2.83 kg/ hr).

During the two year of study, shrimps were recorded as discards only during December 2000, April 2001 and March 2002 (Fig. 7.64). The CPUE was highest during April with 0.37 kg/ hr.

Gastropods, which were one of the dominant epifaunal discards, recorded highest CPUE in December 2000 (3.85 kg/ hr) during the first year and in November 2002 (4.46 kg/ hr) during the second (Fig. 7.65). *Babylonia spirata* was the dominant species in the first (1.52 kg/ hr) and second years (1.76 kg/ hr).

CPUE of echinoderm was highest during November during the first (2.07 kg/ hr) and second years (0.57 kg/ hr) (Fig. 7. 66). This group of discards was found in very lowest minimal quantities during the entire study period.

7.3.16 Variations on the diversity of major epifaunal discards

Shannon's diversity index was computed based on the biomass of major epifaunal discards such as finfishes, crabs and gastropods and the results are given in Fig 7 67. Finfishes showed almost similar diversity values during the both the years, which ranged 0.57 to 1.00 and 0.65 to 1.08 in the first and second years respectively however, highest mean diversity was recorded in the second year with 0.70 against 0.45 in the first year. During the first year, the highest diversity values (1.00) were recorded during December 2000 and

November 2001 while the lowest was recorded during April 2001. During the second year highest values were recorded during March 2002 while the lowest was obtained in May 2001. Significant variation could not be seen in the diversity recorded in both the years (P> 0.01). In crabs, diversity (H') varied between 0.15 and 1.79 and 0.99 and 1.59 in the first and second years whereas during the first year, highest values were recorded during April 2001 while it was lowest in September 2001 whereas during the second year the highest values were observed during November 2002 and it was lowest in March 2002 (Fig. 7.68). A slight decrease in the diversity was noticed in the second year with a mean diversity of 0.81 against 0.91 in the first year. However, significant variation was not observed when compared the diversity values of in the first and second years (P> 0.01). Gastropods also showed almost similar diversity values, ranging between 0.94 and 1.82 and 0.63 and 1.45 in the first and second year of the study. However a slight decrease in diversity was noticed in the second year as 1.0 recorded during second year against 1.22 during first year (Fig. 7.69). Highest diversity was recorded during September 2001 while the lowest was in November 2001 in the first year. During second year, the highest diversity was registered during September 2002 with the lowest during January 2002. There was no significant variation when the diversity values recorded during first and second year of this study were compared (P>0.01).

7.4 Discussion

The results of the present study revealed that bottom trawling operation along the southwest coast of India destroy substantial quantities of fish and other marine invertebrates. Bottom trawling is aimed at capture the benthic organisms particularly shrimps. Over much of the world's continental shelves, benthic dwelling fish and shellfish are captured by trawls and dredges, which are dragged along the bottom (De Groot, 1984; Hutchings, 1990; Watling and Norse, 1998; Kaiser and De Groot, 1999). Modern bottom trawl net is equipped with heavy tickler chains and big steel otter boards facilitated to collect as much benthic organisms by digging and thus leading the disturbed organisms being hauled into the net. After sorting the target species, those with the low economic value which do not fetch any price in the market such as non edible crabs, stomatopods, echinoderms and gastropods along with juveniles and eggs of commercially important fin and shellfishes are thrown back to sea as "discards" Pauly *et al.* (1998) stated that commercial exploitation of the marine stock increased the threat to invertebrate epifaunal and infaunal organisms. The average amount of 1.5 lakh tonnes of epifaunal organisms which are discarded into the sea, computed in the present study undoubtedly support the above statement. The total discards from the bottom trawl fishery during the period was 2.5 lakh tonnes. The study also revealed that about 61% of these discards were contributed by epifaunal organisms. Large amount of unwanted by-catch were observed in the trawl catch (Alverson *et al.*, 1994; Hall, 1996). Several studies reported that the amount of discards were more than 60 % of the total trawl catch (Gueguen and Charuau, 1975; Edwards and Bennett, 1980; Craeymeersch, 1994). Similarly Pranovi *et al.* (2000) observed 50% of the epifaunal organisms in the "rapido" trawling operations. Camphuysen *et al.*

(1993) estimated about 475,000 million tonnes of fish offal and benthic invertebrates were discarded in the North Sea annually. Morrissery and Robles (1992) estimated that between 350,000 and 700,000 tonnes of by-catch were harvested each year in Mexican waters. It would thus be inferred that the bottom trawling operations is annually destroying a substantial amount of epifaunal marine organisms and the results of the present study provides strong evidence to their findings (Lindholm *et al.*, 1999; Bergmann and Morre. 2001).

Several studies have revealed that trawling/ dredging causes heavy destruction to the fish and other marine organisms (Berghahn, 1990; Bergman and Hup, 1992; Britton and Morton, 1994; Hall Spencer, 1995; Kaiser and Spencer, 1996a; Collie *et al.*, 1997; Auster and Langton, 1999; Hall-Spencer and Moore 2000). The passage of heavy otter boards followed by the large trawl net cause injury and damage to the epibenthic organisms (Caddy, 1973; Watling and Norse, 1998; Norse and Watling, 1999; Hoffmann and Dolmer, 2000; Bergman and Santbringk, 2000; Piet *et al.*, 2000; Smith *et al.*, 2000). Bergmann and Moore (2001) observed that about 90% of the total discard in the Nephrops fishery was constituted by decapod crustaceans and echinoderms. The high quantity of non-edible animals such as crabs, gastropods, echiniderms and stomatopods recorded in the present study also agrees to the above statements.

Demersal trawling causes heavy mortality to the epibenthic organisms by crushing, burying and killing them by the scarping action of the otter boards and net (Sainte-Marie, 1986; Nickell and Moore, 1992; Ramsay *et al.*, 1996; Rumohr and Kujawski, 2000; Groenewold and Fonds, 2000). Sainsbury, *et al.* (1997)

estimated 80 % mortality to the epibenthic organisms from a single trawl pass. In the present study it was seen that most of the species, which are destined to be thrown back to the water, were dead on account of lying onboard during the sorting of target species from the catch. Moran and Stephenson (2000) estimated more than 15% destruction of epifaunal in the single pass of trawl net. Data collected from research surveys on the Australian northwest shelf between 1962- 1983 indicated that the abundance of high value commercial species declined with time (Bergman and Hup, 1992). Kaiser and Spencer (1995) estimated 60 to 90% mortality of the epifaunal communities in the trawl net discards in a study conducted to assess the fate of discards. Most of the fish and cephalopod in the discards are dead by the time they are returned to the sea. A few more robust forms such as crabs and some of the gastropods and echinoderms can survive trawling (Juhl and Drummond, 1976; Bergmann *et al*, 2001a). Large number of bivalves and other commercially important and unimportant organisms are damaged by intensive otter trawling (Artnz and Weber, 1970; Kaiser and Spencer, 1994). In the present study, the major groups of epifauna such as crabs, gastropods, stomatopods, bivalves and eels dominated among the discards with a lion's share contributed by juveniles of commercially important prawns and fishes. Eleftheriou (2000) observed large number of less mobile groups such as crabs, starfishes and bivalves in the trawl catches. Pitcher *et al.* (2000) estimated huge loss of gorgonians and sponges due to shrimp trawling in Great Barrier Reef.

The amount of discards purely depends on the trawling pressure exerted in the fishing grounds. In the present observation, discards were observed in maximum quantities during premonsoon seasons than in monsoon. Increased discards in premonsoon season can be attributed to spurt in fishing for shrimps *Metapenaeus dobsoni* by and large inhabits in the inshore waters between depths 0 - 40 m, where the trawlers use trawl nets rigged with heavier tickler chains with more weights to harvest more resources thus resulting in the exploitation of more benthic organisms.

The way in which trawling is conducted affects the survival of all animals caught in trawl, the most important being the duration of the haul, the time spent out of water and the extent of damage from nets (Wassenberg and Hill 1989). Many studies demonstrated that species such as crabs, echinoderms and gastropods can survive onboard better than fishes and they go back to water alive along with the other discards (Wassenberg and Hill, 1990, Poiner *et al.*, 1998), while the post fishery survival of fish is negligible (Main and Sangster, 1990; Van Beek *et al.*, 1990; Fonds, 1994; Bergman *et al.*, 1998). This may lead to the proliferation of these organisms in the fishing grounds as reported by Pauly (1979). In the present study, the predominance of crabs and gastropods encountered from the trawl catches show strong agreement with the above view. Profound abundance of non edible crabs was recorded in the fishing grounds of Kerala coast with a high CPUE of 120-200 kg by Thomas and Kurup (2001).

In the present study, the percentage composition of crabs, gastropods and echinoderms were found increased in the second year The proliferation of these organisms in the trawled grounds may be due to their ability to survive capture and discard processes. Trawling significantly removes the three-dimensional cover provided by epifaunal organisms (Collie, 1998). Of the many natural and anthropogenic factors that disturb the seabed and reduce structural complexity, the leading factor is fishing with mobile gear (Watling and Norse, 1998). Incessant and excessive trawling activities could disturb the benthic productivity by removing larger and smaller organisms present at sea bottom. Jennings *et al.* (2001a) demonstrated the reduction in benthic production due to the depletion of larger bodied, long-lived benthic species and smaller short – lived species on account of excessive and incessant trawling activities in the North Sea.

Several workers have reported that repeated trawling and dredging causes a shift from communities dominated by species with relatively larger adult body towards dominance of higher abundance of smaller bodied organisms (Auster, *et al.*, 1996; Engel and Kvitek, 1998; Kaiser *et al.*, 2000a). Mortality of discards is relatively low for starfish (< 20%), intermediate for most crustaceans and shellfish but quite high for small fish (90%) (Van Beek *et al.*, 1990; Fonds *et al.*, 1992). In the present study, the quantity of echinoderms discarded increased two – fold during the second year and this result strongly corroborate to the findings of Van Beek *et al.* (1990) and Fonds *et al.* (1992). Moreover, the increase of crabs and gastropods in the trawled areas observed in the present study also in conformity with the above concept. So the incessant trawling operation may cause a shift in the community level at the seabed by allowing the existence of organisms such as crab, echinoderms and gastropods, which survive in the discards. In the onboard survey conducted, mortalities were observed during the course of hauling and also during sorting of species on the deck of the trawler. Moreover, in the discards thrown out to water, most of the fish varieties that afloat on the water were consumed by the sea birds and discards with high sinking speed such as gastropods and crabs would survive when compared to fishes. Balber *et al.* (1995), Blaber and Wassenberg (1989) showed that the diet of crested terns, the sea bird, changed markedly between the times when trawling season was compared to times when it closed and observed that 70% of the diet comprised of benthic species during the trawling season.

Otter trawl has been considered as the most destructive fishing gear than other types of gears, because of their widespread use and non selective nature (Collie *et al*, 2000b; Barnette, 2001). The trawl gear can crush, bury or expose marine flora and fauna and reduce structural diversity (Gilkinson *et al.*,1998; Kenchington *et.al.*,2001). Dolah *et al.* (1991) had also reported the decrease in the species diversity in the trawled grounds. The destruction of fauna and flora needs much time to recover. Harrison *et al.*, (1991) postulated that if the interval between the trawls is shorter than the recovery time, the original benthic structure and species population might not have the opportunity to recover to pretrawl conditions. If the trawling intensity remains high, the communities, which were disturbed during trawling, may never recover (Lindeboom and de Groot, 1998). Southwest coast of India is subjected to heavy trawling pressure particularly in the continental shelf waters. The drastic decline in the stomatopods and bivalves in the present study also lead to the conclusion that intensive trawling activities do not give sufficient time for them to recover. Large amount of juvenile prawns and fishes were found to be destroyed onboard. Considering the magnitude of fishery prevalent along the Southwest coast of India, the discarding of juvenile target groups with alteration of the seafloor habitat by demersal trawling activity could magnify the effect of over exploitation by limiting the juvenile survivorship as reported by Lindholm *et al.* (1999)

A large number of invertebrate epifaunal facultative scavengers that have physiological or behavioral adaptation that enable them to survive the capture and discarding processes (Britton and Morton, 1994). Abundance of organisms such as crabs, gastropods and echinoderms in the trawl catches attribute to the high rate of survival among the discards as noticed by Hill and Wassenberg 1990. The increase in non-edible crabs and gastropods in the trawled grounds observed in the present study indicated that uncontrolled trawling operation would pave way to a community shift in the benthic realm. The differential survival of the various trawled organisms may explain the changes in the composition of trawled communities. The disappearance of reefs of the calcareous tubiform worm, *Sabellaria spinulosa* and their replacement by small polychaete communities has earlier been reported as a consequence of heavy dredging activity in the Wadden sea (Riesen and Reise, 1982). Definite evidence had been noticed for the shift in the composition of benthos after 60 years of inordinate trawling (Frid *et al.*, 2000). Similarly, Hall-Spencer (1995) observed heavy destruction of maerl thalli due to scallop dredging. Reduced densities of small crustaceans, polychaete and molluscs were observed in the trawled grounds (Thrush *et al.*, 1995). Repeated trawling activities will reduce the benthic production and the reduction in trawl epifaunal discards in the second year both in onboard surveys and experimental trawling operations strongly support these findings. Sainbury (1987) also noticed drastic reduction of epibenthic organisms when he analysed the trawl landings between 1963 and 1979. Bull (1986) observed the decreased survival of scallop spat in the trawled grounds and the results of the present study also conform to these findings. Moreover, the results of the effect trawling revealed that the degradation of sponge community and associated soft corals and sea fans were partly responsible for the decline of the catches of Emperors and snappers, which sheltered and fed among these emergent fauna (Sainbury, 1987). High diversity of animals live among the emergent epifauna, including polychaetes, brittle stars mussels and small fishes, acting as important prey for commercially exploited fin fishes and shellfishes (Frid *et al.*,1999a). The destruction of these organisms may also lead to the decline in the target species. Auster *et al.* (1996) also noticed drastic decline of shrimps within the areas where there was an absence of hydrozoans due to heavy trawling and dredging activities. The results of the present study also postulate that the reduction of habitat structure may lead to the replacement of fish species. The high quantity of juveniles fishes observed in the discards in the present study also emphasize the need to develop more selective trawl gears with essential management tools to reduce the fish bycatch as implemented in many countries (Broadhurst *et al.*, 1997; Brewer *et al.*, 1998). Though Govt. of Kerala has already imposed strict regulations on the cod end mesh size, no trawl gear with statutory cod end mesh of 35 mm was encountered during onboard participation.

Physical disturbance due to mobile fishing gear is a serous and growing threat to diversity and production in marine benthic habitats. The increase and decrease in the abundance of benthic invertebrates in the trawl catches revealed that there was heavy disturbance on sea bottom due to otter trawling, which reduces the species diversity (Hall and Hardings, 1997). In the present study also, the invertebrates accounted for a high proportion of the discards in the trawl catch of Kerala. Moreover, removal of target species and consequent destruction of epifaunal organisms may affect the number of organisms and diversity (Veale *et al.*, 2000a). This indicates that any adverse effect of fishing on these organisms may lead to substantial change in the habitat complexity and community structure as reported by Rogers *et al.* (1998). Many predator and scavenger fish and other marine invertebrates aggregate over a recently trawled site for their food (Bergmann *et al.*, 2001b). Kaiser and Spencer (1994) observed aggregation of many fish over recently beam-trawled area compared with adjacent unfished areas. Thus heavy trawling on seabed gives rise to the change in fish communities at the marine ecosystem. Abundance of crabs, echinoderms and gastropods in the trawl catches observed in the study also affirm this concept. Drastic decline of many species have been reported, due the heavy exploitation, while comparing the catch and discards on a time series measure (Brown *et al.*, 1976; Overholtz and Tyler, 1985). The lack of sufficient quantitative dataset of discards in southwest coast of India makes it difficult to evaluate the variations on the fish communities due to trawling pressure.

Excessive trawling on the coastal waters may decline the target groups and trigger the emergence of non-edible crabs or other less important fish groups (Sherman, 1991; Murawski and Idoine, 1992). Even though the non-target species are thrown back to sea soon after being brought onboard, the commercially valueless component of the catch has important role in the marine ecosystem (Machias, *et al.* 2000). Kutti (2002) opined that the contact with the trawl gear and re-suspension of surface sediments might cause death, injury and exposure of benthic fauna, thus creating potential food resources for scavenging and predatory fish and invertebrates. The abundance of crab *Charybdis smithii* observed in the trawling grounds during the study period can be considered an aftermath of the ecosystem changes. The emergence of these crabs had earlier been studied as a consequence of ecosystem overfishing by Thomas and Kurup (2001) in lieu of the recordings of Balasubramanian (1993) who reported the occurrence of these crabs beyond 70m in the Kerala coast. Moreover, high quantity of prawns and fishes identified in the alimentary canal of these crabs also revealed that it fed on small prawns and fishes (Thomas and Kurup 2001).

Increase of polychaetes and other tiny marine epibenthos may increase the food supply for fish (De Veen, 1976; Duineveld *et al.*, 1987; Hessen and Dann, 1996; Millner and Whiting, 1996; Rijnsdrop and Leeuwen, 1996; Rijnsdrop and Vingerhoed 2001). Bannister (1978) and Rijnsdrop and Beek (1991) reported the increase of growth rate of fishes such as sole and plaice by feeding on the infaunal polychaetes, which exposed during beam trawling. Moreover, invertebrate scavengers can locate animals damaged by fishing by following the odors released from their injured body tissues (Sainte-Marie, 1986; Nickell and Moore, 1992). So it was inferred that the large amount of juvenile prawns observed in the discarded epibenthos might also attract the scavenging, predatory crabs and gastropods into the trawling grounds and leading to their proliferation. Besides, many of the epibenthic invertebrate fauna observed in this study were scavengers and their presence can be taken as the tangible proof of trawl disturbance as suggested by many researchers (Berghahn, 1990; Britton and Morton, 1994, Kaiser and Ramsay, 1997). So the inordinate trawling activities may result in the reduction of target groups and the dominance of smaller non-target components in the ecosystem. The increase of crabs and gastropods in the trawling grounds of Kerala observed in this study also point out to this fact.

In the present study it could be observed that our coastal waters are subjected to heavy trawling pressure and large amount of fish and other marine invertebrates were destroyed due to the excessive and incessant bottom trawling activities every year. Some of the more resistant invertebrates such as crabs, echinoderms and gastropods may have high survival rates whereas most of the fish are killed. Excessive trawling pressures on the coastal waters reduce the abundance of target groups and give way for the proliferation of commercially unimportant species. The quantity of juveniles and young ones assessed in the trawl discards also revealed that it would definitely reduce the stock of the target groups and affect future fishery. Moreover, the ecosystem with high structural complexity is likely to change most as the fishing pressure increases. The removal of large amount of epifaunal organisms lead to the decline in species diversity and abundance resulting in the shift in communities to those which survive the disturbance as well as the discarding process. The abundance of the scavenger species that flourish in the trawl grounds of Southwest coast of India can be made use of to draw clear evidence of the degradation in structural complexity in the rich ecosystem, creating an inevitable decline in the target groups. Therefore, based on the results of the present study, it will be inferred that the immensely rich coastal waters would lead to the aqua deserts with drastic decline of target species and emergence of unimportant and non-edible organisms due to the excessive bottom trawling. The high rate of discarding of fisheries may cause ecological effects on benthos, vertebrate species and finally the whole ecosystem as well as heavy economic loss as opined by many ecologists (Chen and Gordon, 1997; Philippart, 1998; Stratoudakis *et al.*, 1999a and b; Greenstreet and Rogers, 2000; Ye *et al.*, 2000).

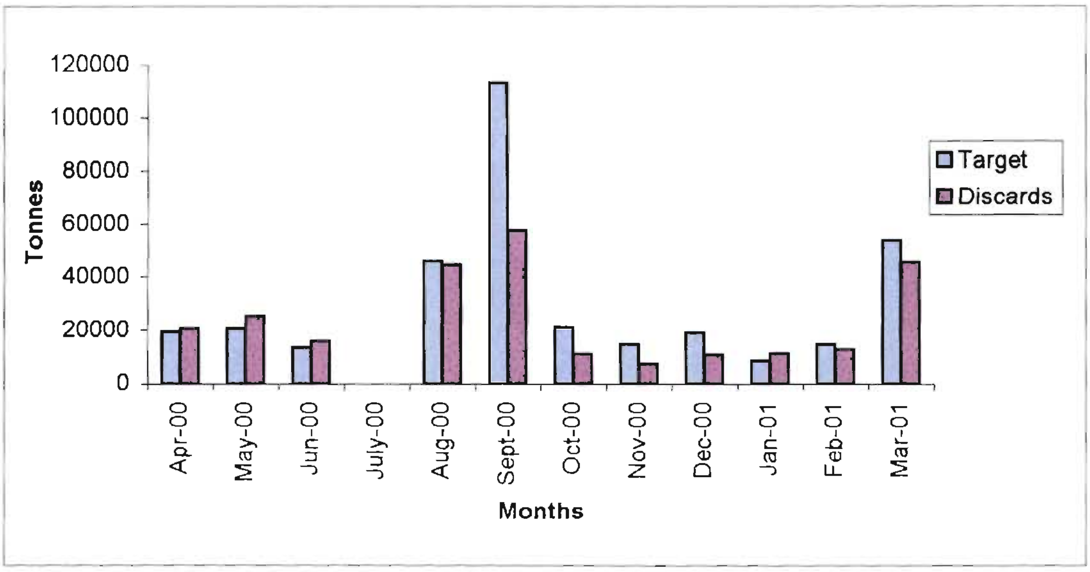


Fig. 7.1 Target and discards along the Kerala coast during April 2000 to March 2001

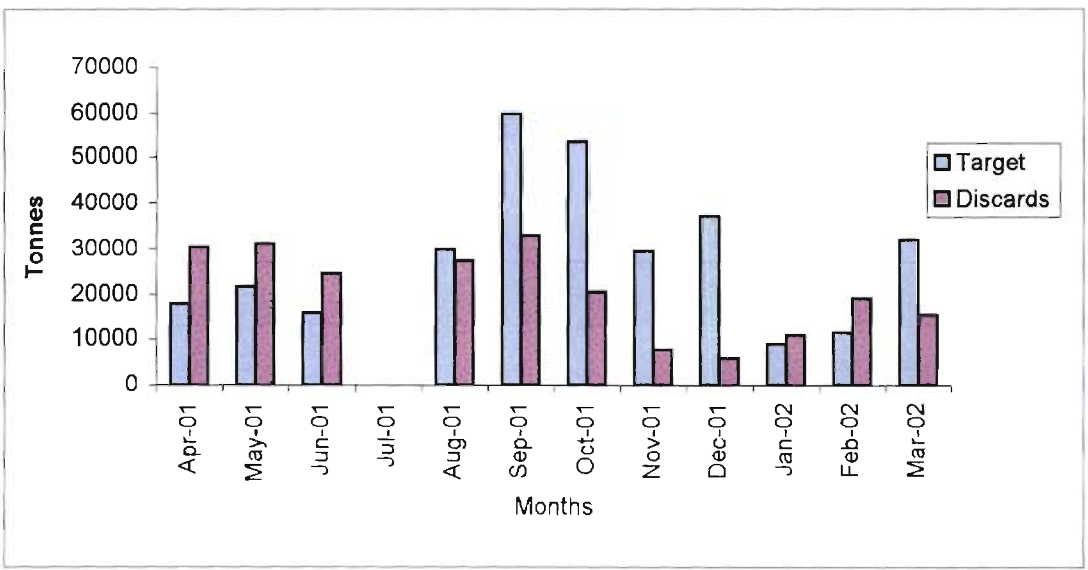


Fig. 7.2 Target and discards along the Kerala coast during April 2001 to March 2002

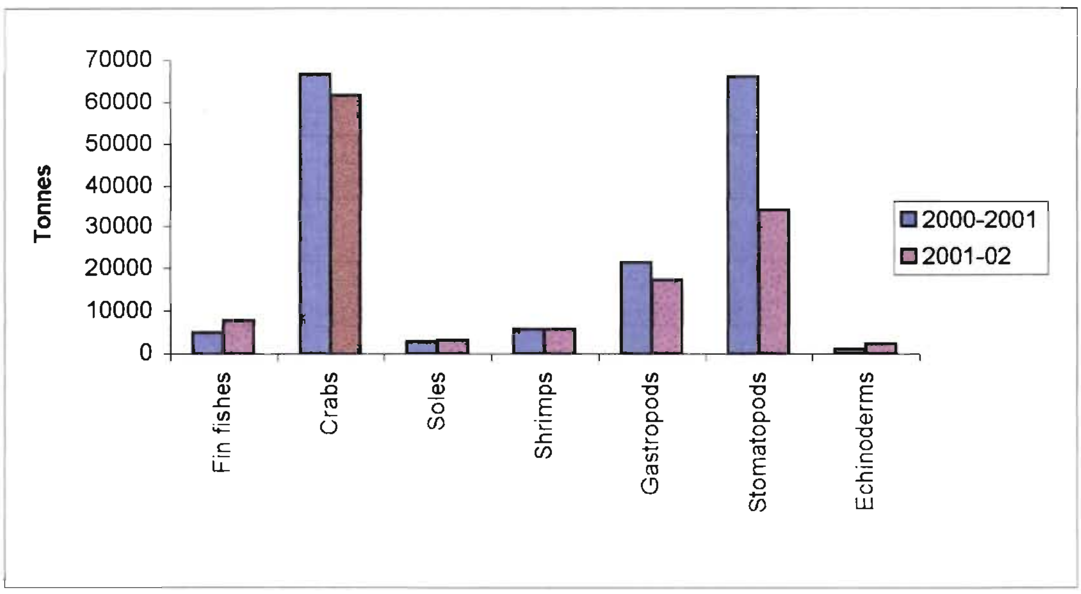


Fig.7.3 Quantity of epibenthos discarded along the Kerala coast during 2000-01 **and 2001-02**

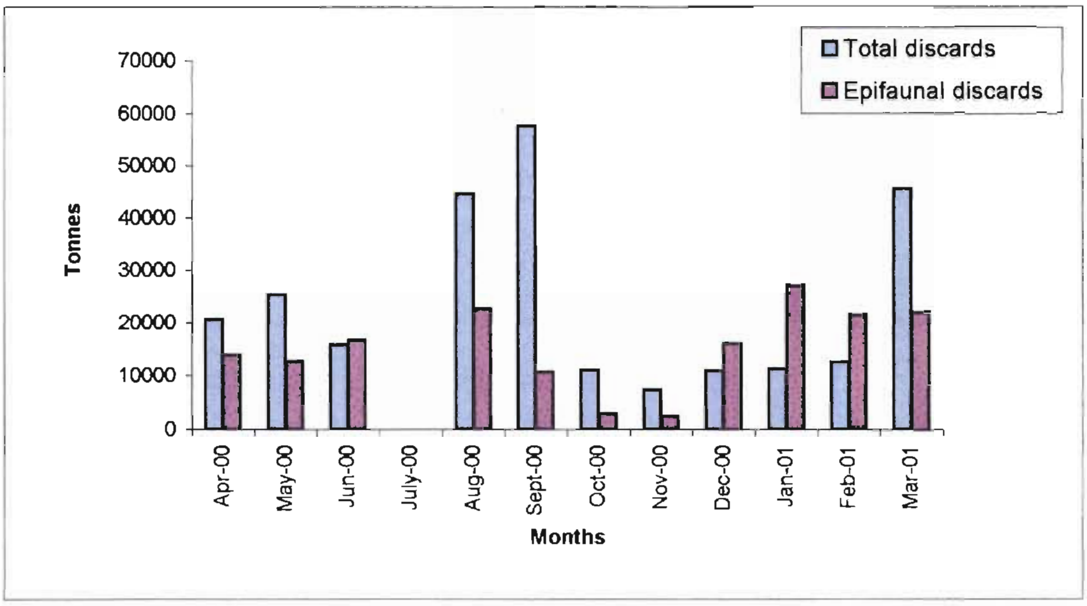


Fig. 7.4 Comparison of temporal variation in total discards and epifaunal discards along the Kerala coast during April 2000 to March 2001.

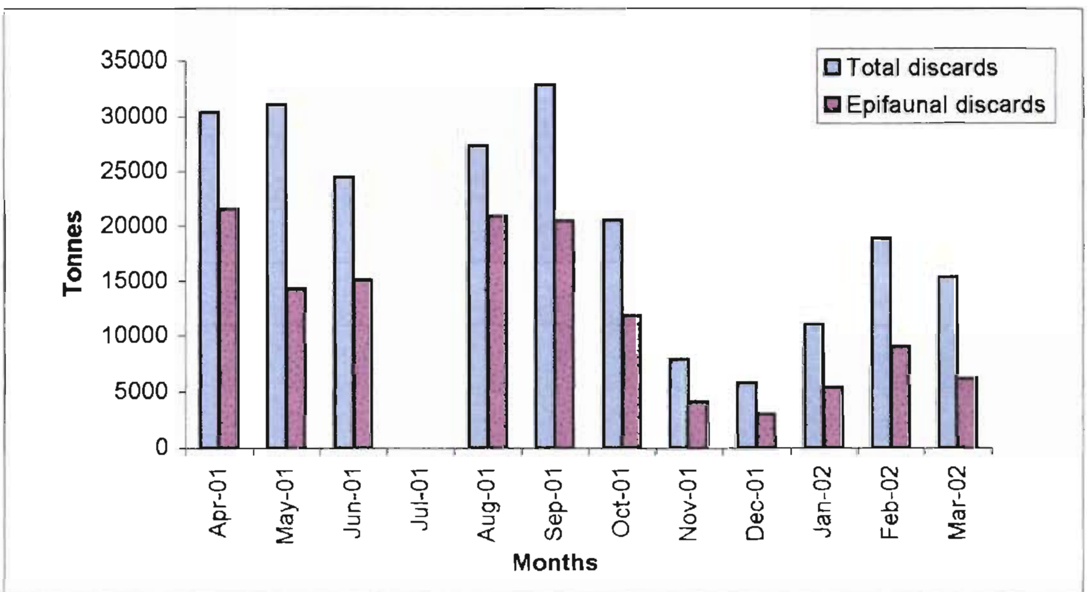


Fig. 7.5 Comparison of temporal variation in total discards and epifaunal discards along the Kerala coast during April 2001 to March 2002

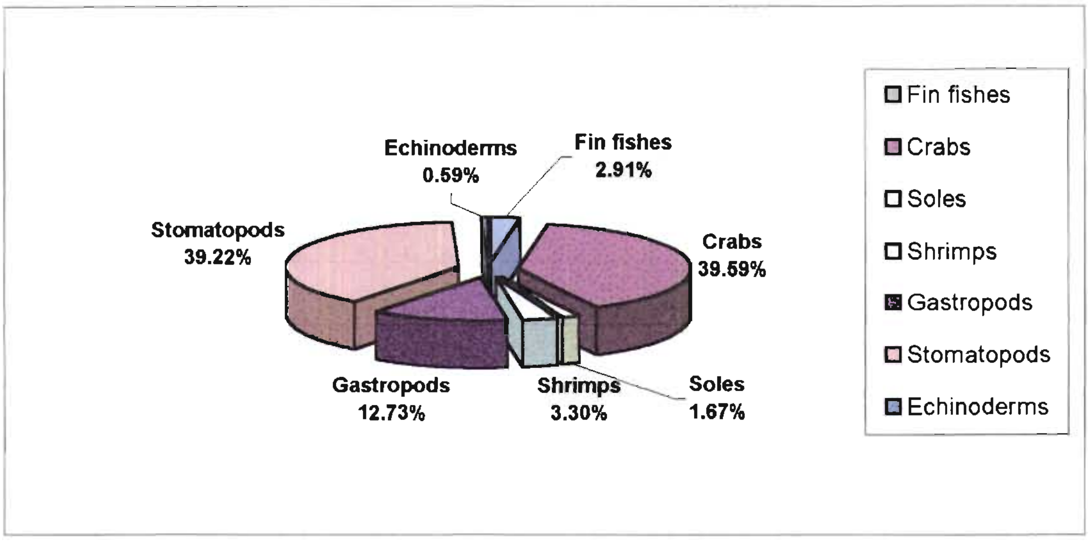


Fig. 7.6 Percentage composition of epibenthic groups discarded along the Kerala coast during 2000-01

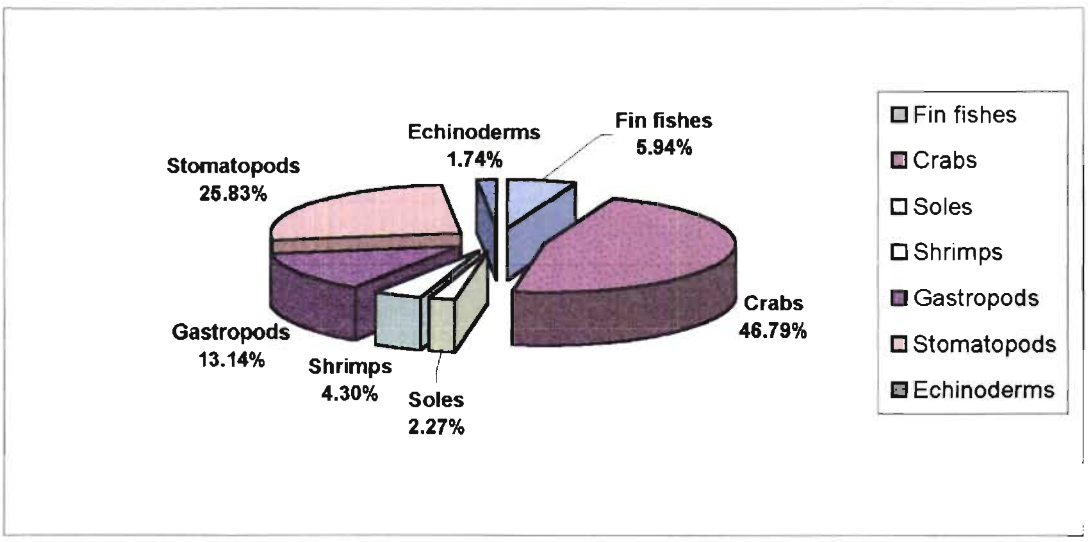


Fig. 7.7 Percentage composition of epibenthic groups discarded along the Kerala coast during 2001-2002

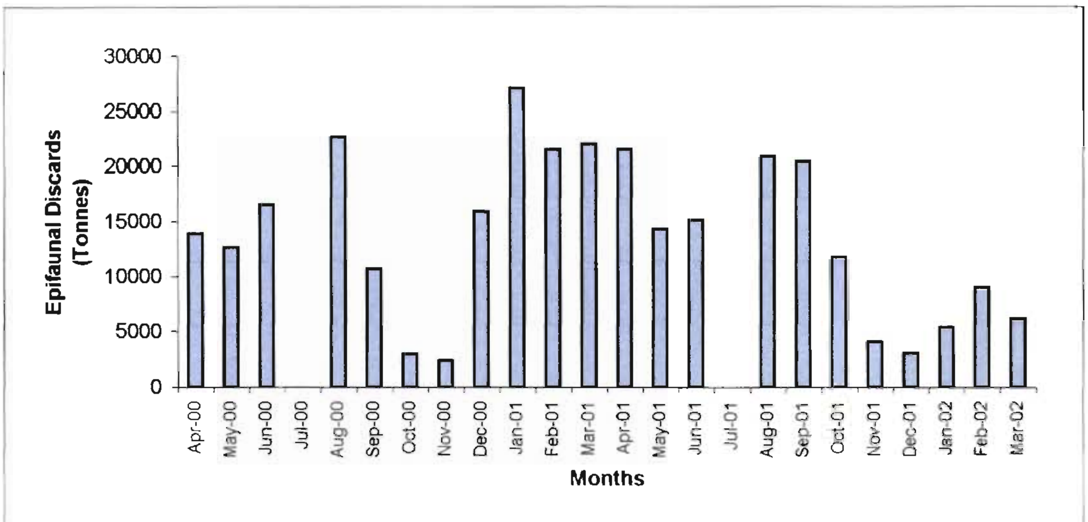


Fig. 7.8 Temporal variations in quantity of epifaunal discards in Kerala during April 2000 to March 2002

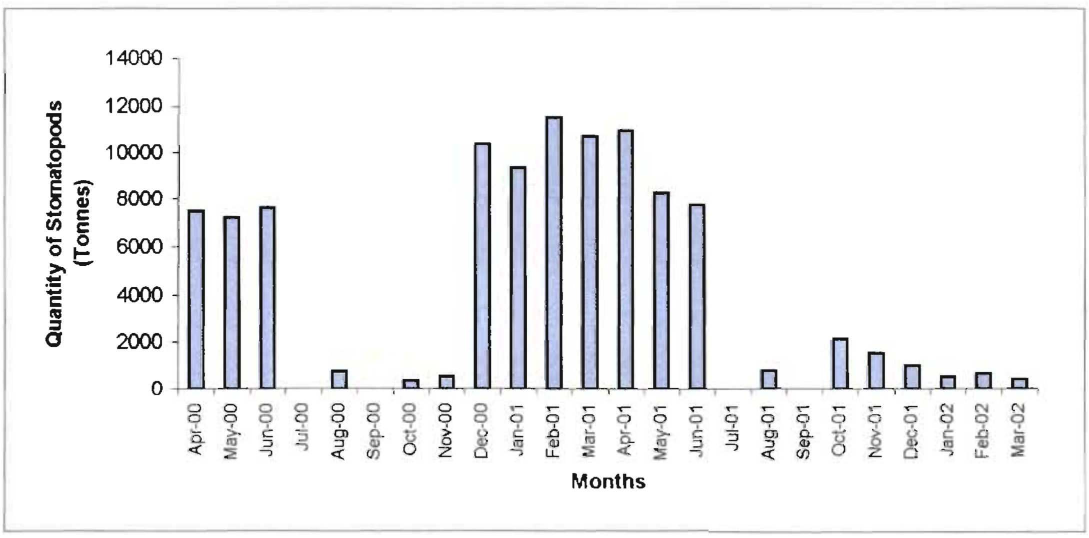


Fig. 7.9 Quantification of stomatopods in epifaunal discards along Kerala coast during April 2000 to March 2002

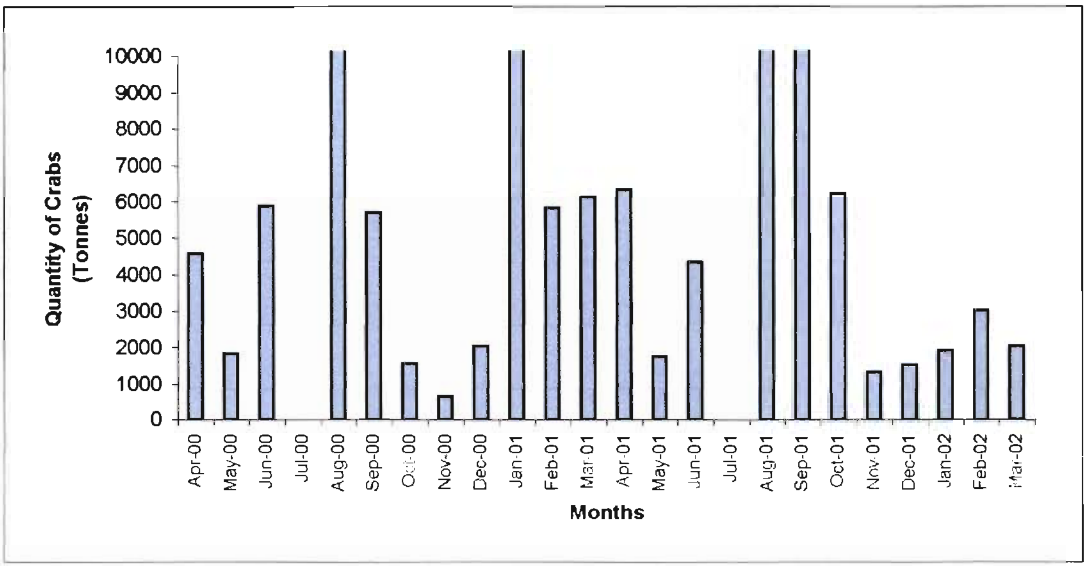


Fig. 7.10 Quantification of crabs in epifaunal discards along Kerala coast during April 2000 to March 2002

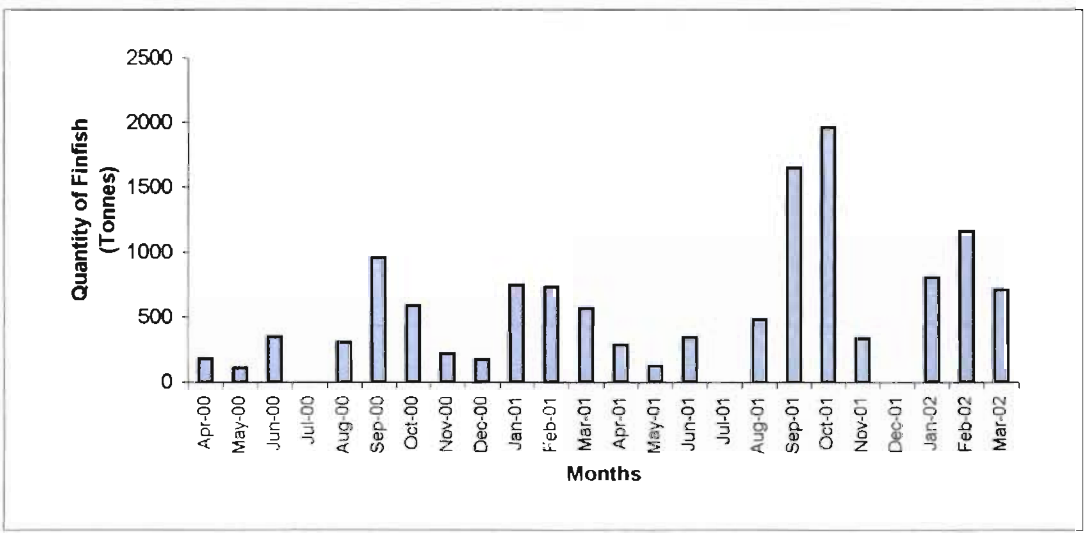


Fig. 7.11 Quantification of finfishes in epifaunal discards along Kerala coast during April 2000 to March 2002

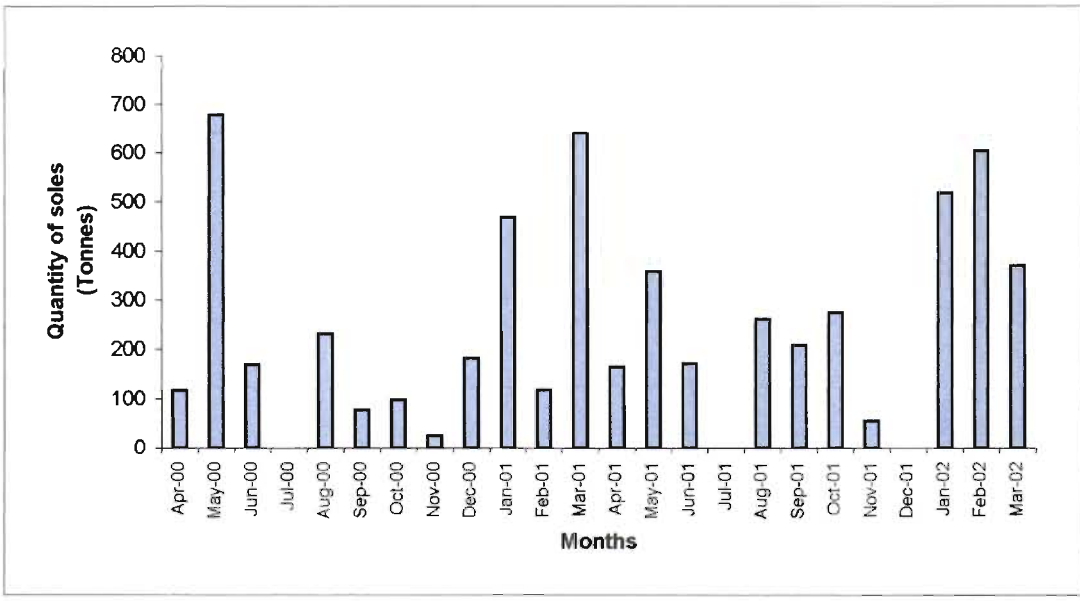


Fig. 7.12 Quantification of soles in epifaunal discards along Kerala during April 2000 to March 2002

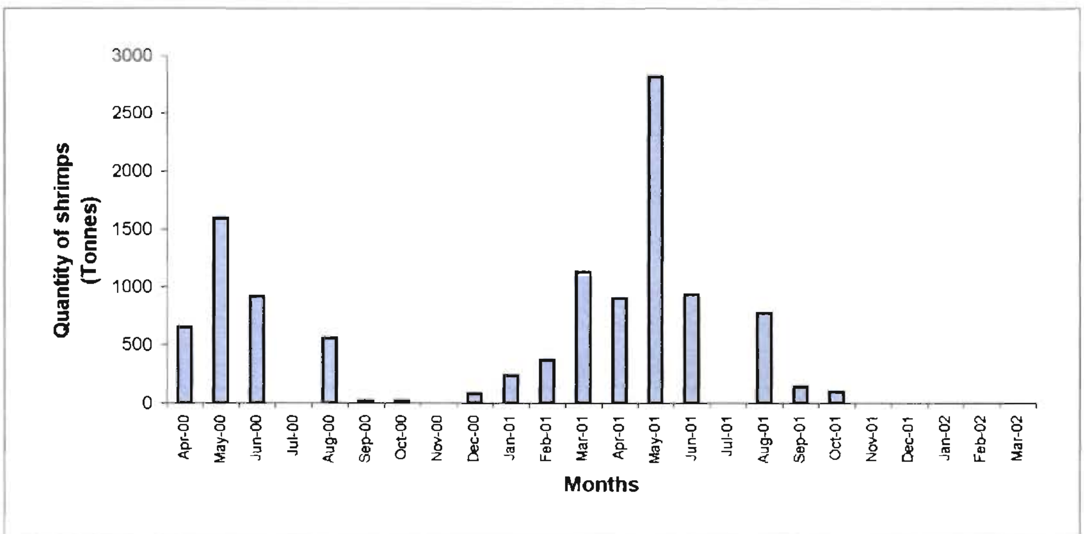


Fig. 7.13 Quantification of shrimps in the epifaunal discards in Kerala during April 2000 to March 2002

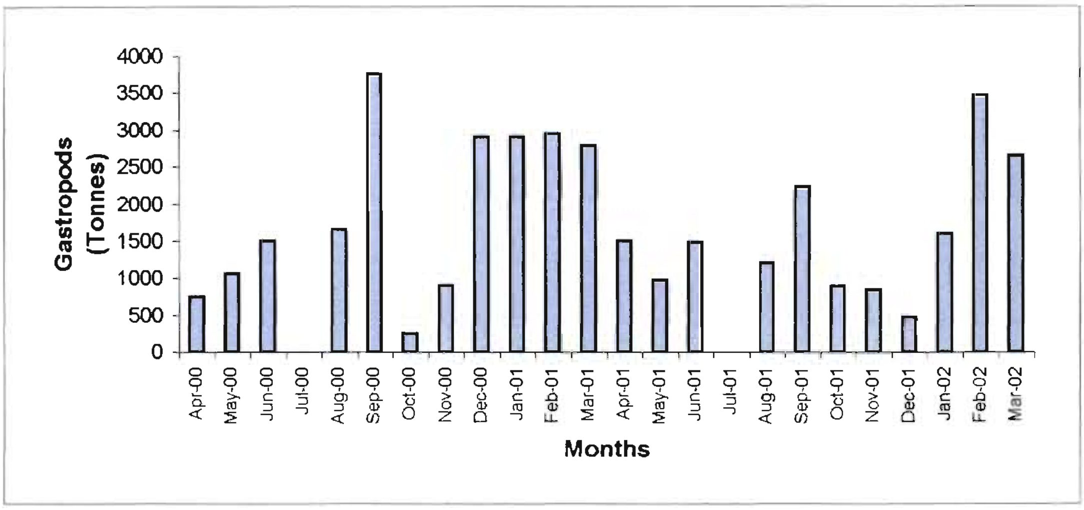


Fig. 7.14 Quantification of gastropods in epifaunal discards along Kerala coast during April 2000 to March 2002

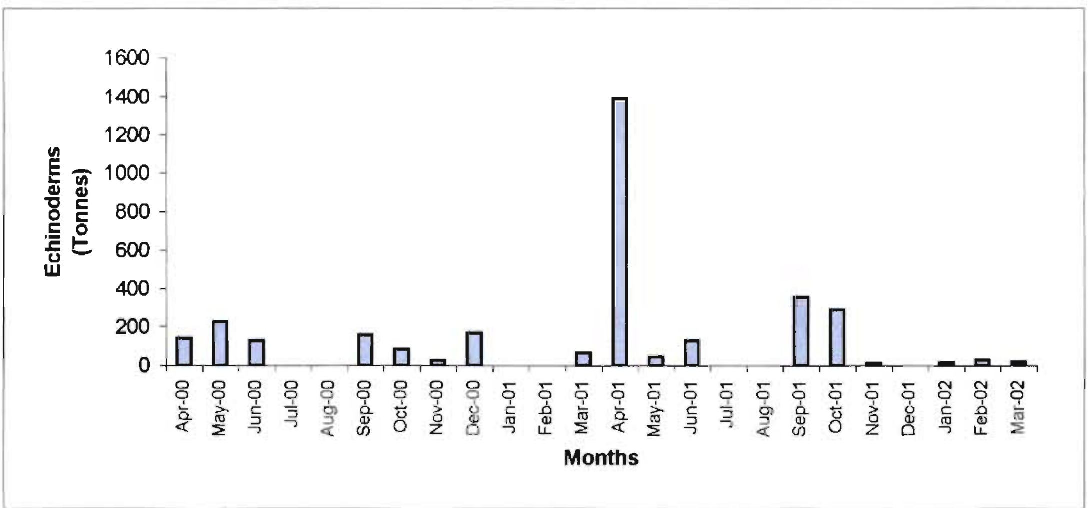


Fig. 7.15 Quantification of echinoderms in epifaunal discards along Kerala coast during April 2000 to March 2002

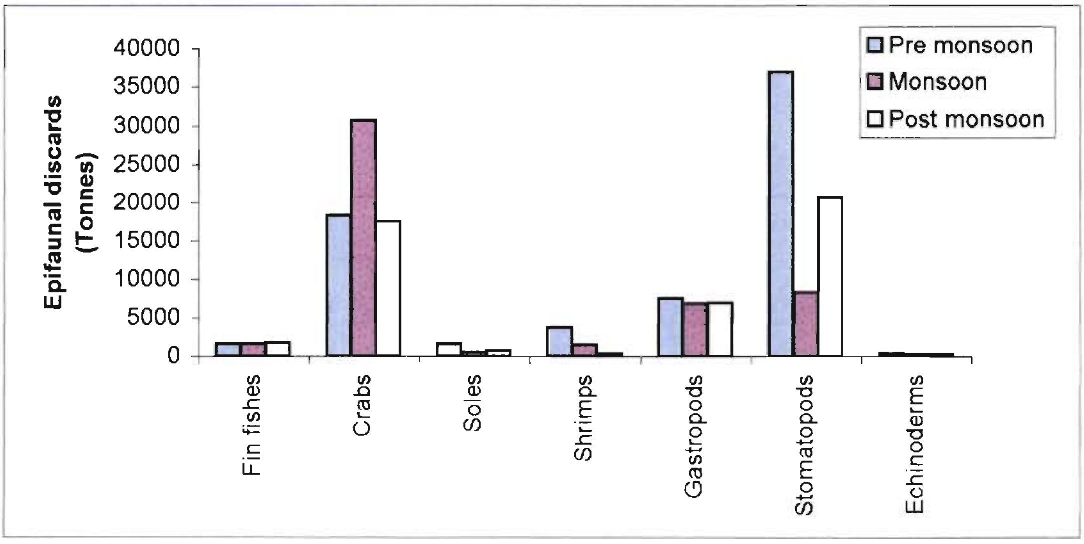


Fig.7.16 Seasonal variation in the epifaunal discards along Kerala coast during 2000-01

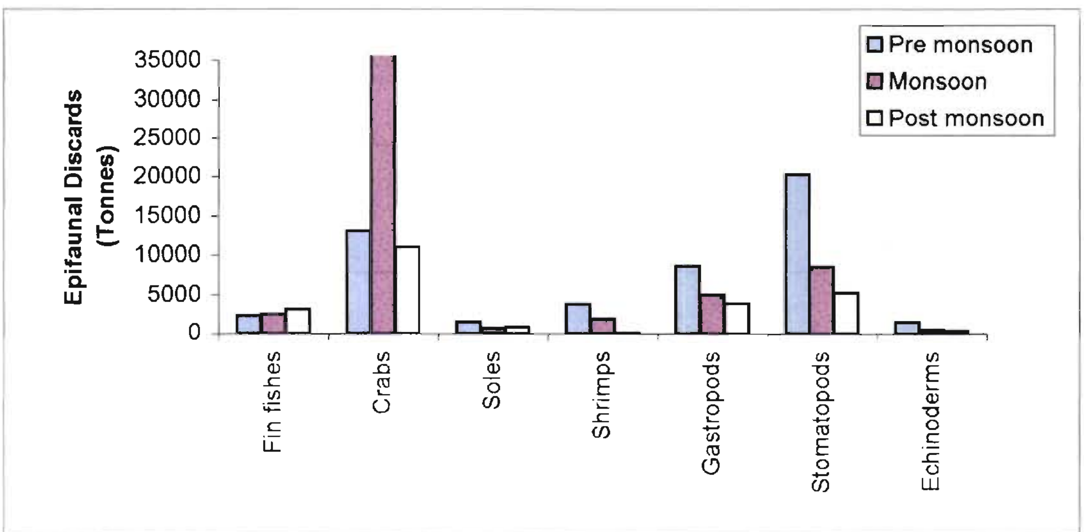


Fig.7.17 Seasonal variation in the epifaunal discards along Kerala coast during 2001-02

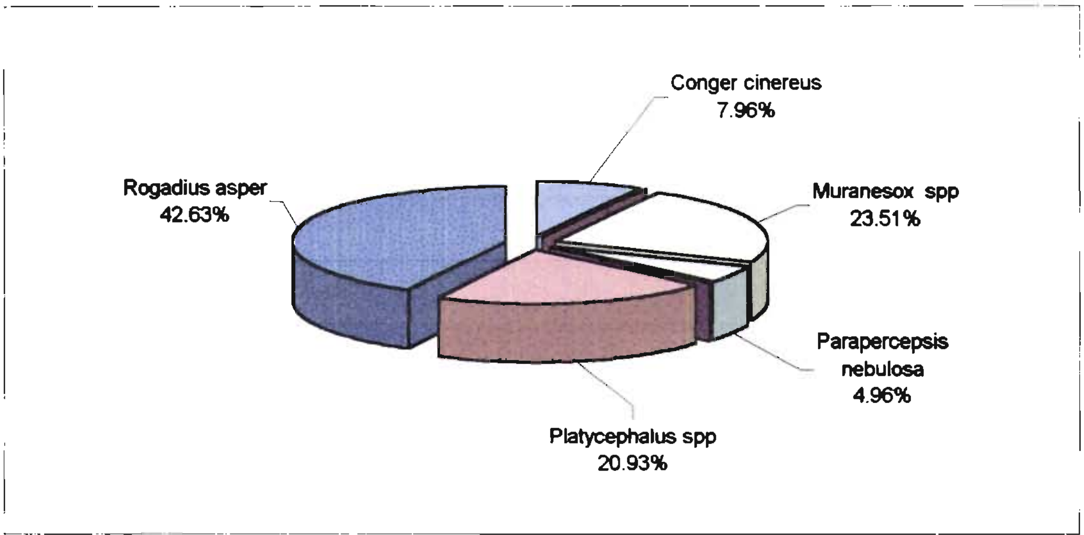


Fig. 7.18 Species composition of finfishes in epifaunal discards along Kerala coast during April 2000 to March 2001

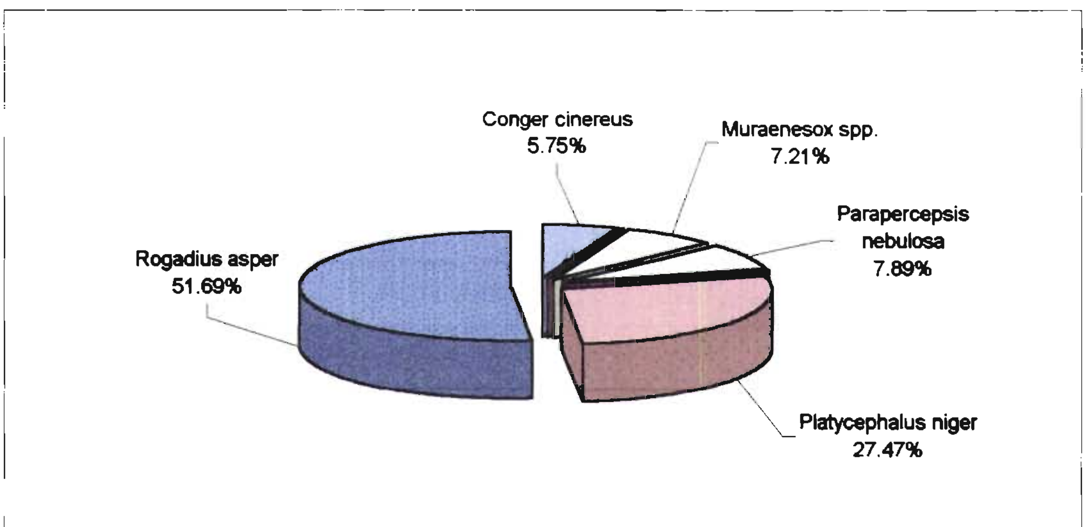


Fig. 7.19 Species composition of finfishes in epifaunal discards along Kerala coast during April 2001 to March 2002

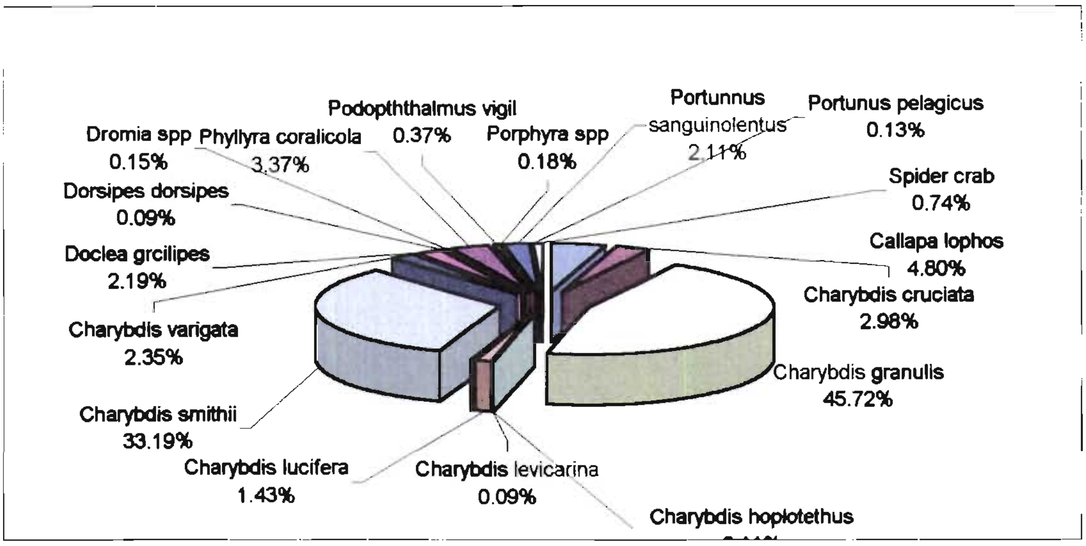


Fig. 7.20 Species composition of crabs in epifaunal discards along Kerala coast during April 2000 to March 2001

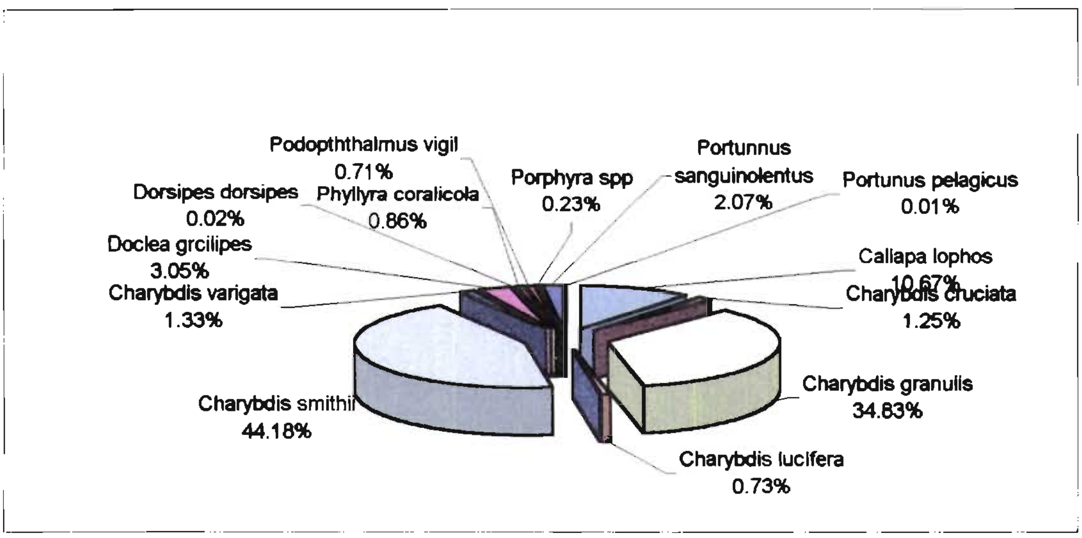


Fig. 7.21 Species composition of crabs in epifaunal discards along Kerala coast during April 2001 to March 2002

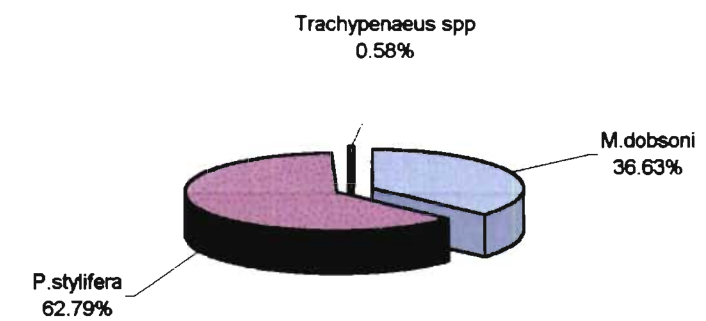


Fig. 7.22. Species composition of shrimps in epifaunal discards along Kerala coast during April 2000 to March 2001

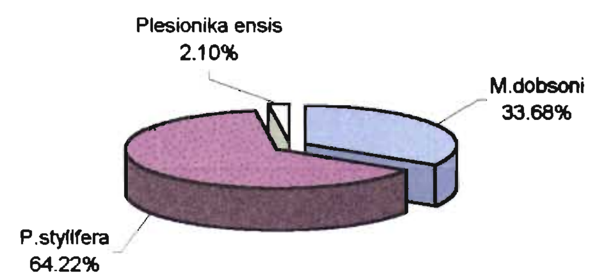


Fig. 7.23. Species composition of shrimps in epifaunal discards along Kerala coast during April 2001 to March 2002

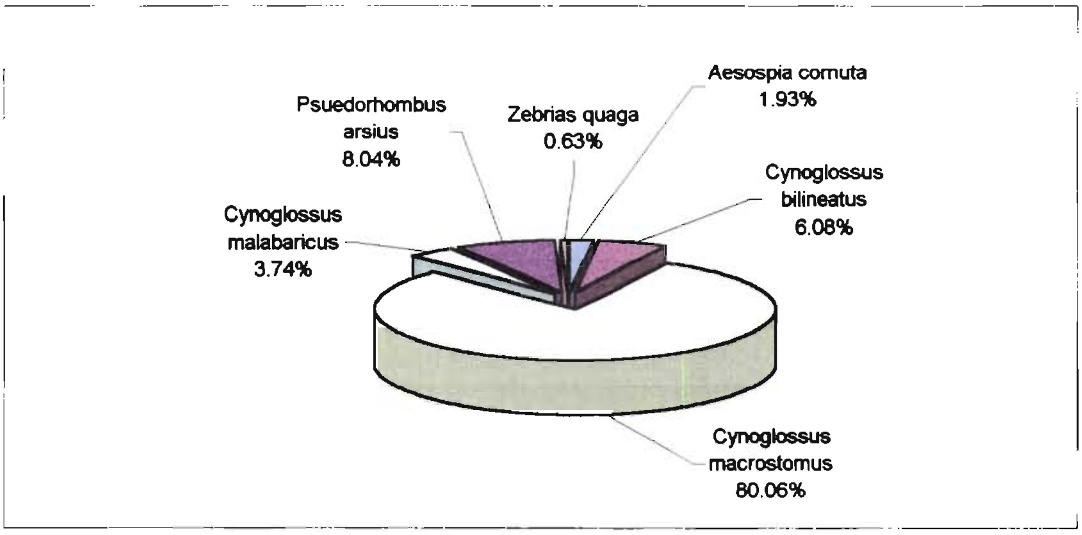


Fig. 7.24. Species composition of soles in epifaunal discards along Kerala coast during April 2000 to March 2001

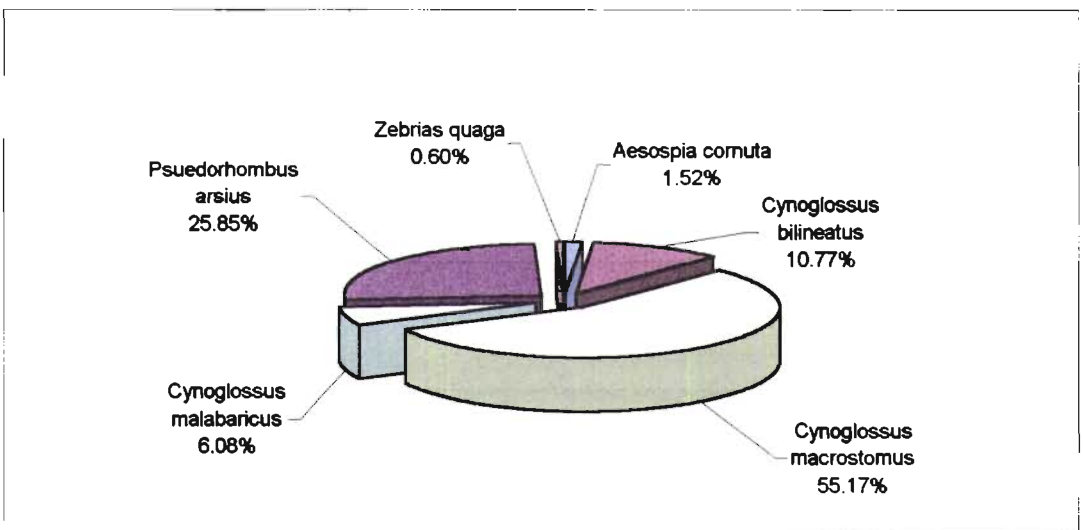


Fig. 7.25. Species composition of soles in epifaunal discards along Kerala coast during April 2001 to March 2002

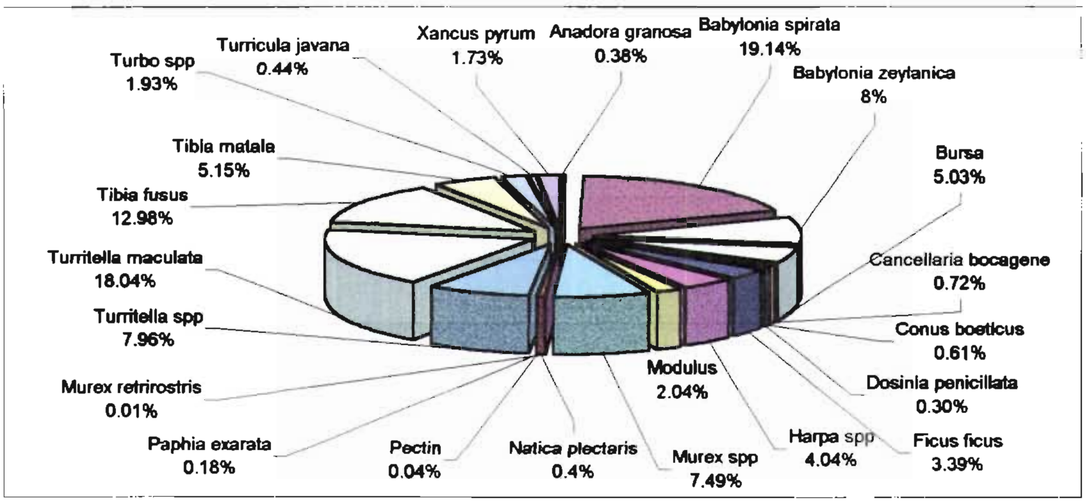


Fig. 7.26. Species composition of gastropods in epifaunal discards along Kerala coast during April 2000 to March 2001

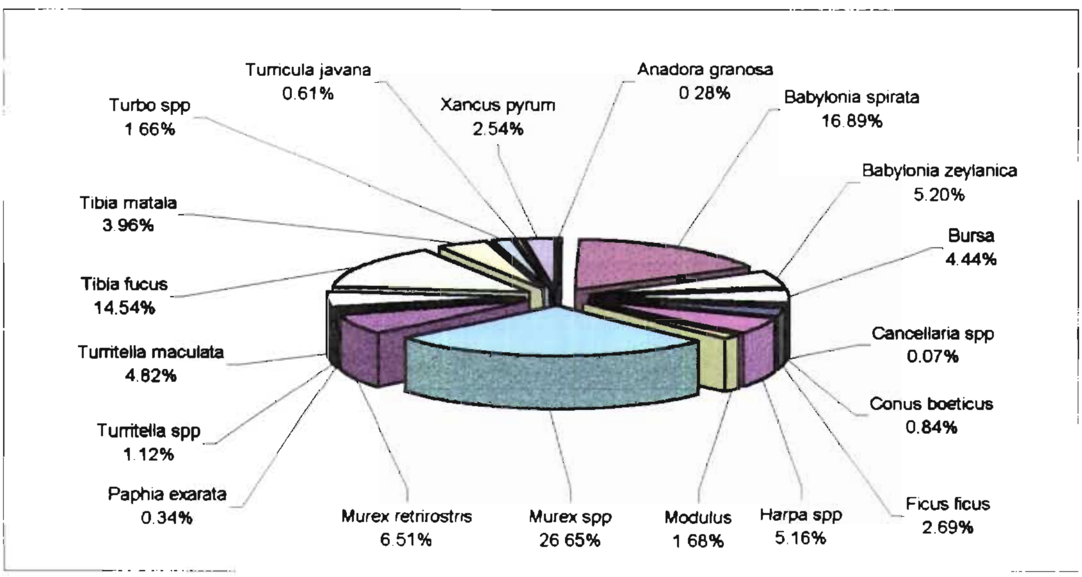


Fig. 7.27 Species composition of gastropods in epifaunal discards along Kerala coast during April 2001 to March 2002

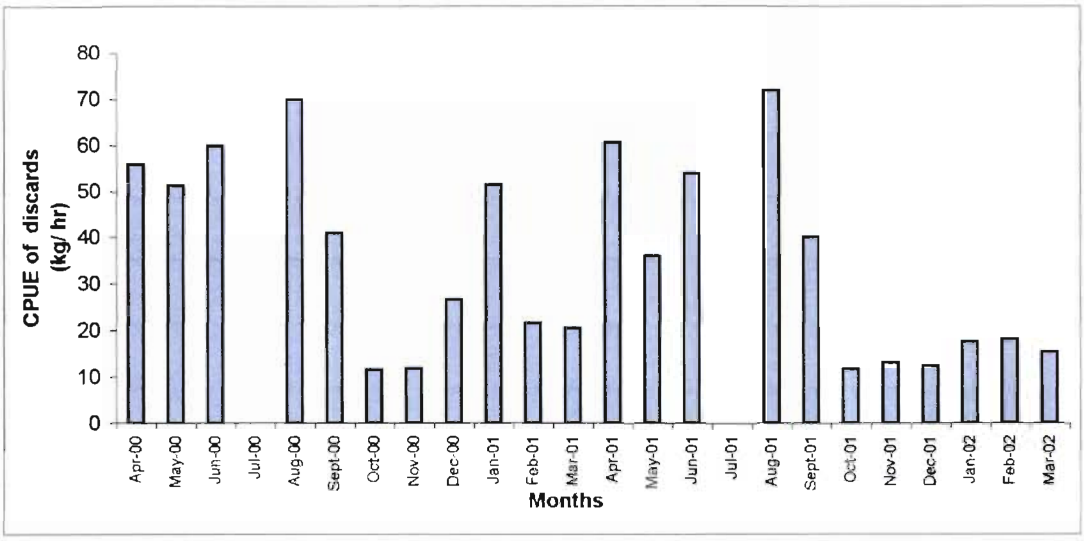


Fig. 7.28. Temporal variations in CPUE of epifaunal discards along Kerala coast during April 2000 to March 2002

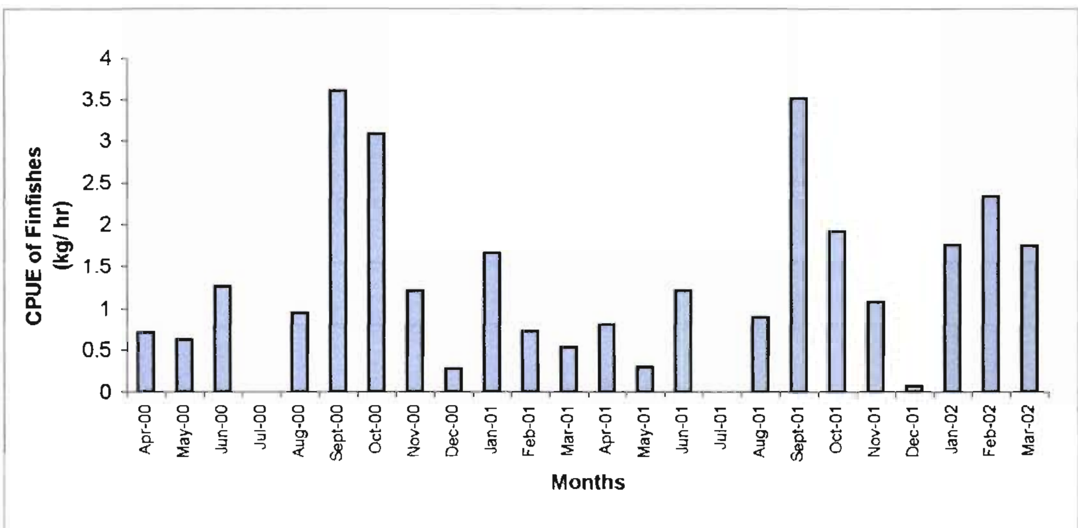


Fig. 7.29 Temporal variations in CPUE of finfishes in epifaunal discards during April 2000 to March 2002

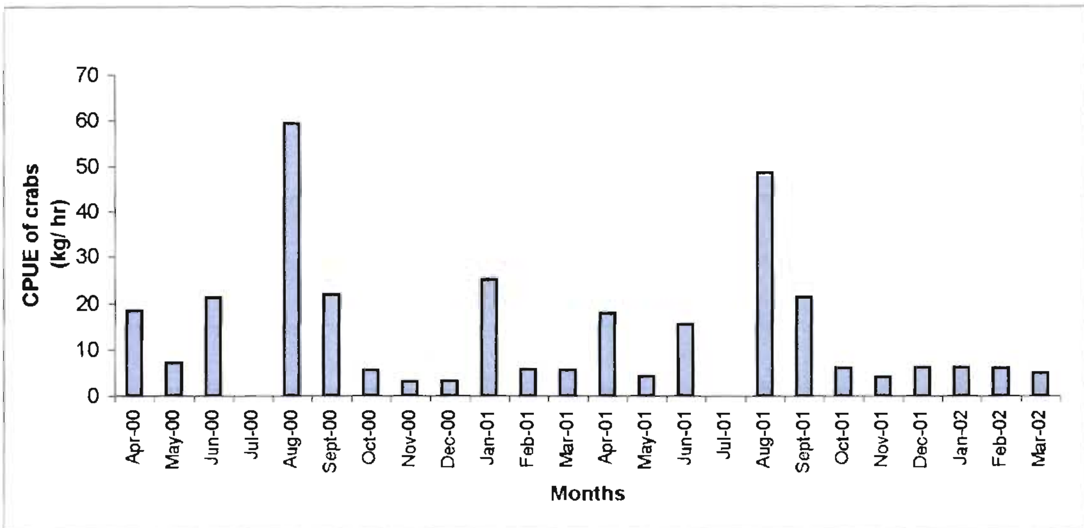


Fig. 7.30 Temporal variations in CPUE of crabs in discards along Kerala during April 2000 to March 2002

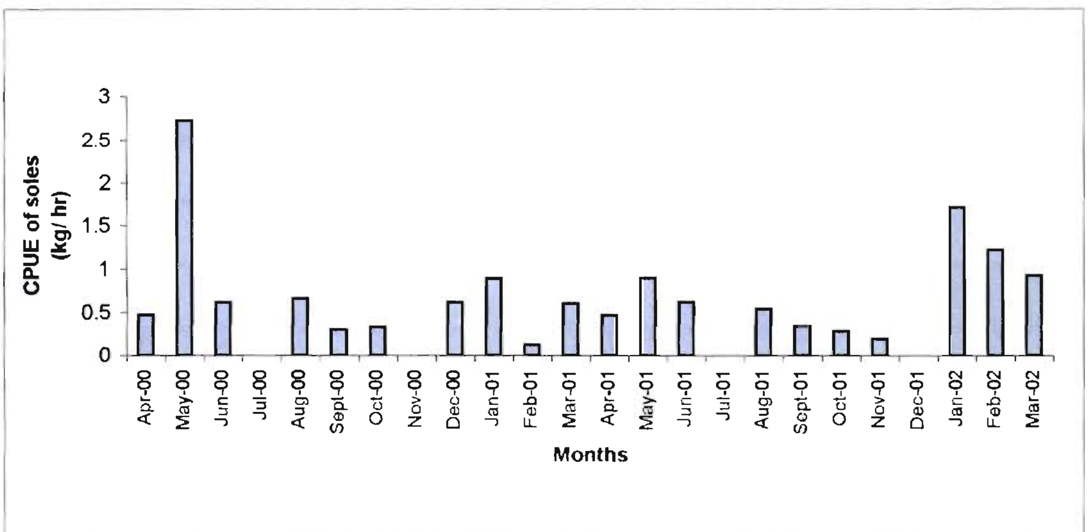


Fig. 7.31 Temporal variations in CPUE of soles in epifaunal discards along Kerala coast during April 2000- March 2002

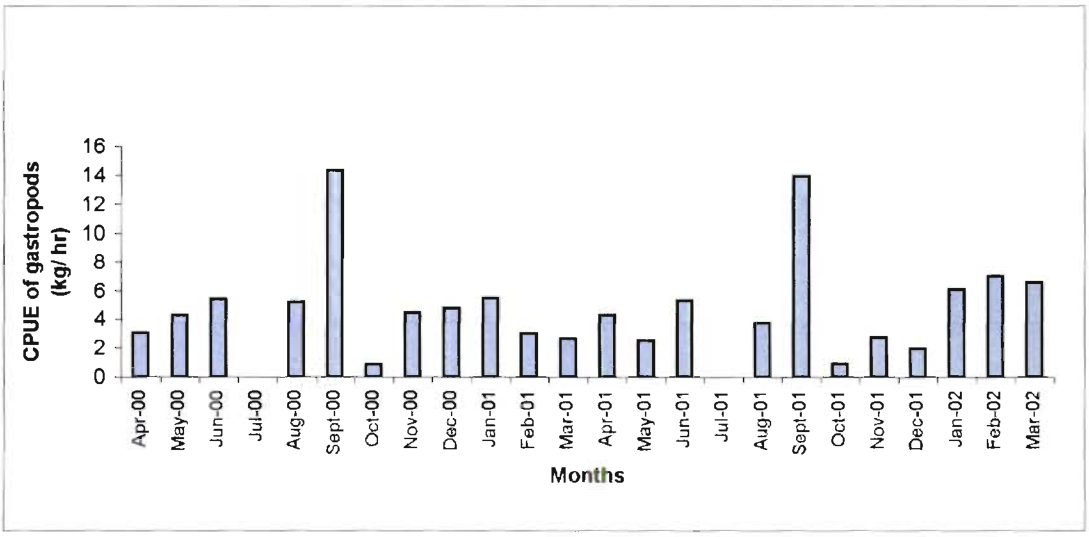


Fig. 7.32 Temporal variations in CPUE of gastropods in discards along Kerala coast during April 2000- March 2002

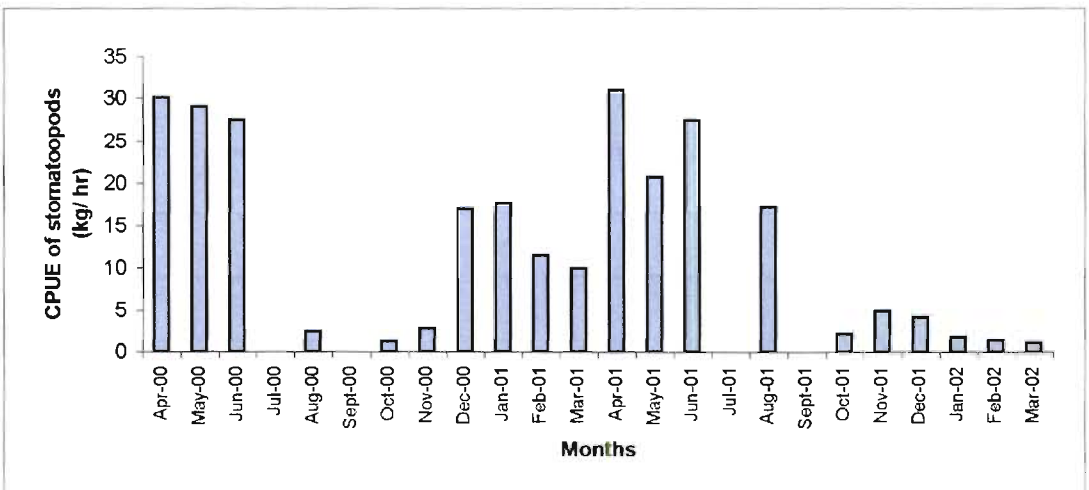


Fig. 7.33 Temporal variations in CPUE of stomatopods in discards along Kerala coast during April 2000- March 2002

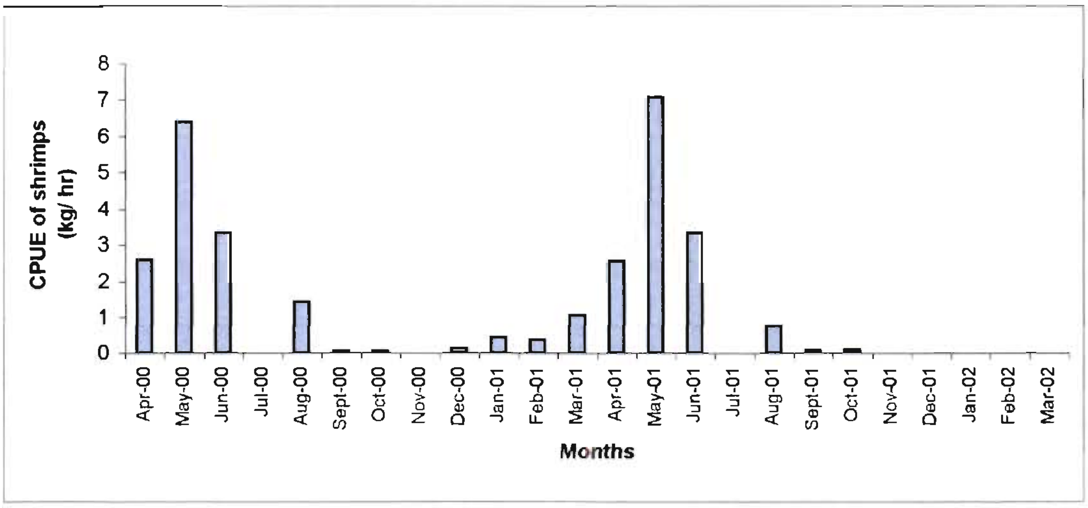


Fig. 7.34 Temporal variations in CPUE of shrimps in discards along Kerala coast during April 2000- March 2002

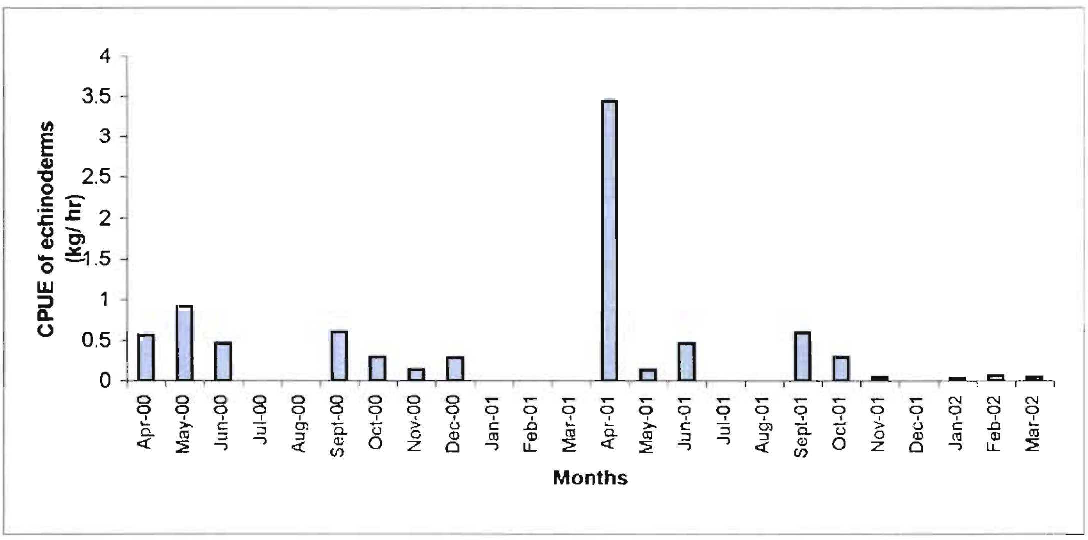


Fig. 7.35 Temporal variations in CPUE of echinoderms in discards along Kerala coast during April 2000- March 2002

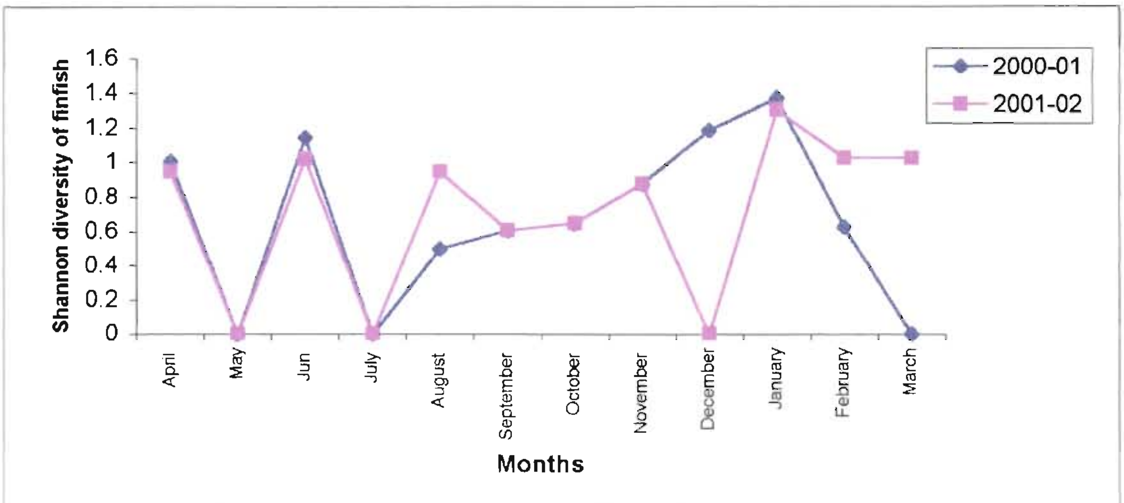


Fig. 7.36 Yearwise variation in Shannon diversity of epifaunal finfishes during April 2000 to March 2002

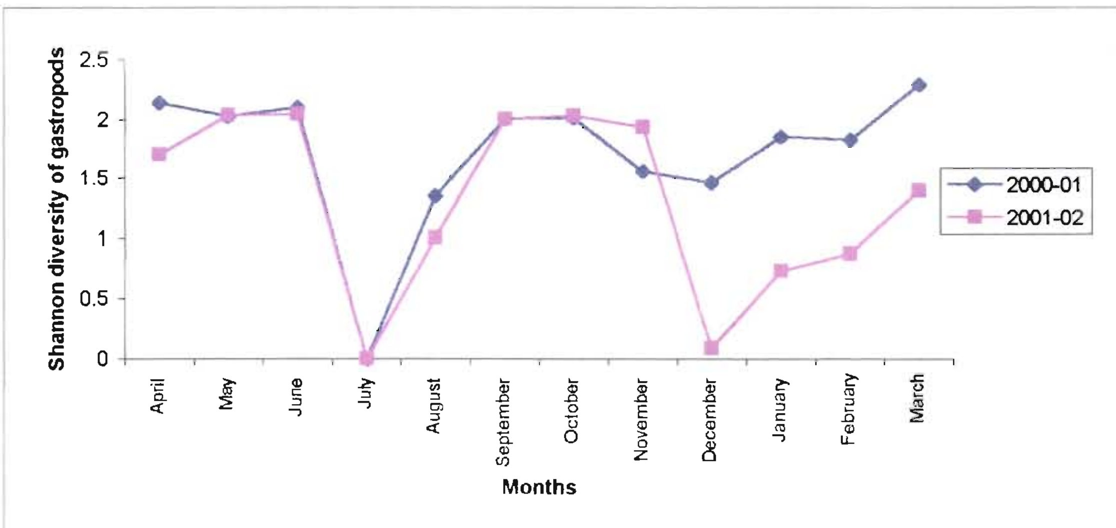


Fig. 7.37. Yearwise variation in Shannon diversity of gastropods during April 2000 to March 2002

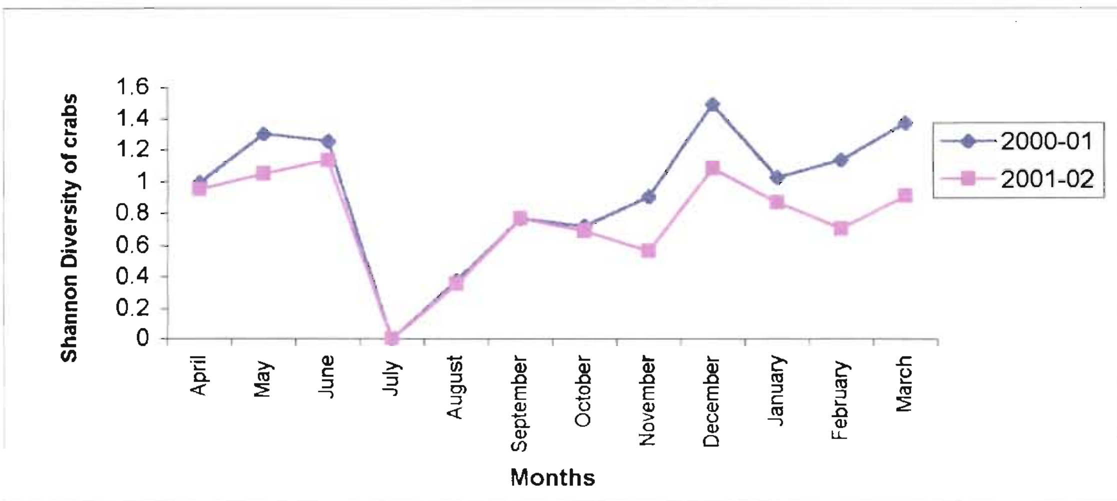


Fig.7.38 Yearwise variation in Shannon diversity of crabs during April 2000 to March 2002

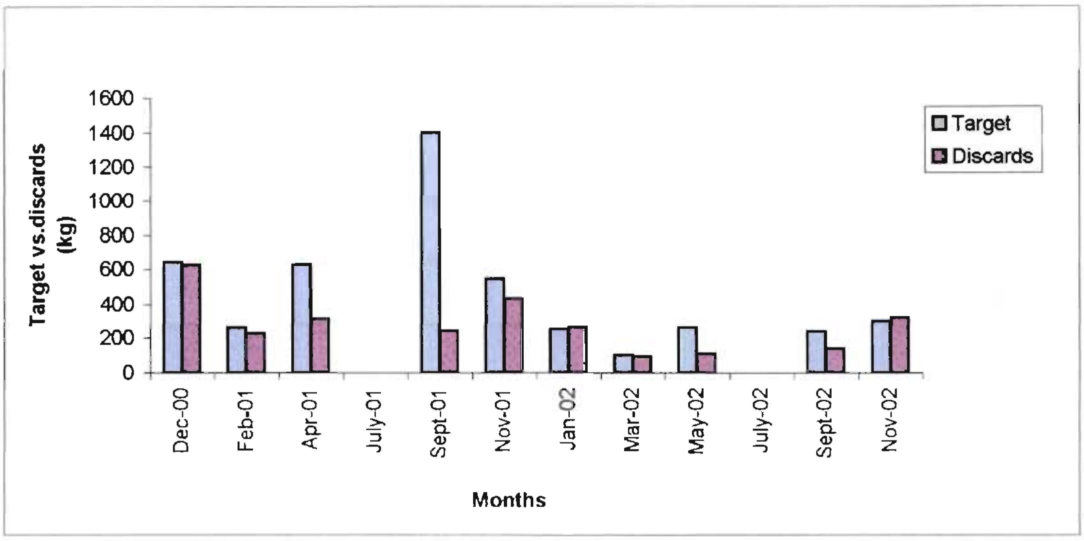


Fig. 7.39 Target vs discards during experimental trawling from Cochin -Munambam during December 2000- November 2002

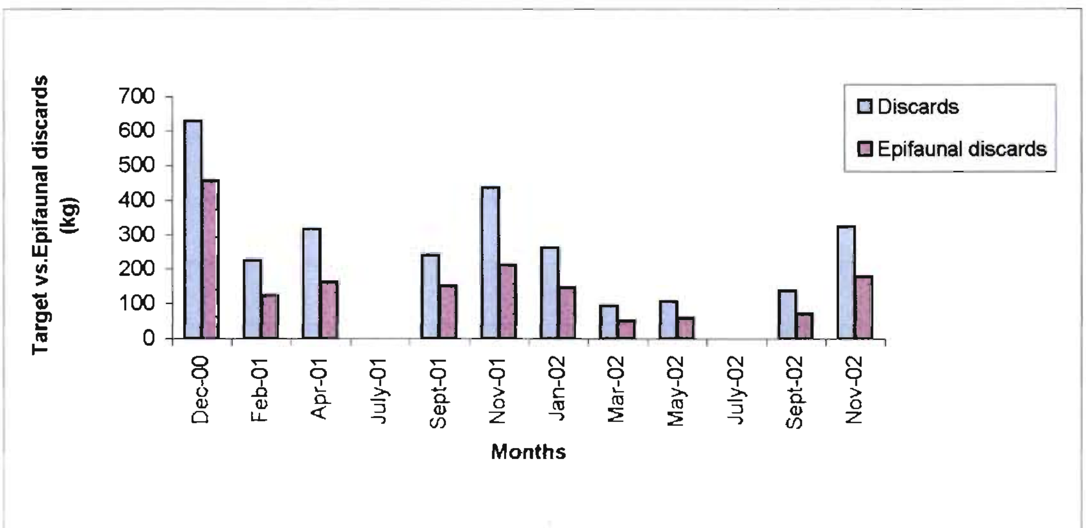


Fig. 7.40 Discards vs Epifauna during experimental trawling from Cochin -Munambam during December 2000 - November 2002

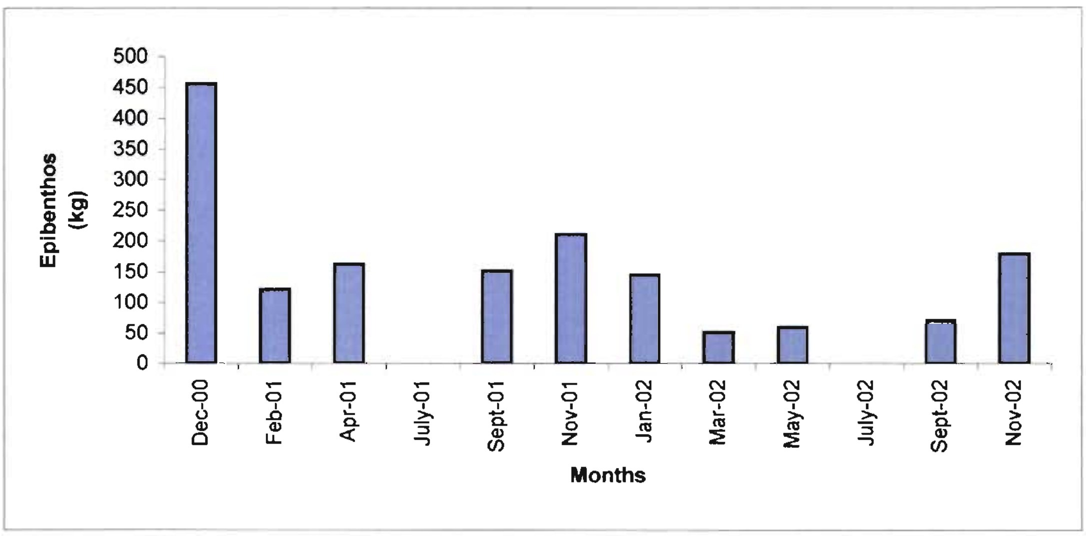


Fig. 7.41 Temporal variation in quantity of epibenthos discarded during experimental trawling from December 2000 to November 2002

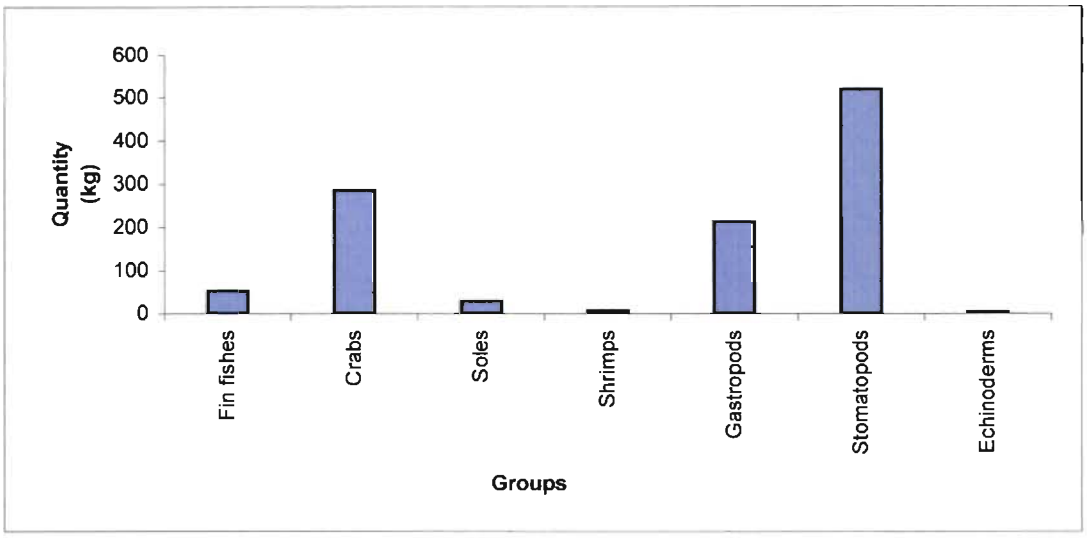


Fig. 7.42. Groupwise quantity of epifauna discarded during experimental trawling from Cochin -Munambam area during December 2000 to November 2001

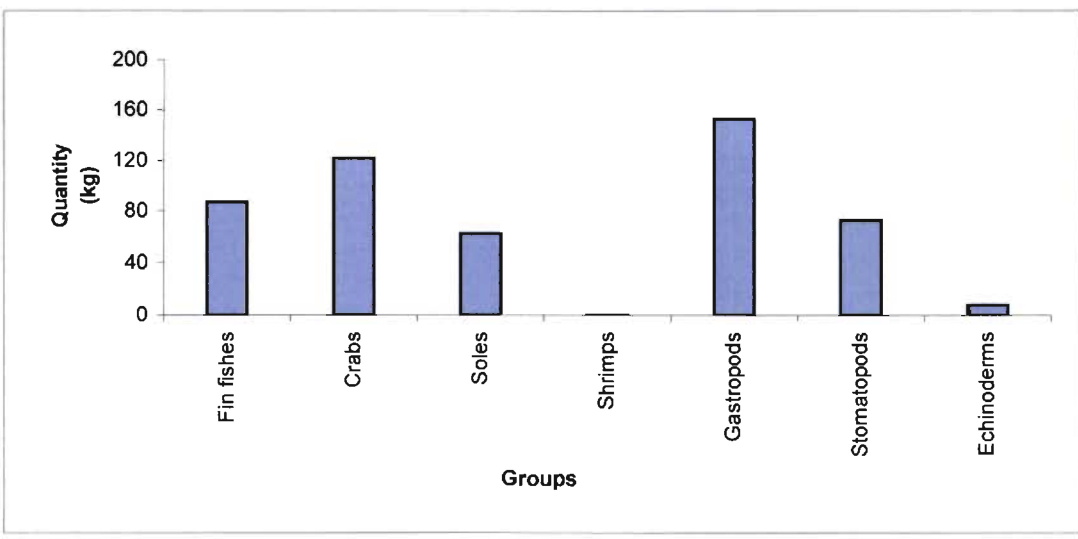


Fig. 7.43. Groupwise quantity of epifauna discarded during experimental trawling from Cochin - Munambam area during January 2002 to November 2002

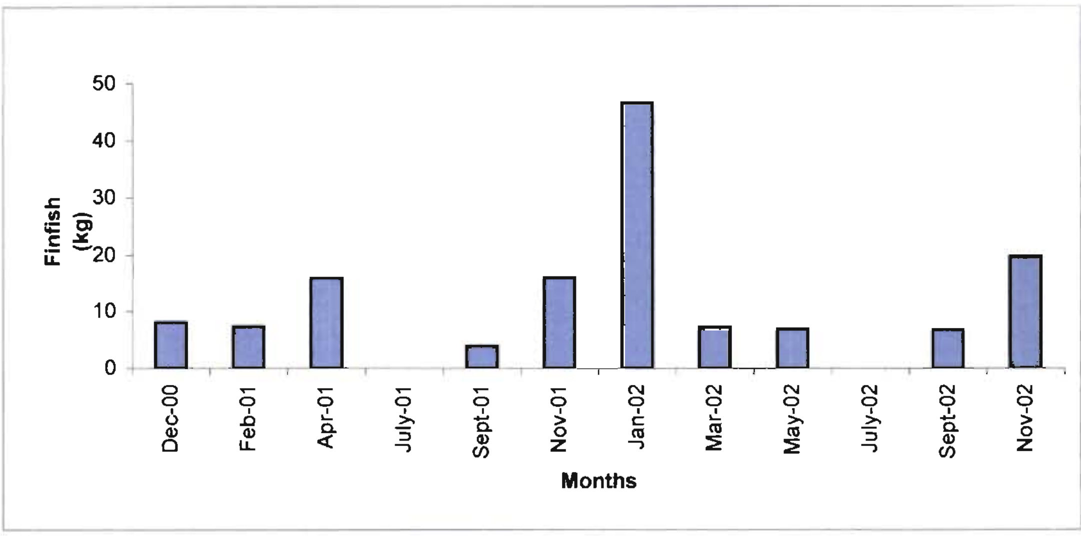


Fig. 7.44 Quantity of epifaunal finfishes discarded during experimental trawling in Cochin - Munambam area during December 2000 to November 2002

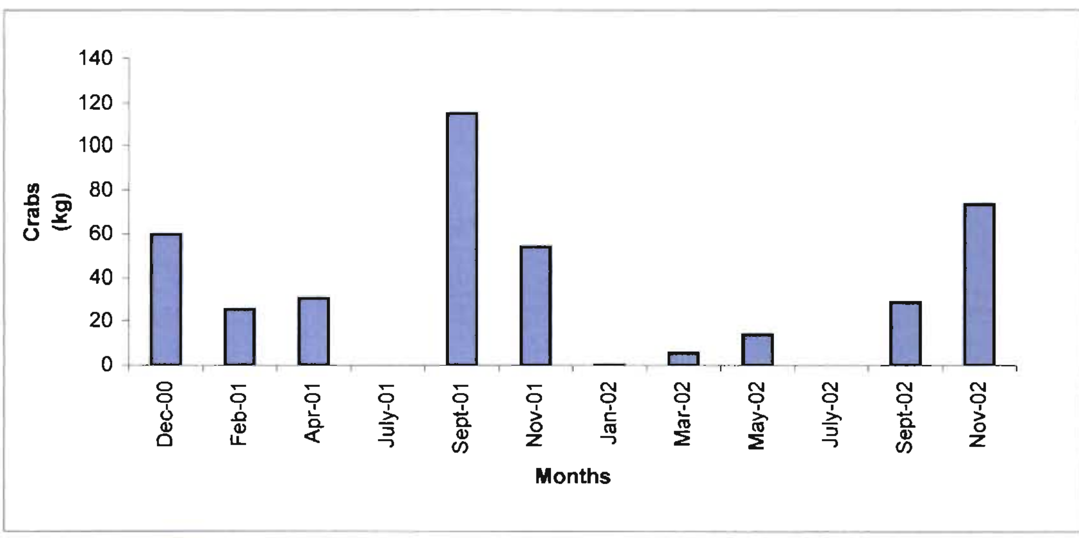


Fig. 7.45 Quantity of crabs discarded during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

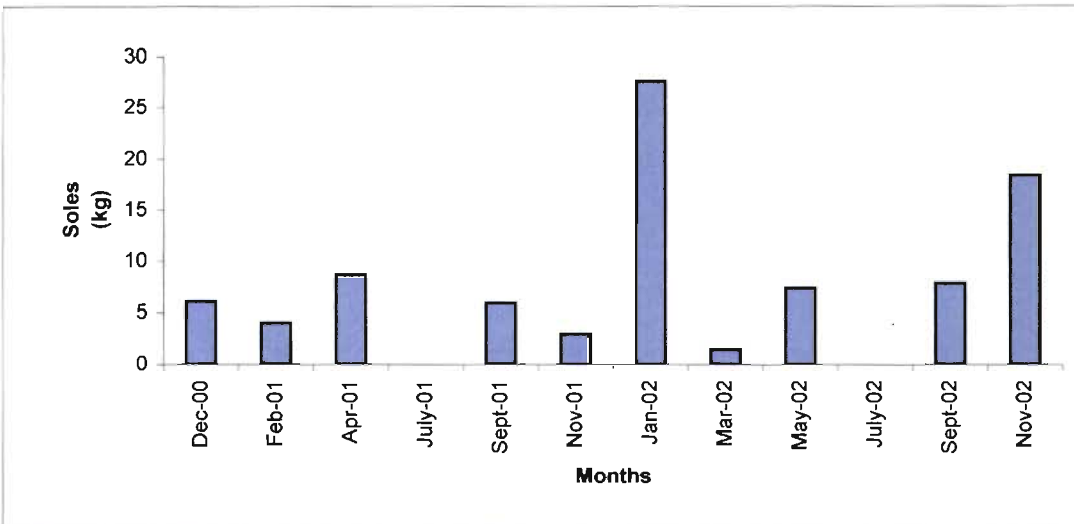


Fig. 7.46 Quantity of soles discarded during experimental trawling in Cochin -Munambam area from December 2000 to November 2002

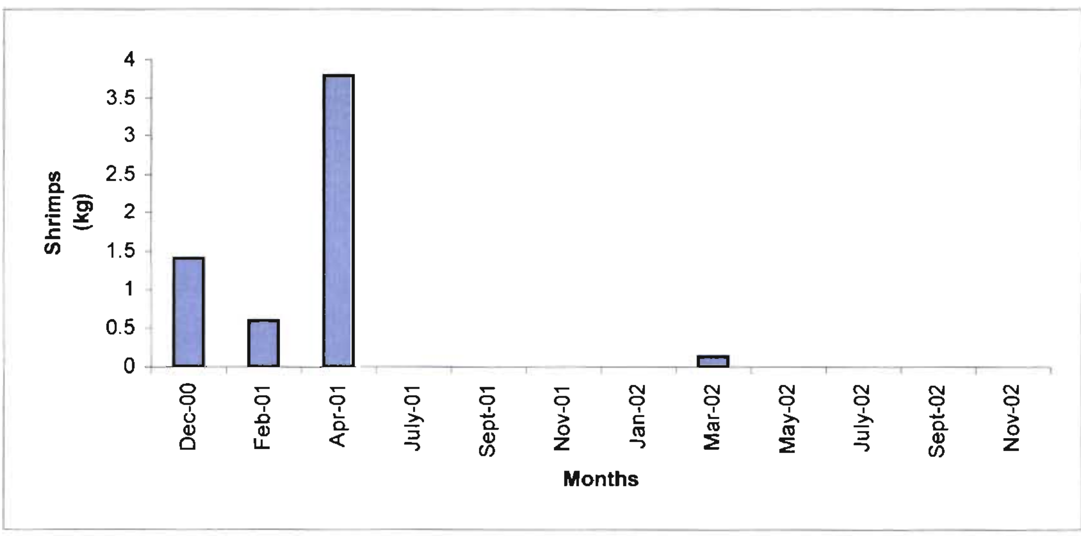


Fig. 7.47 Quantity of shrimps discarded during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

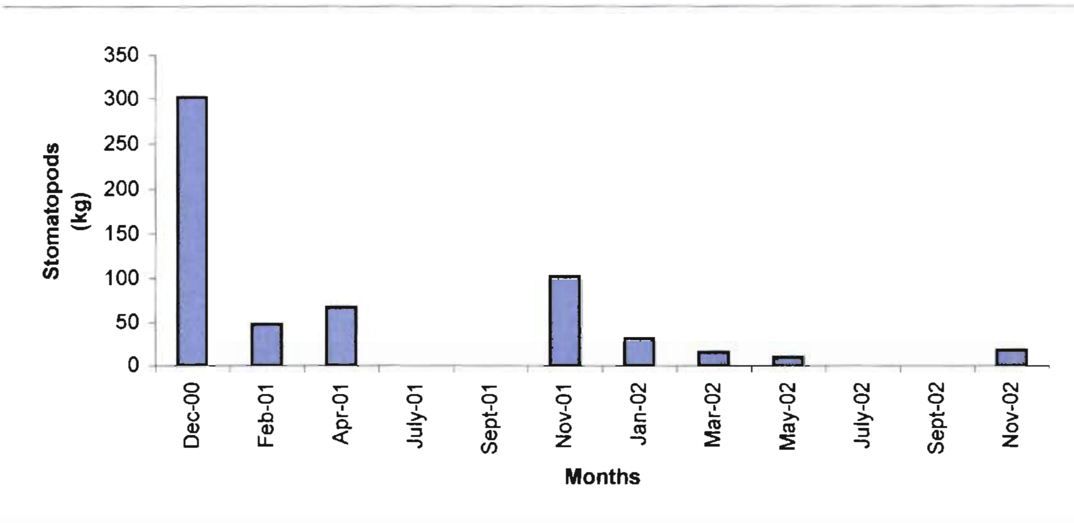


Fig. 7.48. Quantity of epifaunal stomatopods discarded during experimental trawling in Cochin -Munambam area from December 2000 to November 2002

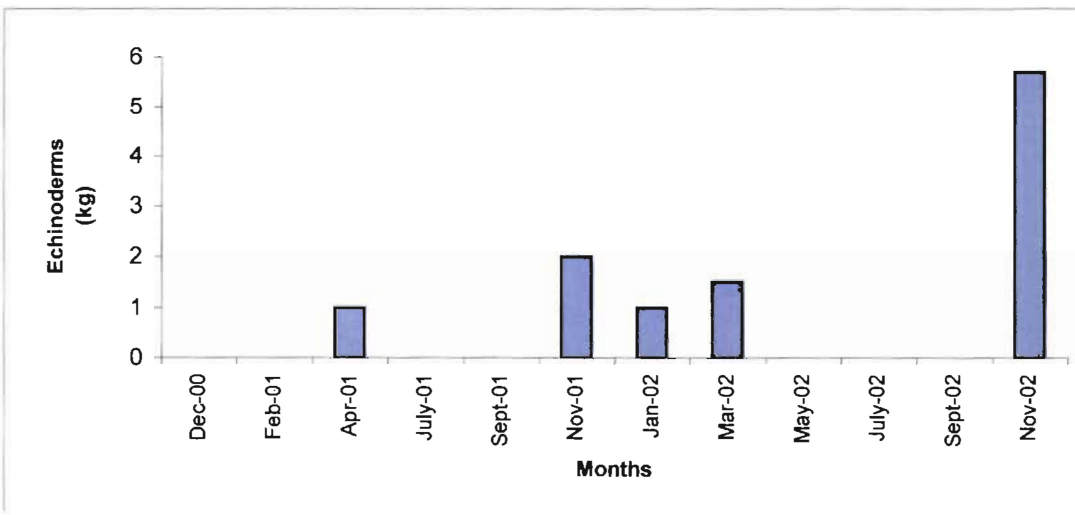


Fig. 7.49 Quantity of echinoderms discarded during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

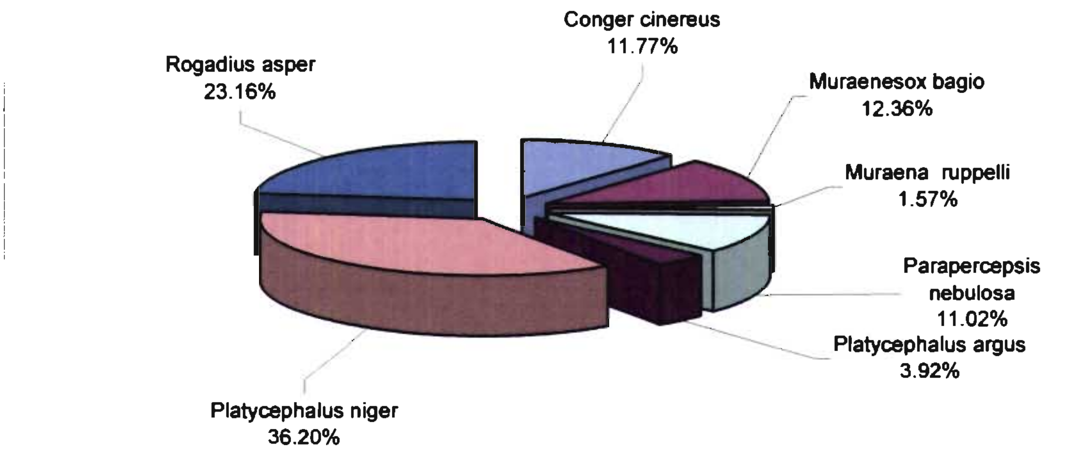


Fig.7.50 Species composition of finfishes in epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2001

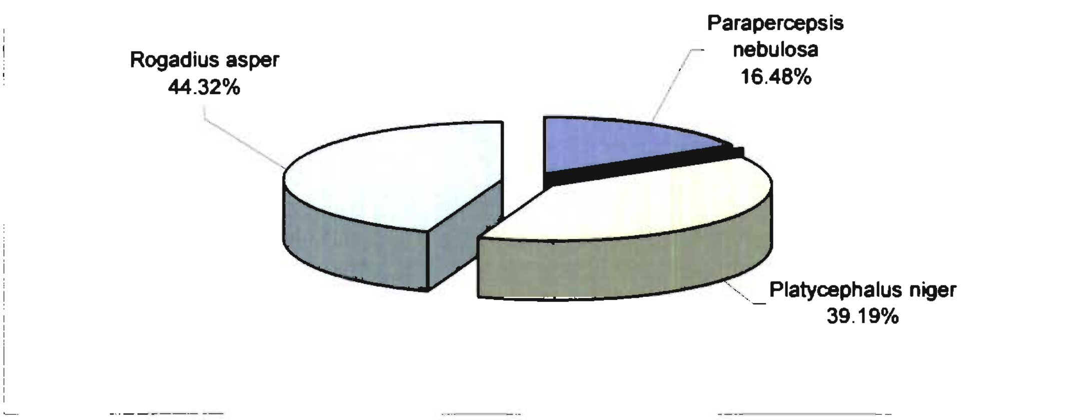


Fig.7 51. Species composition of finfishes in epifaunal discards during experimental trawling in Cochin - Munambam area from January 2002 to November 2002

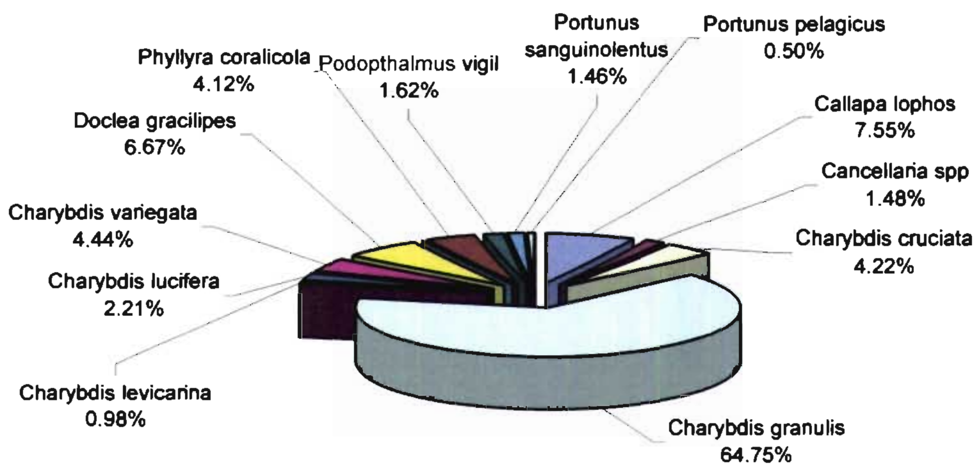


Fig. 7.52 Species composition of crabs in epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2001

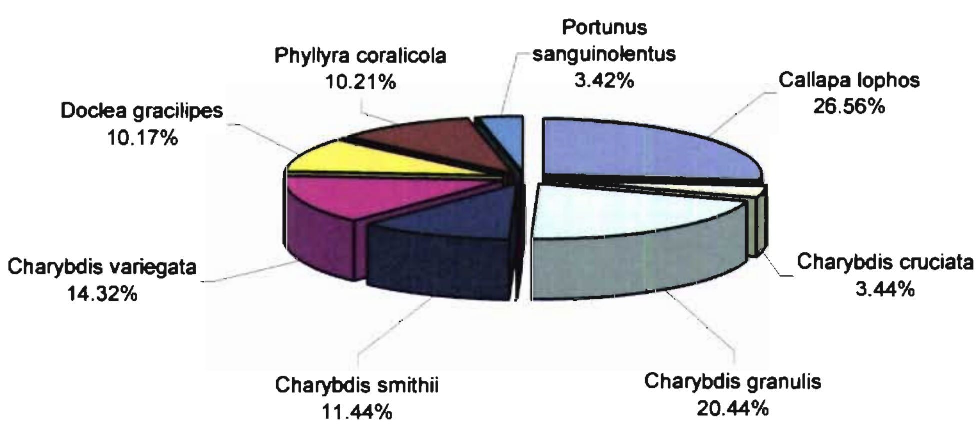


Fig. 7.53 Species composition of crabs in epifaunal discards during experimental trawling in Cochin - Munambam area from January 2002 to November 2002

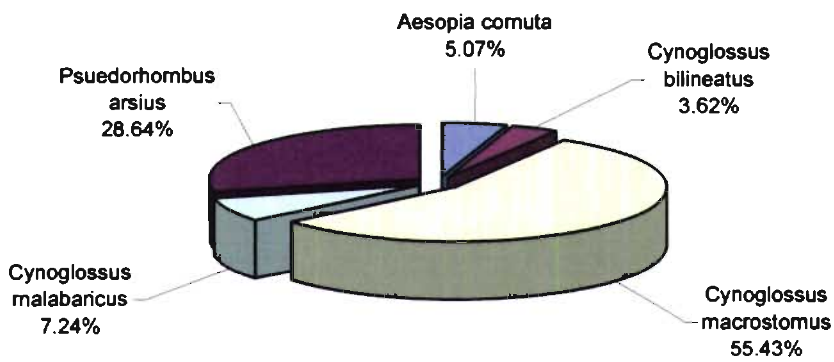


Fig. 7.54 Species composition of soles in epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2001

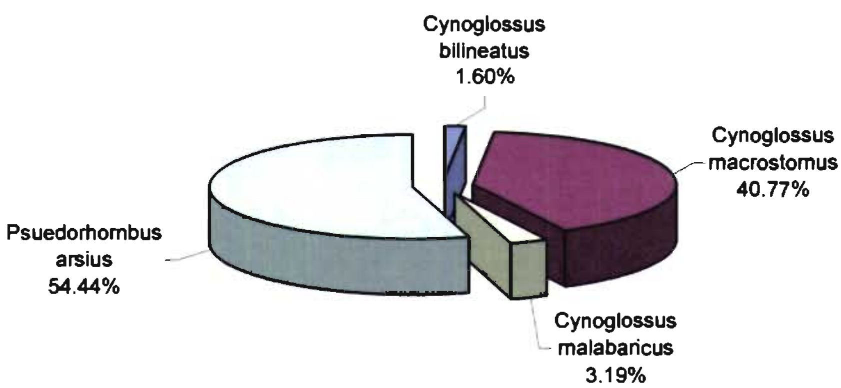


Fig. 7. 55 Species composition of soles in epifaunal discards during experimental trawling in Cochin - Munambam area from January 2002 to November 2002

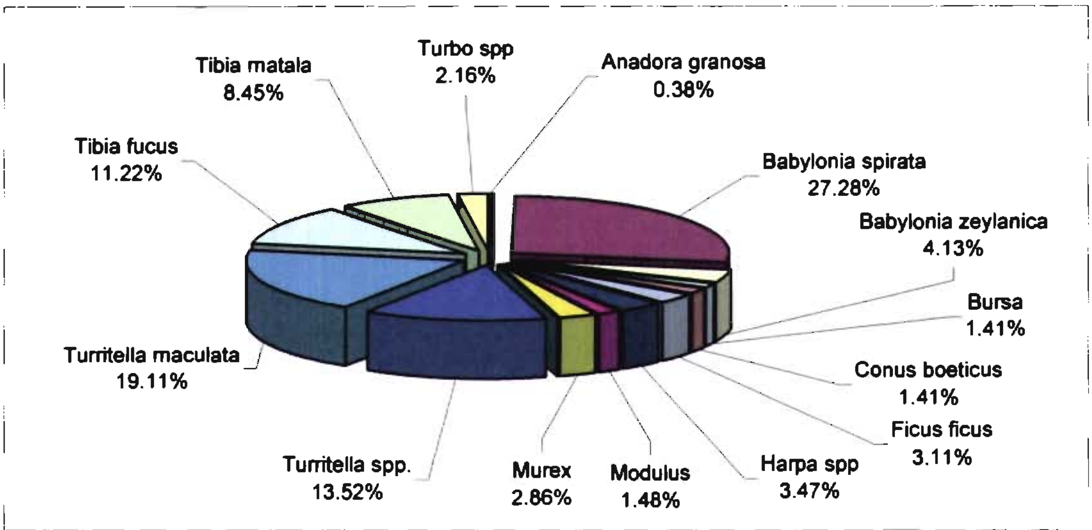


Fig. 7.56 Species comosition of gastropods in epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000- November 2001

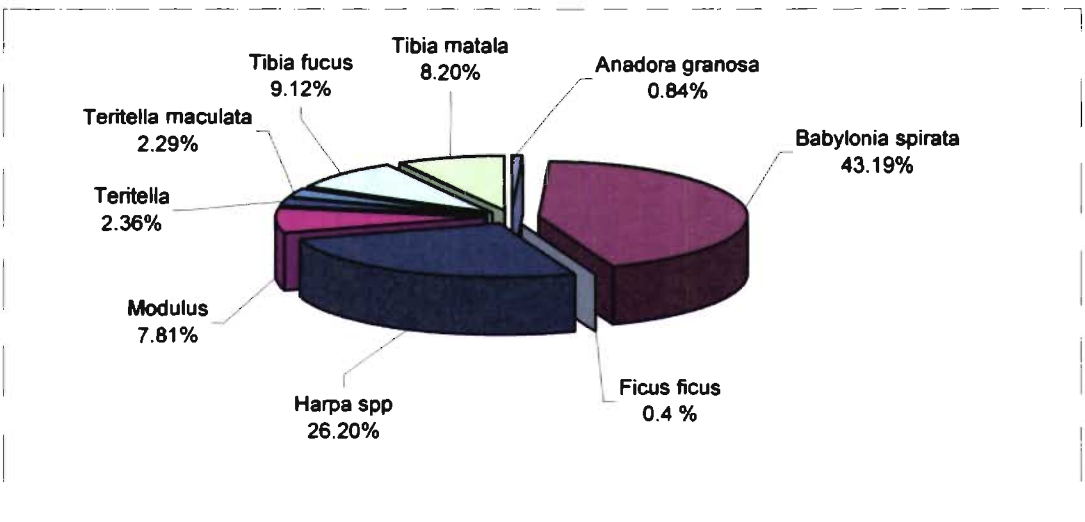


Fig.7.57 Species composition of gastropods in epifaunal discards during experimental trawling in Cochin - Munambam area from January 2002- November 2002

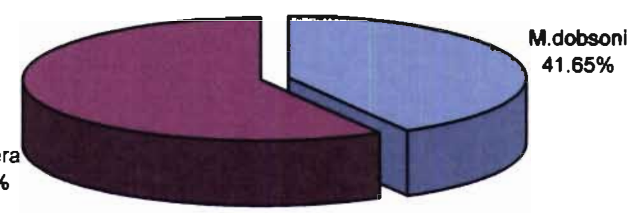


Fig. 7.58 Species composition of shrimps in epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2001

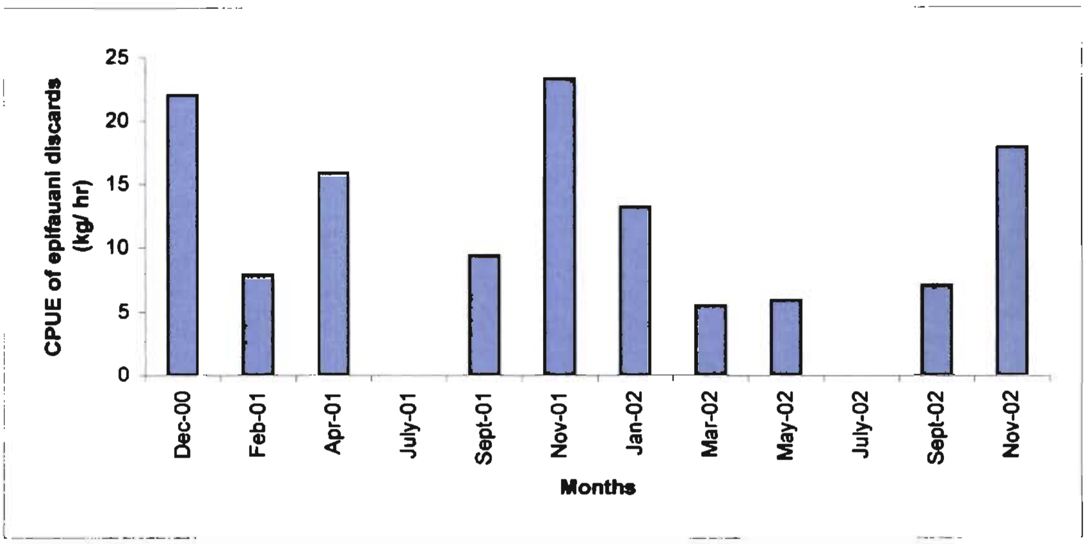


Fig. 7.59 Temporal variations in CPUE of epifaunal discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

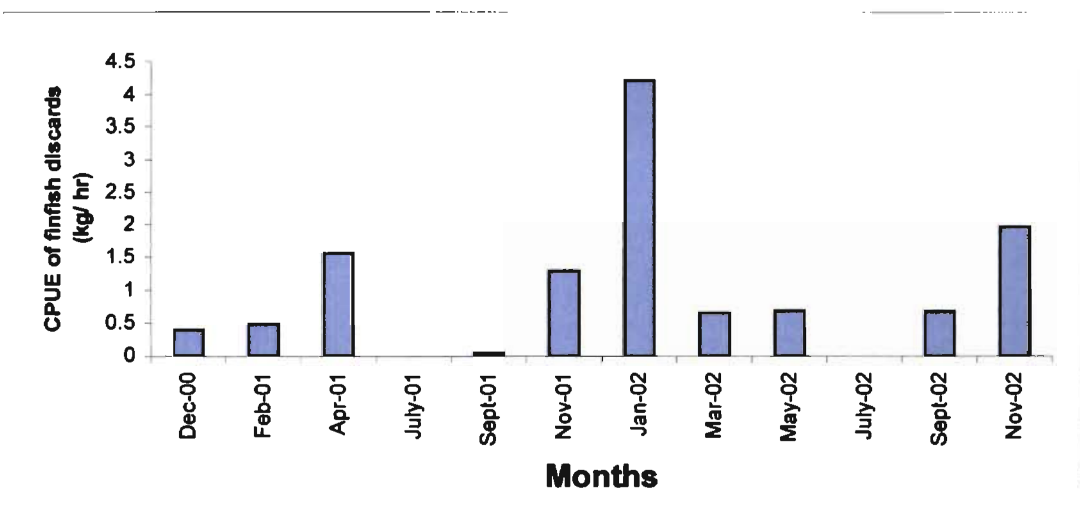


Fig. 7.60 CPUE of finfishes in discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

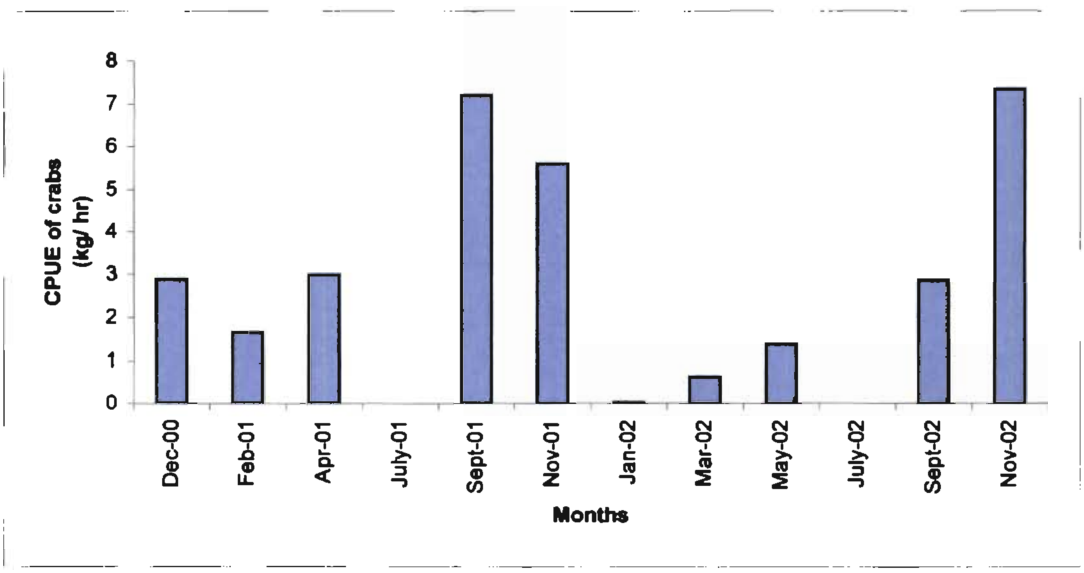


Fig. 7.61 CPUE of crabs in discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

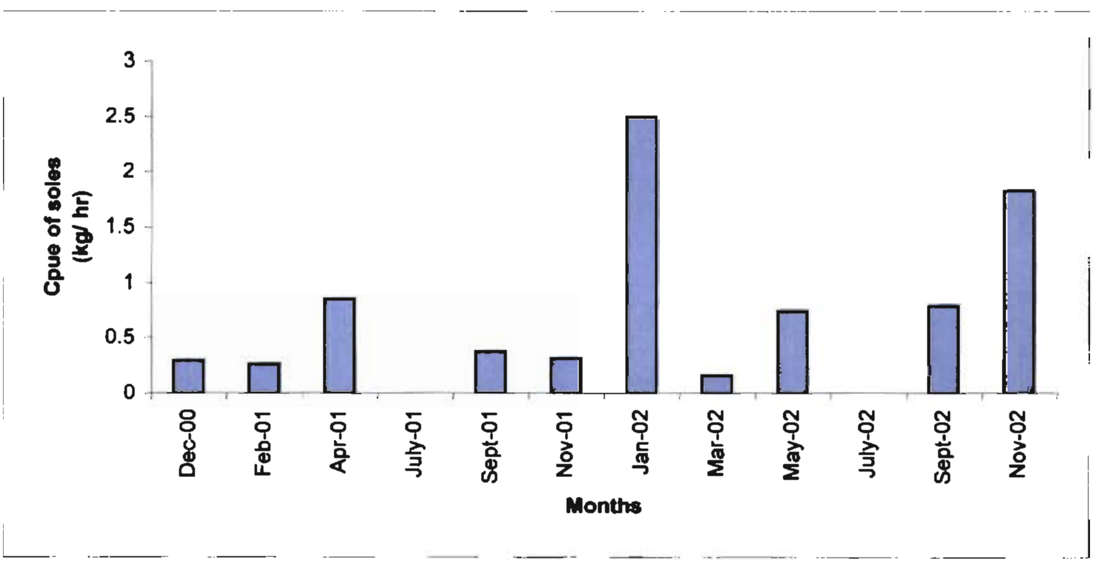


Fig. 7.62 CPUE of soles in discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

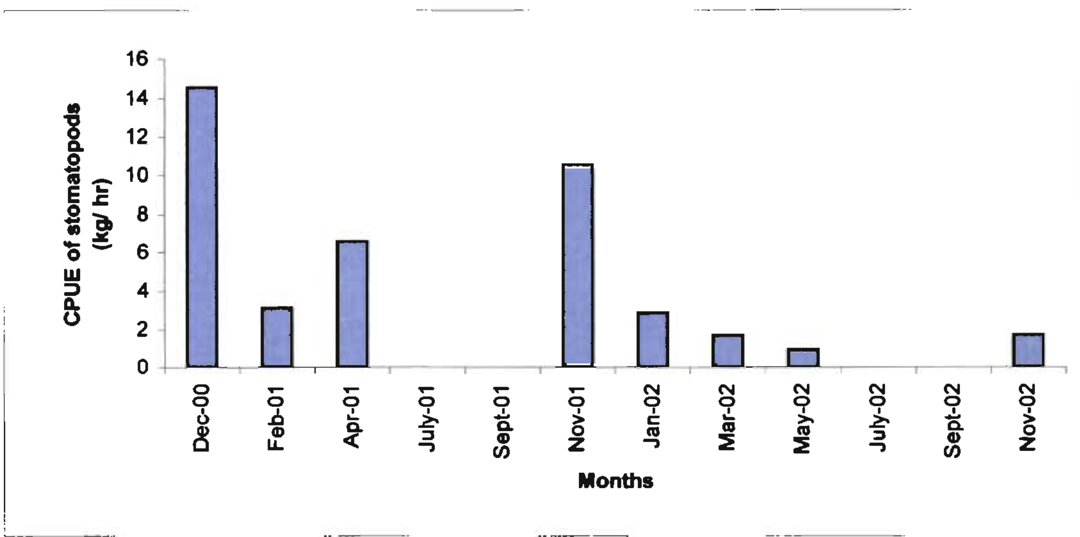


Fig. 7.63. CPUE of stomatopods in discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

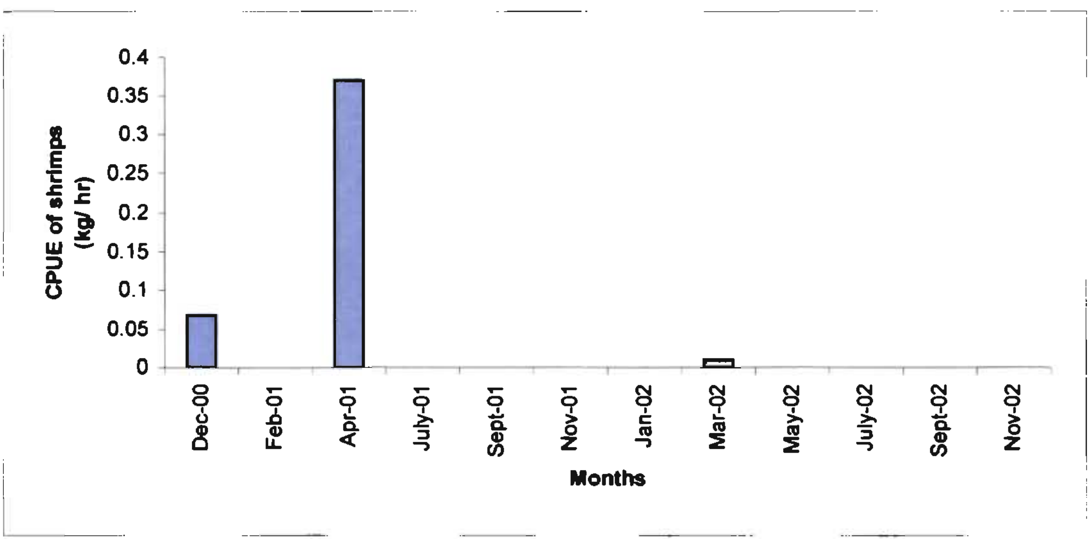


Fig. 7.64 CPUE of shrimps in discards during experimental trawling in Cochin - Munambam area from December 2000 to November 2002

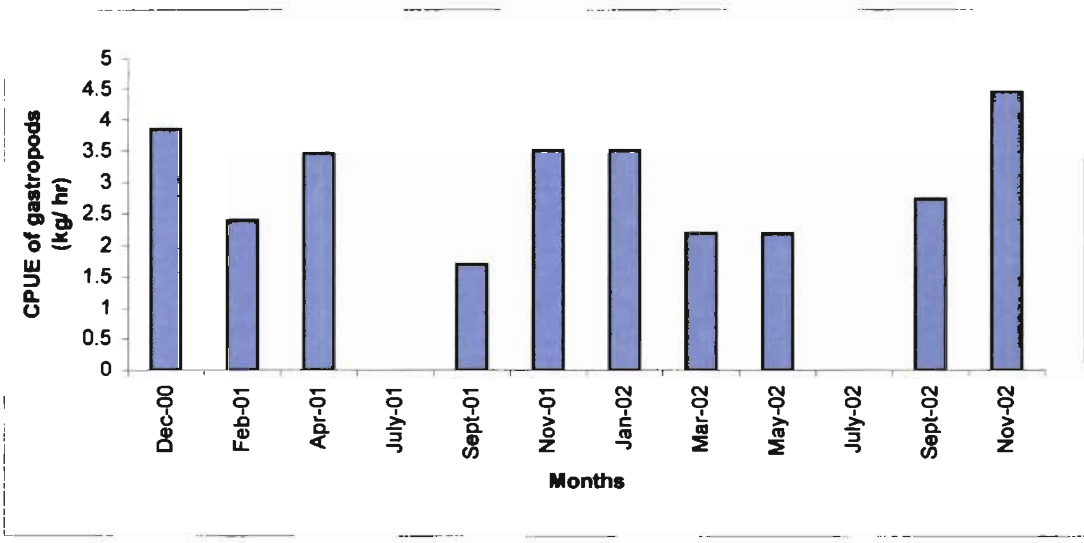


Fig. 7.65 CPUE of gastropods in discards during experimental trawling in Cochin - Munambam area during December 2000 to November 2002

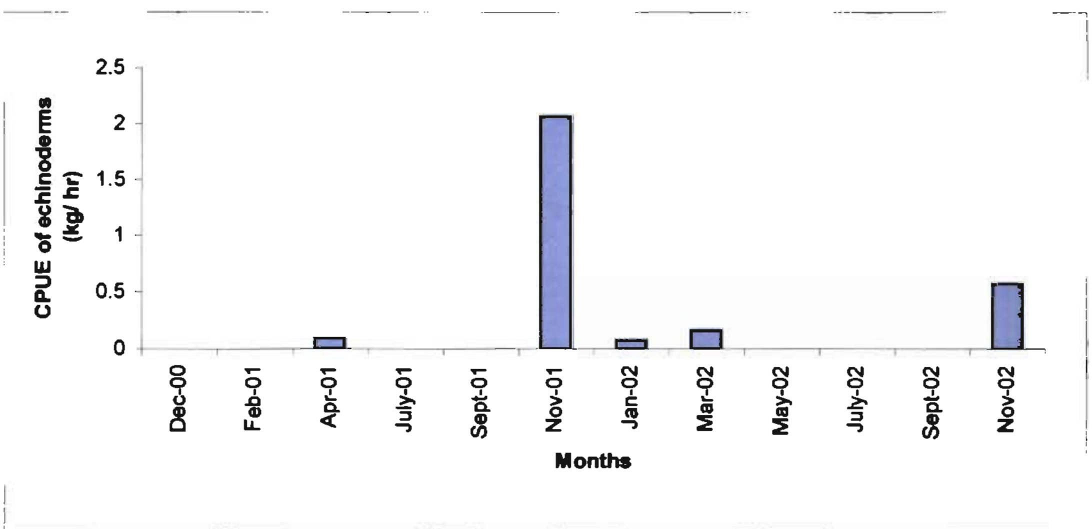


Fig. 7.66 CPUE of echinoderms in discards during experimental trawling in Cochin - Munambam area during December 2000 to November 2002

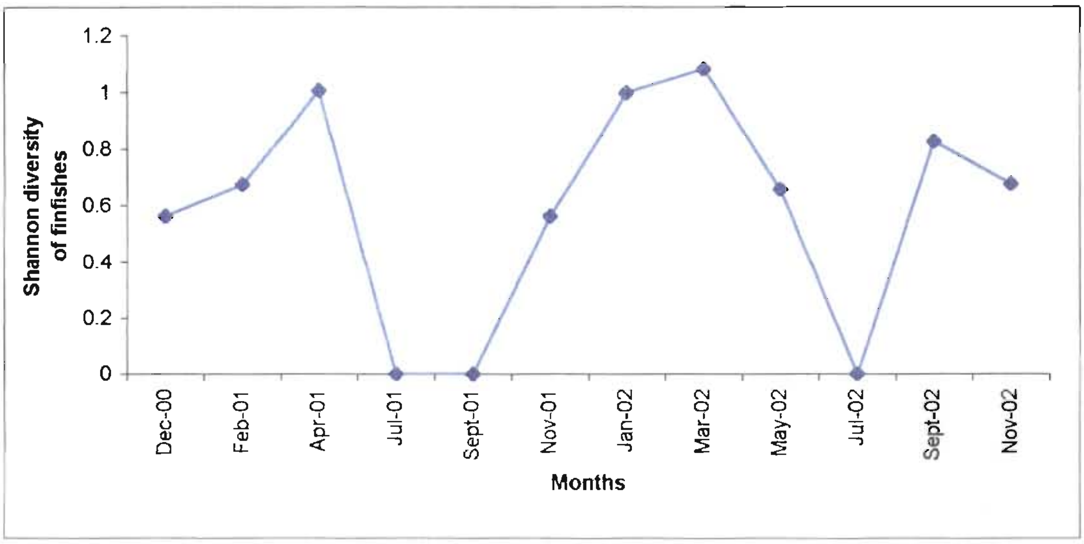


Fig.7.67. Diversity of finfishes during experimental trawling in Cochin -Munambam area from December 2000 to November 2002

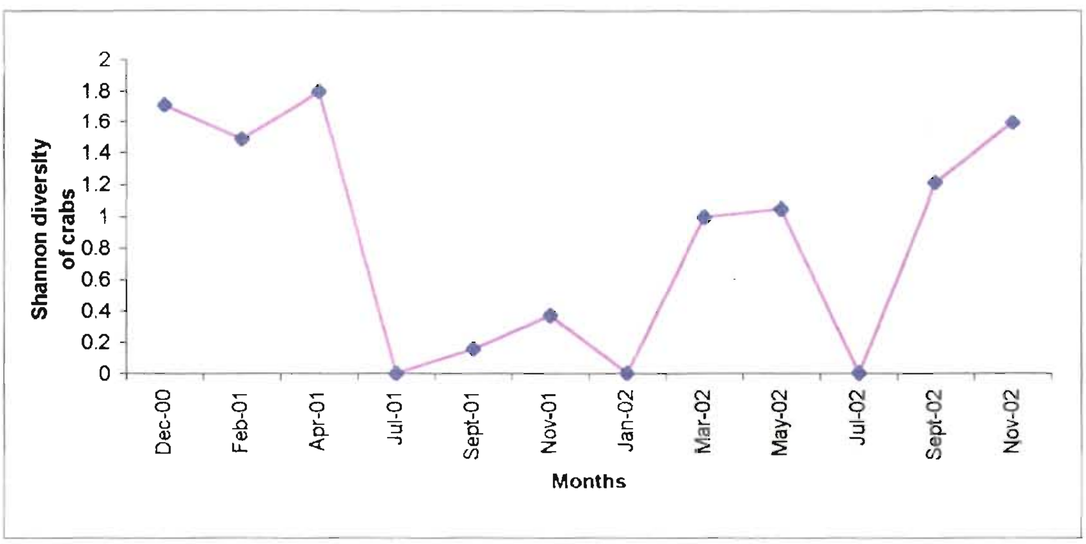


Fig. 7.68 Diversity of crabs during experimental trawling in Cochin -Munambam area from December 2000 to November 2002

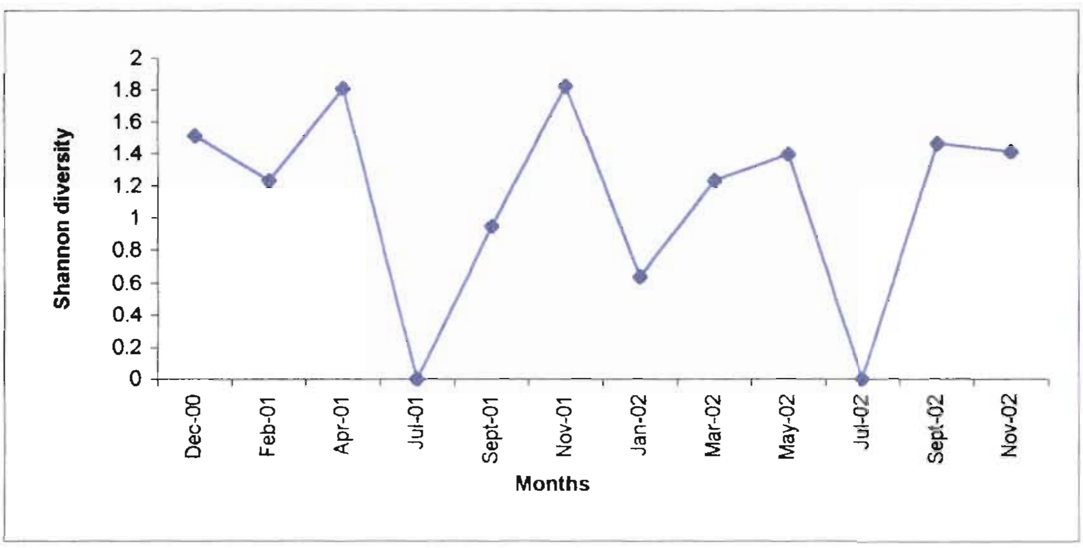


Fig.7.69 Diversity of gastropods during experimental trawling in Cochin -Munambam area from December 2000 to November 2002

Plate 7.1

A. Typical assorted bottom trawl catch

B. Unsorted trawl catch comprising soles and shrimps

Plate 7.2

A. An epibenthic trawl catch

B. Another view of the epibenthos in the trawl catch

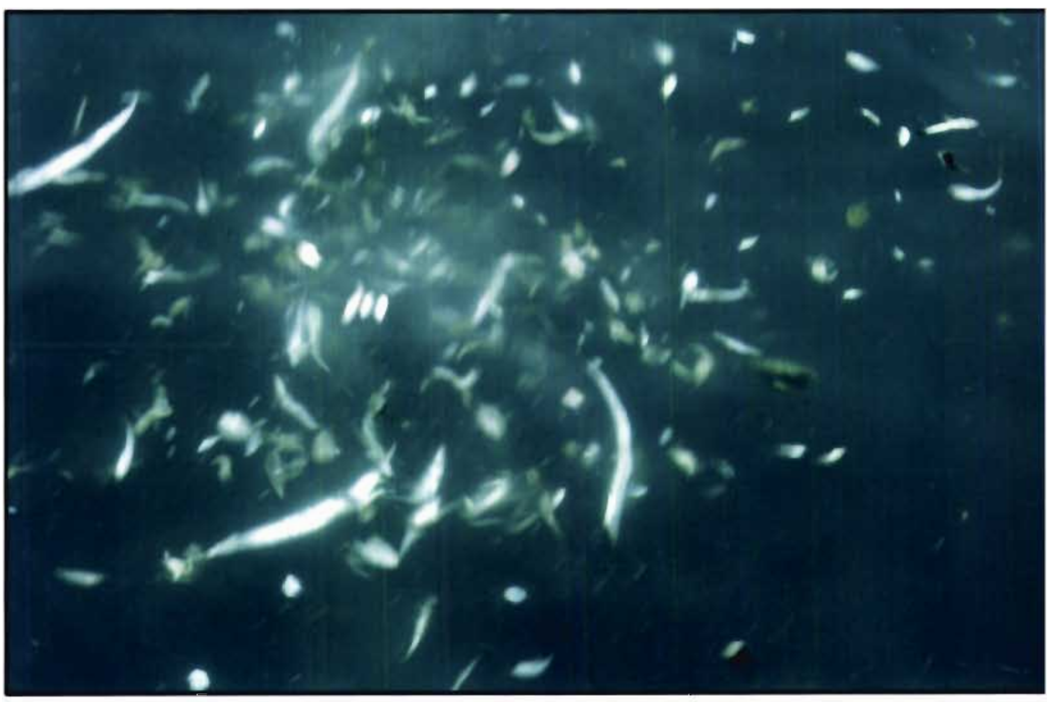
Plate 7.3

A. Process of sorting onboard

B. Sorted fraction of the trawl catch

Plate 7.4

A. Discarding of the unwanted catch



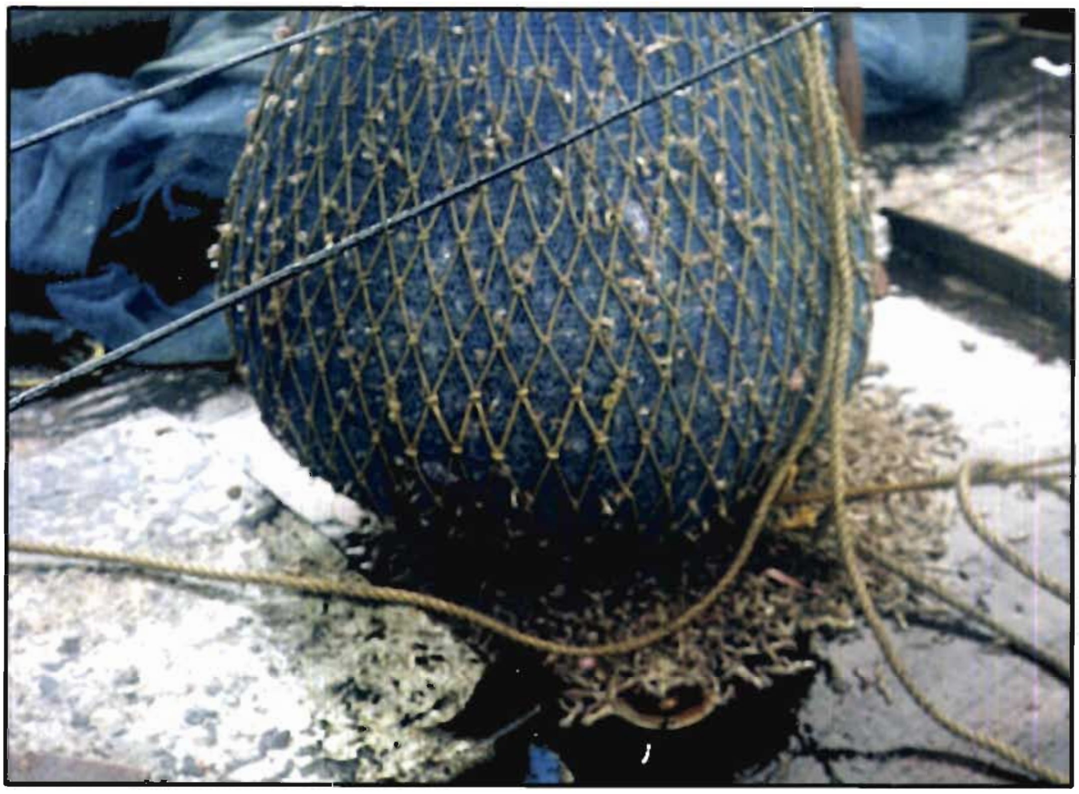
B. Fate of discards

Plate 7.5

A. Haul of *Charybdis smithii* as the major bycatch

B. Huge catch of *Charybdis smithii* onboard

Plate 7.6



A. A haul of Stomatopods

B. Stomatopods spread on the deck

Chapter 8

IMMEDIATE EFFECT OF BOTTOM TRAWLING ON INFAUNAL MACROBENTHOS

8.1 Introduction

Benthos representing the level of the benthic productivity forms the major food resource of demersal fishery resources representing prawns, bottom dwelling fishes and other marine invertebrates thereby serving as an inevitable link in the benthic food chain (Mohammed, 1955). Benthic animals also have a role in releasing nutrients back into the water column and aid in the stability of sediments. The distribution of macrofaunal species on the sea bottom is closely related to salinity, water movement, sediment grain size and organic content of the sediment (Crecutzberg *et al.*, 1984; Duineveld *et al.*, 1991). Availability of benthos at a region can be an indicator of demersal fishery potential since they form an important food reserve for crabs and fishes (Varshney *et al.*, 1988). Benthos are divided into two groups a) epifauna which are living on, protruding from, anchored in, or attached to, the substratum b) infauna which are living entirely within the sediment. Infauna is highly fragile in nature and easily succumbs to the perturbations on the seabed.

Since time immemorial, there have been protests about the presumed damage to fishing grounds and benthic organisms due to trawling activities (Graham, 1955; Bridger, 1970; De Groot, 1984). Bottom trawling has been reported to be the most destructive type of fishing methods prevalent in the world-fishing sector (De Groot, 1984; Bergman and Hup, 1992; Jones, 1992; Lindeboom and de Groot, 1998). Towed bottom fishing gears are used to catch species that live in, on, or in association with the seabed (Kaiser *et al.*, 1999) causing mechanical perturbation on the sea bottom and thus interferes with the physical and chemical properties of the habitat, ultimately leading to the loss of the benthic fauna (Krost, 1990; Auster and Langton 1999; Smith *et al.*, 1999b; Chicharo *et al.*, 2002a). During bottom trawling, a variety of fishes and other invertebrates are caught in the trawl net and after assorting the economically important fishes from the catch, the remaining part is thrown back to the sea as "discards" of which most of them will not survive (Graham, 1955; Bridger, 1970; De Groot, 1973; Fonds, 1994; Bergman *et al.*, 1998). Besides, a significant fraction of infauna which live inside the sediments are destroyed as a result of direct contact with the gear or exposure to predators (Holme, 1983; Brown, 1989; Rees and Eleftheriou, 1989; Krost, 1990; Langton and Robinson, 1990; Bergman and Hup 1992; Brylinski *et al.*, 1994; Kaiser and Spencer, 1996b). Huge trawl nets attached with heavy otter boards and tickler chains penetrate the sea bed to certain depths (upto 30cm), which cause resuspension of the sediments and disturb the sediment structure (Churchill, 1989; Messieh *et al.*, 1991; Schwinghamer *et al.*, 1998b; Black and Parry, 1999; Piet *et al.*, 2000) which result in the exposure and destruction of the benthos (Watling and Norse, 1998; Kutti, 2002).

The magnitude of the disturbance is mainly dependent on many factors like speed, shape, weight and dimension of the gear associated with type of sediment and habitat characteristics (Hall, 1994; Fonteyne, 2000). Flattening of erected sediment mounds (Smith *et al.*, 2000) cause serious injuries and death to the epibenthic and infaunal species (Collie *et al.*, 1997; Freese *et al.*, 1999;

Prena *et al.*, 1999; Ball *et al.*, 2000) and also expose the infauna out to the upper sediment layers (Mayer *et al.*, 1991; McConnaughey *et al.*, 2000).

Bottom gears inflict direct and indirect changes to the seabed. Direct effects of bottom trawling are always immediate and are manifested as changes in the abundance of infaunal and epifaunal species and temporary modification of habitat structure (Dayton *et al.*, 1995b; Veale *et al.,* 2000b). The epifauna and infauna may be damaged, destroyed or removed from the ecosystem. Indirect changes are signified by the alterations in the ecological relation between species in the benthic assemblage (Jennings and Kaiser, 1998; Jennings and Reynolds, 2000). These changes are evident from the perceptible reduction in structural complexity of the benthic habitat through decline in the abundance of larger bodied epifaunal species especially juveniles of many fish and invertebrates (Auster *et al.*, 1995; Watling and Norse, 1998). Studies conducted by many workers revealed that the seabed will take much time to recover the species lost due to trawling and to regain the original status of seabed is quite impossible (Rumohr *et al.*, 1998). Experimentally it has been shown that species diversity, biomass and the abundance of epibenthic and infaunal species vary highly due to the bottom trawling activities (Collie *et al.*, 1997; Kaiser and Spencer, 1996a;Tuck *et al.,* 1998; Kaiser *et al.*, 1998b; Prena *et al.*, 1999; Ball *et al.*, 2000; Kutti 2002).

Many studies have been conducted in order to assess the long term and short-term impacts of bottom trawling around the globe; in New Zealand (Thrush *et al.*, 1995,1998), Australia (Moran and Stephensen, 2000), Canada

(Prena *et al.*, 1999), U.S.A, (Collie *et al.*, 1997, 2000a; Freese *et al.*, 1999) Great Britain (Kaiser *et al.*, 1998 a & b; Tuck *et al.*, 1998; Veale *et al.*, 2000a), the Netherlands (Bergman and Hup, 1992) and Sweden (Hansson *et al.*, 2000). But no concerted attempt has been conducted in Indian waters. The longer - term effects are often harder to demonstrate (Thrush *et al.*, 1998). The short term environmental effect of dredging and trawling on sea bottom have received increased attention in recent years and several studies have characterized changes in the ecosystem due to bottom trawling and dredging (Hall *et al.*, 1990; Bergman and Hup 1992; Eleftheriou and Robertson, 1992; Lambert and Goudreau, 1995; Kaiser and Spencer, 1996b; Pranovi *et al.*, 2000). Most of the present day research on short- term or direct effects focuses on penetration depth of the tickler chains (Bergman *et al.*, 1990; Fonds *et al.*, 1992; Mac Donald *et al.*, 1997), the change in sediments characteristics (Laban and Lindeboom, 1991), effects on benthic communities (Dolah *et al.*, 1991; Kaiser and Spencer, 1996a; Gilkinson et al., 1998).

In Kerala, on the south west coast of India, bottom trawling is the major fishing activity with about 4590 bottom trawlers engaged in the daily fishing operations in the state waters. Kerala, well known for its fishery resources now face the problem of excessive trawling pressures due to the inordinate proliferation of the bottom trawlers. Several studies were conducted to understand the infaunal community structure in the Indian waters (Mohammed, 1955; Parulekar and Wagh, 1975; Harkantra *et al.*, 1982; Raman and Adiseshasai, 1989; Harkantra and Parulekar, 1994). The infaunal productivity in

Kerala is also well documented (Damodaran 1973, Hridayanathan 1981, Sunil Kumar, 1995). This pioneer attempt was made with an aim to study the immediate effect of bottom trawling on the infaunal communities in the inshore waters of southwest coast of India.

8.2 Materials and Methods

Materials and methods are explained in detail under chapter 2.5.

8.3 Results

Immediate impact of bottom trawling on infaunal macrobenthos was studied by comparing the abundance (Nom^{-2}) and biomass ($g\ m^{-2}$) of the macrobenthos obtained from the sediment samples collected before and after experimental trawling conducted at the study area. Wide variations were noticed in the abundance and biomass of polychaetes in the samples collected after trawling when compared to that of before trawling. However, the variations were found statistically insignificant ($P > 0.01$).

8.3.1 Species composition

Based on the results of the two years study at ten stations between Cochin and Munambam, polychaetes emerged as the numerically dominant taxa, in almost all seasons and depths. The other macro infaunal communities included Sipunculids, Amphipods, Nematodes, Penaeids, Gastropods and Bivalves. The polychaetes were represented by 80 genera in which the most commonly occurring were *Ancistrosyllis*, *Cossura, Prionospio, Sternaspis, Lumbrineries, Magelona, Nepthys and Glycera.* (Appendix VI, Tables 1-48). Since polychaetes were encountered in sufficient numbers at all stations regardless of seasons, the group was chosen to comprehend the impact of trawling on infauna. Polychaetes showed a preference for sandy areas (> 40 m depth) and exhibited high abundance in this zone, while silty and clayey regions (0 - 40 m) harbored the lowest abundance of polychaetes (Fig. 8.1).

8.3.2 Abundance and biomass of polychaetes

The abundance of polychaetes in the sediment samples collected before trawling during the study period is given in Fig. 8.1. During the first year, the highest number of polychaetes was recorded in December 2000 with a mean abundance of 4393 no. m^{-2} with the lowest in April 2001 with 437 no. m^{-2} In the second year, highest mean abundance was observed in July 2002 with 1250 no. m^{-2} and the lowest of 395 no. m^{-2} was recorded in September 2002 (Fig. 8.1). Seasonally there exits significant variations in the polychaete abundance ($P< 0.01$, Appendix VI, Table 49 & 50), with the highest abundance during post monsoon months followed by monsoon and premonsoon seasons (Fig.8.1). May 2002, which represent premonsoon, also witnessed high abundance of polychaetes, where mean density of 1182 no. m^{-2} was recorded owing to the profusion in *Magelona sp.* and *Cossura sp.* The polychaete abundance was highest at the sandy stations (stations 9 & 10) at 40 - 50 m depth zone where mean density of 2598 no. m^{-2} was recorded at station 10. The lowest was at the silty sandy area (30 – 40 m) with a mean density of 596 no. m^{-2} registered at station 8, while muddy areas near to shore (> 30 m depth) showed moderate abundance (Fig 8.2). Analysis of sediment samples collected before trawling revealed that, the highest abundance of polychaetes was at station 9 in

February 2000 with 17720 no. m^{-2} during first year while the lowest of 90 no. m^{-2} was observed at station 1 in the same month. During the second year, highest abundance (4000 no. m^{-2}) was obtained at station 10 in July 2002 while it was lowest (40 no m^{-2}) at station 5 in September 2002 (Fig. 8.3).

In the samples collected after trawling, the abundance of polychaetes was found to increase in almost all stations (Fig. 8.4). The mean abundance of polychaetes recorded in the samples collected after trawling during the two year period is depicted in Fig. 8.5. The mean abundance of polychaetes recorded after trawling ranged between 618 and 7182 no. m^{-2} in the first year where the highest was in December 2000 and the lowest in September 2001. During the second year, the mean abundance of polychaetes varied between 385 - 3141 no. m^{-2} where the highest was recorded during May 2002 and the lowest in March 2002. Highest abundance of polychaetes was recorded from the sandy area with a population of 4002 no. m^{-2} recorded at the station 10 while the lowest of 607 no. m^{-2} was recorded at the station 4 in the 20 - 30 m depth zone (Fig. 8.6). In the samples collected after trawling, total number of polychaetes varied between 40 and 29910 no. m^{-2} in the first year while during the second year, it ranged between 80 – 20710 no. m^{-2} Highest abundance was recorded at station 3 in December 2000 and the lowest was at station 6 in April 2001 during the first year study while in the second year, the highest abundance was recorded at the station 9 in May 2002 and the lowest was at stations 5, 7 and 9 in September 2002 (Fig. 8.7). Analysis of polychaete abundance in the samples collected before and after trawling showed that trawling had significant effect on the abundance of polychaete assemblages ($P<0.01$). Highest variation was registered at station 3 in December 2000 during first year, where polychaete abundance increased to 29910 no. m^{-2} after trawling from 8360 no. m^{-2} recorded in the samples collected before trawling. Likewise during the second year, the highest variation in the polychaete abundance was observed at station 9 in May 2002 when 20710 no. m^{-2} was registered in the after trawling samples against 2787 no. m^{-2} recorded in the samples before trawling (Fig. 8.8 a & b). However, there was no significant variation in the abundance of the polychaete in samples collected before and after trawling samples ($P>0.01$, Table 8.1).

Figure 8.9 shows the seasonal variations in average biomass of polychaetes recorded in the samples collected before trawling during the study period. Average biomass recorded in the samples collected before trawling during first year ranged from 1.29 – 4.60 g. m^{-2} where the highest was observed in February and September 2001 while it was lowest in November 2001 (Fig. 8.9). Highest average biomass recorded in February and September 2001 was caused by the presence of comparatively bigger sized *Diopatra sp.* in the samples. During the second year, the average biomass varied between 0.69 – 4.61 g. m^{-2} where the highest biomass was observed in July 2002 and the lowest was recorded during September 2002 (Fig. 8.9). Significant difference ($P< 0.01$ Appendix VI, Table 51) was noticed in the average biomass recorded at the different stations. In the present study, higher biomass of polychaetes was noticed at sandy areas with the highest of 6.2 g. m^{-2} at station 9 (Fig. 8.10). Of the total biomass recorded in different stations, the values ranged between

0.006 and 22.46 g. m^{-2} during the first year during when the highest was recorded at station 9 in February 2001 and the lowest at station 6 in the same month (Fig. 8.11). During the second year, the polychaete biomass ranged between 0.03 and 11.80 g. m^{-2} with the highest in July 2002 at station 10 while lowest was recorded in September 2002 at station 8.

Polychaete biomass was higher in the after trawling samples at almost all stations (Fig. 8.12). Highest biomass was recorded from the samples collected in December 2000 and the lowest in April 2001 during the first year while during the second year the highest was registered during May 2002 and the lowest was in September 2002 (Fig. 8.13). Among the ten stations studied, the biomass was high at stations located in the sandy area with the highest at station 9 and the lowest at station 5 (Fig. 8.14). However no significant variation was observed in the samples collected before trawling, there was significant variation ($P > 0.01$,) Appendix VI, Table 52) in the total biomass observed in the samples collected after trawling. During the first year, total biomass ranged between 0.04 - 17.51 g. m^{-2} with the highest at station 1 in December 2000 and the lowest at station 3 in November 2001. During the second year, the biomass ranged from 0.01 – 12.64 g. m^{-2} (Fig. 8.15). Wide variations could be observed at many stations (Fig. 8.16) while comparing the polychaete biomass in the samples collected before and after trawling operations. The highest variation was observed at station 3 in December 2000 where biomass increased to 34.53 g m^{-2} in the samples collected after trawling from 7 16 g. m^{-2} recorded before trawling during the first year (Fig. 8.16 a & b). Effect of trawling was very glaring in the second year also, with the highest variation in biomass at station 7 in January 2002 where 9.44 g. m^{-2} was recorded in the samples collected after trawling against 0.4 g. m^{-2} before trawling. Nevertheless, significant variation could not be observed in the polychaete biomass registered in samples collected before and after trawling ($P>0.01$).

8.3.3 Multivariate analysis based on abundance and biomass

Multivariate community analyses based on both species abundance and biomass of polychaetes were performed to investigate the similarity between the stations sampled during the experiment. In the cluster analyses of abundance data of before trawling samples, four well-defined clusters could be discernable in the dendrogram. Stations located in the same depth zones showed higher similarity of fauna (Fig. 8.17) and highest similarity (90%) was observed between stations located in the muddy areas (stations 1 6). In the after trawling samples, only three well marked clusters could be identified in the dendrogram. Similarity between stations 9 and 10 was reduced to 60% from the 85% before trawling (Fig. 8.18). Dendrogram comparing abundance of polychaetes at the ten stations before and after trawling showed 85% similarity among first five stations sampled before trawling and the stations sampled after trawling showed lesser similarity (60%) indicating wide disparity in the polychaete abundance after trawling (Fig. 8.19). Stations 2 and 3 became more dissimilar after trawling (60%). Cluster analysis based on the biomass of polychaete also showed higher similarity (80%) between stations 2 – 6 and three major clusters were discernible in the before trawling samples (Fig.8.20). Dendrogram formed by the stations sampled after trawling showed four major clusters and the similarity between the 2- 6 stations decreased to 60 % (Fig.8.21). Wide variations were noticed in the similarities of the stations comparing both before and after trawling (Fig. 8.22). Inshore stations 1 – 6, which showed strong similarity before trawling (80%), exhibited only 70% similarity after trawling. Similarly sandy stations (9 & 10) with 80% similarity before trawling reduced to a mere 65% after trawling. This comparison indicates the variation of biomass due to trawling.

Non-metric multi-dimensional scaling (MDS) plots based on the polychaete abundance obtained before trawling showed that the stations at same depth were located closely (Fig. 8.23), while after trawling, they became more dissimilar (Fig. 8.24). This indicates that the polychaete abundance was more or less same at the stations located at the same depth zone in the samples collected before trawling whereas after trawling it varied. Abundance of polychaete both before and after trawling in MDS comparison showed that all stations before trawling were distant from the corresponding after trawling stations indicating remarkable displacement of polychaetes due to trawling (Fig. 8.25).

MDS plots based on the polychaete biomass resembled that of abundance, with stations located at the same depth located closer in the plot (Fig.8.26). The "Euclidean distance" between the same stations after trawling was much more than that seen before trawling (Fig.8.27). Figure 8.28 illustrates the difference in polychaete biomass at all stations before and after trawling, indicating a clear variation in polychaete biomass after trawling.

8.3.4 Diversity based on polychaete abundance

Diversity indices based on the polychaete abundance was carried out using Shannon's diversity index (H') which varied between 1.04 – 1.56 in the samples collected before trawling. The highest diversity was noticed at station 8 and lowest at station 10. After trawling the diversity was found increased in six stations -1, 4, 6, 7, 8, and 10 while station 2, 3 and 9 showed the lesser diversity. Station 5 was found to be stable with equal diversity indices before and after trawling (Fig.8.29). After trawling, the Shannon's diversity ranged between 1.00 and 1.67 where the highest was noticed at station 7 and the lowest at station 9. Average diversity (H') calculated for all stations before trawling was 1.25 (Table 8.1), which increased to 1.32 after trawling. Simpson's diversity (D') was calculated for all stations before trawling and ranged from 0.46 to 0.65 units where the highest was recorded at station 8 and the lowest at station 10 (Fig. 8.30). After trawling, the diversity (D') was found high and varied from 0.38 to 0.72. Stations 1, 2, 4, 5, 6, 7 and 8 showed higher diversity after trawling while stations 3, 9 and 10 exhibited low diversity values when compared to similar valus recorded before trawling. The highest diversity was recorded at station 7 while it was lowest at station 9. Average diversity (D') calculated for all stations before trawling was 0.57 (Table 8.1), while the same increased to 0.59 after trawling. However, ANOVA showed that trawling had no significant effect on the diversity (H' and D') of the polychates ($P > 0.01$, Appendix VI, Table 53 & 56).

Richness showed that polychaete species assemblage was more in the sandy stations (Table 8.1) in the samples collected before trawling. Richness recorded before trawling ranged from 0.71 – 1.19, where the highest was recorded at station 8 while it was lowest at station 2. After trawling the richness was found increased in almost all stations (Fig. 8.31). Stations 1, 2, 4, 6, 7, 8, 9 and 10 showed higher richness after trawling when compared to that before trawling (Fig. 8.31). Richness after trawling varied from 0.70 to 1.38 where the highest was recorded at station 8 while it was lowest at station 3. Sandy stations showed higher richness than stations with muddy texture. Overall richness after trawling increased to 0.99 from 0.87 recorded before trawling. (Table 8.1). Though richness showed a remarkable increase after trawling, it was not statistically significant ($P > 0.01$, Appendix VI, Table 55). Pielou's evenness measured before trawling was in the range between 0.26 – 0.75. Evenness was highest at station 8 and the lowest at station 10. When the overall evenness measured at all station was analyzed, high values were found in the near shore stations (station 1-6) than sandy stations. Contrary to the diversity and richness, evenness was found to decline after trawling when compared to that of before trawling (Fig. 8.32). Average evenness measured at all stations decreased from 0.67 to 0.66 after trawling (Table 8.1). After trawling, evenness varied from 0.40 to 0.82 where the highest was at station 4 and the lowest at station 9. Richness and evenness based on the polychaete abundance before and after trawling showed no significant effect due to bottom trawling ($P > 0.01$, Appendix VI, Table 54 & 55).

8.3.5 Variations on diversity based on polychaete biomass:

Biomass data showed similar changes as in the case of diversity indices measured based on the abundance. Diversity and richness increased in the stations after trawling while evenness decreased (Table 8.1). Shannon's diversity based on biomass measured before trawling ranged from 0.83 to 1.23 where the highest was noticed at station 6 and the lowest at station 10. After trawling, the diversity (H') ranged from 0.92 to 1.52 where the highest diversity was recorded at station 8 and the lowest at station 10. Overall diversity (H') measured at all stations showed an average of 1.02 before trawling, while the same increased to 1.13 after trawling. While comparing the diversity registered before and after trawling, stations 1, 2, 4, 6, 8, 9 and 10 showed high diversity after trawling, on the contrary, stations 3, 5 and 7 showed a reduction in the diversity after trawling. (Fig. 8.33). Simpson's diversity calculated on polychaete biomass varied from 0.83 to 11.53 before trawling. Highest diversity (D') was recorded at station 10 while it was lowest at station 8. (Table 8.1). Diversity of the biomass after trawling ranged from 0.51 – 15.71 where the highest was recorded at station 2 while the lowest was reported at station 10. While comparing the overall diversity of all the stations, it appeared that diversity (D') increased after trawling with an average of 3.68 from 2.67 before trawling (Fig.8.34). However, no significant variation ($P > 0.01$, Appendix VI, Table 57 & 60) was seen when the average diversity (H' & D') computed before and after trawling, where compared.

Richness measured on the polychaete biomass also showed higher values after trawling when compared to that of before trawling. Richness calculated on the biomass obtained before trawling ranged from 3.54 to 51.85 where the highest richness was recorded at station 10 and the lowest at station 4 (Table 8.1). Figure 8.35 shows the increase in richness after trawling when compared to the values recorded in the stations before trawling. Richness measured after trawling ranged from 5.44 to 165.96 with the highest at station 2 and the lowest at station 9. On comparing the richness obtained before and after trawling (Fig.8.35), stations 1,2,3,4,6,7, and 8 showed higher richness after trawling whereas stations 5, 9 and 10 showed lesser values. When the richness obtained in all stations were pooled, the richness after trawling was found increased to 35.80 from 14.85 registered before trawling. Pielou's evenness measured before and after trawling based on polychaete biomass also showed a similar trend as noticed in the case of diversity studies based on polychaete abundance. Evenness recorded at stations before trawling varied from 0.48 (station 10) to 0.68 at station 6. Similarly, while comparing evenness recorded after trawling, the highest evenness of 0.71 was measured at station 5 and it was lowest (0.39) at station 10 (Table, 8.1). On analyzing the overall evenness recorded at all stations before and after trawling Stations such as 3, 6, 7, 9 and 10 showed a reduction of evenness during after trawling while stations 2, 4, 5 and 8 showed higher evenness after trawling. Station 1 stands apart due to the possession of more or less similar values before and after trawling. (Fig.8.36). However, overall evenness after trawling decreased to 0.58 from 0.59 observed before trawling (Table 8.1). Similar to richness and evenness recorded based on the polychaete abundance, no significant changes were observed on the basis of polychaete biomass, thus manifesting very little effect on the polychaete biomass due to bottom trawling (P>0.01, Appendix VI, Table 58 & 59).

8.4 Discussion

Immediate effect of bottom trawling on infaunal macrobenthos in the inshore (0 - 50 m) waters of Kerala was analysed by comparing the abundance and biomass of macrobenthos from the sediment samples collected both before and after trawling. The results revealed that bottom trawling inflicted irreversible damages to the infaunal macrobenthos due to exposure from their tubicolous habitation. Polychaetes were adjudged to evaluate the effect of bottom trawling since it represents the mainstay in the infaunal community around the year Other infaunal organisms such as bivalves and other crustaceans could not be brought under the purview of this study since their representation were very poor.

In the marine environment, benthic organisms have long been recognized as an integral part of the marine ecosystems (Raman and Adiseshasai, 1989), either at the secondary level as feeders of detritus and plant material or at tertiary level as food for predators like crabs and fishes (Parulekar *et al.*, 1982). Samples collected before trawling demonstrated that the polychaetes contributed to the major portion of the infaunal macrobenthos, followed by amphipods, bivalves and crustaceans. Polychaetes were encountered at all stations and seasons whereas amphipods were common in the sandy stations.

Many studies conducted in the west and east coasts of India especially along the shelf waters reported the dominance of polychaetes in the infaunal macrofauna (Damodaran 1973; Parulekar and Wagh, 1975; Hridayanathan, 1981; Harkantra *et al.,* 1982). Parulekar and Ansari (1981) also reported that polychaetes were the most important group (70%) in the macrobenthic assemblage in the Andaman Sea. Moreover polychaete constituted the major bulk of the macrobenthos in the Cochin backwaters (Pillai, 1977; Varshney *et al.*, 1988; Sunil Kumar, 1995). The high polychaete population obtained in the samples collected before trawling strongly corroborate to the above findings. Variations in faunal abundance and richness are closely related to the environmental parameters and sediment stability (Rachor, 1990). Among these factors, sediment grain size and water movements are the most important (Mohammed, 1955). In the present observations, high abundance of polychaete were noticed at the sandy stations, which also corroborate to the findings of Harkantra (1982). Bottom layers of sand with a mixture of silt or clay form ideal substrates for polychaete and bivalves (Parulekar and Wagh, 1975). According to Sunil Kumar (1995) high population density of polychaetes are normally encountered in the sandy substratum followed by silty sand.

In the present study, highest abundance and biomass was recorded during post monsoon period followed by premonsoon and monsoon. Harkantra and Parulekar (1994) reported the replenishment of benthic fauna with high species diversity after southwest monsoon. The present findings show very strong agreement with the above view. However, a second peak was observed in July, during the trawl ban period along the Kerala coast imposed by the Govt. of Kerala. It appears that the polychaetes get an opportunity for their recoupment and regeneration on sea bottom is totally free from any sort of disturbance due to the imposition of ban for bottom trawlers.

During the study, the number and biomass of the polychaetes were found increased in the samples collected immediately after trawling. This increase in abundance and biomass may be attributed to their exposure due to the removal of top sediment layer associated with the settlement of dispersed organisms after trawling. Polychaetes showed high abundance after beam trawling in an experiment conducted by Bergman and Hup (1992). Kutti (2002) observed significant increase in the total abundance during the study conducted using otter trawl along the waters of Bear Islands. Most of the polychaetes observed throughout this study were small in size and this clearly indicated the extreme disturbance on the sediment. Communities become dominated by juvenile stages where extensive and repeated fishing disturbance are prevalent (Sainsbury 1988; Bergman and Hup 1992; Eleftheriou and Robertson,1992). These organisms do not get the opportunity to grow into larger size because of the continuous trawling disturbance at the bottom. Polychaetes are generally fast growing species and especially species like *Ancistrosyllis*, *Cossura*, *Diopatra*, *Lumbrineries*, *Heteromastus* and *Nephtys* are continuous breeders (Parulekar and Wagh, 1975). Among polychaetes *Lumbrineries*, *Cossura*, *Magelona*, *Heteromastus*, *Diopatra* emerged as major species. The distribution and abundance of these species may be due to their continuous breeding habits

(Murugan and Ayyakkannu, 1991). As the magnitude of disturbance increased further, diversity decreased but abundance of smaller species increased as reported by several workers (Pearson and Rosenberg, 1978; Rosenberg, 1985).

Based on the results of the present study, it can be confirmed that bottom trawling brought about pronounced changes in the diversity and richness of polychaetes with ostensible increase after trawling and firmly complement with that of Tuck *et al.* (1998), who also observed the disproportionate increase of certain taxa after bottom trawling. This clearly indicates the short term impacts of bottom trawling, as manifested by variation in diversity and richness of the polychaetes. Kutti (2002) also noticed significant increase in diversity due to bottom trawling. Chicharo *et al.* (2000) also reported the increase in abundance and diversity of polychaetes in the dredge tracks off the coast of south Portugal. Moreover, multivariate analysis based on the abundance and biomass of the polychaetes obtained during the study also pointed out the variations, which took place in the polychaete community due to trawling. The faunal composition, abundance and biomass in stations situated in the same depth zone were similar and hence located closer together in the MDS plots. The wide distance between before and after trawling stations in the MDS comparison indicated variations in the abundance and biomass of the polychaetes by dint of bottom trawling. Dendrogram charts based on the abundance and biomass showed distinct clusters of high similarity among the before trawled stations located at the same depth zone. Decrease of similarities between after trawling and before trawling stations also indicated the variations in polychaete abundance and biomass. These results bring to light the obvious disturbance on the benthic ecosystem due to bottom trawling. Significant variations encountered in the diversity, richness and evenness of the polychaete abundance and biomass also manifest the amount of disturbance inflicted on these fragile organisms during bottom trawling. Variations in the benthic populations due to bottom trawling have also been noticed earlier by Pranovi *et al.* (2000) with significant higher total number of individuals. Sanchez *et al.* (2000) reported that there was an overall increase in species abundance and biomass, which is caused by short-, lived opportunistic species. Ball *et al.* (2000) also confirmed that there is an increase in the polychaete species immediately after bottom trawling.

Bottom trawling is depicted as the most dangerous and destructive fishing method on account of its destructive impacts in the marine ecosystem (Graham, 1955; Kaiser and Spencer, 1994; Watling and Norse, 1998). In marine ecosystem fishing represents the biggest anthropogenic impact (Dayton *et al.*, 1995a; Jennings and Kaiser, 1998). During bottom fishing with otter trawls, large quantity of epifaunal and infaunal organisms are injured, removed and killed by the passage of heavy otter boards and nets (Graham, 1955; Bridger, 1972; Auster *et al.*, 1996; McConnaughey *et al.*, 2000). Besides fish, invertebrate species are caught in the nets and most of them will not survive after they have been returned to the sea as discards (Houghton *et al.*, 1971). A large fraction of the mortality occurs in the trawl path because many animals that are not caught in the net are damaged or killed by the trawl nets as it passes over the seabed (Craeymaeersch *et al.*, 2000). The total direct mortality varies from 10 to 80% and fragile or superficial living species experience the highest mortalities (Lindeboom and de Groot, 1998; Bergman and Santbrink, 2000). Ample evidence is available showing serious damage and mortalities caused to coelenterates due to trawling (Graham, 1955; Margetts and Bridger, 1971).

Experimental trawling conducted in the present study revealed profound effects on infaunal organisms. In the present study, the variations in the abundance and biomass noticed after trawling when compared to before trawling in many of the stations signify the fact that the relative abundance and biomass of the infaunal communities could be altered as an immediate of bottom trawling. Short-term experimental studies had demonstrated serious effects on certain taxa, especially that of slow growing fragile species (Thrush, *et al.*, 1995, 1997; Kaiser *et al.*, 1996, Ramsay *et al.*, 1998, Tuck et *al.*, 1998; Mac Donald *et al.*, 1997). Thrush *et al.* (1998) proved that the relative abundance and biomass of species in benthic communities are affected by trawling activities. Several studies, both long -term comparative studies (Thrush *et al.*, 1998) and short-term experimental studies (Prena *et al.*, 1999) have shown that the relative abundance of species in the benthic community could be significantly varied due to the bottom trawling. In the present study, trawling did not seem to have immediate significant effect on the structure of the benthic assemblages, however, the wide variations noticed in the diversity and richness at many stations indicates that there were remarkable changes on the benthic populations due to bottom trawling.

In the marine environment, benthic organisms form an important component of the food web and are regarded as the efficient recyclers of nutrients (Parulekar and Wagh, 1975; Murugan and Ayyakkannu, 1991). The ability of marine benthic animals to establish and maintain themselves under certain environmental conditions are correlated with factors such as salinity, water movement, organic content, oxygen content and microbial biomass of sediments (Maurer and Leathem, 1981; Pearson and Rosenberg, 1986; Gaston, 1987; Gagnon and Haedrich, 1991). Benthic assemblages may occur in either spatial or temporal manner due to natural causes. Besides changes in species assemblage due to natural variations, human activity also causes changes in the bottom communities (Heip *et al.*, 1992). Many experiments demonstrated the penetration of otter boards into the sediments as the major reason of the decrease or increase of the infaunal communities (Lindeboom and de Groot, 1988; Bergman and Santbrink, 2000). The results obtained in the present study also corroborate with this. The exposure of infaunal macrobenthos observed in the present study also hint out the heavy perturbations on the animals that live inside the sediments due to bottom trawling.

The abundance and distribution of benthic fauna is highly dependent on the sediment characteristics (Duineveld *et al.*, 1991). The disturbance and removal of the top layer of the sediments lifts the epifaunal communities to the water column and also lead to the exposure of animals, which live inside the sediments (Messiah *et al.*, 1991; Riemann and Hoffmann, 1991; Jones, 1992). Experimental trawling conducted to investigate the immediate effect of trawling during this study revealed that the infaunal communities were exposed out of the sediments during trawling. Long-term effect of trawling was not incorporated in this study, while it investigated the effects that were immediate. Even though the increase of abundance, biomass and diversity were noticed in this study, it may be inferred that the long term effect of trawling would lead to the progressive reduction of bottom communities in total. The destruction of both epifaunal and infaunal organisms during trawling eventually culminates in the reduction of these organisms at the trawling grounds. Studies conducted on the long-term effect of trawling / dredging revealed the heavy reduction of species diversity, biomass and density of both epifauna and infauna at the sea bottom as reported by Reish (1963); Kaplan *et al.* (1975); Stickney and Perlmutter (1975); Rosenberg (1977); Brown (1989); Hall *et al.* (1990); Langton and Robinson (1990) Lindeboom and de Groot (1998); and Bergman and Santbrink (2000). The polychaetes showed wide variations between two years in the present study with a drastic reduction during the second year. The natural increase in abundance and biomass during post monsoon period (Damodaran, 1973; Harkantra and Parulekar, 1994) was followed by drastic decline as noticed during premonsoon and monsoon months. Another peak in the abundance and biomass was noticed during the trawling ban period (July), which indicated that the ban was useful in giving some respite to polychates for their regeneration and recoupement. This may be attributed to the lack of bottom disturbance on account of trawling ban along Kerala coast. Heavy reduction of polychaetes observed during monsoon months after July may be due to the heavy trawling pressure exerted immediately after the trawl ban period. These results also indicate the vast amount of destruction of benthic communities taking place yearly due to the bottom trawling. Many studies showed that the bottom trawling would eventually decrease the benthic populations (Bradstock and Gordon, 1983, Bergman and Hup, 1992, Kaiser and Spencer 1994; Collie *et al.*, 1997, Lindeboom and de Groot, 1998; Prena *et al.*, 1999; Ball *et al.*, 1999; Kutti, 2002).

Comparative studies conducted at the fishing grounds and control areas showed huge variations in benthic populations (Bergman *et al.*, 2001c). However, in the present study such a comparison work could not be made due to the lack of any non-fishing zone in the inshore waters of the Kerala state since relentless trawling takes place right from 5- 200 meters depth range. Long - term studies are quite helpful to understand the future of the benthic populations at area subjected to heavy trawling pressure and the areas closed to fishing may be the only way to evaluate the longer-term impacts of fishing on benthos (Riesen and Reise, 1982). Intensive trawling activities reduce the benthic populations (McConnaughey *et al.*, 2000). Repeated trawling at the experimental areas resulted in the reduction in density of polychaetes, echinoderms and molluscs (Bergman and Hup, 1992). McConnaughey *et al.* (2000) reported that the overall abundance and diversity of macrofauna were reduced by trawlers and the reduction was high in the fished areas. The variations observed in the infaunal macrobenthos during trawling experiments conducted in the present study area also indicated the same. Ball *et al.* (2000) opined that the mortality of infaunal invertebrates may occur primarily on the seabed and is caused by disturbance and passage of the net rather than by damage or by catch. Many other experimental investigators of trawl impact have found lower biomass of benthic fauna in trawled areas when compared to trawled reference areas (Collie *et al.*, 1997; Prena *et al.*, 1999; Ball *et al.*, 2000). Lower species diversity and species richness had been found in trawled areas when compared to undisturbed areas (Collie *et al.*, 2000a). The wide decrease in polychaete observed in the second year of this study also show strong agreement with this.

Bottom trawling causes shift in benthic communities by removing the epifaunal and infaunal organisms, allowing the exposed animals to heavy and easy predation and dispersion of light infaunal organisms along with the sediment clouds formed during trawling. Caddy (1973) and Kaiser and Spencer (1994) studied scavenging by finfish in the wake of trawling or dredging. Contact with the trawl gear and resuspension of surface sediments may cause death, injury and exposure of benthic fauna, thus creating potential food resources for scavenging and predatory fish and invertebrate species (Kutti, 2002). The major impact on infaunal communities is by way of being uncovered during trawling/ dredging and thus making them vulnerable to predation by invertebrates and demersal fish (Currie and Parry, 1996). Kaiser and Spencer (1996a) noticed the movement of predatory and scavenging species to the trawled areas. The few benthic species that were abundant in the trawling area were mainly predators and scavengers (Smith *et al.*, 2000). Benthic scavengers may benefit from the additional food supply from discards or animals damaged in the trawl path (Kaiser and Spencer 1994; Collie *et al.*, 1997; Lindeboom and de Groot 1998; Groenewold and Fonds, 2000; Fonds and Groenewold, 2000; Ramsay *et al.*, 2000). The high abundance of polychaetes observed immediately after trawling in the present study also indicate that more and more infaunal species succumb to easy predation by fishes and other marine invertebrates. The decrease in the polychaete abundance obtained in the second year may also point to the possibility of destruction and removal of these fragile organisms due to predation.

Trawling is a threat to the rich and diverse fauna of the benthic ecosystem both directly and indirectly. Bottom trawling induces large–scale spatial and temporal variability. This was noticed by Lindegarth *et al.* (2000), who reported large temporal changes in benthos after twelve months of intensive experimental trawling. Trawling reduces benthic complexity by destroying many benthic organisms and lead to the reduction in benthic productivity. Bottom trawling reduces the homogenous nature of the sea bottom. The undisturbed benthic community is relatively homogenous (Prena *et al.*, 1999) and the redistribution of the organisms takes place in the trawled areas, which will decrease the homogeneity of the sea bottom (Bergman and Hup, 1992, Eleftheriou and Robertson, 1992). Degradation of infaunal communities on the sea bottom due to bottom trawling was well understood by many workers (Graham, 1955; Gibbs *et al.*, 1980). The reduction in polychaete abundance noticed in the second year of this study also points to the loss of infaunal communities due to bottom disturbance. Otter trawling on benthic ecosystem can produce detectable change on both benthic habitat and communities (Prena *et al.*, 1999) by its destructive nature and also has direct role in determining the abundance and composition of coastal macrofauna (Frid *et al.*, 1999 a). The abundance of scavengers and predators were noticed in the trawling and dredging grounds (Currie and Parry, 1996). Bradshaw *et al.* (2002) observed that the community composition changed at all sites; mobile, robust and scavenging taxa had increased in abundance while slow moving or sessile, fragile taxa had decreased. The increased variability can be interpreted as an indication of decreased homogeneity (Warwick and Clarke, 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).

Bottom fauna form an important source of food for a variety of fishes and other marine organisms in the sea (Mohammed, 1955; Murugan and Ayyakkannu, 1991). The availability of benthos at a region can be an indicator of demersal fishery potential since they form an important food resource for crabs and fishes (Varshney *et al.*, 1988). The exposure of polychaetes after trawling operations may lead to the disruption of this important link in the food chain by the total elimination from the fishing ground. Kaiser and Spencer (1994) observed high quantity of amphipods in the diet of gurnards fish, which feed on amphipods in the sediments of the trawled areas. Continuous trawling reduces the abundance of herbivores and increases the abundance of suspension feeders and scavengers (Ramsey *et al.*, 1998). Frid and Hall (1999) observed high quantity of scavenging polychaetes in the diet of fish obtained from the intensely trawled areas. So the demersal fishing activities provide food for scavengers in the form of damaged animals which are left in the trawled / dredged track (Ramsay *et al.*, 1998). Frid *et al.* (1999b) demonstrated that consumption of benthos by fish predators has changed both in quantity and composition during the period of heavy trawling. This means that the bottom trawling had augmented the removal of benthic population indirectly by improving the feeding condition of certain fishes by enhancing the abundance of small opportunistic benthic species such as polychaetes in the heavily trawled areas as suggested by Rijnsdorp and Vingerhoed (2001) and presumably lead to the dietary changes of fish in the benthic ecosystem as postulated by Kaiser and Spencer (1994). Intensive trawling might lead to changes in the benthic habitat resulting in the shift of fish communities as reported by Sainsbury *et al.* (1997). This experiment presented here described the short- term changes in macrobenthic community structure associated with bottom disturbance from bottom trawling. The ostensible variations observed in the infaunal population in the trawled areas demonstrate that incessant and prolonged bottom trawling activities in the inshore waters lead to the loss of biomass of infaunal organisms in the trawled grounds including changes in the habitat structure and biogeochemical exchanges between the sediment and water column affecting the suitability of the seabed as habitat for both adult and younger life stages of marine organisms. Considering the results obtained in the study, it is clear that bottom trawling alter seafloor habitat, reduce habitat complexity, may lead to increased predation on infaunal species and affect the total ecosystem productivity.

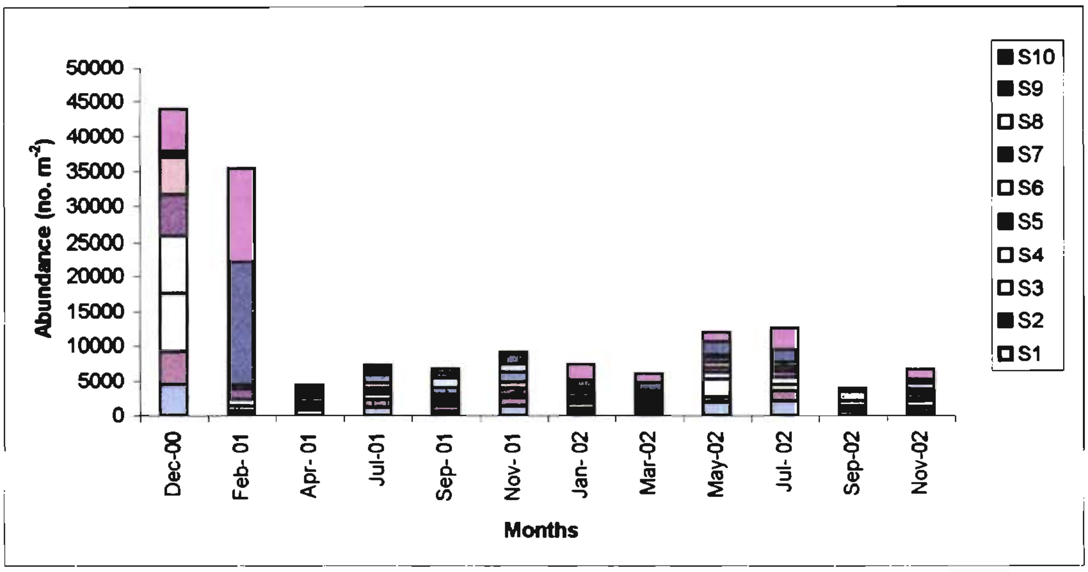


Fig. 8.1 Mean density of polychates recorded at the study area before trawling during December 2000 to November 2002

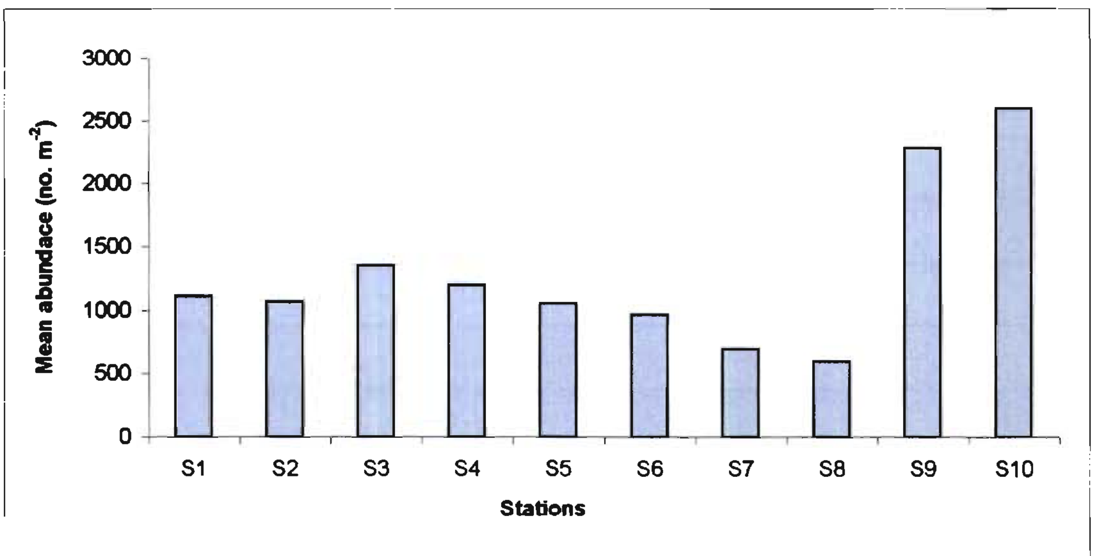


Fig. 8.2. Mean abundance of polychaetes recorded before trawling at stations 1 to 10 during December 2000 to November 2002

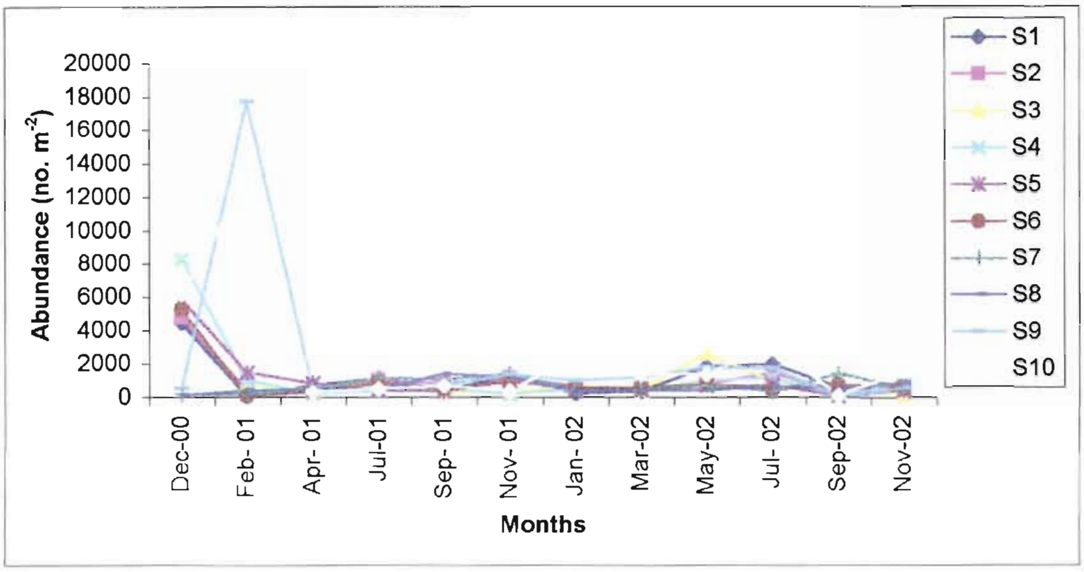


Fig. 8.3 Abundance of polychates before trawling in stations 1 to 10 during December 2000 to November 2002

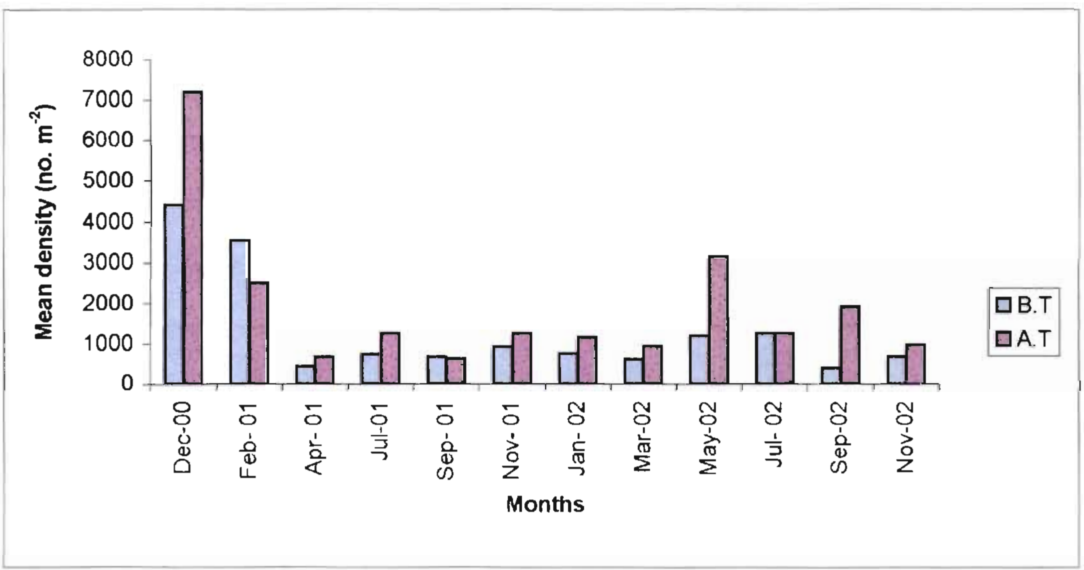


Fig. 8. 4 Variations in polychaete abundance before and after trawling at the study area during December 2000 to November 2002.

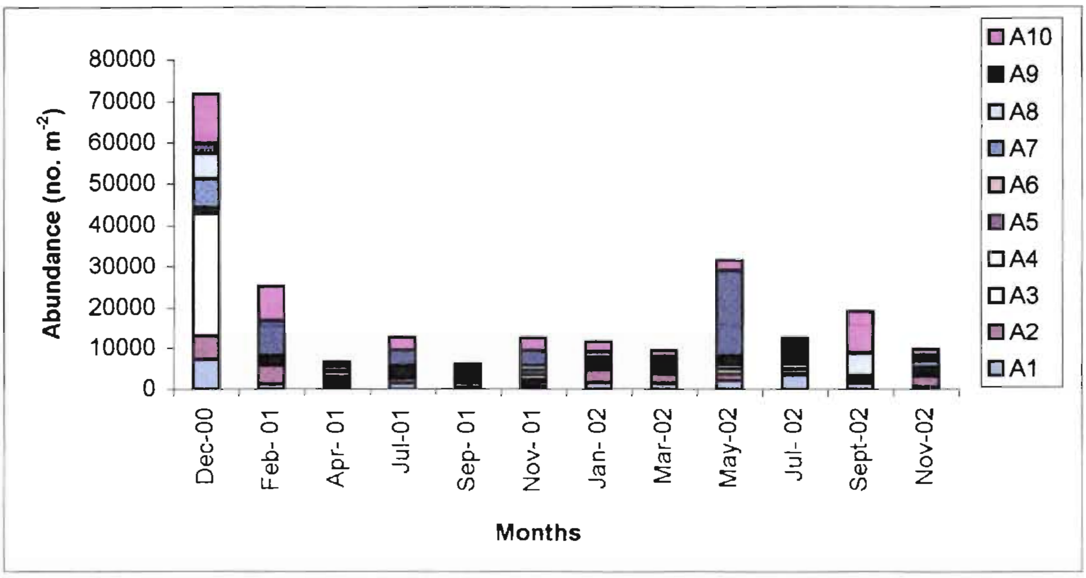


Fig. 8.5 Mean abundance of polychaetes in the stations 1 to 10 after trawling during December 2000 to November 2002

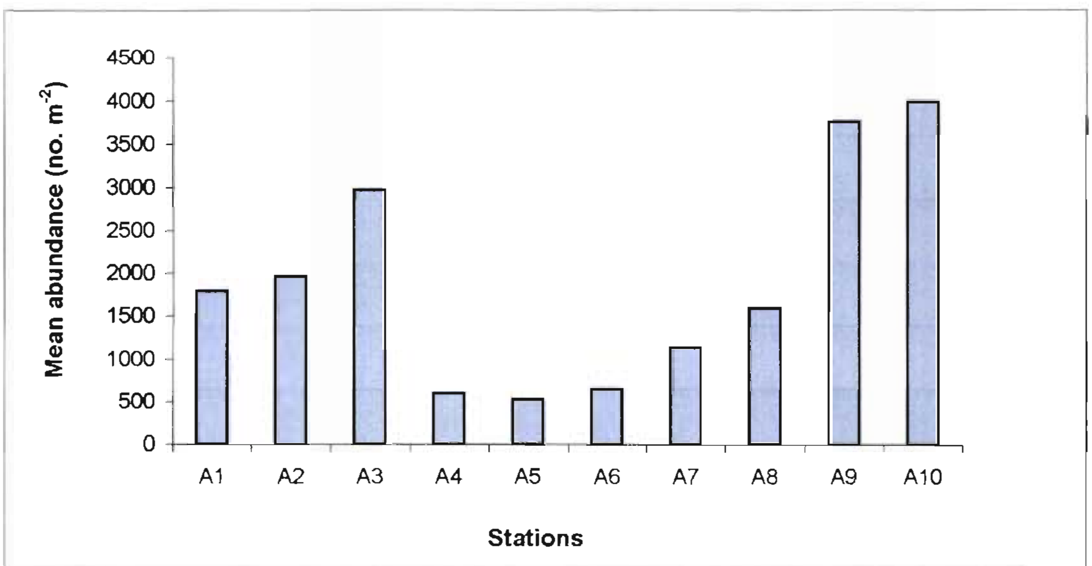


Fig. 8.6 Mean abundance of polychaetes obtained from stations 1 to 10 after trawling during December 2000 to November 2002

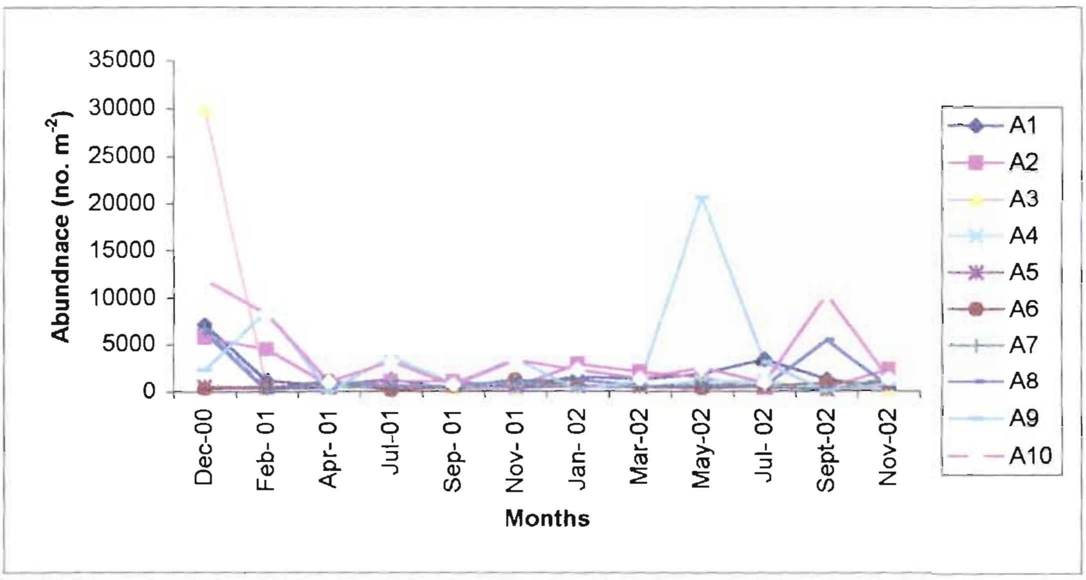


Fig. 8.7 Abundance of polychates recorded after trawing in stations 1 to 10 during December 2000 to November 2002

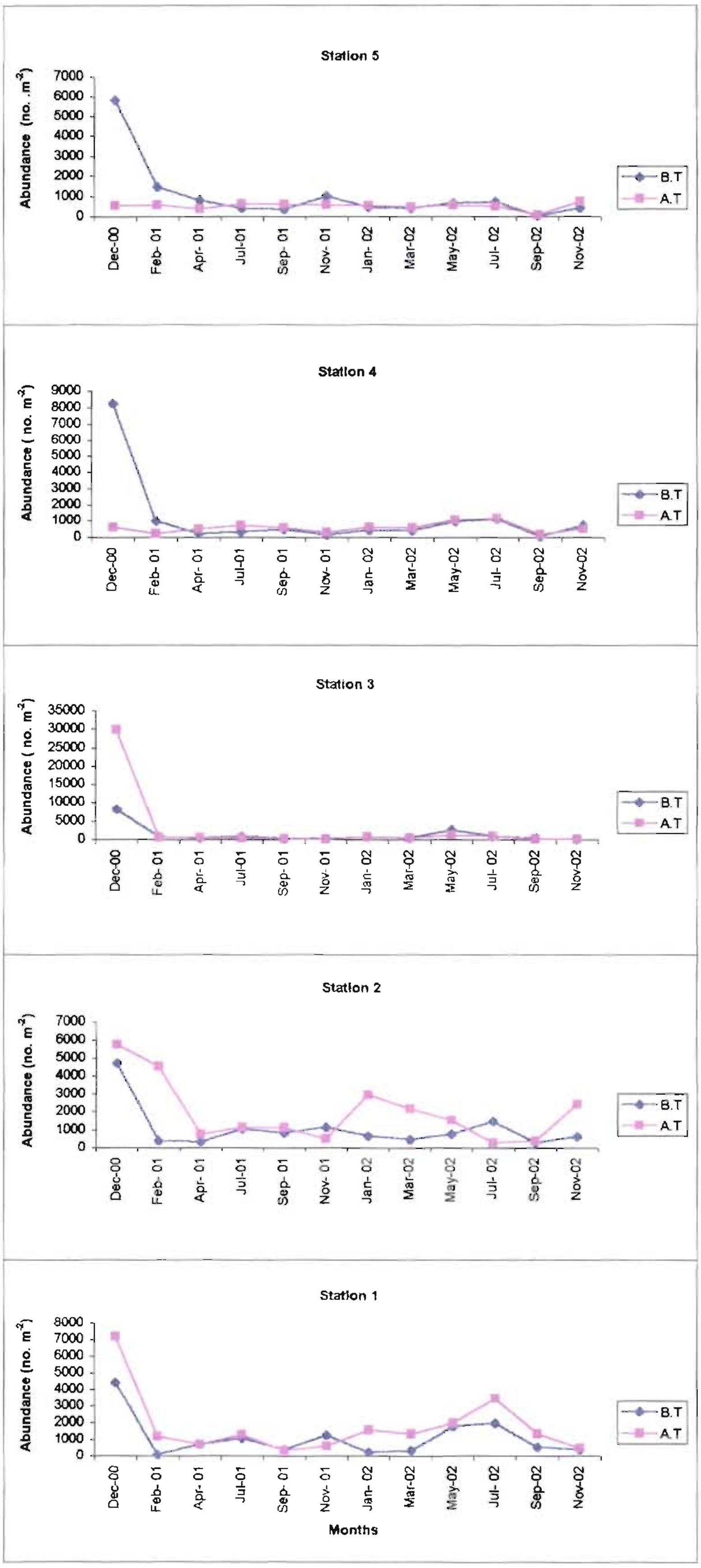


Fig 8.8a. Variations in polychaete abundance before and after trawling at the study area during December 2000 to November 2002

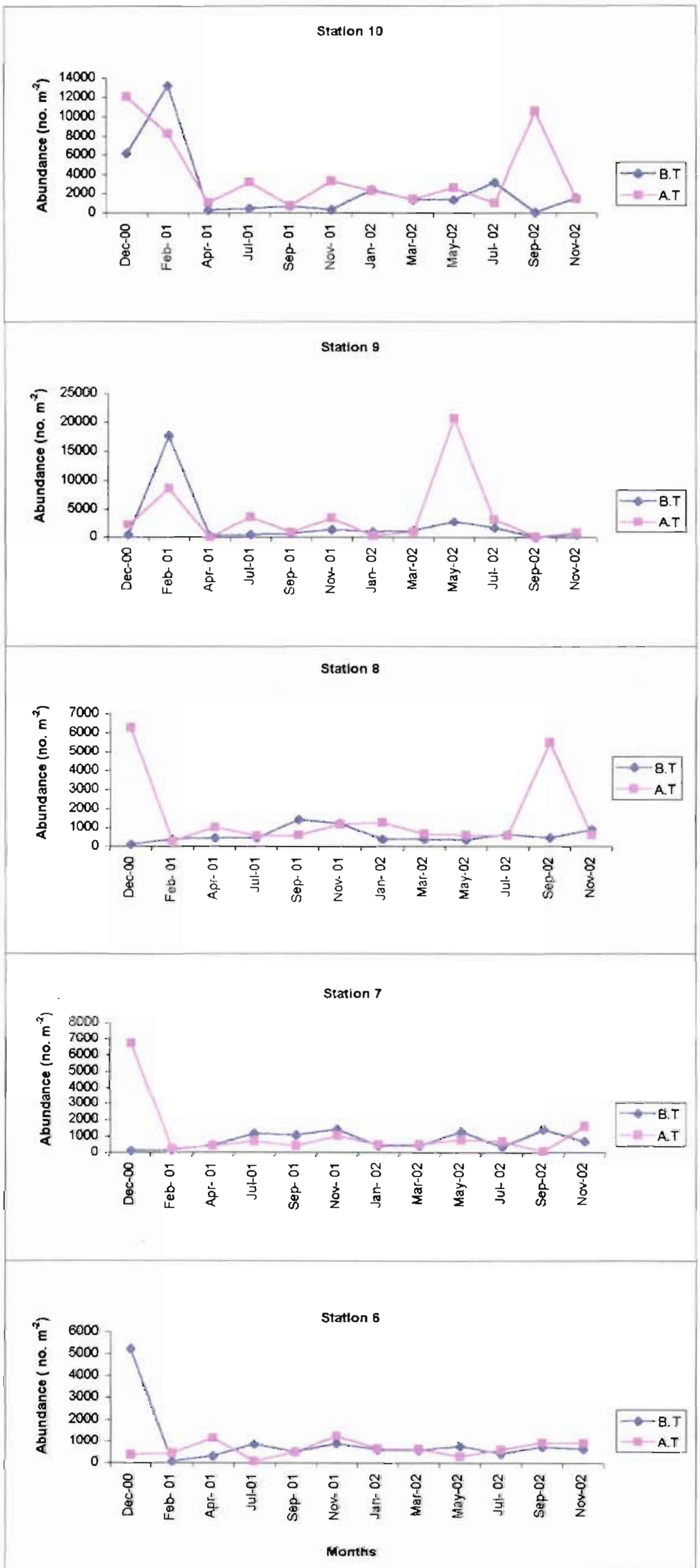


Fig. 8.8b Variations in polychaete abundance before and after trawling at the study area during December 2000 to November 2002

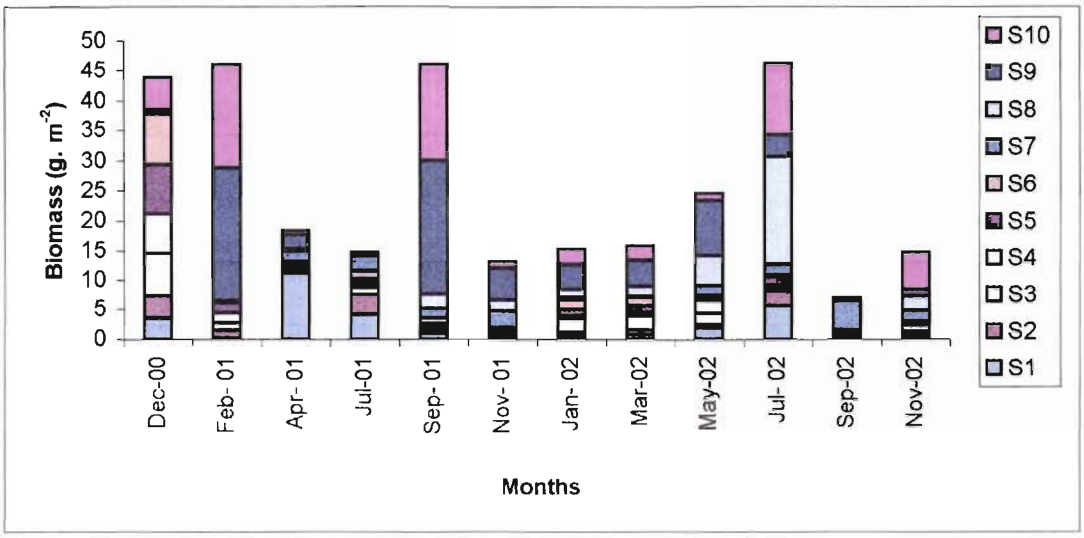


Fig. 8.9. Polychaete biomass before trawling in stations 1 to 10 during December 2000 to November 2002

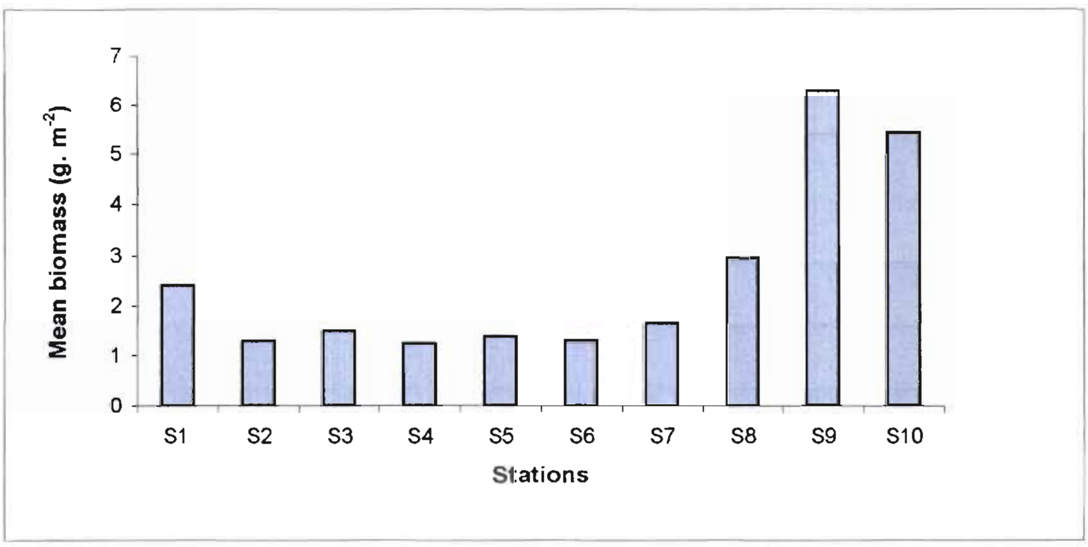


Fig. 8.10. Average biomass of polychaetes before trawling at stations 1 to 10 during December 2000 to November 2002.

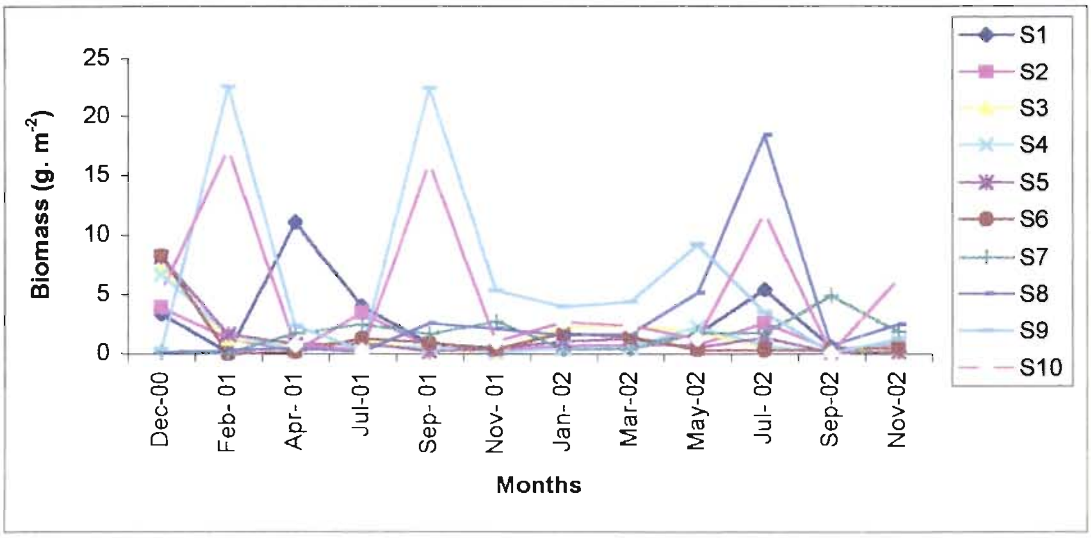


Fig. 8.11 Polychaete biomass before trawling in stations 1 to 10 during December 2000 to November 2002.

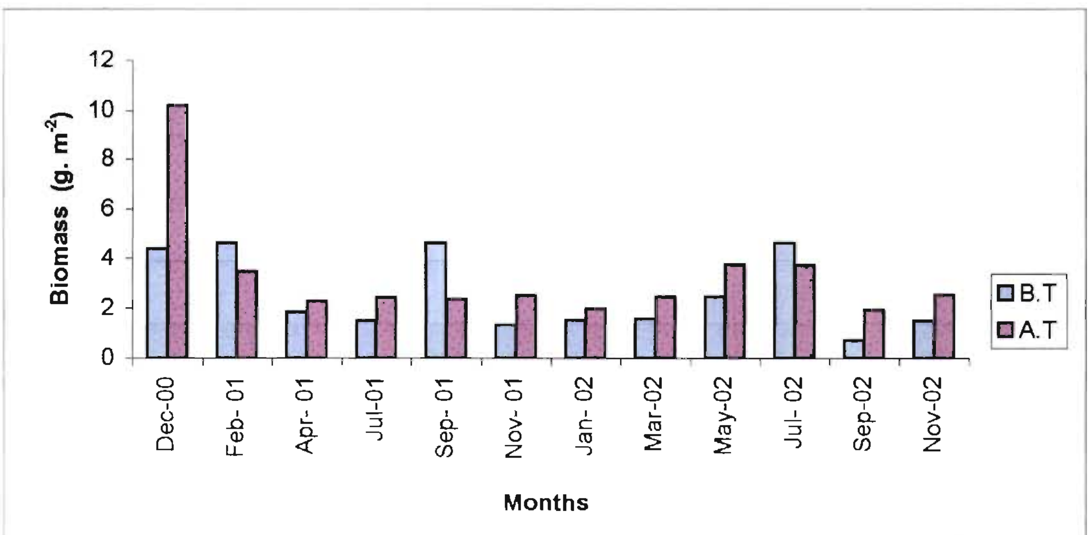


Fig.8.12 Comparison of the average biomass of polychaetes before and after trawling during December 2000 to November 2002.

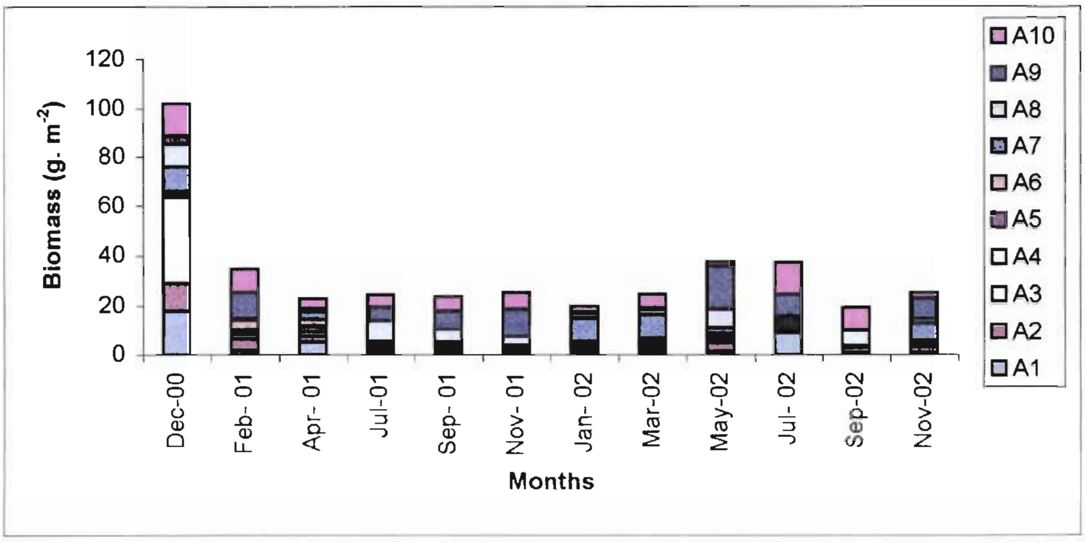


Fig. 8.13 Polychaete biomass after trawling at stations 1 to 10 during December 2000 to November 2002

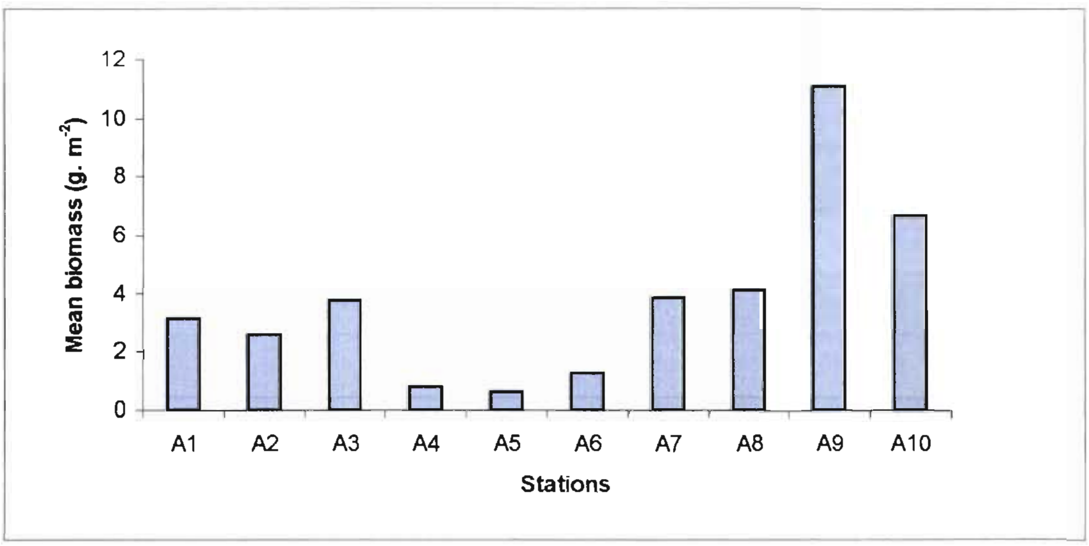


Fig. 8.14 Average biomass of polychaetes obtained after trawling at stations 1 to 10 during December 2000 to November 2002.

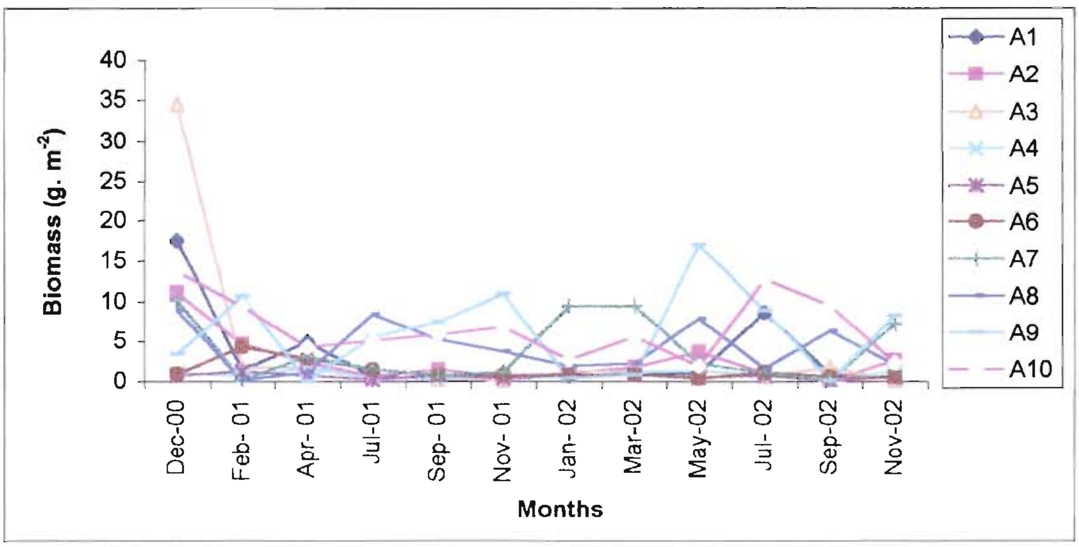


Fig. 8.15 Polychaete biomass after trawling at station 1 to 10 during December 2000 to November 2002.

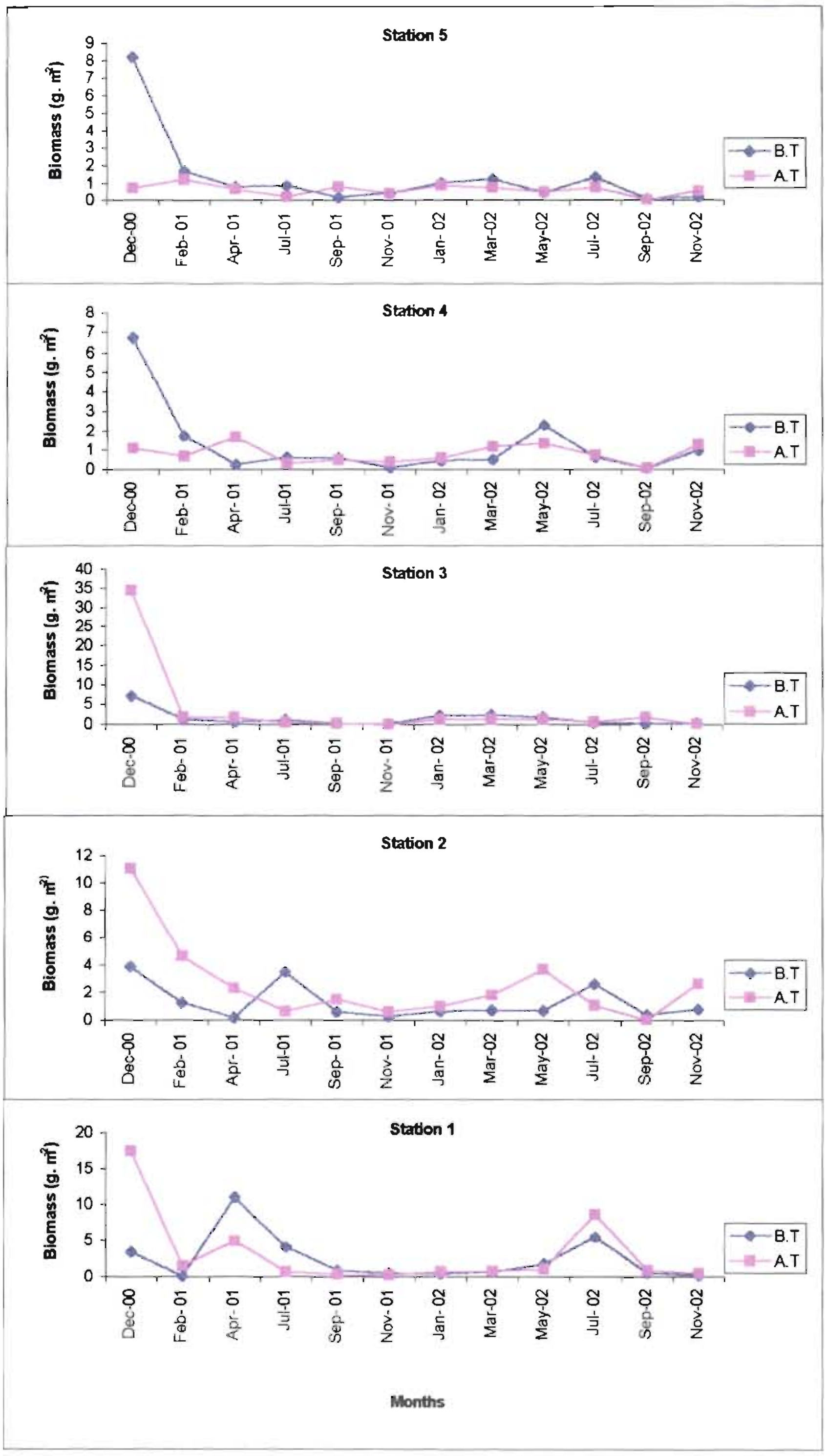


Fig. 8.16a Variations in polychaete biomass before and after trawling in the study area during December 2000 to November 2002.

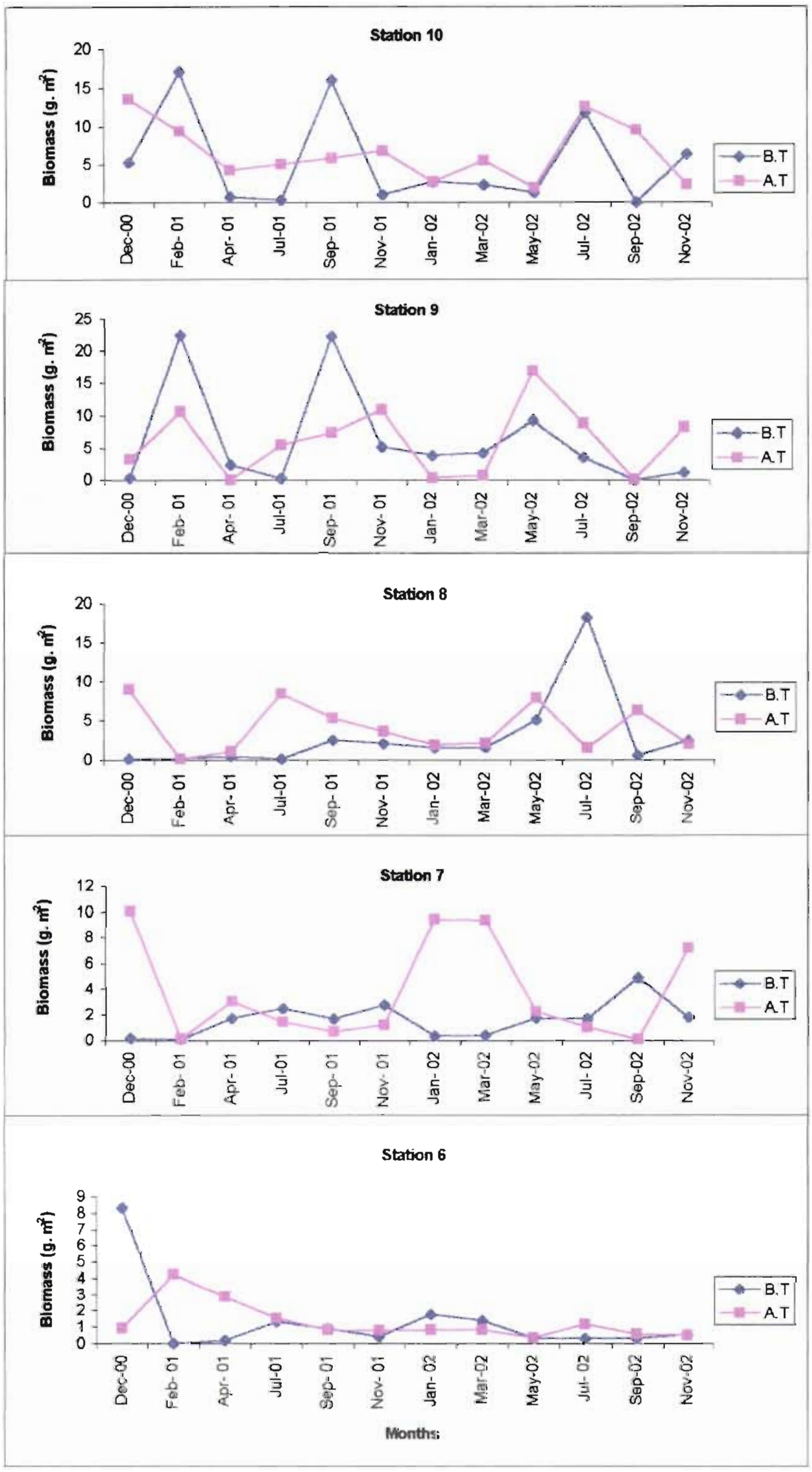


Fig. 8.16b Variations in polychaete biomass before and after trawling in the study area during December 2000 to November 2002

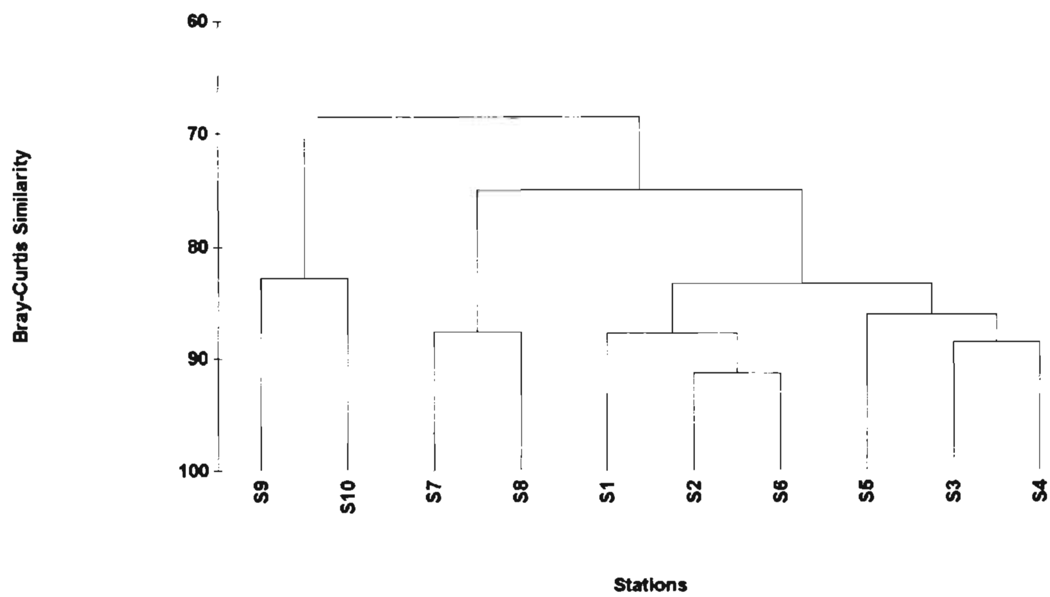


Fig. 8.17 Similarity dendrogram of polychaete abundance before trawling for stations 1 to 10

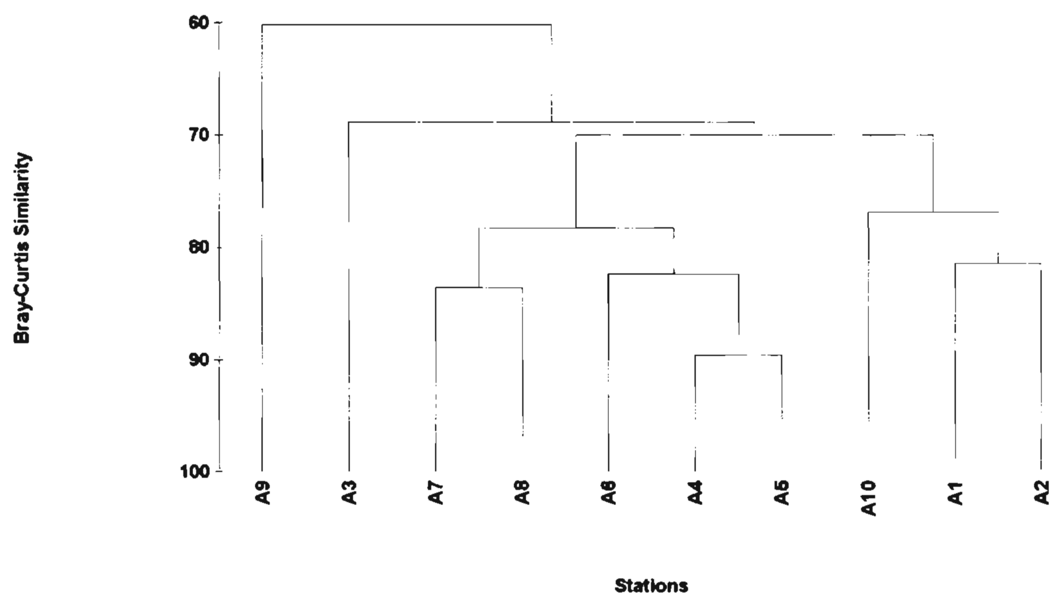


Fig. 8.18. Similarity dendrogram of polychaete abundance after trawling for stations 1 to 10.

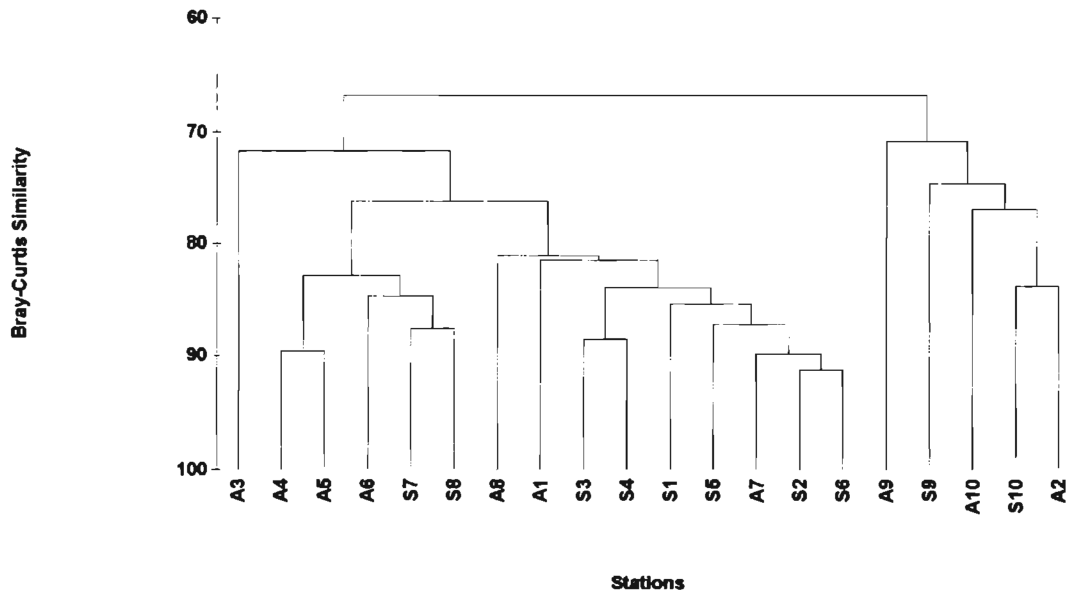


Fig. 8.19. Similarity dendrogram of polychaete abundance before and after trawling at stations 1 to 10

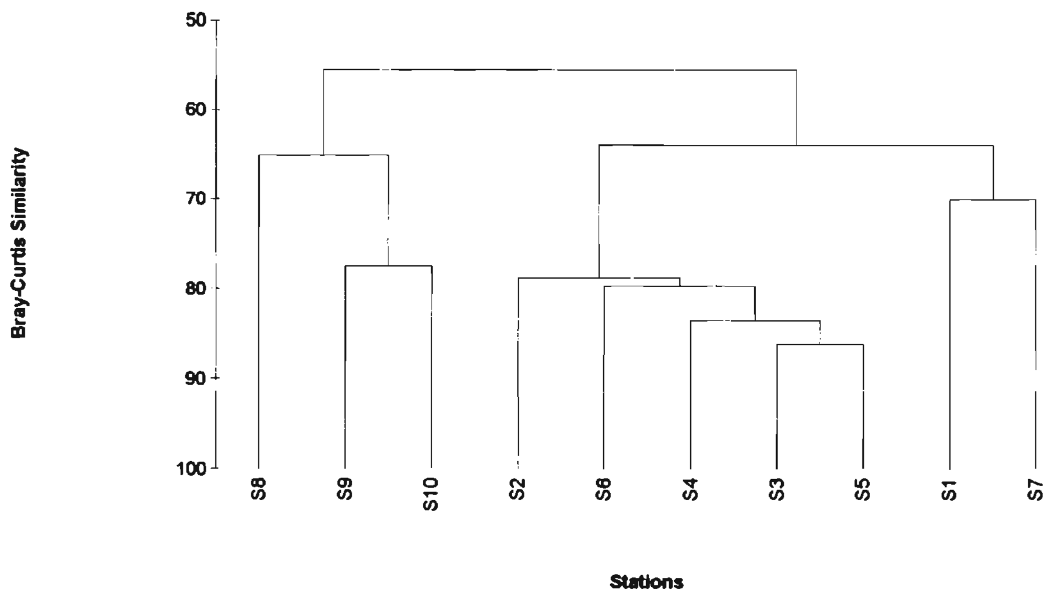


Fig. 8.20 Similarity dendrogram of polychaete biomass before trawling at stations 1 to 10

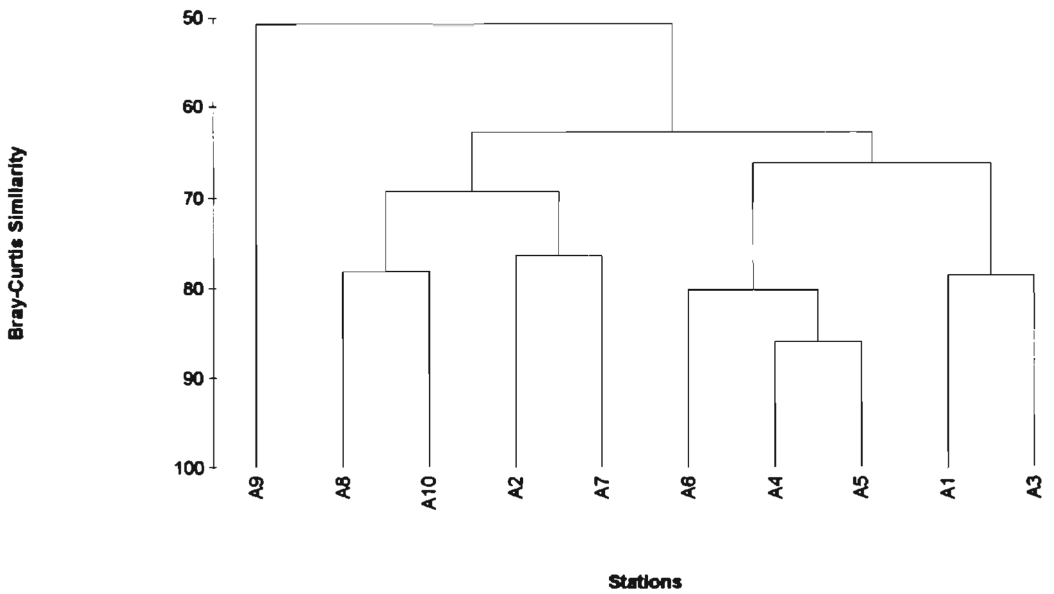


Fig. 8.21. Similarity dendrogram of polychaete biomass after trawling at stations 1 to 10.

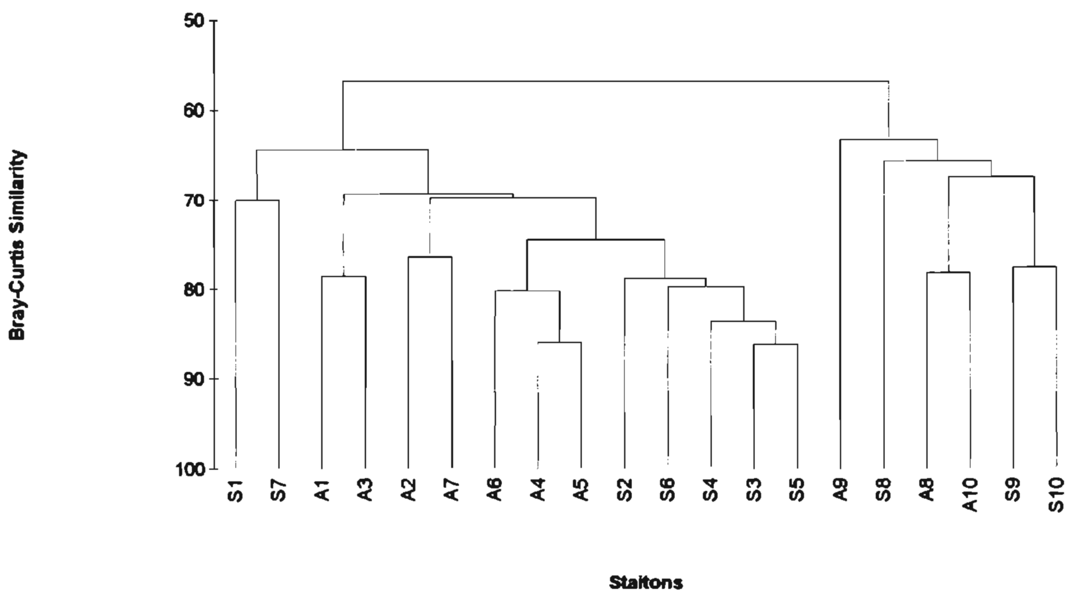


Fig. 8.22. Similarity dendrogram of polychaete abundance before and after trawling

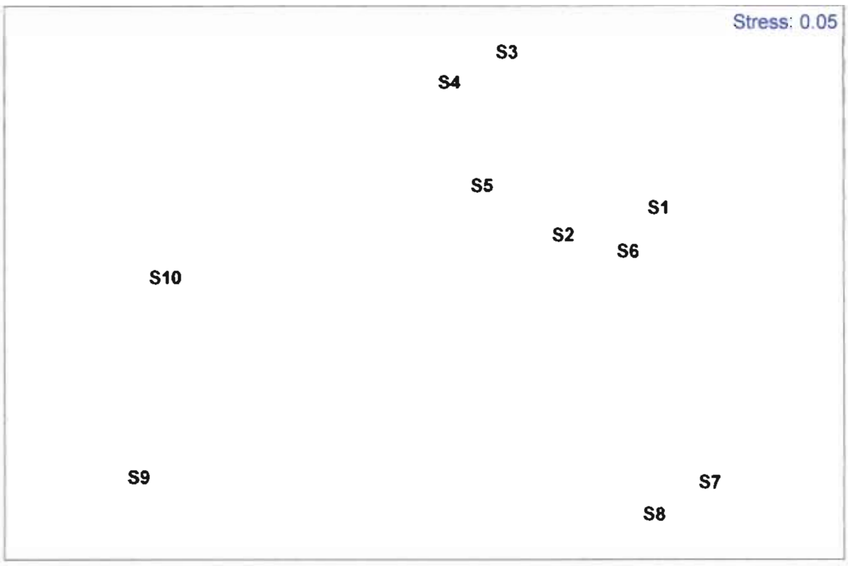


Fig. 8.23. MDS ordination plot of polychaete abundance before trawling at stations 1 to 10 during December 2000 to November 2002.

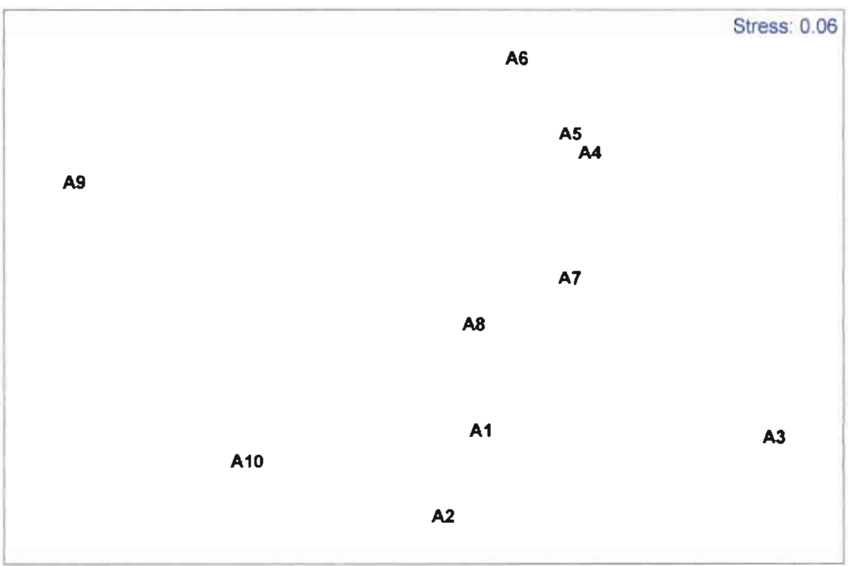


Fig. 8.24. MDS ordination plot of polychaete abundance after trawling at stations 1 to 10 during December 2000 to November 2002.

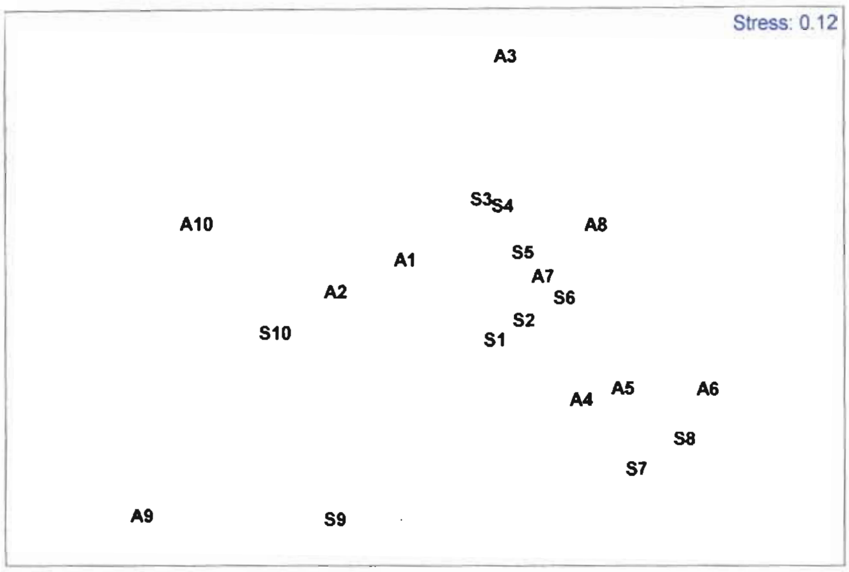


Fig. 8.25. MDS ordination plot of comparison of polychaete abundance before and after trawling during Dec.2000 to Nov.2002.

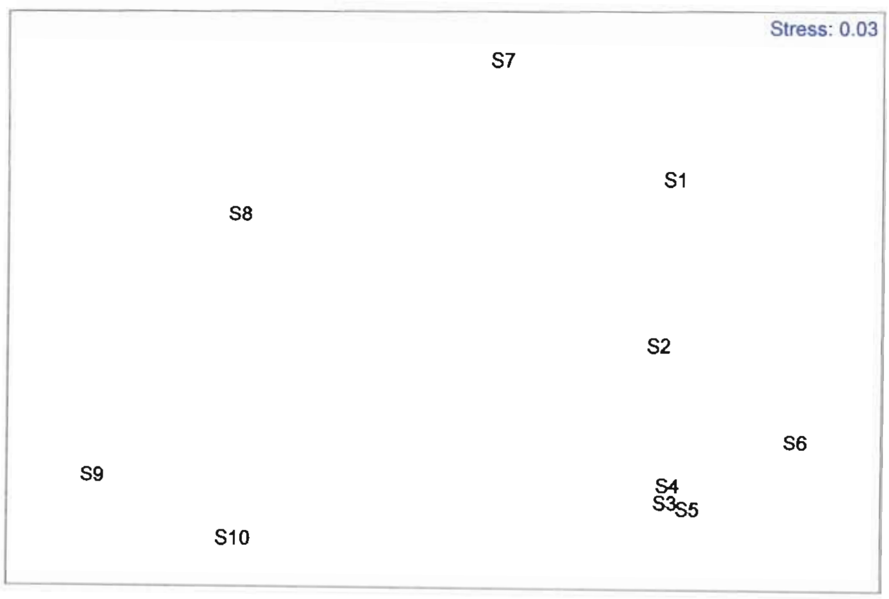


Fig. 8.26. MDS ordination plot of polychaete biomass before trawling at stations 1 to 10 during Dec.2000 to Nov.2002.

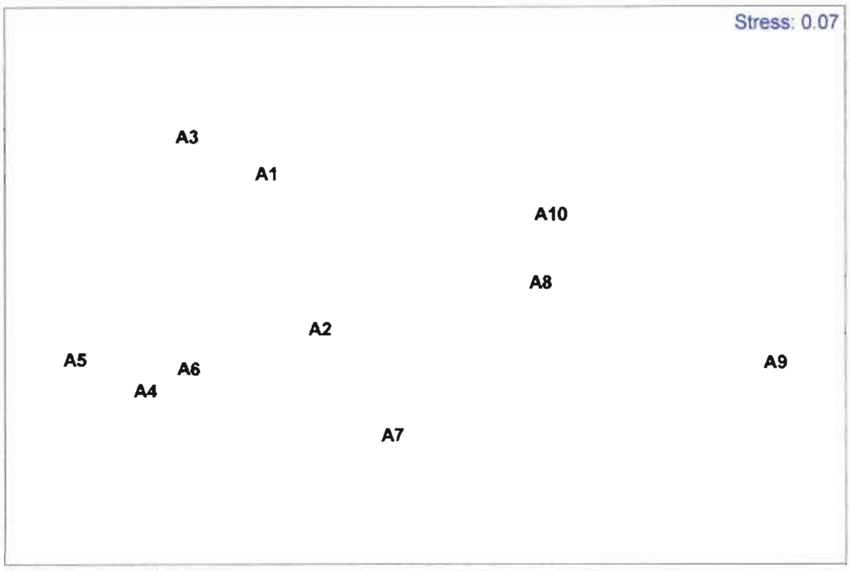


Fig. 8.27. MDS ordination plot of polychaete biomass after trawling at stations 1 to 10 during Dec.2000 to Nov.2002.

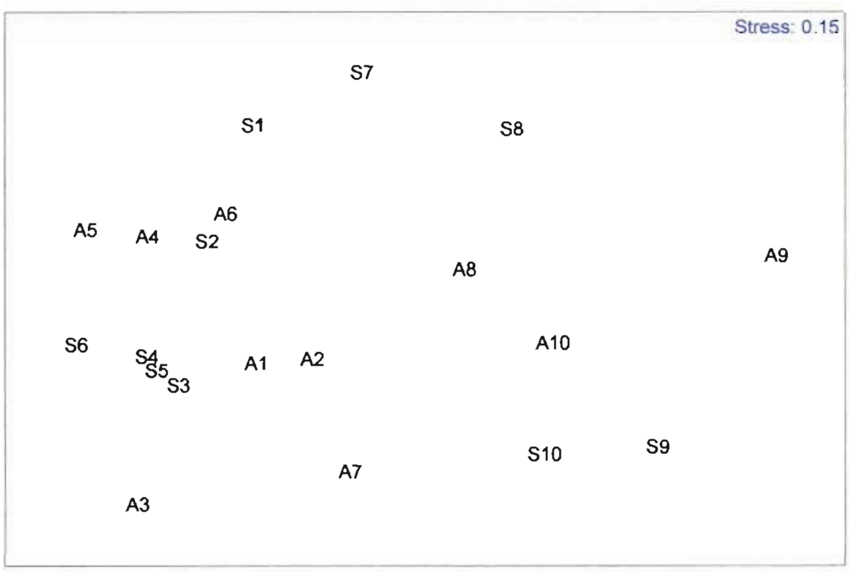


Fig. 8.28. MDS ordination plot of comparison of polychaete biomass before and after trawling during Dec.2000 to Nov.2002.

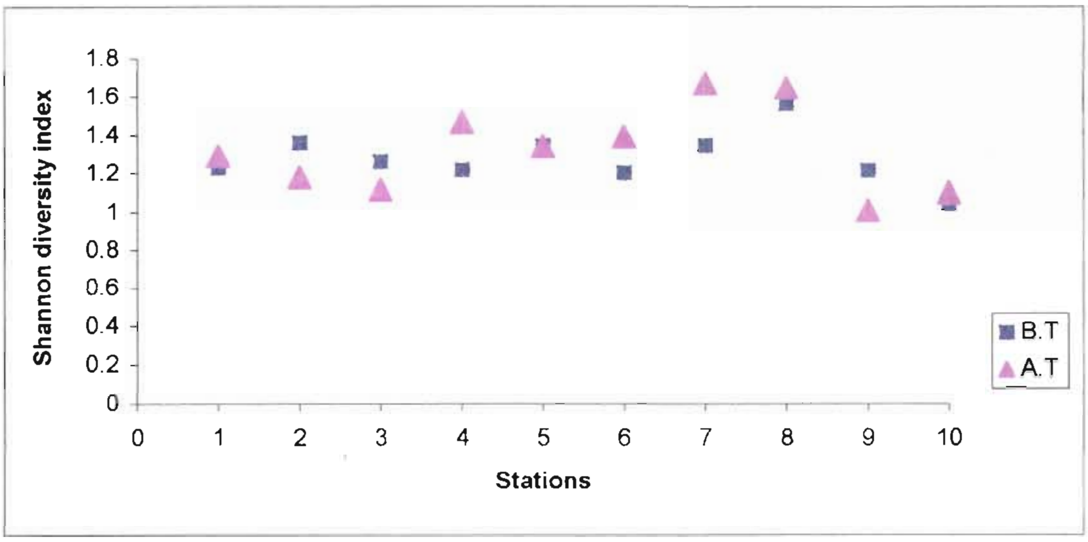


Fig. 8.29 Shannon diversity (Mean abundance) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

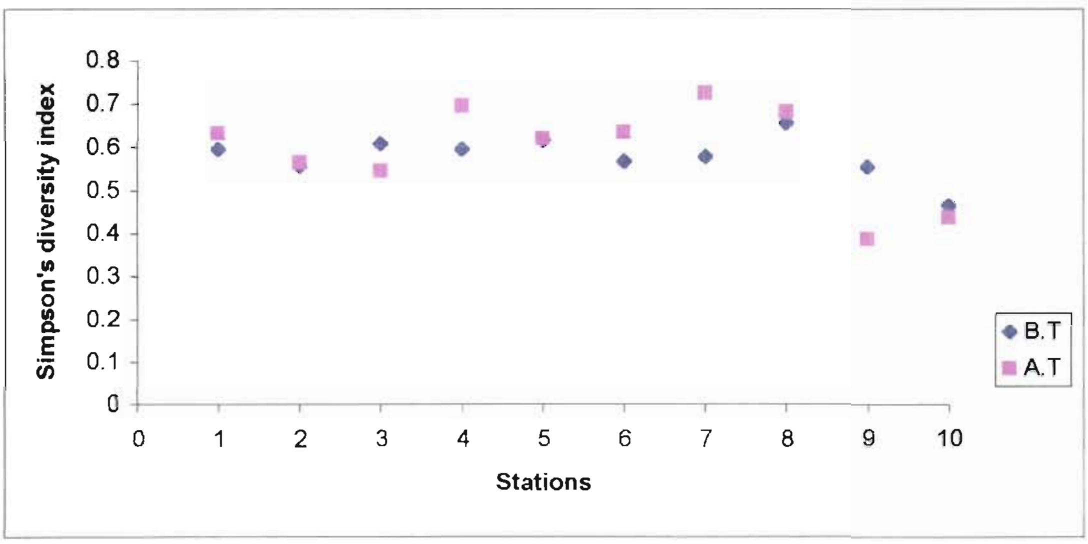


Fig. 8.30 Simpson's diversity (Mean abundance) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

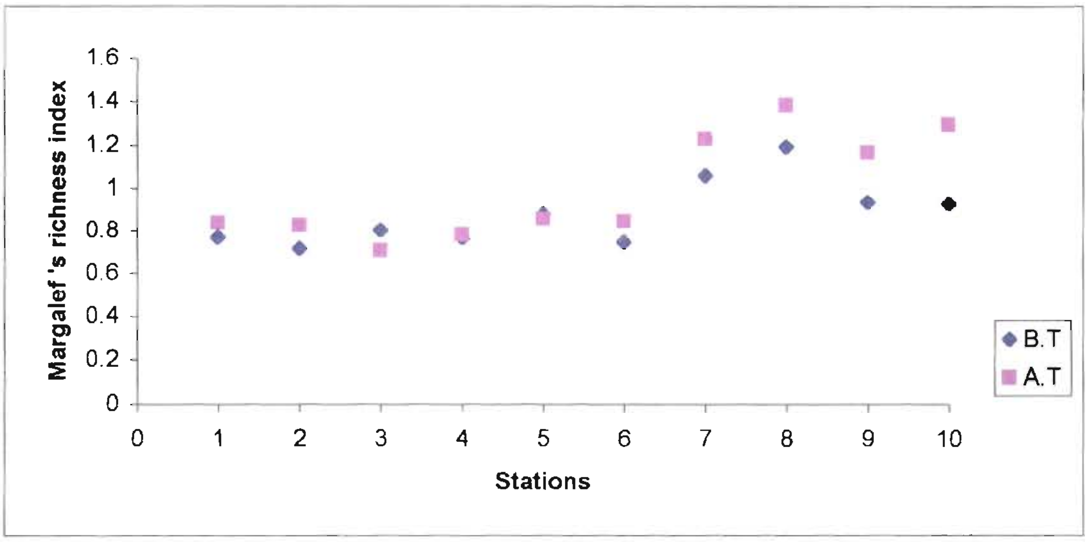


Fig. 8.31 Margalef richness (Mean abundance) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

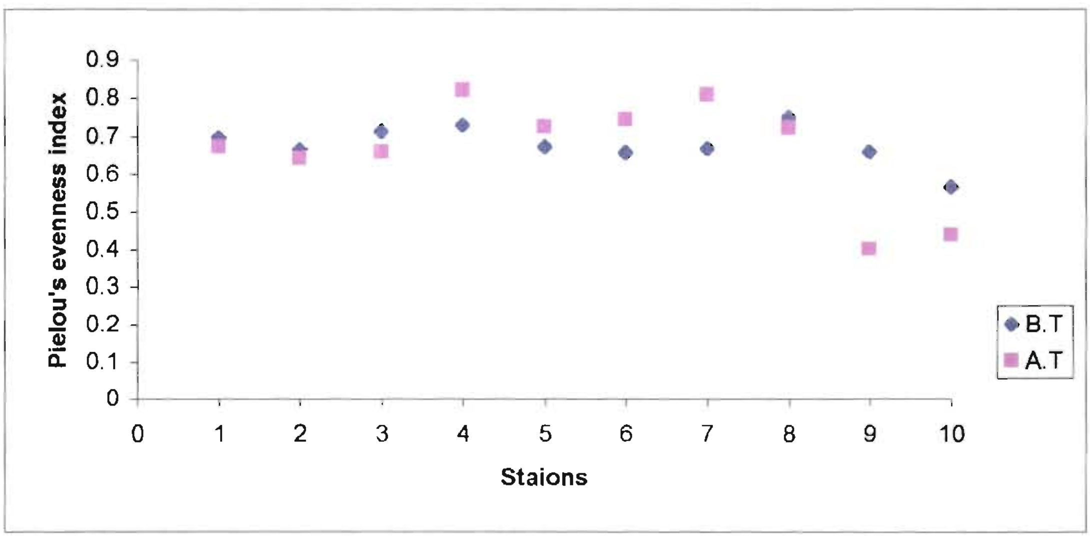


Fig. 8.32 Pielou's evenness (Mean abundance) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

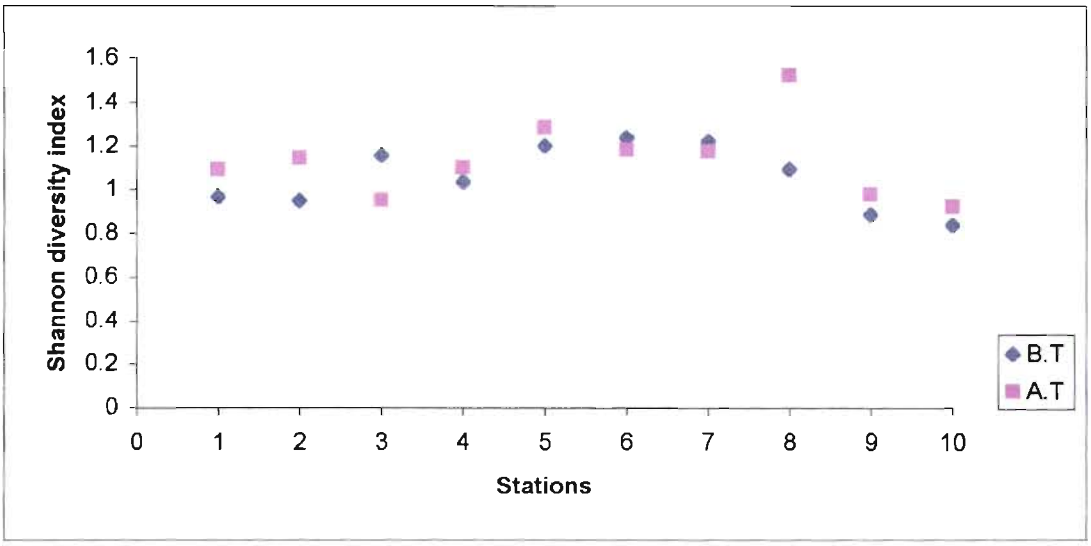


Fig. 8.33 Shannon diversity (Mean biomass) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002.

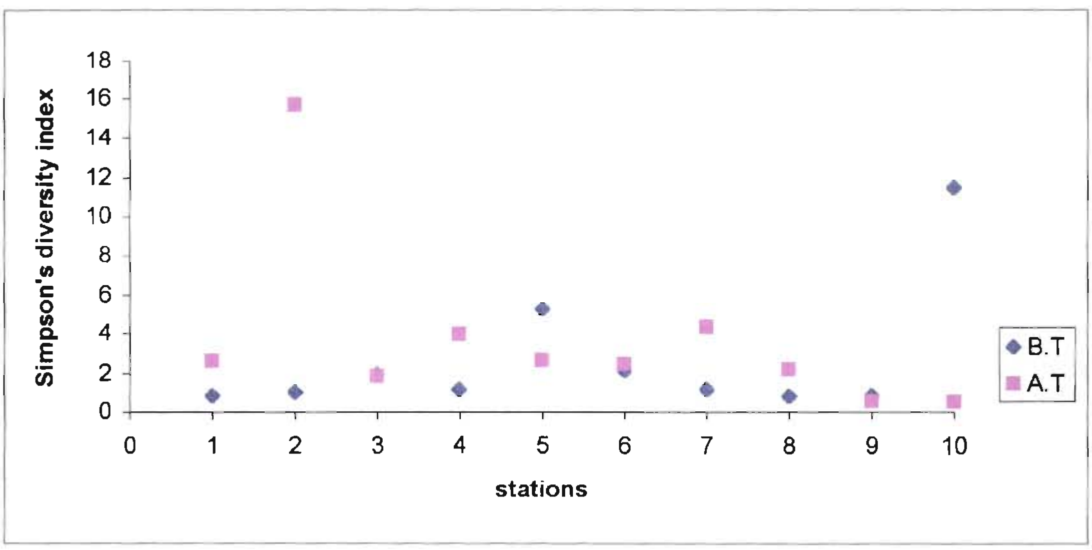


Fig. 8.34 Simpson's diversity (Mean biomass) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

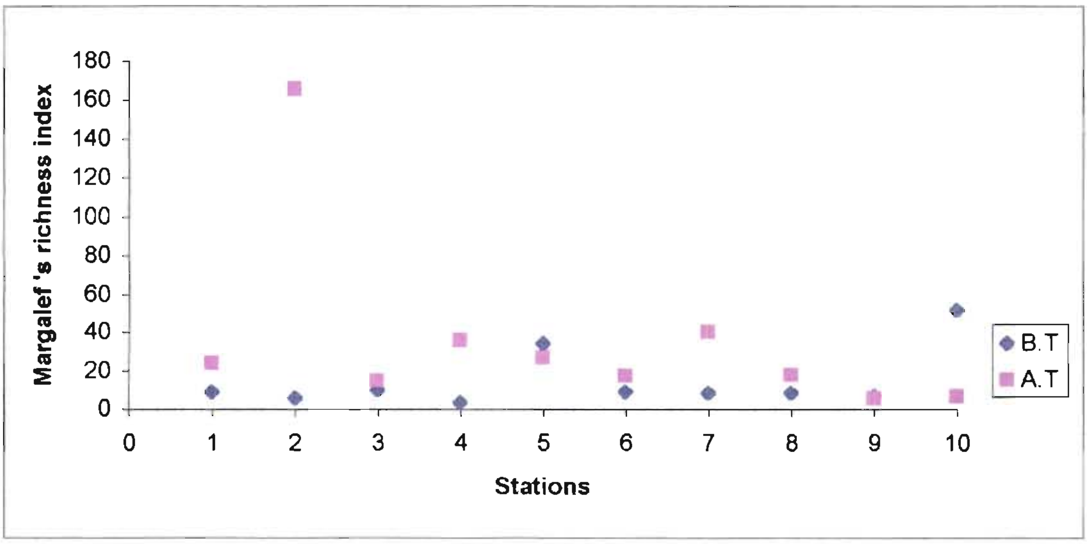


Fig. 8.35 Margalef's richness (Mean biomass) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

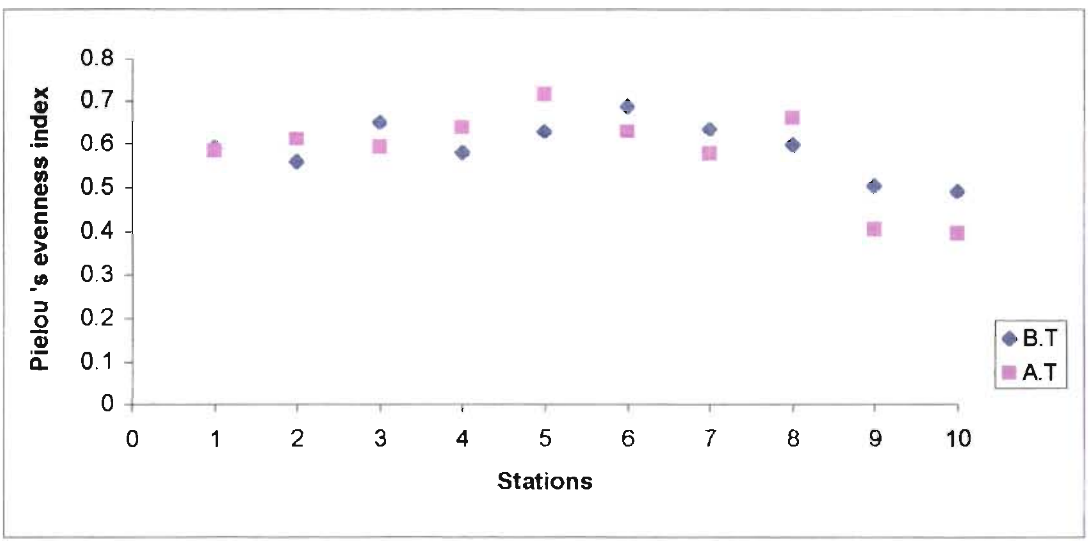


Fig. 8. 36 Pielou's evneness (Mean abundance) of polychaetes before and after trawling at stations 1 to 10 during December 2000 to November 2002

Chapter 9

SUMMARY AND RECOMMENDATIONS

A. Summary

Fishing is the most widespread human exploitative activity in the marine environment. Among the different fishing methods, trawling is the most popular fishing technique prevalent in the world fisheries, of which bottom trawling occupies the foremost position. The origin of trawling is veiled in obscurity. Concern over the possible effect of trawls on the seabed has existed as long as the fishing method itself. Complaints concerning the use of trawl gear date back from the 13th and 14th centuries in the United Kingdom and from the 16th century in The Netherlands. In 1970, International Council For The Exploration Of Seas (ICES) at its 68th Council meeting in Copenhagen took a significant decision to study the effect of trawls and dredges on the seabed. Many studies were conducted on the effect of trawling on sea bottom internationally as an aftermath of the ICES decision. ICES convened a study group on the effect of bottom trawling in 1988, due to the widespread protest the extensive use of bottom trawls. This led to the renewed surge of interest in this field with several countries undertaking systematic studies on the direct and indirect effect of bottom fishing activities on seabed and the associated organisms that live in or on it. Subsequently, studies were undertaken with international collaboration involving different countries, which aimed to evaluate the deleterious effects of bottom trawling on the marine environment.

In India, introduction of trawlers in the mid 60s was received with great enthusiasm because of the high returns. This method of fishing was adopted by an increasing number of people, which resulted in the proliferation of this gear

and its establishment as the most dominant fishing technique in almost all trawlable coasts of India. Southwest coast of India became most vulnerable to the trawling activities because of its rich pelagic and demersal resources; the most valued being that of shrimp. In Kerala, the southernmost state of India, the number of bottom trawlers increased excessively without any control to the present status where more than 5000 boats are engaged in fishing activities round the year. Most of the trawlers are equipped with a 30 m horizontal and 3-4 m vertical mouth opening trawl nets with a tickler chain in the foot tope and a cod end mesh size of mostly around 16-18 mm against the statutory size of 35 mm. The estimated bottom area scraped by one trawl net per day is around 0.5 - 0.7 km^2 Besides, due to rapid increase in the fishing pressures by the shrimp trawlers beyond the rational limits, disproportionate destruction of non-target groups comprising the juveniles of commercially important finfishes and shell fishes, other bottom dwelling and benthic animals which are neither economically important nor have edible use, are also indiscriminately destroyed. The wanton destruction of these animals, though economically not important occupying key positions in the food web of the marine ecosystem, may adversely affect the life supporting system of the sea bottom. It has well been recognized by the scientists and techno-administrators that the fishing pressures in coastal waters of Kerala have reached a stagnant stage which could lead to possible depletion and destruction of living aquatic resources in the shelf waters. Against this background, they advocated for a reduction of fishing effort for the conservation and management of the resources of the sea. Most of them are sharply inclined towards the view that trawling is a destructive fishing method and therefore deleterious to the fishery wealth, benthic fauna and bottom conditions of the sea apart from destroying eggs, juveniles and young ones of commercially important fin and shell fishes. The removal of selected population from the marine ecosystem may eventually result in altering the food web whereby it may impose severe threat to the sustainable yield. Though many studies have been conducted internationally on the possible effects of bottom trawling on the marine environment, no such studies have been witnessed in Indian waters so as to make a meticulous assessment on the effects of coastal bottom trawling on the habitat and the biotic devastation of the sea bottom, qualitative and quantitative post harvest wastage of benthic and other demersal resource diversity. Therefore, in the present study, an attempt is made to assess the impact of excessive bottom trawling exerted on the sea bottom habitat and its living communities which would be useful in impressing up on the seriousness of habitat degradation and biotic devastation, so enabling the concerned for adoption of relevant conservation and management of the resources for sustainable exploitation.

The study area is the coastal stretch from Cochin to Munambam having a distance of 30 km. The study area was divided in to five depth zones such as 0-9, 10-19, 20-29, 30-39 and 40-49 m. Two stations were selected from each depth zones thus covering a total of ten stations. Experimental trawling was conducted with the help of a hired commercial "shrimp trawler" Samples of water and sediment were collected from each station before and after trawling from different depth layers such as surface, bottom, 5 and 10 m above bottom. The parameters such as dissolved oxygen; temperature, salinity, turbidity, pH and nutrients in water were analyzed to study the effect of trawling on the physico-chemical parameters of seawater. Variations on the chlorophyll pigment concentrations due to bottom trawling were evaluated by measuring the chlorophyll pigments in the water samples collected before and after trawling experiments. Effect of trawling on the sediments was studied by analyzing the organic matter and sediment pattern in the sediment samples collected from sea bottom. Possible variations on the infaunal macrobenthos were analyzed by qualitative and quantitative estimation of infauna sorted out from the sediment samples. The intensity of destruction of epifauna due to bottom trawling was assessed by generating database from onboard fishing surveys conducted at major fishing harbours of Kerala such as Saktikulangara, Kochi, Ponani and Puthiyappa.

Analyzing the effect of bottom trawling on physico-chemincal parameters in water indicated that trawling activities would not generate any variations on the temperature, salinity and pH, but drastic variations were observed in the dissolved oxygen content and turbidity. Dissolved oxygen content in the water decreased after trawling with significant variations at bottom, 5 meters and 10 meters above sea bottom. Though extensive variations were noticed at many stations in the surface waters, significant variations could not be observed. The decrease in oxygen concentrations was due to the increase of turbidity in water in the wake of sediment clouds raised during the ploughing action of the trawl gear. The decrease in oxygen concentration is always hazardous for the subsistence of the living communities, especially at bottom where the oxygen is bare minimum. 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 depths. Oxygen concentration was found less in the monsoon period due to the influx of turbid river waters and heavy downpour. 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. Interestingly, the intensity of trawling was found high in the monsoon months especially at the inshore waters due to the heavy shrimp trawling. The results of this study clearly demonstrated the origin of hypoxic conditions in the water column due to intense trawling operations along the coastal waters.

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 surface, bottom, 5 meter and 10 meter above sea bottom in the samples collected after trawling compared to that of before trawling. Highest variations were noticed at bottom waters with an average 2 – 4 fold increase after trawling 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 conducted on the effect of bottom trawling on nutrients showed that there are definite variations in nitrite nitrogen and phosphate phosphorus in the marine environment. Phosphate concentrations were elevated after trawling with an average 2 3 fold increase when compared to the values obtained before trawling. Analysis of nitrite concentration revealed around two fold increase in the samples collected after trawling when compared to that of before trawling. Significant variations noticed in the nutrients recorded both before and after trawling in almost all sub surface layers clearly indicated that excessive nutrients were released during the bottom trawling with the highest variations at the bottom waters. Moreover, among different stations studied, near shore stations (1 - 6) showed steep variations in the turbidity due to trawling, where the sea bottom was muddy in nature whereas stations 7-10 showed less extent of variations where the percentage of sand was higher. The increase of nutrients observed in the after trawling samples revealed that there was the release of nutrients from the sediments into the water column due to the churning action inflicted by otter boards and trawls nets at the seabed.

Chlorophyll pigments also showed an increasing trend in the samples collected after trawling. Though significant variations could not be obtained in the chlorophyll concentrations analyzed before and after trawling operations, however, high values observed in the after trawling samples indicated that bottom trawling released sediment chlorophyll pigments along with the sediment particles dispersed during trawling. Distinct variations noticed at the bottom waters when compared to that of surface indicated that these photosynthetic pigments were emanated from the bottom sediments during trawling. The chlorophyll concentration showed a peak during the monsoon period due to the accumulation of heavy nutrients and minerals from the river discharge. Average two-fold increase was noticed in the chlorophyll *a*, *b* and *c* analysed in the trawled samples. It can be postulated that the bottom trawling operations may decrease the chlorophyll pigment concentrations in the sediments due to the heavy perturbations brought about on the seabed.

Variations in the sediment structure due to bottom trawling were studied by analyzing the sediment pattern in the samples collected before and after trawling experiment. The variations came across in the sediment structure obtained in the after trawling samples is useful in equivocally establish the fact that trawling operations are responsible in bringing about serious alterations of the natural sediment texture of the trawling grounds. A change in sediment pattern into more sandy and silty after trawling by way of losing clay fraction in the area manifests the heavy dispersion and restructuring of sediments during trawling. After trawling, the heavier sand particles settle faster than the clay particles, which make the ground coarser in nature. Stations 1 - 6, which were clayey silt and silty clay in nature in the samples collected before trawling turned into clayey silt after trawling suggesting a loss of clay particles in water Sediments at stations 7 and 8 were silty sand before trawling which showed the same nature after trawling but with a further reduction of clay fraction. 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. These changes demonstrated that trawling causes structural variation on the type of sediment particles at the sea bottom. Moreover, the extent of decrease in clay after trawling was more pronounced in the inshore stations (1 - 6) where the clay fraction was more in the samples collected before trawling. The detailed grain size analysis showed that there were no significant variations on the grain size of the sediment refuting the chance of pulverization during trawling. The decrease of clay fraction clearly indicated that trawling removes the light clay particles from the trawling grounds and the repeated actions of trawl nets might change the natural sediment structure of the sea bottom.

Organic matter analyzed from the trawled grounds showed that the trawling 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 may severely affect the growth of many benthic organisms, which depend on these food reserves for their growth and subsistence.

Wanton destruction of benthic organisms due to the bottom trawling activities was observed during onboard participation in the commercial trawlers from the four major harbours of Kerala such as Saktikulangara, Cochin, Ponani and Puthiyappa. Two year study was conducted to quantify the epibenthic organisms discarded in the Kerala regions and it was quantified that an average of 1.5 lakh tonnes of organisms were discarded from the trawlers which accounts for around 60 % of the total trawl discards along Kerala coast. Among the epibenthic discards, the major items where crabs, gastropods, stomatopods, echinoderms and fishes. Crabs and gastropods dominated the discards with an average of 64,000 and 20,000 tonnes respectively landed annually. The high percentage contribution of crabs and gastropods in the trawl discards in Kerala indicated that the bottom trawling activities caused drastic changes in the benthic community. During trawling, the unwanted animals are discarded after sorting out the economically important finfishes and shellfishes, which fetch high price in the market. During the survey conducted onboard, it was observed that most of the discarded organisms are returned to the water dead except organisms such as crabs and gastropods, which are capable of withstanding the harsh and alien environment onboard. The increase of crabs and gastropods in the trawl catches can be attributed to the high survival of these organisms in the trawl landings. Most of the finfishes and stomatopods die during sorting and becomes the food for the seabirds. High amount of juveniles and sub adults of both economically important and unimportant fishes and shellfishes discarded in the trawl catches clearly explain the magnitude of devastation of these organisms which are prone to bottom trawl fishing. On an average 5600 tonnes of juvenile shrimps were discarded per year. So it can reasonably inferred that trawling activities destroy large amount of marine invertebrates and the removal of fishes and shellfishes especially the young ones would affect the recruitment during subsequent years. Moreover, the destruction of epibenthic organisms, which play a major role in the benthic food web, definitely affects the sustainability of the benthic ecosystem. Results of the present study also indicated that a shift in benthic community had taken place due to the incessant trawling activities in the coastal waters. The destruction and removal of fragile epibenthic organisms will undoubtedly pave way for the shift in community to that of other invertebrates such as crabs and gastropods that survive the trawl catches as observed during in the present study.

Effect of trawling on the infaunal macrobenthc organisms was studied by analyzing the macrofauna from the sediment samples collected before and after trawling experiments. Among infaunal macrobenthos, polychaete formed the dominant group followed by Sipunculids, Amphipods, Nematodes, Penaeids, Gastropods and Bivalves. The polychaetes were represented by 80 genera among this the most commonly occurring genera were *Ancistrosyllis*, *Cossura, Prionospio, Sternaspis, Lumbrineries Magelona, Nepthys and Glycera.* Wide variations were observed in the abundance, biomass and diversity of macrobenthos in the samples collected after trawling, thus indicating heavy destruction caused to infaunal organisms due to bottom trawling. The increase in abundance, biomass and diversity recorded in the after trawling samples was due to the exposure of infaunal organisms owing to the removal of the top layer of the sediments. During trawling, the fragile organisms, which live in the upper layers of the sediments, are dispersed into the water column along with the sediment clouds, to resettle after a certain period of time. Though significant variations were not obtained in the abundance and biomass of the polychaetes recorded immediately after trawling operations, variations observed in the abundance, biomass and diversity at many stations can clearly explain the changes that occur in the communities of these fragile organisms due to bottom trawling. The highest variations were noticed in these stations, which are located near shore (stations 1-6), where the sediment disturbance was found comparatively high due to the high penetration of otter boards and nets in the muddy sediments. On the otherhand, the penetration of otter boards was relatively low at stations 7-10, where sand and silt were predominated. Multidimensional scaling based on the abundance and biomass of the polychaetes obtained before and after trawling clearly indicated the amount of variation, which occurred at the stations after trawling. The exposure and dispersal of polychaetes in the trawled grounds would pave the way for the destruction of these animals in due course. Moreover, the changes in the sediment structure due to the bottom trawling activities disturb the natural habitat of these organisms. It would thus appear that bottom trawling activities in the marine ecosystems by all means inflict deleterious effects to sea bottom communities by the removal and destruction of the infaunal organisms. The increase in abundance and biomass of polychaetes observed during July during when a ban on bottom trawls is in vogue in Kerala, indicated that the ban was useful in giving some respite for the regeneration and recoupement of polychates when there is no disturbance at the sea bottom.

Based on the results of the present study, it can equivocally be established that the bottom trawls have two major effects on the marine environment. Firstly, the trawl net is responsible for removing, destroying and damaging a number of organisms per unit area. Secondly, the trawl gear (wires, otter boards, sweeps and net) brought about significant disturbance to the sediment surface. The latter effect can in turn, lead to a number of secondary effects either of positive or negative in nature. Positive effects could be from the churning of the sediment surface, oxygenation of deeper sediments and release of buried organic matter, release of nutrients and chlorophyll pigments, which can contribute to the stimulation of local production. However negative effect is more dangerous as it destroys the habitat and results in a lot of mortality in the bottom population, thus eventually leading to an overall reduction in benthic productivity. The abrupt release of nutrients, organic matter and chlorophyll from the sediment surface may disturb the natural ecosystem cycle and may generate lethal algal blooms notorious for massive fish kill. Moreover, the removal of organic matter, nutrients and chlorophyll pigments from the sediment surface may decrease the productivity of the sediment layer. The sediment clouds formed due to the re-suspension of sediments is causing an increase to the turbidity and the oxygen demand at the water column which presumably lead to the migration of animals to other areas and also affect the growth and development of many benthic organisms especially larvae and young ones of the species of commercial importance. This study is favorable to give a scientific back up to any movement to restrain the proliferation and uncontrolled operation of bottom trawlers in the coastal waters.

B. Recommendations

1. The present results will serve as an authentic database in resisting the proliferation of incessant fishing operations along Kerala coast and forming strategies to regulate their number for the sustenance of the stock and preservation of sea bottom habitat and the living communities.
2. Vide KMFRA, the regions from Kollemoode to Paravoor, mechanical fishing is prohibited up to 30m depth and from Paravoor to Manjeswar

up to 20m depths. Based on the results of the present study, the limits of the above zones can be increased up to 50 m in Kollemoodu to Paravoor and 40 m from Paravoor to Manjeswar.

3. Regulate the number of bottom trawlers operating along Kerala coast within 2500 units.

4. It has been noticed that large amount of fishes and other benthic organisms especially young ones and sub adults are being destroyed due to the bottom trawling being carried out in the coastal waters. So strict enforcement of 35 mm size for the cod end mesh of the bottom trawl gear (vide KMFRA) are found necessary in order to reduce the quantity of juveniles of fish and shellfishes in trawl discards.

5. The total number of hours trawling should be limited and the distribution of the fleet throughout the different zones controlled by legislation and policed through a satellite vessel monitoring system.

6. It has been noticed that the trawl net and accessories presently used causes heavy damage to the seabed by penetrating into it and dispersing off the top layer of sediments. So measures should be taken to design environment friendly gears to mitigate the effect of trawling on the sediments.

7. Implement necessary technical modification of trawl gear such separate panels, sorting grids, square mesh cod ends, square mesh panels or windows to reduce the capture of undersized fish and discards.

8. Incorporate technological innovations to the trawl gear such as electrical stimulation device at the footrope or release holes at the cod ends to reduce mortality and capture of benthic organisms.

9. Establish "no trawling zones" in selective region of continental shelf and slope ecosystems along Kerala coast as a measure to recoup the benthic communities after demersal fishing.

10. Marine protection areas (MPAs) should be designed to protect habitats and prevent population collapse.

11. Since the ban imposed on bottom trawling during June July for a period of 45 days was found very effective into the regeneration and recoupement of benthic communities, it is recommended that the fishing holidays may be increased to 65 days in consonance with the uniform ban being proposed for all the west coast stated by the Govt. of India

12. Bottom trawler shall be fitted with regular facilities to keep the bycatch in live condition and return the same to the sea in living condition without damage. Necessary provision shall be made in to KMFRA in this regard and vessels having these facilities shall only be permitted for bottom trawling.

13. Minimum landing size (MLS) system should be implemented to curb landings of juveniles and young ones. This will be most useful as a conservation measure if individuals below the minimum landing size can be measured *in situ* or returned to the sea alive.

14. Govt. of Kerala should formulate suitable projects for the effective utilization of discards from the bottom trawling. These valuable fractions can be used for the manufacture of fishing byproducts, fishmeal, poultry feed, fertilizers, etc. The account of discard quantity available along Kerala coast unfold enormous potential on setting up of fish meal plant or other similar units in Kerala on public or private sectors.

15. Educate the boat owners, workers, middlemen, and those who are involved in the fishing sector about the adverse impact of trawl fishing and necessity of protecting the discard fraction in view of their role in sustenance of marine capture fisheries.

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Appendix I

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

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	344.4929	11	31.31754	26.09218	1.56E-24	1.886683
Stations	19.44675	9	2.16075	1.800227	0.077506	1.975806
Error	118.8263	99	1.200265			
Total	482.7659	119				

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

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	389.6323	11	35.42111	30.88862	3.29E-27	1.886683
Stations	7.302083	9	0.811343	0.707523	0.70071	1.975806
Error	113.5269	99	1 146737			
Total	510.4613	119				

Table 3. Results of two- way ANOVA on temperature recorded at bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	745.4509	11	67.76827	44.47849	2.24E-33	1.886683
Stations	7.69875	9	0.855417	0.561438	0.825491	1.975806
Error	150.8382	99	1.523619			
Total	903.9879	119				

Table 4. Results of two- way ANOVA on temperature recorded at bottom after trawling.

ANOVA

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

Table 5. Results of two- way ANOVA on temperature recorded at five meter above before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	532.1862	11	48.38057	86.73835	1.05E-38	1.915303
Stations	5.94125	7	0.84875	1.521668	0.172522	2.130989
Error	42.94875	77	0.557776			
Total	581.0762	95				

Table 6. Results of two- way ANOVA on temperature recorded at five meter above bottom bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	427.2462	11	38.84056	63.44033	5.57E-34	1.915303
Stations	3.919732	7	0.559962	0.914615	0.499923	2.130989
Error	47.14231	77	0.612238			
Total	478.3082	95				

Table 7. Results of two- way ANOVA on temperature recorded at ten meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	204.5594	11	18.59631	28.90846	6.04E-19	1.967546
Stations	5.046111	5	1.009222	1.568862	0.184194	2.382826
Error	35.38056	55	0.643283			
Total	244.9861	71				

Table 8. Results of two- way ANOVA on temperature recorded at ten meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	218.0533	11	19.82303	37.48124	1.42E-21	1.967546
Stations	0.958333	5	0.191667	0.362402	0.872028	2.382826
Error	29.08833	55	0.528879			
Total	248.1	71				

Table 9. Results of two- way ANOVA on salinity recorded at surface before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	375.6229	11	34.14754	16.57935	5.37E-18	1.886683
Stations	44.05842	9	4.89538	2.376811	0.017701	1.975806
Error	203.9046	99	2.059642			
Total	623.5859	119				

Table 10. Results of two- way ANOVA on salinity recorded at surface after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	404.2509	11	36.75008	16.86357	3.19E-18	1.886683
Stations	96.30842	9	10.70094	4.910356	1.91E-05	1.975806
Error	215.7466	99	2.179258			
Total	716.3059	119				

Table 11. Results of two- way ANOVA on salinity recorded at bottom before trawling.

ANOVA

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

Table 12. Results of two- way ANOVA on salinity recorded at bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	344.7482	11	31.34074	23.0874	1 14E-22	1.886683
Stations	11.74022	9	1.304469	0.960947	0.476923	1.975806
Error	134.3908	99	1.357483			
Total	490.8792	119				

Table 13. Results of two- way ANOVA on salinity recorded at five meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
months	243.6596	11	22.15087	17.5081	9.12E-17	1.915303
Stations	2.69125	7	0.384464	0.303881	0.950106	2.130989
Error	97.41875	77	1.265179			
Total	343.7696	95				

Table 14. Results of two- way ANOVA on salinity recorded at five meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	297 1758	11	27.01598	36.3877	5.16E-26	1.915303
Stations	3.344091	7	0.477727	0.643449	0.718617	2.130989
Error	57 1685	77	0.742448			
Total	357.6883	95				

Table 15. Results of two- way ANOVA on salinity recorded at ten meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	224.4861	11	20.40783	30.14675	2.31E-19	1.967546
Stations	7.034444	5	1.406889	2.078277	0.08198	2.382826
Error	37.23222	55	0.676949			
Total	268.7528	71				

Table 16. Results of two- way ANOVA on salinity recorded at ten meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	304.9971	11	27.72701	96.22118	8.39E-32	1.967546
Stations	0.672917	5	0.134583	0.467045	0.799114	2.382826
Error	15.84875	55	0.288159			
Total	321.5188	71				

Table 17 Results of two- way ANOVA on pH recorded at surface before trawling.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Months	9.084667	11	0.825879	31.40264	1 77E-27	1.886683
Stations	0.230333	9	0.025593	0.973115	0.466939	1.975806
Error	2.603667	99	0.0263			
Total	11.91867	119				

Table 18. Results of two- way ANOVA on pH recorded at surface after trawling.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Months	7.404917	11	0.673174	31.42238	1.73E-27	1.886683
Stations	0.160083	9	0.017787	0.830262	0.589894	1.975806
Error	2.120917	99	0.021423			
Total	9.685917	119				

Table 19. Results of two- way ANOVA on pH recorded at bottom before trawling.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Months	10.62367	11	0.965788	56.19886	1.44E-37	1.886683
Stations	0.194667	9	0.02163	1.258621	0.269089	1.975806
Error	1 701333	99	0.017185			
Total	12.51967	119				

Table 20. Results of two- way ANOVA on pH recorded at bottom after trawling.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Months	7.990917	11	0.726447	18.81897	1.02E-19	1.886683
Stations	0.403417	9	0.044824	1.16119	0.328277	1.975806
Error	3.821583	99	0.038602			
Total	12.21592	119				

Table 21. Results of two- way ANOVA on pH recorded at five meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	8.176146	11	0.743286	51.2678	7.47E-31	1.915303
Stations	0.114896	7	0.016414	1.132127	0.352058	2.130989
Error	1.116354	77	0.014498			
Total	9.407396	95				

Table 22. Results of two- way ANOVA on pH recorded at five meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	8.293646	11	0.753968	51.05185	8.6E-31	1.915303
Stations	0.171563	7	0.024509	1.659522	0.131646	2.130989
Error	1.137188	77	0.014769			
Total	9.602396	95				

Table 23. Results of two- way ANOVA on pH recorded at ten meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	6.60375	11	0.600341	57.21661	4.72E-26	1.967546
Stations	0.047917	5	0.009583	0.913357	0.479256	2.382826
Error	0.577083	55	0.010492			
Total	7.22875	71				

Table 24 Results of two- way ANOVA on pH recorded at ten meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	6.886667	11	0.626061	63.76543	3.12E-27	1.967546
Stations	0.053333	5	0.010667	1.08642	0.3782	2.382826
Error	0.54	55	0.009818			
Total	7.48	71				

Table 25. Results of two- way ANOVA on Dissolved oxygen recorded at surface before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	13.11435	11	1.192213	5.303066	1.52E-06	1.886683
Stations	4.76043	9	0.528937	2.352755	0.018859	1.975806
Error	22.25677	99	0.224816			
Total	40.13155	119				

Table 26. Results of two- way ANOVA on dissolved oxygen recorded at surface after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	9.951787	11	0.904708	4.599364	1.25E-05	1.886683
Stations	4.00802	9	0.445336	2.264002	0.023804	1.975806
Error	19.47358	99	0.196703			
Total	33.43339	119				

Table 27 Results of two- way ANOVA on dissolved oxygen recorded at bottom before trawling.

ANOVA

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

Table 28. Results of two- way ANOVA on dissolved oxygen recorded at bottom after trawling.

ANOVA

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

Table 29. Results of two- way ANOVA on dissolved oxygen recorded at five meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	10.14586	11	0.922351	5.752999	1.06E-06	1.915303
Stations	1.503433	7	0.214776	1.339628	0.243406	2.130989
Error	12.34504	77	0.160325			
Total	23.99433	95				

Table 30. Results of two- way ANOVA on dissolved oxygen recorded at five meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	8.547021	11	0.777002	5.270859	3.81E-06	1.915303
Stations	1.751246	7	0.250178	1.697104	0.122142	2.130989
Error	11.35093	77	0.147415			
Total	21.6492	95				

Table 31. Results of two- way ANOVA on dissolved oxygen recorded at ten meter above bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	18.6765	11	1.697864	6.58021	7.26E-07	1.967546
Stations	2.594883	5	0.518977	2.011337	0.091326	2.382826
Error	14.19142	55	0.258026			
Total	35.4628	71				

Table 32 Results of two- way ANOVA on dissolved oxygen recorded at ten meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	10.27785	11	0.93435	4.834264	3.55E-05	1.967546
Stations	0.43804	5	0.087608	0.453278	0.8091	2.382826
Error	10.63021	55	0.193277			
Total	21.3461	71				

Table 33. Results of two- way ANOVA on turbidity recorded at surface before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	2425.405	11	220.4913	30.33243	6.46E-27	1.886683
Stations	101.467	9	11.27411	1.550951	0.140828	1.975806
Error	719.647	99	7.269162			
Total	3246.519	119				

Table 34. Results of two- way ANOVA on turbidity recorded at surface after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	5417.273	11	492.4794	38.2659	8.98E-31	1.886683
Stations	174.6021	9	19.40023	1.507408	0.155725	1.975806
Error	1274.123	99	12.86993			
Total	6865.998	119				

Table 35. Results of two- way ANOVA on turbidity recorded at bottom before trawling.

ANOVA

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

Table 36. Results of two- way ANOVA on turbidity recorded at bottom after trawling.

ANOVA

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

Table 37 Results of two- way ANOVA on turbidity recorded at five meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	1374.466	11	124.9514	27.92191	1.79E-22	1.915303
Stations	216.895	7	30.985	6.923972	2.18E-06	2.130989
Error	344.5775	77	4.475032			
Total	1935.938	95				

Table 38. Results of two- way ANOVA on turbidity recorded at five meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
months	5407.25	11	491.5682	35.75745	8.96E-26	1.915303
Stations	279.2083	7	39.8869	2.901437	0.00956	2.130989
Error	1058.542	77	13.74729			
Total	6745	95				

Table 39. Results of two- way ANOVA on turbidity recorded at ten meter above bottom before trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	685.815	11	62.34682	17.64297	2.73E-14	1.967546
Stations	22.46851	5	4.493701	1.271633	0.289317	2.382826
Error	194.3592	55	3.533804			
Total	902.6428	71				

Table 40 Results of two- way ANOVA on turbidity recorded at ten meter above bottom after trawling.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	5026.205	11	456.9277	56.01194	8.03E-26	1.967546
Stations	110.5924	5	22.11847	2.711367	0.029241	2.382826
Error	448.6726	55	8.157684			
Total	5585.47	71				

Appendix II

Table 1. Results of the two-way ANOVA on nitrite nitrogen recorded at surface before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	9.433369	11	0.857579	6.276268	9.06E-08	1.886683
Stations	2.369839	9	0.263315	1.927098	0.056534	1.975806
Error	13.5272	99	0.136638			
Total	25.33041	119				

Table 2. Results of the two-way ANOVA on nitrite nitrogen recorded at surface after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	18.11271	11	1.64661	6.968385	1.31E-08	1.886683
Stations	2.693879	9	0.29932	1.266709	0.26457	1.975806
Error	23.39343	99	0.236297			
Total	44.20002	119				

Table 3. Results of the two-way ANOVA on nitrite nitrogen recorded at bottom before trawling

ANOVA

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

Table 4. Results of the two-way ANOVA on nitrite nitrogen recorded at bottom after trawling

ANOVA

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

Table 5. Results of the two-way ANOVA on nitrite nitrogen recorded at five meters above bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	18.24942	11	1.659038	5.507782	2.03E-06	1.915303
Staions	2.306162	7	0.329452	1.093735	0.375674	2.130989
Error	23.19372	77	0.301217			
Total	43.74931	95				

Table 6. Results of the two-way ANOVA on nitrite nitrogen recorded at five meters above bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	23.03546	11	2.094133	5.652469	1.38E-06	1.915303
Stations	2.792224	7	0.398889	1.076679	0.386519	2.130989
Error	28.52705	77	0.370481			
Total	54.35473	95				

Table 7 Results of the two-way ANOVA on nitrite nitrogen recorded at ten meters above bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	8.322181	11	0.756562	3.881179	0.00036	1.967546
Stations	1.76653	5	0.353306	1.812468	0.125563	2.382826
Error	10.7212	55	0.194931			
Total	20.80991	71				

Table 8. Results of the two-way ANOVA on nitrite nitrogen recorded at ten meters above bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	18.29527	11	1.663206	4.078147	0.000221	1.967546
Stations	0.765021	5	0.153004	0.375163	0.863585	2.382826
Error	22.43086	55	0.407834			
Total	41.49115	71				

Table 9. Results of the two-way ANOVA on phosphate phosphorus recorded at surface before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	44.70949	11	4.064499	10.15967	3.66E-12	1.886683
Stations	1.431492	9	0.159055	0.397575	0.933595	1.975806
Error	39.60615	99	0.400062			
Total	85.74713	119				

Table 10. Results of the two-way ANOVA on phosphate phosphorus recorded at surface after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	77.74388	11	7.067626	12.33082	2.62E-14	1.886683
Stations	2.551429	9	0.283492	0.494606	0.875053	1.975806
Error	56.74359	99	0.573168			
Total	137.0389	119				

Table 11. Results of the two-way ANOVA on phosphate phosphorus recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	228.7201	11	20.79273	24.49221	1.46E-23	1.886683
Stations	3.701173	9	0.411241	0.48441	0.882013	1.975806
Error	84.04632	99	0.848953			
Total	316.4675	119				

Table 12. Results of the two-way ANOVA on phosphate phosphorus recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	230.5089	11	20.95535	24.07782	2.65E-23	1.886683
Staions	4.37949	9	0.48661	0.559118	0.827314	1.975806
Error	86.16144	99	0.870318			
Total	321.0498	119				

Table 13. Results of the two-way ANOVA on phosphate phosphorus recorded at five meters above bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	149.7655	11	13.61505	41.7234	6.5E-28	1.915303
Stations	1.647258	7	0.235323	0.721148	0.654366	2.130989
Error	25.12639	77	0.326317			
Total	176.5392	95				

Table 14. Results of the two-way ANOVA on phosphate phosphorus recorded at five meters above bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	203.6607	11	18.51461	36.79127	3.64E-26	1.915303
Stations	11.41813	7	1.631161	3.241359	0.004565	2.130989
Error	38.74899	77	0.503234			
Total	253.8278	95				

Table 15. Results of the two-way ANOVA on phosphate phosphorus recorded at ten meters above bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	76.51908	11	6.95628	19.71653	2.71E-15	1.967546
Stations	0.256079	5	0.051216	0.145164	0.980672	2.382826
Error	19.4048	55	0.352815			
Total	96.17996	71				

Table 16. Results of the two-way ANOVA on phosphate phosphorus recorded at ten meters above bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	85.8341	11	7.8031	20.94665	7.5E-16	1.967546
Stations	0.243234	5	0.048647	0.130587	0.984752	2.382826
Error	20.48874	55	0.372523			
Total	106.5661	71				

Appendix III

Table 1. Results of two-way ANOVA on chlorophyll *a* recorded at surface before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	500.4671	5	100.0934	32.95026	5.61E-14	2.422084
Stations	57.53055	9	6.392283	2.104308	0.049076	2.095753
Error	136.6971	45	3.037713			
Total	694.6948	59				

Table 2. Results of two-way ANOVA on chlorophyll *a* recorded at surface after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	315.4848	5	63.09696	16.13351	4.28E-09	2.422084
Stations	144.3187	9	16.03541	4.100157	0.000674	2.095753
Error	175.9916	45	3.910925			
Total	635.7951	59				

Table 3. Results of two-way ANOVA on chlorophyll *a* recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	352.9024	5	70.58048	7.912932	2.05E-05	2.422084
Stations	344.4326	9	38.27028	4.290565	0.000457	2.095753
Error	401.3837	45	8.919637			
Total	1098.719	59				

Table 4. Results of two-way ANOVA on chlorophyll *a* recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	516.6563	5	103.3313	6.536982	0.00012	2.422084
Stations	469.4234	9	52.15816	3.299649	0.003616	2.095753
Error	711.3231	45	15.80718			
Total	1697.403	59				

Table 5. Results of two-way ANOVA on chlorophyll *b* recorded at surface before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	0.829345	5	0.165869	2.901555	0.023575	2.422084
Stations	0.6066	9	0.0674	1.179033	0.33129	2.095753
Error	2.572448	45	0.057166			
Total	4.008393	59				

Table 6. Results of two-way ANOVA on chlorophyll *b* recorded at surface after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	2.638496	5	0.527699	1.41003	0.238914	2.422084
stations	1.800695	9	0.200077	0.534613	0.841477	2.095753
Error	16.84111	45	0.374247			
Total	21.2803	59				

Table 7. Results of two-way ANOVA on chlorophyll *b* recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	1.522573	5	0.304515	1.652431	0.165771	2.422084
Stations	1.224166	9	0.136018	0.738096	0.672129	2.095753
Error	8.292727	45	0.184283			
Total	11.03947	59				

Table 8. Results of two-way ANOVA on chlorophyll *b* recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	1.195804	5	0.239161	0.834506	0.532183	2.422084
Stations	2.013146	9	0.223683	0.780499	0.635112	2.095753
Error	12.89653	45	0.28659			
Total	16.10548	59				

Table 9. Results of two-way ANOVA on cholorophyll *c* recorded at surface before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	14.34641	5	2.869281	8.076415	1.68E-05	2.422084
Stations	1.844651	9	0.204961	0.576922	0.808749	2.095753
Error	15.987	45	0.355267			
Total	32.17806	59				

Table 10. Results of two-way ANOVA on cholorophyll *c* recorded at surface after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	7.263935	5	1.452787	2.112375	0.081278	2.422084
Stations	11.17375	9	1.241528	1.805201	0.093664	2.095753
Error	30.94877	45	0.687751			
Total	49.38646	59				

Table 11. Results of two-way ANOVA on chlorophyll *c* recorded at bottom before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	10.02517	5	2.005033	2.95313	0.02175	2.422084
Stations	13.23535	9	1.470594	2.165977	0.042893	2.095753
Error	30.55283	45	0.678952			
Total	53.81335	59				

Table 12. Results of two-way ANOVA on chlorophyll *c* recorded at bottom after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	3.573532	5	0.714706	1.443897	0.227167	2.422084
Stations	6.649378	9	0.73882	1.492613	0.179961	2.095753
Error	22.27429	45	0.494984			
Total	32.4972	59				

Appendix IV

Table 1. Results of two-way ANOVA on sand fractions recorded at sediments before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	11541.2	11	1049.2	3.190235	0.000967	1.886683
Stations	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 sand fractions recorded at sediments after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	8558.41	11	778.0373	1.935782	0.043457	1.886683
Stations	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 fractions recorded at sediments before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	11161.46	11	1014.678	11.21634	3.13E-13	1.886683
Stations	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 fractions recorded at sediments after trawling

ANOVA

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

Table 5. Results of two-way ANOVA on clay fractions recorded at sediments before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	2278.655	11	207.1504	1.49241	0.146267	1.886683
Stations	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 fractions recorded at sediments after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	2499.975	11	227.2704	1.259322	0.25938	1.886683
Stations	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 organic matter recorded in sediments before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	103.7977	11	9.436158	6.363946	7.06E-08	1.886683
Stations	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 organic matter recorded in sediments after trawling

ANOVA

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

Appendix V

Table 1. Results of two way ANOVA on CPUE of finfish discarded between April 2000-March 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	21.83645	11	1.985131	7.878039	0.000936	2.817927
Years	0.040837	1	0.040837	0.162065	0.694976	4.844338
Error	2.771813	11	0.251983			
Total	24.6491	23				

Table 2. Results of two way ANOVA on CPUE of crabs discarded between April 2000-March 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	4694.647	11	426.7861	22.29957	6.15E-06	2.817927
Years	51.62667	1	51.62667	2.697493	0.128757	4.844338
Error	210.5263	11	19.13876			
Total	4956.8	23				

Table 3. Results of two way ANOVA on CPUE of gastropods discarded between April 2000-March 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	267.9538	11	24.35944	10.52826	0.000247	2.817927
years	0.097538	1	0.097538	0.042156	0.841073	4.844338
Error	25.45091	11	2.313719			
Total	293.5023	23				

Table 4. Results of two way ANOVA on CPUE of echinoderms discarded between April 2000-March 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	7.013133	11	0.637558	1.610715	0.220883	2.817927
Years	0.14415	1	0.14415	0.364178	0.558433	4.844338
Error	4.35405	11	0.395823			
Total	11.51133	23				

Table 5. Results of paired t test on CPUE of finfish discarded between years 2000-01 and 2001-02

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	1.218333	1.300833
Variance	1.198433	1.038681
Observations	12	12
Pearson Correlation	0.776708	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.40257	
P(T<=t) one-tail	0.347488	
t Critical one-tail	1.795884	
P(T<=t) two-tail	0.694976	
t Critical two-tail	2.200986	

Table 6. Results of paired t test on CPUE of crabs discarded between years 2000-01 and 2001-02

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	14.7475	11.81417
Variance	271.0357	174.8891
Observations	12	12
Pearson Correlation	0.936181	
Hypothesized Mean Difference	0	
df	11	
t Stat	1.642405	
P(T<=t) one-tail	0.064379	
t Critical one-tail	1.795884	
P(T<=t) two-tail	0.128757	
t Critical two-tail	2.200986	

Table 7. Results of paired t test on CPUE of gastropods discarded between years 2000-01 and 2001-02

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	4.443333	4.570833
Variance	12.89679	13.77637
Observations	12	12
Pearson Correlation	0.826963	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.20532	
P(T<=t) one-tail	0.420536	
t Critical one-tail	1.795884	
P(T<=t) two-tail	0.841073	
t Critical two-tail	2.200986	

Table 8. Results of paired t test on CPUE of echinoderms discarded between years 2000-01 and 2001-02

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.269167	0.424167
Variance	0.093027	0.940354
Observations	12	12
Pearson Correlation	0.408658	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.60347	
P(T<=t) one-tail	0.279217	
t Critical one-tail	1.795884	
P(T<=t) two-tail	0.558433	
t Critical two-tail	2.200986	

Table 9. Results of one -way ANOVA on diversity of finfish discarded between years 2000-01 and 2001-02

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.007569	1	0.007569	0.034493	0.854364	4.300944
Within years	4.82742	22	0.219428			
Total	4.834989	23				

Table 10. Results of one -way ANOVA on diversity of gastropods discarded between years 2000-01 and 2001-02

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.940676	1	0.940676	1.95735	0.175738	4.300944
Within years	10.5729	22	0.480586			
Total	11.51358	23				

Table 11. Results of one -way ANOVA on diversity of crabs discarded between years 2000-01 and 2001-02

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.216322	1	0.216322	1.471833	0.237922	4.300944
Within years	3.233435	22	0.146974			
Total	3.449757	23				

Table 12. Results of one -way ANOVA on diversity of finfish discarded in the experimetal trawling between Dec 2000- Nov 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.17284	1	0.17284	1.127656	0.313248	4.964591
Within years	1.532737	10	0.153274			
Total	1.705577	11				

Table 13. Results of one -way ANOVA on diversity of crabs discarded in the experimetal trawling between Dec 2000- Nov 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.03767	1	0.03767	0.067111	0.800845	4.964591
Within years	5.613134	10	0.561313			
Total	5.650805	11				

Table 14. Results of one -way ANOVA on diversity of gastropods discarded in the experimetal trawling between Dec 2000- Nov 2002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between years	0.118462	1	0.118462	0.290344	0.601789	4.964591
Within years	4.080063	10	0.408006			
Total	4.198525	11				

Appendix VI

Table 1. Abundance of infaunal macrobenthos obtained before trawling during December 2000 (no.m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	40	50	60	60	140	120	20	20	0	0
Aricidea sp.	0	0	0	0	0	0	0	0	40	40
Cirratulus sp.	20	20	20	20	0	0	0	0	20	20
Cossura sp.	120	100	100	110	410	400	0	0	0	0
Disoma sp.	60	40	80	80	0	0	0	0	0	0
Dorvillea sp.	20	20	20	20	20	20	0	0	0	0
Euclymene sp.	0	0	0	0	40	40	0	0	0	0
Eunice sp.	0	0	0	0	20	20	0	0	0	0
Glycera sp.	20	20	40	40	20	0	0	0	0	0
Goniada sp.	40	20	20	20	0	0	0	0	0	0
Isolda sp.	0	0	0	0	0	0	20	0	0	0
Lumbrineries sp.	1500	800	1900	1800	200	300	0	0	0	220
Magelonidae sp.	2500	3500	5850	5860	4500	4000	110	100	460	5840
Nephtys sp.	40	60	60	60	40	20	0	0	0	0
Nereis sp.	20	40	50	50	70	40	0	0	0	80
Opisthosyllis sp.	20	20	100	100	40	20	0	0	0	0
Paralacydonia sp.	0	0	0	0	20	0	0	0	0	0
Prionospio sp.	0	0	0	0	80	60	0	0	20	0
Sternaspis sp.	40	60	60	60	250	200	0	0	0	0
Other groups										
Amphipoda	60	100	0	0	120	100	0	0	0	0
Bivalvia	0	0	0	0	20	0	0	0	0	0
Brachuyra	0	0	0	0	20	0	0	0	0	0
Euphuasid	0	0	0	0	20	0	20	0	0	0
Gastropoda	20	20	0	0	20	0	0	0	0	0
Isopoda	0	0	0	0	20	0	20	20	0	0
Palinuridae	0	0	0	0	20	0	0	0	0	0
Penaeidea	20	0	0	0	0	0	0	0	0	0
Sipunculidae	20	40	0	0	40	40	0	0	0	0

Table 2. Abundance of infaunal macrobenthos obtained before trawling during February 2001 (no.m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0	220	240	0	60	40	250	240
Cirratulus sp.	0	0	0	0	0	0	0	0	20	20
Cossura sp.	20	90	140	100	290	80	60	200	240	220
Disoma sp.	0	20	140	120	0	0	0	60	60	60
Dorvillea sp.	0	20	0	0	0	0	0	40	40	40
Euclymene sp.	0	20	20	20	0	0	20	0	0	0
Glycera sp.	0	20	0	20	0	0	0	0	0	0
Lumbrineries sp.	30	150	430	400	840	0	0	0	220	200
Magelonidae sp.	0	20	0	0	0	0	40	40	16650	12200
Nephtys sp.	0	0	20	60	50	0	0	0	160	140
Onuphis sp.	0	20	0	20	0	0	0	0	0	0
Paralacydonia sp.	0	20	0	0	0	0	0	0	20	20
Prionospio sp.	20	0	0	20	20	0	0	0	60	60
Rhynchospio sp.	0	0	0	20	20	0	0	0	0	0
Siphanophanes sp.	0	20	0	0	0	0	0	0	0	0
Sternaspis sp.	20	20	20	20	20	0	0	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	120	100
Bivalvia	0	0	0	100	120	0	0	0	40	40
Gastropoda	0	0	440	20	20	0	60	60	20	20
Nematoda	0	0	0	20	20	0	0	0	0	0
Sipuncula	0	40	0	20	20	0	0	60	60	60
Stomatopoda	0	0	0	0	0	0	0	0	20	20

Table 3. Abundance of infaunal macrobenthos obtained before trawling during April 2001 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	20	20	20	0	20	0	0	0	0	0
Cirratulus sp.	0	0	0	20	0	0	0	0	0	0
Cossura sp.	90	60	80	20	300	180	40	40	0	20
Euclymene sp.	20	0	0	0	60	0	0	0	0	0
Glycera sp.	20	0	0	0	0	0	20	20	80	130
Lumbrineries sp.	412	170	180	150	260	20	20	20	20	20
Magelonidae sp.	20	0	0	20	60	80	360	350	240	100
Nephtys sp.	30	20	20	20	80	20	20	20	0	0
Nereis sp.	0	0	0	0	20	0	0	0	0	0
Paralacydonia sp.	20	0	0	0	0	0	0	0	0	0
Pectinaria sp.	0	0	0	0	0	0	0	0	0	20
Prionospio sp.	20	0	0	0	0	0	0	0	0	0
Sternaspis sp.	60	70	110	0	20	20	0	0	0	0
Othe groups										
Amphipoda	0	0	0	0	0	0	0	0	40	30
Bivalvia	0	0	0	20	0	0	0	0	40	20
Gastropoda	0	20	270	0	60	0	0	0	100	250
Holothuroidea	0	0	0	0	0	20	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	20
Nematoda	0	0	0	0	0	0	0	0	160	0
Ophiuroidea	20	0	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	20	0	0	0	20	60
Sipunculidae	20	0	0	0	0	0	0	0	50	50
Stomatopoda	0	0	0	0	0	0	0	0	20	0

Table 4. Abundance of infaunal macrobenthos obtained before trawling during July 2001 (no.m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Cirratulus sp.	0	0	40	20	20	20	0	0	0	0
Cossura sp.	110	100	140	50	150	180	70	200	40	40
Euclymene sp.	100	90	20	20	20	20	40	0	0	0
Lumbrineries sp.	550	500	440	200	200	400	720	60	40	40
Magelonidae sp.	0	0	0	0	0	0	20	0	330	300
Nephtys sp.	0	0	0	0	0	20	0	0	0	0
Prionospio sp.	60	60	100	0	0	40	210	160	0	0
Siphanophanes sp.	40	40	0	0	0	0	0	0	0	0
Sternaspis sp.	260	250	120	60	40	180	100	20	120	100
Other groups										
Palinuridae	0	0	0	0	0	0	20	20	0	0
Sipunculidae	0	0	0	0	0	0	20	0	0	0

Table 5. Abundance of infaunal macrobenthos obtained before trawling during September 2001 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Amphitrite sp.	0	0	0	40	0	0	0	0	0	0
Ancistrosyllis sp.	0	0	0	20	20	80	60	40	240	220
Cirratulus sp.	0	0	20	0	0	0	0	20		20
Cossura sp.	70	220	50	30	40	40	0	0	40	40
Diopatra sp.	20	0	0	0	0	0	0	0	120	110
Euclymene sp.	0	0	0	0	0	20	0	0	0	0
Lumbrinerles sp.	200	520	80	140	90	140	40	40	20	20
Magelonidae sp.	20	0	20	0	100	40	120	180	0	0
Nephtys sp.	0	0	0	0	0	0	0	0	40	40
Nereis sp.	0	0	0	0	0	30	20	20	20	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	40	60
Phyllodoce sp.	0	0	0	0	0	0	0	100	100	80
Phylocapensis sp.	0	0	0	0	0	0	0	0	0	
Potamilla sp.	0	0	0	0	0	0	0	0	20	20
Prionospio sp.	60	20	110	190	90	90	800	1000	60	60
Pulliella sp.	0	0	0	0	0	0	0	0	0	
Sternaspis sp.	40	60	20	60	20	70	0	0	0	0
Syllis sp.	0	0	0	0	0	0	20	20	20	20
Other groups										
Brachyura	0	0	0	0	0	0	0	0	20	40
Amphipoda	0	0	0	0	0	0	20	20	20	0
Juvenile fish	20	0	0	0	0	0	0	0	20	20
Bivalvia	0	0	0	0	0	20	20	20	0	0
Gastropoda	0	0	0	20	20	0	0	0	0	0
Sipunculidae	0	0	0	0	0	0	60	80	0	0
Sea Anemone	0	0	0	20	20	100	0	0	0	0
Asteroidea	0	0	0	0	0	0	0	0	20	20

Table 6. Abundance of infaunal macrobenthos obtained before trawling during November 2001 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	20	20	0	0	20	20	40	60	290	260
Cirratulus sp.	0	0	0	0	0	0	80	60	0	0
Cossura sp.	1090	1000	60	40	650	600	0	0	20	20
Diopatra sp.	0	0	20	0	0	0	0	0	0	0
Eunice sp.	0	0	0	0	0	0	20	20	0	0
Glycera sp.	0	0	0	0	0	0	20	0	30	40
Lumbrineries sp.	140	120	60	40	60	40	1140	1000	70	60
Magelonidae sp.	0	0	0	0	0	0	0	0	610	0
Nephtys sp.	20	20	0	0	0	0	0	0	0	0
Nereis sp.	0	0	0	0	20	20	20	20	0	0
Notomastus sp.	0	0	20	20	20	20	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	20	20	0	0
Phyllodoce sp.	0	0	0	0	0	0	20	20	40	0
Prionospio sp.	0	0	0	0	0	0	20	20	270	0
Sternaspis sp.	0	0	80	80	250	200	0	0	40	0
Trypanosyllis sp.	0	0	0	0	0	0	20	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	30	0
Bivalvia	0	0	0	0	0	0	20	20	0	0
Brachyura	0	0	0	0	0	0	0	0	20	0
Gastropoda	0	0	0	0	0	0	0	0	20	0
Holothuroidea	0	0	0	0	20	20	0	0	0	0
Nematoda	0	0	0	0	0	0	20	0	20	0
Penaeidea	0	0	0	0	0	0	0	0	20	0
Sipunculidae	0	0	0	0	0	0	40	60	20	0
Stomatopoda	0	0	0	0	0	0	0	0	20	0

Table 7. Abundance of infaunal macrobenthos obtained before trawling during January 2002 (no.m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0	20	60	80	0	20	350	100
Aricidea sp.	0	0	0	0	0	0	0	20	0	0
Cirratulus sp.	0	0	20	20	0	0	20	120	0	20
Cossura sp.	200	180	50	40	200	190	20	20	0	0
Diopatra sp.	0	0	0	0	0	0	0	20	0	0
Dorvillea sp.	0	0	0	0	0	0	20	0	0	0
Euclymene sp.	0	0	20	0	20	0	20	0	40	0
Glycera sp.	0	0	0	0	0	0	20	0	20	20
Goniada sp.	0	0	0	0	0	0	0	20	0	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	120	0
Lumbrineries sp.	20	430	520	310	50	230	40	20	110	160
Magelonidae sp.	0	0	20	0	0	0	0	0	0	2040
Maldanella sp.	0	0	0	0	0	20	0	0	0	0
Nephtys sp.	20	0	0	20	0	40	0	0	0	0
Nereis sp.	0	0	0	0	0	0	200	60	0	20
Notomastus sp.	0	20	20	0	30	20	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	80
Phyllocomus sp.	0	0	0	0	20	0	40	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	20	0	0
Potamilla sp.	0	0	0	0	0	0	0	0	20	0
Prionospio sp.	0	20	0	0	20	0	0	20	0	0
Scoloplella sp.	0	0	0	0	0	0	0	0	260	0
Sternaspis sp.	0	30	50	50	80	30	40	20	0	0
Syllis sp.	0	0	0	0	0	0	0	0	60	0
Terebellidae stroemi	0	0	20	0	0	0	0	20	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	40	0
Asteroidea	0	20	0	0	0	0	20	0	0	0
Bivalvia	0	20	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	20	0	0	0
Penaeidea	0	0	0	0	0	0	0	20	20	20
Sipuncula	0	0	0	0	0	0	60	120	20	20

Table 8. Abundance of infaunal macrobenthos obtained before trawling during March 2002 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	20	20	60	60	20	20	200	100
Aricidea sp.	0	0	0	0	0	0	0	20	0	0
Cirratulus sp.	0	0	20	20	0	0	20	80	0	20
Cossura sp.	150	200	40	20	150	150	20	20	0	0
Diopatra sp.	0	0	0	0	0	0	0	20	0	0
Dorvillea sp.	0	0	0	0	0	0	20	20	0	0
Euclymene sp.	0	0	20	0	20	20	20	20	40	20
Glycera sp.	0	0	0	0	0	0	20	20	20	20
Goniada sp.	0	0	0	0	0	0	0	20	0	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	80	100
Lumbrineries sp.	100	200	200	300	40	200	40	20	110	160
Magelonidae sp.	0	0	20	0	0	0	0	0	650	800
Maldanella sp.	0	0	0	0	20	20	0	0	0	0
Nephtys sp.	20	20	20	20	0	40	0	0	0	0
Nereis sp.	0	0	0	0	0	0	200	60	0	20
Notomastus sp.	20	20	20	0	30	20	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	80
Phyllocomus sp.	0	0	0	0	20	20	40	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	20	0	0
Potamilla sp.	0	0	0	0	0	0	0	0	20	0
Prionospio sp.	20	20	0	0	20	20	0	20	0	0
Sternaspis sp.	20	30	40	40	60	30	40	20	0	0
Syllis sp.	0	0	0	0	0	0	0	0	60	40
Terebellidae stroemi	0	0	20	0	0	0	0	20	0	0
Other groups										
Sipunculidae	0	0	0	0	0	0	60	120	20	20
Penaeidea	0	0	0	0	0	0	0	20	20	20
Brachyura	0	0	0	0	0	0	20	0	0	0
Bivalvia	0	20	0	0	0	0	0	0	0	0
Asteroidea	0	20	0	0	0	0	20	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	40	0

Table 9. Abundancee of infaunal macrobenthos obtained before trawling during May 2002 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	30	0	40	0	200	0	20	40	60	20
Aricidea sp.	0	0	0	0	0	0	0	60	0	0
Cirratulus sp.	0	0	0	0	0	0	0	0	60	0
Cossura sp.	790	410	1620	220	40	580	0	20	20	20
Dorvillea sp.	0	0	0	0	0	0	40	0	0	20
Euclymene sp.	0	0	20	20	0	0	20	0	0	0
Eunice sp.	0	0	0	0	0	0	0	0	20	20
Glycera sp.	30	0	0	0	0	0	0	40	80	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	0	20
Heteromastus sp.	0	20	0	0	0	0	0	0	0	0
Lumbrineries sp.	600	210	300	420	160	110	60	110	40	20
Magelonidae sp.	0	0	0	0	0	0	400	0	1387	1220
Maldanella sp.	0	0	0	0	0	0	0	0	20	0
Nephtys sp.	0	20	20	20	20	0	0	40	0	20
Nereis sp.	0	0	0	0	0	0	80	0	0	0
Nichomache sp.	0	0	0	0	0	0	0	0	20	0
Notomastus sp.	60	0	0	20	0	0	0	20	0	0
Onuphis sp.	0	0	0	0	0	0	0	0	20	0
Ophelia sp.	0	0	0	0	0	0	20	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	20	20
Phalacrophorus sp.	0	0	0	0	0	0	0	20	0	0
Polycirrus sp.	0	0	0	0	0	0	0	0	20	0
Prionospio sp.	20	0	0	40	0	0	0	0	0	0
Sabellaria sp.	0	0	0	0	0	0	0	0	20	0
Sternaspis sp.	280	90	630	250	240	80	20	20	0	0
Streblosoma sp.	0	0	0	0	20	0	0	0	0	0
Other groups										
Amphipoda	0	0	0	0	20	20	0	0	70	30
Asteroidea	0	0	0	0	0	0	0	0	0	0
Bivalvia	0	40	0	0	0	0	20	0	20	40
Brachyura	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	20
Caulina	0	0	0	0	0	0	0	0	0	50
Euphuasid	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	13500	370	0	0	250	0	180	0	40
Holothuroidea	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	20	0
Juvenile fish	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0
Ophiuroidea	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0
Palinuridae	0	0	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	20	0	20	0
Sipuncula	0	20	0	0	0	0	0	0	110	20
Stomatopoda	0	0	0	0	0	0	0	20	20	100

Table 10. Abundance of infaunal macrobenthos obtained before trawling during July 2002 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Amaena sp.	0	0	0	0	0	0	20	0	0	0
Ancistrosyllis sp.	20	0	0	0	20	0	20	20	30	40
Aricidea sp.	0	0	0	0	0	0	40	160	100	60
Cirratulus sp.	0	0	0	0	0	0	60	20	0	0
Cossura sp.	360	1150	600	420	430	200	0	0	20	40
Dorvillea sp.	0	0	0	0	0	0	0	0	0	40
Euclymene sp.	80	0	0	0	0	0	40	20	40	60
Eunice sp.	0	0	0	0	0	0	20	0	0	0
Glycera sp.	0	0	0	0	0	0	40	20	20	20
Glyphanostomum sp.	0	0	0	0	0	0	0	0	60	0
Lumbrineries sp.	960	240	140	610	80	70	0	170	470	90
Magelonidae sp.	0	0	0	0	0	0	0	0	660	2500
Nephtys sp.	0	0	0	0	0	0	0	0	0	20
Nereis sp.	0	0	0	0	20	0	50	40	120	70
Notomastus sp.	40	0	0	0	40	20	20	0	20	0
Paralacydonia sp.	0	0	0	0	0	0	0	20	0	0
Pherusa sp.	0	0	0	0	0	0	0	20	0	0
Phyllodoce sp.	0	0	0	0	0	0	20	20	0	0
Prionospio sp.	60	0	80	0	20	20	0	60	120	180
Sabellidae sp.	0	0	0	0	0	0	0	0	20	0
Scoloplos sp.	0	0	0	0	0	0	0	20	0	0
Sternaspis sp.	450	70	120	100	130	110	0	0	0	20
Syllis sp.	0	0	0	0	0	0	20	40	0	20
Terebellidae stroemi	0	0	0	0	0	0	0	0	20	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0	20
Asteroidea	30	40	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	20	0	0
Gastropoda	20	0	3700	2000	0	160	0	0	0	0
Juvenile fish	0	0	20	0	0	0	0	0	0	0
Nassarius	0	0	20	0	0	0	0	0	0	0
Sipunculidae	0	20	0	0	0	0	50	30	0	20
Stomatopoda	0	0	0	0	0	20	0	0	0	0
Teritella	0	0	80	0	0	0	0	0	0	0

Table 11 Abundance of infaunal macrobenthos obtained before trawling during September 2002 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Amaena sp.	0	0	0	0	0	0	0	0	0	0
Ancistrosyllis sp.	0	0	0	0	0	0	90	0	0	0
Aricidea sp.	0	0	0	0	0	0	0	20	20	0
Cirratulus sp.	0	0	0	0	0	0	20	50	0	0
Cossura sp.	60	120	70	0	0	440	20	20	0	0
Diopatra sp.	0	0	0	0	0	0	20	0	0	0
Dorvillea sp.	0	0	0	0	0	0	20	0	0	0
Euclymene sp.	0	0	0	0	0	0	20	0	0	0
Lumbrineries sp.	340	140	230	20	40	210	40	0	0	0
Magelonidae sp.	0	0	0	0	0	40	940	140	0	0
Nereis sp.	0	0	0	0	0	0	150	20	0	0
Notomastus sp.	0	0	20	0	0	0	0	40	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	40
Phylocapensis sp.	0	0	0	0	0	0	20	0	0	0
Prionospio sp.	0	0	0	0	0	0	20	0	0	0
Scoloplos sp.	0	0	0	0	0	0	0	20	20	20
Sternaspis sp.	160	20	20	40	0	40	20	90	0	0
Syllis sp.	0	0	0	0	0	0	0	60	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	20	0	20	0
Anphioxus	0	0	0	0	0	0	20	30	0	0
Asteroidea	0	0	0	0	0	0	40	0	0	0
Bivalvia	0	0	0	20	0	0	0	0	0	0
Crab larvae	0	0	0	0	0	0	20	0	0	0
Gastropoda	80	590	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	20	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	20
Juvenile fish	0	20	0	0	0	20	20	0	0	0
Nassarius	0	0	260	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	20	0	0
Penaeidea	0	0	0	0	0	0	0	0	20	40
Sipuncula	0	0	20	0	0	0	20	0	0	20
Stomatopoda	0	0	880	0	0	100	0	0	0	0
Teritella	0	0	0	0	0	20	0	0	0	0

Table 12 .Abundance of infaunal macrobenthos obtained before trawling during November 2002 (no. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	20	20	0	60	80	0	200	270	200	540
Aricidea sp.	0	20	0	0	0	0	40	70	80	280
Cirratulus sp.	0	0	0	0	20	0	120	170	40	120
Cossura sp.	170	330	0	430	60	90	0	0	0	0
Disoma sp.	0	220	110	80	0	0	0	0	0	0
Euclymene sp.	0	0	0	0	0	0	0	20	0	0
Eunice sp.	0	0	0	0	0	0	0	0	0	20
Glycera sp.	0	0	0	0	0	0	20	20	20	80
Lumbrineries sp.	80	0	50	140	80	160	60	40	40	140
Magelonidae sp.	0	0	0	0	0	0	40	50	0	20
Nephtys sp.	0	0	0	0	20	30	20	0	20	20
Nereis sp.	0	0	0	0	0	0	0	20	0	20
Notomastus sp.	20	0	0	0	0	0	40	60	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0	0	80
Prionospio sp.	0	0	0	0	0	0	20	20	0	0
Sprophanes sp.	0	0	0	0	0	0	20	40	0	0
Spiophanes sp.	0	0	0	0	0	0	0	0	40	120
Sternaspi sp	100	60	20	40	160	350	0	0	0	0
Syllis sp.	0	0	0	0	0	0	0	0	0	80
Trypnosyllis sp.	0	0	0	0	0	0	0	0	80	20
Terebellidae stroemi	0	0	0	0	0	0	80	110	0	0
Other groups										
Isopoda	0	0	0	0	0	0	0	0	0	40
Amphipoda	0	0	20	0	0	0	0	0	40	140
Bivalvia	0	0	0	20	0	0	0	40	0	0
Gastropoda	0	0	80	0	0	980	0	0	0	0
Sipuncula	0	0	0	0	0	0	40	40	0	280
Asteroidea	0	0	0	0	0	0	20	20	0	0
Nassarius	0	0	100	0	0	1240	0	0	0	0
Oliva	0	0	20	0	0	0	0	0	0	0
Amphioxus	0	0	0	0	0	0	20	20	0	20

Table 13. Abundance of infaunal macrobenthos obtained after trawling during December 2000 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	60	0	40	60	0	20	20	20	40	40
Aricidea sp.	0	0	0	0	0	0	0	0	0	20
Cirratulus sp.	60	40	0	0	0	80	0	0	40	0
Cossura sp.	140	80	0	220	20	0	0	0	0	0
Disoma sp.	60	40	40	40	0	0	0	0	0	20
Dorvillea sp.	40	60	0	0	0	0	0	0	0	20
Euclymene sp.	0	0	0	0	40	0	0	0	0	0
Eunice sp.	0	0	0	0	0	0	20	20	20	20
Glycera sp.	60	40	0	0	20	0	20	20	0	0
Goniada sp.	40	60	0	0	0	0	0	0	20	0
Liomia sp.	0	0	0	0	0	0	0	0	40	0
Lumbrineries sp.	3000	1200	60	220	250	60	0	0	60	0
Magelonidae spp	3600	4100	29670	0	0	0	5790	5400	1770	11543
Megalomma sp.	0	0	20	0	0	0	0	0	0	0
Nephtys sp.	60	60	20	20	20	20	20	20	60	0
Nereis sp.	20	20	20	0	20	0	40	40	40	0
Opisthosyllis sp.	20	20	0	0	0	0	0	0	0	0
Paralacydonia sp.	0	0	20	0	0	0	20	0	20	0
Pectinaria sp.	0	0	0	0	0	0	20	20	0	0
Pelagobia sp.	0	0	0	0	0	0	0	0	0	40
Phyllodoce sp.	0	0	0	0	0	20	0	0	0	0
Prionospio sp.	0	0	0	20	190	120	760	740	230	300
Sternaspis sp.	40	60	20	20	20	40	0	0	0	20
Syllis sp.	0	0	0	40	0	0	0	0	0	0
Other groups										
Amphipoda	20	20	0	20	0	0	40	20	0	0
Bivalvia	20	0	20	0	0	0	60	60	20	0
Brachyura	0	0	0	0	0	0	0	0	40	0
Echiurida	0	0	60	0	0	0	0	0	0	0
Euphuasid	0	0	0	0	0	0	0	0	0	20
Isopoda	0	0	0	0	0	0	20	20	20	40
juvenile fish	0	0	0	0	20	0	0	0	0	0
Nematoda	0	0	20	0	0	0	0	0	0	0
Palinuridae	20	20	20	20	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	20	0	20	0
Sipunculidae	60	40	0	0	0	20	0	0	60	0

Table 14. Abundance of infaunal macrobenthos obtained after trawling during February 2001 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	20	40	20	0	20	60	40	0	20	20
Cirratulus sp.	0	0	0	0	0	40	0	0	0	0
Cossura sp.	70	0	60	0	320	150	100	100	0	0
Disoma sp.	0	0	140	20	0	0	0	0	0	0
Euclymene sp.	0	0	50	0	20	0	0	0	0	0
Glycera sp.	0	0	100	0	0	0	0	0	0	0
Goniada sp.	0	0	0	0	0	0	0	0	40	40
Lumbrineries sp.	590	300	50	70	150	160	120	100	40	40
Magelonidae sp	400	4060	0	0	0	0	0	70	8570	8200
Nephtys sp.	80	20	20	20	40	40	0	0	0	0
Phalacrophorus sp.	20	0	0	0	0	0	0	0	0	0
Prionospio sp.	0	0	140	30	20	0	0	20	0	0
Sternaspis sp.	20	120	20	100	40	0	0	0	0	0
Other groups										
Amphipoda	0	0	0	20	0	0	0	0	60	60
Bivalvia	0	20	0	60	0	0	0	0	20	20
Euphuasid	0	0	0	20	0	0	0	0	20	20
Gastropoda	0	0	0	0	60	0	60	60	0	0
Nematoda	0	0	0	0	0	160	0	0	0	0
Penaeidea	0	0	0	20	0	0	0	0	20	20
Sipuncula	0	20	0	0	0	0	0	0	0	0

Table 16. Abundance of infaunal macrobenthos obtained after trawling during April 2001 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	20	0	20	20	140	0	20	240	0	0
Cirratulus sp.	20	40	20	20	0	0	20	0	0	0
Cossura sp.	320	80	220	200	70	170	20	60	0	20
Diopatra sp.	0	0	0	0	0	0	0	20	0	0
Euclymene sp.	70	30	0	0	0	0	20	20	0	0
Glycera sp.	20	0	0	0	0	0	40	0	0	0
Haploscoloplos sp.	0	0	0	0	0	20	0	0	0	0
Liomia sp.	0	0	20	20	0	0	20	0	0	0
Lumbrineries sp.	110	480	160	140	180	110	20	60	0	20
Magelonidae sp.	40	0	20	20	0	700	190	20	40	1010
Nephtys sp.	40	50	20	20	0	60	30	0	0	0
Nereis sp.	0	0	0	0	0	20	0	0	0	0
Pectinaria sp.	0	0	0	0	0	0	0	0	0	20
Polydora sp.	0	0	0	0	0	0	20	0	0	0
Prionospio sp.	40	0	0	0	0	0	0	600	0	0
Pulliella sp.	0	20	0	0	0	0	0	0	0	0
Siphanophanes sp.	0	0	0	0	0	0	20	0	0	0
Sternaspis sp.	40	50	80	80	0	60	0	20	0	20
Other groups										
Amphipoda	30	0	0	0	0	0	0	0	50	240
Bivalvia	0	0	0	0	0	0	0	0	40	30
Brachyura	0	0	20	20	0	0	0	20	0	20
Gastropoda	20	0	20	20	0	60	20	0	20	40
Juvenile fish	0	0	20	20	0	0	0	20	0	0
Nematoda	0	300	0	0	0	0	20	0	0	340
Ophiuroidea	20	0	0	0	0	0	20	0	0	0
Palinuridae	20	0	0	0	0	0	20	0	0	0
Penaeidea	0	0	20	20	0	0	20	0	20	20
Sipunculidae	0	0	0	0	0	0	0	0	120	20
Stomatopoda	0	0	0	0	0	0	0	0	90	20

Table 16. Abundance of infaunal macrobenthos obtained after trawling during July 2001 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis	0	0	0	0	0	0	0	0	30	20
Cirratulus	0	0	0	0	0	0	30	20	0	0
Cossura	580	500	160	230	180	0	280	90	0	0
Diopatra	0	0	0	0	0	0	0	0	20	20
Dorvillea	0	0	0	0	0	0	0	0	20	0
Euclymene	0	0	20	20	20	0	0	0	20	20
Glycera	0	0	0	0	0	0	0	0	20	20
Harmothoe	0	0	0	0	0	0	0	0	20	0
Liomia	0	0	0	0	0	0	0	0	20	0
Lumbrineries	540	480	70	250	220	70	90	140	60	80
Mageionidae spp	80	60	20	20	20	0	0	0	0	0
Nephtys	0	0	0	0	0	0	0	20	20	20
Nereis	0	0	0	0	0	0	0	0	40	40
Onuphis	0	0	0	0	0	0	0	0	20	20
Prionospio	0	0	60	80	60	0	230	270	3230	2800
Sternapsis	120	100	110	150	160	20	80	40	100	120
Streblosoma	0	0	0	0	0	0	0	0	40	40
Other groups										
Penaeidea	0	0	0	0	0	0	0	0	20	0
Palinuridae	0	0	0	0	0	0	0	20	0	0
Sipunculidae	0	0	0	0	0	0	0	0	20	0
Holothuroidea	0	0	0	0	0	0	20	0	0	0

Table 17. Abundance of infaunal macrobenthos obtained after trawling during September 2001 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0	20	40	240	0	20	20	0	240	220
Cirratulus sp.	0	20	0	0	20	0	0	20	20	20
Cossura sp.	80	190	60	110	300	0	0	0	0	0
Diopatra sp.	0	0	0	0	0	0	0	60	20	20
Euclymene sp.	0	0	0	0	20	0	0	0	0	0
Harmothoe sp.	0	0	0	0	0	0	0	0	20	20
Liomia sp.	0	0	0	0	0	0	0	0	40	0
Lumbrineries sp.	260	570	30	130	240	220	200	60	50	40
Magelonidae sp.	0	0	60	60	40	120	100	0	190	140
Megalomma sp.	0	30	0	0	0	0	0	0	0	0
Nephtys sp.	0	0	0	0	0	0	0	0	50	60
Nereis sp.	0	0	0	0	0	0	0	0	100	100
Pectinaria capensis	0	0	0	0	0	0	0	0	20	20
Phyllodoce sp.	0	0	0	0	0	0	0	300	0	0
Potamilla sp.	0	0	0	0	0	0	0	0	20	20
Prionospio sp.	20	60	60	0	0	50	40	180	120	110
Sternaspis sp.	0	220	0	50	0	100	80	0	0	0
Syllis sp.	0	0	0	0	0	0	0	0	20	
Other groups										
Amphipoda	0	0	0	0	0	0	0	20	20	0
Asteroidea	0	0	0	0	0	0	0	0	40	40
Bivalvia	0	0	0	0	0	20	0	0	0	0
Cephalopoda	0	0	0	0	0	0	0	20	0	0
Cumacea	0	0	0	0	0	0	0	20	0	0
Euphuasid	0	0	0	20	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	60	40
Juvenile fish	40	20	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	20	0
Penaeidea	0	0	0	0	0	0	0	0	20	20
Sea Anemone	0	0	0	0	0	20	0	0	0	0
Sipuncula	0	0	0	0	0	0	0	80	30	60
Stomatopoda	0	0	0	0	0	0	0	20	0	0

Table18. Abundance of infaunal macrobenthos obtained after trawling during November 2001 (no.m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Amphicteis sp.	0	0	0	0	0	0	0	0	20	0
Ancistrosyllis sp.	20	0	0	0	30	60	230	150	580	400
Cirratulus sp.	20	0	0	0	0	0	0	20	50	60
Cossura sp.	260	280	130	100	0	800	150	30	20	20
Diopatra sp.	0	0	0	0	0	0	0	0	20	0
Dorvillea sp.	0	0	0	0	0	0	0	0	40	40
Euclymene sp.	0	0	0	0	0	0	30	20	20	0
Eunice sp.	0	0	0	0	0	0	0	0	50	60
Glycera sp.	20	20	0	0	0	0	0	400	20	0
Goniada sp.	0	0	0	0	0	0	220	160	0	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	20	20
Isolda sp.	0	0	0	0	0	0	0	20	0	0
Liomia sp.	0	0	0	0	0	0	0	0	0	20
Lumbrineries sp.	210	100	0	60	470	200	80	60	60	40
Magelonidae sp.	0	0	0	0	0	0	160	200	2200	2000
Nephtys sp.	0	20	0	40	20	20	0	0	0	20
Nereis sp.	0	0	0	0	0	0	0	20	0	0
Notomastus sp.	0	0	0	40	0	0	20	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	40	20
Pectinaria sp.	0	0	0	0	0	0	0	20	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0	80	20
Potamilla sp.	0	0	0	0	0	0	20	0	0	
Prionospio sp.	20	20	0	20	20	40	40	40	240	600
Pulliella sp.	0	0	0	0	0	0	0	0	20	20
Sabellaria sp.	0	0	0	0	0	0	0	0	20	0
Sternaspis sp.	70	70	0	40	70	150	70	40	0	0
Streblosoma sp.	0	0	0	0	0	0	0	0	20	0
Other groups										
Amphipoda	0	20	0	0	0	0	0	20	20	80
Asteroidea	0	0	0	0	0	0	0	20	0	0
Bivalvia	30	20	0	0	0	0	20	20	0	0
Brachyura	0	0	0	0	0	0	0	0	20	0
Bryozoa	0	0	0	0	0	0	0	20	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	20
Juvenile fish	0	0	0	0	0	0	0	0	0	20
Nematoda	0	0	0	0	0	20	40	20	60	30
Palinuridae	0	0	0	0	0	0	0	0	0	
Penaeidea	0	0	0	0	0	0	0	20	20	50
Sea Anemone	0	0	0	0	20	0	0	0	0	0
Sipuncula	0	20	0	0	0	20	20	0	0	20
Stomatopoda	0	0	0	0	0	0	0	0	0	100

Table 19. Abundance of infaunal macrobenthos obtained after trawling during January 2002 ($no.m^{-2}$)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ammotrypan sp.	0	0	0	0	0	0	0	0	40	0
Ampharete sp.	0	0	0	0	0	0	0	0	20	0
Ancistrosyllis sp.	110	40	40	40	0	40	20	20	20	110
Aricidea sp.	0	0	0	0	0	0	0	0	0	20
Cirratulus sp.	20	0	20	0	20	0	20	30	40	80
Cossura sp.	640	810	70	80	0	90	20	540	0	30
Diopatra sp.	0	0	0	0	0	0	0	20	0	0
Euclymene sp.	0	20	20	20	0	0	40	50	0	20
Eunice sp.	0	0	0	0	0	0	20	0	40	20
Glycera sp.	30	60	0	0	40	0	120	20	40	0
Haploscoloplos sp.	0	0	0	0	20	0	0	0	0	0
Isolda sp.	0	0	0	0	0	0	0	40	0	0
Johnstonia sp.	0	0	0	0	0	0	0	20	0	0
Liomia sp.	0	0	0	0	0	0	0		0	0
Lumbrineries sp.	570	1810	440	320	170	340	110	220	0	70
Magelonidae sp.	0	40	0	0	0	0	0	0	20	1790
Malacoceros sp.	0	0		0	0	0	0	0	0	0
Maldanella sp.	0	0	20	0	0	0	0	20	0	0
Nephtys sp.	20	20	30	40	40	50	0	20	0	20
Nereis sp.	0	0	0	0	20	0	20	20	0	20
Nicolea sp.	0	0	0	0	0	0	0	0	0	20
Notomastus sp.	40	60	0	0	0	0	0	20	0	0
Onuphis sp.	0	0	0	0	20	0	0	0	0	0
Paralecydonia sp.	0	0	0	0	0	0	0	80	20	20
Pectinaria sp.	0	0	0	0	0	0	20	0	0	0
Phyllocornus sp.	0	0	0	0	0	0	20	0	0	0
phyllodoce sp.	0	0	0	0	0	0	40	20	0	0
Prionospio sp.	0	40	0	20	40	30	20	20	20	90
Rhynchospio sp.	0	0	0	0	0	0	0	20	0	0
Sternaspis sp.	150	70	90	110	190	100	0	40	0	0
Syllis sp.	0	0	0	0	0	0	20	20	0	20
Terebellidae stroemi	0	0	0	0	0	0	20	0	0	0
Trichobranchus sp.	0	0	0	0	0	0	0	20	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0	70
Brachyura	0	20	0	0	0	0	0	0	0	20
Holothuroidea	0	0	0	0	20	0	0	0	0	0
Juvenile fish	0	0	0	0	20	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	50
Penaeidea	0	0	0	0	0	0	20	0	0	0
Sipunculidae	0	0	0	0	40	40	40	60	20	40
Sponges	0	0	0	0	0	0	0	20	0	0
Stomatopoda	0	0	0	0	0	0	0	0	0	20

Table 20. Abundance of infaunal macrobenthos obtained after trawling during March 2002 (no. m-^{2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ampharete sp.	0	0	0	0	0	0	0	0	20	0
Ammotrypan sp.	0	0	0	0	0	0	0	0	40	0
Ancistrosyllis sp.	60	40	40	40	0	40	20	20	20	110
Aricidea sp.	0	0	0	0	0	0	0	0	0	20
Cirratulus sp.	20	0	20	0	20	0	20	30	40	80
Cossura sp.	440	600	40	60	0	60	20	90	0	30
Diopatra sp.	0	0	0	0	0	0	20	20	0	0
Euclymene sp.	20	20	20	20	0	0	40	50	0	20
Eunice sp.	0	0	0	0	0	0	20		40	20
Glycera sp.	30	60	0	0	40	40	120	20	40	0
Haploscoloplos sp.	0	0	0	0	20	0	0	0	0	0
Isolda sp.	0	0	0	0	0	0	0	40	0	0
Johnstonia sp.	0	0	0	0	0	0	0	20	0	0
Lumbrineries sp.	570	1200	200	300	170	200	90	90	0	70
Magelonidae sp.	0	40	0	0	0	0	0	0	800	900
Maldanella sp.	0	0	20	20	0	0	0	20	0	0
Nephtys sp.	20	20	30	40	40	40	0	20	0	20
Nereis sp.	0	0	0	0	20	0	20	20	0	20
Nicolea sp.	0	0	0	0	0	0	0	0	0	20
Notomastus sp.	40	60	0	0	0	0	0	20	0	0
Onuphis sp.	0	0	0	0	20	20	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	80	20	20
Pectinaria sp.	0	0	0	0	0	0	20	0	0	0
Phyllocomus sp.	0	0	0	0	0	0	20	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	40	20	0	0
Prionospio sp.	0	40	0	20	40	30	20	20	20	90
Rhynchospio sp.	0	0	0	0	0	0	0	20	0	0
Sternaspis sp.	150	70	90	110	120	190	0	40	0	0
Syllis sp.	0	0	0	0	0	0	20	20	0	20
Terebellidae stroemi	0	0	0	0	0	0	20	0	0	0
Trichobranchus sp.	0	0	0	0	0	0	0	20	0	0
Other groups										
Brachyura	0	20	0	0	0	0	0	0	0	20
Penaeidea	0	0	0	0	0	0	20	0	0	0
Sponges	0	0	0	0	0	0	0	20	0	0
Stomatopoda	0	0	0	0	0	0	0	0	0	20
Amphipoda	0	0	0	0	0	0	0	0	0	70
Juvenile fish	0	0	0	0	20	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	50
Sipunculidae	0	0	0	0	40	40	40	60	20	40
Holothuroidea	0	0	0	0	20	0	0	0	0	0

Table 21. Abundances of infaunal macrobenthos obtained after trawling during May 2002 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis	30	40	0	20	0	0	60	40	130	20
Aricidea	0	0	0	0	0	0	0	20	80	0
Cirratulus	0	0	20	0	0	0	200	20	20	20
Cossura	1310	490	810	240	60	140	0	40	410	100
Diopatra	0	20	0	0	0	0	0	0	0	0
Dorvillea	20	0	0	0	0	0	0	0	0	40
Euclymene	0	40	0	0	0	0	0	20	0	0
Eunice	0	0	0	0	0	0	0	0	0	20
Glycera	20	40	0	0	0	20	260	60	20	0
Goniada	20	0	0	0	0	0	0	0	0	0
Heteromastus	0	0	0	0	0	0	0	40	0	0
Isolda	0	0	0	0	0	0	20	0	0	0
Lumbrineries	520	410	320	340	70	20	20	90	520	660
Magelonidae spp	0	30	0	0	0	0	0	0	19220	1500
Maldanella	0	0	0	0	0	0	0	20	0	0
Nephtys	0	40	0	60	0	0	0	40	20	
Nereis	0	0	0	0	0	0	80	120	20	20
Notomastus	50	0	0	60	20	20	20	0	0	40
Paralacydonia	0	0	0	0	20	0	100	0	20	40
phyllodoce	0	0	0	0	0	0	0	0	0	20
Phylocapensis	0	0	0	0	0	0	0	0	30	
Pilargia	0	0	0	0	0	0	0	0	20	20
Potamilla	0	0	0	0	0	0	0	0		0
Prionospio	0	160	0	20	20	0	0	70	60	140
Scoloplos	0	0	0	0	0	0	20	0	20	0
Sternaspis	0	260	80	360	370	60	0	30	120	0
Streblosoma	0	0	0	0	0	20	0	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	500	0
Bivalvia	0	0	0	0	0	0	0	20	0	30
Brachyura	0	0	0	0	0	0	0	0	20	20
Gastropoda	0	20	620	0	160	190	0	410	0	0
Juvenile fish	0	0	0	0	20	0	0	0	0	0
Nematoda	0	20	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	0	0	20	0
Sipuncula	50	20	20	0	0	0	220	60	250	0
Stomatopoda	0	0	0	0	0	0	20	0	0	80
										0

Table 22. Abundance of infaunal macrobenthos obtained after trawling during July 2002 (no.m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ampharete sp.	0	0	0	0	0	0	0	0	0	80
Ancistrosyllis sp.	20	0	0	0	0	20	60	140	50	100
Aricidea sp.	0	0	0	0	0	20	120	80	100	210
Bhawania sp.	0	0	0	0	0	0	0	0	20	0
Cirratulus sp.	0	0	0	0	0	0	100	60	20	40
Cossura sp.	1020	70	520	270	400	410	0	0	0	30
Dorvillea sp.	0	0	0	0	0	0	0	0	0	20
Euclymene sp.	60	50	0	0	20	20	70	20	0	0
Glycera sp.	0	0	0	0	0	0	0	0	0	20
Heteromastus sp.	0	0	0	0	0	0	0	0	60	0
Lepidonotus sp.	0	0	0	0	0	0	0	0	20	0
Lumbrineries sp.	1700	120	390	760	60	60	20	20	20	70
Magelonidae sp.	0	0	0	0	0	0	40	0	2340	160
Melinna sp.	0	0	0	0	0	0	0	0	100	0
Nephtys sp.	0	0	0	0	0	20	0	0	0	0
Nereis sp.	0	20	0	0	0	0	100	70	140	60
Notomastus sp.	20	0	0	0	0	40	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	20	20	0
Pectinaria sp.	0	0	0	0	0	0	0	0	0	20
Polycirrus sp.	0	0	0	0	0	0	0	0	60	0
Prionospio sp.	140	20	20	0	20	0	160	140	120	180
Sternaspis sp.	500	0	70	170	0	20	0	0	20	20
Syllis sp.	0	0	0	0	0	0	20	20	40	20
Terebellidae stroemi	0	0	0	0	0	0	0	0	30	0
Other groups										
Stomatopoda	0	0	0	0	0	0	20	80	0	0
Amphipoda	0	0	0	0	0	0	20	0	0	100
Gastropoda	80	120	1400	1640	280	140	0	0	0	0
Sipunculidae	0	0	0	0	0	0	120	80	190	20
Asteroidea	80	120	0	0	0	0	0	0	0	0
Teritella	0	20	0	60	0	0	0	0	0	0

Table 23 Abundance of infaunal macrobenthos obtained after trawling during Septermber 2002 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0	0	0	0	20	0	0	0	0	40
Aricidea sp.	0	0	0	0	0	0	40	80	0	0
Cirratulus sp.	20	0	0	0	0	0	0	40	0	110
Cossura sp.	540	160	60	60	20	560	20	0	0	0
Diopatra sp.	0	0	0	0	0	0	0	20	0	0
Euclymene sp.	0	0	20	0	0	0	0	30	0	0
Loandalia sp.	0	0	0	0	0	0	20	0	0	0
Lumbrineries sp.	660	220	60	70	0	290	0	0	0	20
Magelonidae sp.	0	0	0	0	20	20	0	5040	0	10173
Nereis sp.	0	0	0	0	0	0	0	90	80	80
Notomastus sp.	20	0	20	0	0	40	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	20	0	0
Prionospio sp.	0	0	0	0	0	20	0	100	0	0
Scoloplos sp.	0	0	0	0	0	0	0	20	0	0
Sternaspis sp.	90	0	0	60	20	20	0	30	0	0
Other groups										
Amphioxus	0	0	0	0	0	0	0	20	0	0
Amphipoda	0	0	0	0	0	0	0	0	120	100
Bivalvia	0	0	0	0	0	0	0	0	0	20
Gastropoda	0	3600	600	560	0	1200	0	0	0	0
Isopoda	0	0	0	0	20	0	0	0	0	20
Juvenile fish	0	0	0	0	0	0	0	0	0	20
Nassarius	0	280	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	0	0	0	50
Prawn larvae	0	0	0	0	0	0	0	0	20	0
Sipuncula	0	0	40	20	20	0	40	0	0	0

Table 24. Abundance of infaunal macrobenthos obtained after trawling during November 2002 (no. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	60	160	0	20	20	40	160	30	70	480
Aricidea sp.	0	20	0	0	20	20	80	0	20	60
Bhawania sp.	0	0	0	0	0	0	0	0	0	40
Cirratulus sp.	0	0	0		20	20	260	120	80	60
Cossura sp.	150	310	180	340	50	120	20	0	0	20
Disoma sp.	80	1670	0	0	0	0	0	80	0	0
Euclymene sp.	0	0	0	20	20	0	50	20	0	0
Glycera sp.	0	0	0	0	20	20	50	100	120	120
Goniada sp.	0	0	0	0	0	0	0	0	0	40
Isolda sp.	0	0	0	0	0	0	20	0	0	0
Lumbrineries sp.	160	220	40	100	40	120	40	40	40	120
Magelonidae sp.	0	0	0	0	20	20	650	0	390	420
Nephtys sp.	0	0	0	0	20	20	0	0	0	0
Nereis sp.	0	20	0	0	0	0	40	0	0	20
Notomastus sp.	0	0	0	0	0	20	30	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	20	40
Phyllodoce sp.	0	0	0	0	0	0	20	80	20	0
Prionospio sp.	0	0	0	0	0	20	30	90	0	0
Sternaspi sp	40	20	0	40	510	490	50	20	0	0
Syllis sp.	0	0	0	0	0	0	20	20	0	0
Terebellidae stroemi	0	0	0	0	0	0	20	0	20	20
Other groups										
Brachyura	0	0	0	0	0	0	0	0	20	0
Penaeidea	0	0	0	0	0	0	0	0	20	0
Stomatopoda	0	0	0	0	0	0	0	0	20	0
Isopoda	0	0	0	0	0	0	0	0	0	20
Amphipoda	0	0	0	0	0	0	0	20	140	100
Juvenile fish	0	0	0	0	20	0	0	0	0	0
Gastropoda	0	0	60	0	1540	5560	0	0	0	0
Sipuncula	0	0	0	0	20	100	20	0	140	50
Asteroidea	0	0	0	0	0	0	0	0	0	20
Teritella	0	0	20	0	0	20	0	0	0	0
Nassarius	0	0	60	0	640	3220	0	0	0	0
Amphioxus	0	0	0	0	0	0	20	20	0	20

Table 25. Biomass of infaunal macrobenthos obtained before trawling during December 2000 (g. m^{-2})

Polychaetes

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
Ancistrosyllis sp.	0.067	0.08	0.1	0.1	0.328	0.29	0.012	0.015	0	0
Aricidea sp.	0	0	0	0	0	0	0	0	0.018	0.016
Cirratulus sp.	0.041	0.044	0.042	0.05	0	0	0	0	0.006	0.004
Cossura sp.	0.05	0.038	0.034	0.035	0.058	0.055	0	0	0	0
Disoma sp.	0.25	0.02	0.36	0.35	0	0	0	0	0	0
Dorvillea sp.	0.002	0.002	0.002	0.003	0.03	0.03	0	0	0	0
Euclymene sp.	0	0	0	0	0.104	0.11	0	0	0	0
Eunice sp.	0	0	0	0	1.762	1.8	0	0	0	0
Glycera sp.	0.011	0.011	0.024	0.025	0.122	0	0	0	0	0
Goniada sp.	0.006	0.006	0.002	0.002	0	0	0	0	0	0
Isolda sp.	0	0	0	0	0	0	0.05	0	0	0
Lumbrineries sp.	0.23	0.13	0.289	0.266	0.354	0.42	0	0	0	0.862
Magelonidae sp.	2.49	3.2	5.837	5.44	4.972	4.55	0.124	0.13	0.283	3.528
Nephtys sp.	0.07	0.13	0.118	0.112	0.072	0.04	0	0	0	0
Nereis sp.	0.12	0.2	0.254	0.244	0.101	0.86	0	0	0	0.914
Opisthosyllis sp.	0.01	0.015	0.072	0.08	0.034	0.02	0	0	0	0
Paralacydonia sp.	0	0	0	0	0.076	0	0	0	0	0
Prionospio sp.	0	0	0	0	0.147	0.11	0	0	0.077	0
Sternaspis sp.	0.02	0.03	0.029	0.03	0.057	0.041	0	0	0	0

Other groups

	S1	S2	S3	S4	S5	S6	S7	S8	S9	
Amphipoda	0.05	0.08	0	0	0.094	0.082	0	0	0	0
Bivalvia	0	0	0	0	0.0021	0	0	0	0	0
Brachuyra	0	0	0	0	30.738	0	0	0	0	0
Euphuasid	0	0	0	0	0.002	0	0.012	0	0	
Gastropoda	0.08	0.08	0	0	0.094	0	0	0	0	0
Isopoda	0	0	0	0	0.01	0	0.02	0.02	0	0
Palinuridae	0	0	0	0	0.046	0	0	0	0	0
Penaeidea	0.05	0	0	0	0	0	0	0	0	0
Sipuncula	0.17	0.14	0	0	0.162	0.15	0	0	0	0

Table 26. Biomass of infaunal macrobenthos obtained before trawling during February 2001 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0	0	0.088	0	0.014	0.009	0.249	0.235
Cirratulus sp.	0	0	0	0	0	0	0	0	0.102	0.102
Cossura sp.	0.002	0.013	0.022	0.015	0.085	0.006	0.03	0.028	0.034	0.016
Disoma sp.	0	0.016	0.2	0.18	0	0	0	0.024	0.248	0.228
Dorvillea sp.	0	0.074	0	0	0	0	0	0.176	0.189	0.18
Euclymene sp.	0	0.04	0.778	0.74	0	0	0.002	0	0	0
Glycera sp.	0	0.07	0	0	0	0	0	0	0	0
Lumbrineries sp.	0.07	0.738	0.145	0.135	0.687	0	0	0	3.948	3.428
Magelonidae sp	0	0.006	0	0	0	0	0.034	0.035	16.995	12.4
Nephtys sp.	0	0	0.142	0.435	0.644	0	0	0	0.42	0.35
Onuphis sp.	0	0.044	0	0.045		0	0	0	0	0
Paralacydonia sp.	0	0.06	0	0	0	0	0	0	0.028	0.025
Prionospio sp.	0.004	0	0	0.005	0.005	0	0	0	0.254	0.244
Rhynchospio sp.	0	0	0	0.16	0.18	0	0	0	0	0
Siphanophanes sp.	0	0.01	0	0	0	0	0	0	0	0
Sternaspis sp.	0.012	0.205	0.002	0.002	0.002	0	0	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0.079	0.066
Bivalvia	0	0	0	0	0.024	0	0	0	0.024	0.024
Gastropoda	0	0	0.23	0	0.002	0	1.344	0.135	0.052	0.052
Nematoda	0	0	0	0.022	0.022	0	0	0	0	0
Sipuncula	0	0.108	0	0.045	0.042	0	0	0.182	0.192	0.199
Stomatopoda	0	0	0	0	0	0	0	0	0.09	0.08

Table 27. Biomass of infaunal macrobenthos obtained before trawling during April 2001 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0.018	0.018	0.01	0	0.011	0	0	0	0	0
Cirratulus sp.	0	0	0	0.008	0	0	0	0	0	0
Cossura sp.	0.078	0.004	0.022	0.012	0.09	0.02	0.012	0.012	0	0.002
Euclymene sp.	0.095	0	0	0	0.018	0	0	0	0	0
Glycera sp.	7.956	0	0	0	0	0	1.082	0.104	2.128	0.565
Lumbrineries sp.	0.273	0.135	0.108	0.137	0.261	0.022	0.064	0.066	0.007	0.016
Magelonidae sp	0.116	0	0	0.046	0.11	0.068	0.36	0.056	0.256	0.149
Nephtys sp.	2.428	0.002	0.396	0.04	0.288	0.07	0.22	0.22	0	0
Nereis sp.	0	0	0	0	0.024	0	0	0	0	0
Paralacydonia sp.	0.172	0	0	0	0	0	0	0	0	0
Pectinaria sp.	0	0	0	0	0	0	0	0	0	0.018
Prionospio sp.	0.086	0	0	0	0	0	0	0	0	0
Sternaspis sp.	0.014	0.032	0.03	0	0.004	0.004	0	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0.002	0.002
Bivalvia	0	0	0	0.02	0	0	0	0	0.917	3.064
Gastropoda	0	0.088	5.941	0	0.544	0	0	0	0.226	7.93
Holothuroidea	0	0	0	0	0	1.464	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0.006
Nematoda	0	0	0	0	0	0	0	0	0.008	0
Ophiuroidea	0.06	0	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	0.014	0	0	0	0.012	0.392
Sipunculidae	0.022	0	0	0	0	0	0	0	0.047	0.038
Stomatopoda	0	0	0	0	0	0	0	0	0.948	0

Table 28 Biomass of infaunal macrobenthos obtained before trawling during July 2001 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Cirratulus sp.	0	0	0.532	0.002	0.31	0.3	0	0	0	0
Cossura sp.	0.054	0.053	0.015	0.009	0.02	0.028	0.024	0.038	0.004	0.005
Euclymene sp.	3.11	3.08	0.355	0.376	0.31	0.312	1.086	0	0	0
Lumbrineries sp.	0.55	0.048	0.022	0.21	0.22	0.312	1.149	0.048	0.002	0.002
Magelonidae sp.	0	0	0	0	0	0	0.072	0	0.202	0.2
Nephtys sp.	0	0	0	0	0	0.184	0	0	0	0
Prionospio sp.	0.025	0.024	0.16	0	0	0.064	0.102	0.056	0	0
Siphanophanes sp.	0.06	0.06	0	0	0	0	0	0	0	0
Sternaspis	0.219	0.217	0.08	0.012	0.01	0.104	0.048	0.004	0.092	0.082
Other groups										
Palinuridae	0	0	0	0	0	0	0.11	0.088	0	0
Sipunculidae	0	0	0	0	0	0	0.022	0	0	0

Table 29. Biomass of infaunal macrobenthos obtained before trawling during September 2001 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Amphitrite sp.	0	0	0	0.022	0	0	0	0	0	0
Ancistrosyllis sp.	0	0	0	0.002	0.008	0.002	0.002	0.002	0.092	0.085
Cirratulus sp.	0	0	0.022		0	0	0	0.032		0.022
Cossura sp.	0	0.04	0.003	0.014	0.04	0.006	0	0	0.004	0.004
Diopatra sp.	0.742	0	0	0	0	0	0	0	14.318	13.21
Euclymene sp.	0	0	0	0	0	0.428	0	0	0	0
Lumbrineries sp.	0.032	0.347	0.093	0.135	0.09	0.193	0.029	0.028	4.5	0.402
Magelonidae sp.	0.004	0	0.006	0	0.01	0.012	0.04	0.06	0	0
Nephtys sp.	0	0	0	0	0	0	0	0	0.558	0.56
Nereis sp.	0	0	0	0	0	0.028	0.05	0.044	0.01	
Paralacydonia sp.	0	0	0	0	0	0	0	0	0.03	0.05
Phyllodoce sp.	0	0	0	0	0	0	0	0.42	0.42	0.032
Potamilla sp.	0	0	0	0	0	0	0	0	1.994	1.56
Prionospio sp.	0.018	0.023	0.099	0.229	0.023	0.125	1.56	1.992	0.298	0.03
Sternaspis sp.	0.083	0.18	0.03	0.168	0.022	0.096	0	0	0	0
Syllis sp.	0	0	0	0	0	0	0.002	0.002	0.138	0.14
Other groups										
Brachyura	0	0	0	0	0	0	0	0	3.352	5.2
Amphipoda	0	0	0	0	0	0	0.022	0.022	0.02	0
Juvenile fish	0	0	0	0	0	0	0	0	0.124	0.13
Bivalvia	0	0	0	0	0	0.012	1.4	1.788	0	0
Gastropoda	0	0	0	0.408	3.86	0	0	0	0	0
Sipunculidae	0	0	0	0	0	0	0.03	0.04	0	0
Sea Anemone	0	0	0	0.262	0.338	5.419	0	0	0	0
Asteroidea	0	0	0	0	0	0	0	0	0.3813	0.34

Table 30. Biomass of infaunal macrobenthos obtained before trawling during November 2001 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0.002	0.002	0	0	0.004	0.005	0.019	0.022	0.313	0.299
Cirratulus sp.	0	0	0	0	0	0	0.134	0.122	0	0
Cossura sp.	0.198	0.0186	0.018	0.012	0.131	0.121	0	0	0.002	0.004
Diopatra sp.	0	0	0.02	0	0	0	0	0	0	0
Eunice sp.	0	0	0	0	0	0	0.44	0.44	0	0
Glycera sp.	0	0	0	0	0	0	0.43	0	0.152	0.148
Lumbrineries sp.	0.053	0.043	0.011	0.011	0.033	0.023	1.38	1.22	0.676	0.555
Magelonidae sp.	0	0	0	0	0	0	0	0	1.547	0
Nephtys sp.	0.242	0.221	0	0	0	0	0	0	0	0
Nereis sp.	0	0	0	0	0.005	0.004	0.036	0.026	0	0
Notomastus sp.	0	0	0.004	0.004	.0.016	0.014	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0.172	0.166	0	0
Phyllodoce sp.	0	0	0	0	0	0	0.09	0.08	0.229	0
Prionospio sp.	0	0	0	0	0	0	0.002	0.002	2.392	0
Sternaspis sp.	0	0	0.068	0.058	0.245	0.235	0	0	0.002	0
Trypanosyllis sp.	0	0	0	0	0	0	0.062	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0.013	0
Bivalvia	0	0	0	0	0	0	0.098	0.078	0	0
Brachyura	0	0	0	0	0	0	0	0	0.022	0
Holothuroidea	0	0	0	0	7 15	6.55	0	0	0	0
Nematoda	0	0	0	0	0	0	0.001	0	0.001	0
Penaeidea	0	0	0	0	0	0	0	0	0.028	0
Sipunculidae	0	0	0	0	0	0	0.16	0.18	0.018	0
Stomatopoda	0	0	0	0	0	0	0	0	0.0528	0

Table 31. Biomass of infaunal macrobenthos obtained before trawling during January 2002 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0	0.002	0.008	0.048	0	0.002	0.208	0.05
Aricidea sp.	0	0	0	0	0	0	0	0.004	0	0
Cirratulus sp.	0	0	0.44	0.002	0	0	0.012	0.046	0	0.002
Cossura sp.	0.032	0.062	0.008	0.012	0.064	0.017	0.002	0.002	0	0
Diopatra sp.	0	0	0	0	0	0	0	0.08	0	0
Dorvillea sp.	0	0	0	0		0	0.002	0	0	0
Euclymene sp.	0	0	0.088	0	0.11	0	0.142	0	0.054	0
Glycera sp.	0	0	0	0	0	0	0.004	0	0.112	0.112
Goniada sp.	0	0	0	0	0	0	0	0.011	0	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	0.508	0
Lumbrinerles sp.	0.1	0.285	0.348	0.135	0.04	0.55	0.056	0.044	3.06	0.675
Magelonidae sp.	0	0	0.018	0	0	0	0	0	0	1.836
Maldanella sp.	0	0	0	0	0	0.238	0	0	0	0
Nephtys sp.	0.286	0	0	0.218	0	0.4	0	0	0	0
Nereis sp.	0	0	0	0	0	0	0.088	0.026	0	0.008
Notomastus sp.	0	0.25	0.028	0	0.681	0.476		0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	0.026
Phyllocomus sp.	0	0	0	0	0.056	0	0.02	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0.012	0	0
Potamilla sp.	0	0	0	0	0	0	0	0	0.002	0
Prionospio sp.	0	0.032	0	0	0.058	0	0	0.004	0	0
Sternapsis sp.	0	0.014	0.018	0.076	0.012	0.011	0.074	0.004	0	0
Syllis sp.	0	0	0	0	0	0	0	0	0.03	0
Terebellidae stroemi	0	0	1.318	0	0	0	0	1.3	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0.074	0
Asteroidea	0	18.75	0	0	0	0	0.046	0	0	0
Brachyura	0	0	0	0	0	0	1.134	0	0	0
Penaeidea	0	0	0	0	0	0	0	0.05	0.092	0.092
Sipunculidae	0	0	0	0	0	0	0.078	0.034	0.073	0.016

Table 32. Biomass of infaunal macrobenthos obtained before trawling during March 2002 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0.002	0.002	0.008	0.033	0.002	0.002	0.109	0.05
Aricidea sp.	0	0	0	0	0	0	0	0.004	0	0
Cirratulus sp.	0	0	0.44	0.002	0	0	0.012	0.028	0	0.002
Cossura sp.	0.024	0.068	0.009	0.011	0.054	0.015	0.002	0.002	0	0
Diopatra sp.	0	0	0	0	0	0	0	0.08	0	0
Dorvillea sp.	0	0	0	0	0	0	0.002	0.002	0	0
Euclymene sp.	0	0	0.088		0.11	0.1	0.142	0.142	0.054	0.023
Glycera sp.	0	0	0	0	0	0	0.004	0.003	0.114	0.116
Goniada sp.	0	0	0	0	0	0	0	0.011		
Haploscoloplos sp.	0	0	0	0	0	0	0	0	0.354	0.467
Lumbrineries sp.	0.065	0.14	0.21	0.222	0.02	0.044	0.056	0.044	3.06	0.675
Magelonidae sp.	0	0	0.018	0	0	0	0	0	0.62	0.96
Maldanella sp.	0	0	0	0	0.224	0.238	0	0	0	0
Nephtys sp.	0.286	0.222	0.211	0.218	0	0.4	0	0	0	0
Nereis sp.	0	0	0	0	0	0	0.088	0.026	0	0.008
Notomastus sp.	0.24	0.25	0.028	0	0.681	0.476	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	0.026
Phyllocomus sp.	0	0	0	0	0.056	0.044	0.02	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0.012	0	0
Potamilla sp.	0	0	0	0	0	0	0	0	0.002	0
Prionospio sp.	0.022	0.032	0	0	0.058	0.038	0	0.004	0	0
Sternapsis sp.	0.011	0.014	0.058	0.066	0.011	0.011	0.074	0.004	0	0
Syllis sp.	0	0	0	0	0	0	0	0	0.03	0.02
Terebellidae stroemi	0	0	1.318	0	0	0	0	1.3	0	0
Other groups										
Brachyura	0	0	0	0	0	0	1.134	0	0	0
Penaeidea	0	0	0	0	0	0	0	0.05	0.092	0.092
Amphipoda	0	0	0	0	0	0	0	0	0.074	0
Sipunculidae	0	0	0	0	0	0	0.078	0.034	0.073	0.016
Asteroidea	0	18.75	0	0	0	0	0.046	0	0	0

Table 33. Biomass of infaunal macrobenthos obtained before trawling during May 2002 ($g.m^{-2}$)

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis	0.016	0	0.006	0	0.046	0	0.056	0.026	0.118	0.002
Aricidea	0	0	0	0	0	0	0	0.06	0	0
Cirratulus	0	0	0	0	0	0	0	0	0.006	0
Cossura	0.214	0.122	0.433	0.148	0.002	0.11	0	0.002	0.002	0.005
Dorvillea	0	0	0	0	0	0	0.05	0	0	0.018
Euclymene	0	0	0.196	0.196	0	0	0.096	0	0	0
Eunice	0	0	0	0	0	0	0	0	0.007	0.006
Glycera	0.067	0	0	0	0	0	0	4.2	2.24	0
Haploscoloplos	0	0	0	0	0	0	0	0	0	0.019
Heteromastus	0	0.124	0	0	0	0	0	0	0	0
Lumbrineries	0.736	0.189	0.442	0.356	0.306	0.209	0.19	0.134	0.693	0.102
Magelonidae spp	0	0	0	0	0	0	0.998	0	2.149	1.09
Maldanella	0	0	0	0	0	0	0	0	0.008	0
Nephtys	0	0.168	0.606	0.246	0.034	0	0	0.132	0	0.014
Nereis	0	0	0	0	0	0	0.234	0	0	0
Nichomache	0	0	0	0	0	0	0	0	0.616	0
Notomastus	0.251	0	0	0.95	0	0	0	0.078	0	0
Onuphis	0	0	0	0	0	0	0	0	0.001	0
Ophelia	0	0	0	0	0	0	0.004	0	0	0
Paralacydonia	0	0	0	0	0	0	0	0	0.002	0.001
Phalacrophorus	0	0	0	0	0	0	0	0.44	0	0
Polycirrus	0	0	0	0	0	0	0	0	3.41	0
Prionospio	0.104	0	0	0.256	0	0	0	0	0	0
Sabellaria	0	0	0	0	0	0	0	0	0.004	0
Sternaspis	0.294	0.078	0.143	0.115	0.072	0.01	0.096	0.012	0	0
Streblosoma	0	0	0	0	0.014		0	0	0	0
Other groups										
Amphipoda	0	0	0	0	0.002	0.054	0	0	0.069	0.02
Asteroidea	0	0	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	1.64	0	0.224	0
Brachyura	0	0	0	0	0	0	0	0	0	0
Brachyura	0	0	0	0	0	0	0	0	0	0.141
Caulina	0	0	0	0	0	0	0	0	0	0
Euphuasid	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0
Holothuroidea	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0.21	0
Juvenile fish	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0
Ophiuroidea	0	0	0	0	0	0	0	0	0	0
Ostracoda	0	0	0	0	0	0	0	0	0	0
Palinuridae	0	0	0	0	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	0.54	0	0.27	0
Sipuncula	0	0.082	0	0	0	0	0	0	0.259	0.014
Stomatopoda	0	0	0	0	0	0	0	0.52	0.52	2.898

Table 34. Biomass of infaunal macrobenthos obtained before trawling during July 2002 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Amaena sp.	0	0	0	0	0	0	0.624	0	0	0
Ancistrosyllis sp.	0.002	0	0	0	0.002	0	0.002	0.052	0.005	0.058
Aricidea sp.	0	0	0	0	0	0	0.024	2.648	0.122	0.04
Cirratulus sp.	0	0	0	0	0	0	0.081	0.405	0	0
Cossura sp.	0.096	2.13	0.122	0.034	0.077	0.044	0	0	0.002	0.004
Dorvillea sp.	0	0	0	0	0	0	0	0	0	0.024
Euclymene sp.	2.715	0	0	0	0	0	0.29	0.171	0.452	0.002
Eunice sp.	0	0	0	0	0	0	0.472	0	0	0
Glycera sp.	0	0	0	0	0	0	0.018	0.004	0.094	0.194
Glyphanostomum sp.	0	0	0	0	0	0	0	0	0.072	0
Lumbrineries sp.	1.27	0.318	0.18	0.53	0.082	0.196	0	0.186	1.63	2.444
Magelonidae sp.	0	0	0	0	0	0	0	0	0.66	8.443
Nephtys sp.	0	0	0	0	0	0	0	0	0	0.03
Nereis sp.	0	0	0	0	0.08	0	0.156	0.28	0.072	0.129
Notomastus sp.	0.516	0	0	0	1.054	0.026	0.008	0	0.008	0
Paralacydonia sp.	0	0	0	0	0	0	0	0.002	0	0
Pherusa sp.	0	0	0	0	0	0	0	14.43	0	0
Phyllodoce sp.	0	0	0	0	0	0	0.018	0.06	0	0
Prionospio sp.	0.006	0	0.042	0	0.006	0.012	0	0.016	0.006	0.1999
Sabellidae sp.	0	0	0	0	0	0	0	0	0.092	0
Scoloplos sp.	0	0	0	0	0	0	0	0.076	0	0
Sternaspis sp.	0.841	0.155	0.118	0.055	0.048	0.008	0	0	0	0.224
Syllis sp.	0	0	0	0	0	0	0.008	0.024	0	0.016
Terebellidae stroemi	0	0	0	0	0	0	0	0	0.2942	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0	0.016
Asteroidea	2.856	3.54	0	0	0	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	0.65	0	0
Isopoda	0	0	0	0	0	0	0	0	0	
Juvenile fish	0	0	8.902	0	0	0	0	0	0	0
Sipunculidae	0	0.026	0	0	0	0	0.029	0.098	0	0.022
Stomatopoda	0	0	0	0	0	0.068	0	0	0	

Table 35 Biomass of infaunal macrobenthos obtained before trawling during September 2002 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0	0	0	0	0	0	0.0764	0	0	0
Aricidea sp.	0	0	0	0	0	0	0	0.006	0.006	0
Cirratulus sp.	0	0	0	0	0	0	0.038	0.07	0	0
Cossura sp.	0.023	0.006	0.005	0	0	0.173	0.002	0.002	0	0
Diopatra sp.	0	0	0	0	0	0	0.426	0	0	0
Dorvillea sp.	0	0	0	0	0	0	0.008	0	0	0
Euclymene sp.	0	0	0	0	0	0	0.252	0	0	0
Lumbrineries sp.	0.365	0.31	0.046	0.054	0.054	0.06	0.076	0	0	0
Magelonidae sp.	0	0	0	0	0	0.062	3.66	0.06	0	0
Nereis sp.	0	0	0	0	0	0	0.318	0.3	0	0
Notomastus sp.	0	0	0.046	0	0	0	0	0.007	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0	0.006
Phylocapensis sp.	0	0	0	0	0	0	0.016	0	0	0
Prionospio sp.	0	0	0	0	0	0	0.02	0	0	0
Scoloplos sp.	0	0	0	0	0	0	0	0.084	0.025	0.026
Sternaspis sp.	0.136	0.024	0.024	0	0	0.01	0.002	0.07	0	0
Syllis sp.	0	0	0	0	0	0	0	0.038	0	0
Other groups										
Penaeidea	0	0	0	0	0	0	0	0	0.088	1.022
Isopoda	0	0	0	0	0	0	0	0	0	0.022
Amphipoda	0	0	0	0	0	0	0.004	0	0.04	0
Anphioxus	0	0	0	0	0	0	0.01	0.054	0	0
Juvenile fish	0	2.326	0	0	0	0.208	0.2	0	0	0
Nematoda	0	0	0	0	0	0		0	0	0
Sipuncula	0	0	0.008	0	0	0	0.01	0	0	0.01
Asteroidea	0	0	0	0	0	0	0.174	0	0	0
Holothuroidea	0	0	0	0	0	1.42	0	0	0	0
Crab larvae	0	0	0	0	0	0	0.202	0	0	0

Table 36. Biomass of infaunal macrobenthos obtained before trawling during November 2002 (g. m^{-2})

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Polychaetes										
Ancistrosyllis sp.	0.028	0.01	0	0.002	0.002	0	0.118	0.165	0.068	0.32
Aricidea sp.	0	0.116	0	0	0	0	0.062	0.096	0.902	0.022
Cirratulus sp.	0	0	0	0	0.002	0	0.185	0.204	0.004	0.15
Cossura sp.	0.061	0.09	0	0.107	0.04	0.014	0	0	0	0
Disoma sp.	0	0.531	0.24	0.506	0	0	0	0	0	0
Euclymene sp.	0	0	0	0	0	0	0	0.078	0	0
Eunice sp.	0	0	0	0	0	0	0	0	0	0.02
Glycera sp.	0	0	0	0	0	0	0.004	0.006	0.002	0.116
Lumbrineries sp.	0.022	0	0.04	0.352	0.036	0.117	0.297	0.198	0.118	4.54
Magelonidae sp.	0	0	0	0	0	0	0.065	0.085	0	0.026
Nephtys sp.	0	0	0	0	0.044	0.164	0.124	0	0.066	0.008
Nereis sp.	0	0	0	0	0	0	0	0.139	0	0.002
Notomastus sp.	0.042	0	0	0	0	0	0.124	0.154	0	0
Phyllodoce sp.	0	0	0	0	0	0	0	0	0	0.956
Prionospio sp.	0	0	0	0	0	0	0.066	0.094	0	0
Spiophanes sp.	0	0	0	0	0	0	0	0	0.006	0.13
Sprophanes sp.	0	0	0	0	0	0	0.12	0.27	0	0
Sternaspi sp	0.023	0.018	0.002	0.002	0.036	0.21	0	0	0	0
Syllis sp.	0	0	0	0	0	0	0	0	0	0.04
Terebellidae stroemi	0	0	0	0	0	0	0.638	0.977	0	0
Trypnosyllis sp.	0	0	0	0	0	0	0	0	0.026	0.004
Other groups										
Amphioxus	0	0	0	0	0	0	0.004	0.004	0	0.01
Amphipoda	0	0	0.02	0	0	0	0	0	0.002	0.112
Asteroidea	0	0	0	0	0	0	0.005	0.004	0	0
Bivalvia	0	0	0	36	0	0	0	23.93	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0.14
Sipuncula	0	0	0	0	0	0	0.199	0.204	0	0.34

Table 37. Biomass of infaunal macrobenthos obtained after trawling during December 2000 ($g.m^{-2}$)

	A1	A2	A3	A4	A5	A6	A7		A9	
Polychaetes										
Ancistrosyllis sp.	0.072	0	0.048	0.056	0	0.014	0.012	0.011	0.018	0.076
Aricidea sp.	0	0	0	0	0	0	0	0	0	0.0016
Cirratulus sp.	0.616	0.411	0	0	0	0.822	0	0	0.004	0
Cossura sp.	0.034	0.019	0	0.054	0.004	0	0	0	0	0
Disoma sp.	0.311	0.256	0.878	0.244	0	0	0	0	0	0.002
Dorvillea sp.	0.048	0.072	0	0	0	0	0	0	0	0.024
Euclymene sp.	0	0	0	0	0.362	0	0	0	0	0
Eunice sp.	0	0	0	0	0	0	0.938	0.995	0.056	0.002
Glycera sp.	0.085	0.059	0	0	0.028	0	0.088	0.084	0	0
Goniada sp.	0.017	0.085	0	0	0	0	0	0	0.008	0
Liomia sp.	0	0	0	0	0	0	0	0	0.224	0
Lumbrineries sp.	11.65	4.66	0.228	0.133	0.068	0.04	0	0	0.862	0
Magelonidae sp.	3.72	4.33	32.654	0	0	0	5.817	5.124	1.781	11.546
Megalomma sp.	0	0	0.194	0	0	0	0	0	0	0
Nephtys sp.	0.057	0.059	0.019	0.186	0.202	0.024	0.058	0.046	0.212	0
Nereis sp.	0.36	0.41	0.38	0	0.014		0.104	0.1	0.054	0
Opisthosyllis sp.	0.28	0.32	0	0	0	0	0	0	0	0
Paralacydonia sp.	0	0	0.008	0	0	0	0.086	0	0.008	0
Pectinaria sp.	0	0	0	0	0	0	2.528	2.13	0	0
Pelagobia sp.	0	0	0	0	0	0	0	0	0	0.054
Phyllodoce sp.	0	0	0	0	0	0.002	0	0	0	0
Polydora sp.	0	0	0	0		0	0	0	0	0
Prionospio sp.	0	0	0	0.01	0.038	0.026	0.46	0.44	0.167	1.82
Pulliella sp.	0	0	0	0	0	0	0	0		0
Sternaspis sp.	0.262	0.38	0.124	0.026	0.024	0.008	0	0	0	0.11
Syllis sp.	0	0	0	0.388	0	0	0	0	0	0
Other groups										
Amphipoda	0.004	0.004	0	0.002	0	0	0.014	0.01	0	0
Bivalvia	0.68	0	0.644	0	0	0	0.528	0.55	1.744	0
Brachyura	0	0	0	0	0	0	0	0	4.712	0
Echiurida	0	0	0.106	0	0	0	0	0	0	0
Euphuasid	0	0	0	0	0	0	0	0	0	0.002
Isopoda	0	0	0	0	0	0	0.016	0.01	0.044	0.04
juvenile fish	0	0	0	0	1.968	0	0	0	0	0
Nematoda	0	0	0.56	0	0	0	0	0	0	0
Palinuridae	0.0146	0.016	0.142	0.054	0	0	0	0	0	0
Penaeidea	0	0	0	0	0	0	0.712	0	0.14	0
Sipuncula	0.41	0.288	0	0	0	0.134	0	0	0.042	0

Table 38. Biomass of infaunal macrobenthos obtained after trawling during February 2001 ($g.m^{-2}$)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0.002	0.006	0.008	0	0.01	0.012	0.011	0	0.01	0.01
Cirratulus sp.	0	0	0	0	0	3.124	0	0	0	0
Cossura sp.	0.027	0	0.102	0	0.05	0.017	0.012	0.012	0	0
Disoma sp.	0	0	0.196	0.016	0	0	0	0	0	0
Euclymene sp.	0	0	0.123	0	0.144	0	0	0	0	0
Glycera sp.	0	0	0.168	0	0	0	0	0	0	0
Goniada sp.	0	0	0	0	0	0	0	0	1.846	1.66
Lumbrineries sp.	0.191	0.416	0.037	0.082	0.155	0.165	0.111	0.121	0.046	0.05
Magelonidae sp.	0.423	4.076	0	0	0	0	0	0.053	8.73	7.66
Nephtys sp.	0.762	0.146	0.694	0.146	0.828	0.926	0	0	0	0
Phalacrophorus sp.	0.044	0	0	0	0	0	0	0	0	0
Prionospio sp.	0	0	0.426	0.372	0.02	0	0	0.004	0	0
Sternaspis sp.	0.004	0.024	0.012	0.05	0.04	0	0	0	0	0
Other groups										
Amphipoda	0	0	0	0.06	0	0	0	0	0.064	0.056
Bivalvia	0	0.004	0	0.024	0	0	0	0	0.012	0.012
Euphuasid	0	0	0	0.248	0	0	0	0	0.002	0.002
Gastropoda	0	0	0	0	0.024	0	0.6	0.605	0	0
juvenile fish	0	0	0		0	0	0	0		
Nematoda	0	0	0	0	0	0.046	0	0	0	0
Penaeidea	0	0	0	0.016	0	0	0	0	0.05	0.04
Sipuncula	0	0.62	0	0	0	0	0	0	0	0

Table 39. Biomass of infaunal macrobenthos obtained after trawling during April 2001 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0.01		0.02	0.02	0.03	0	0.017	0.174	0	0
Cirratulus sp.	0.266	1.178	0.146	0.144		0	0.066	0	0	0
Cossura sp.	0.056	0.032	0.05	0.045	0.016	0.055	0.006	0.055	0	0.022
Diopatra sp.	0	0	0	0	0	0	0	0.02	0	0
Euclymene sp.	2.249	0.212	0	0	0	0	0.094	0.072	0	0
Glycera sp.	0.078	0	0	0	0	0	0.208	0	0	0
Haploscoloplos sp.	0	0	0	0	0	0.288	0	0	0	0
Liomia sp.	0	0	1.286	1 18	0	0	0.164	0	0	0
Lumbrineries sp.	0.253	0.37	0.142	0.132	0.64	0.85	0.036	0.316	0	0.47
Magelonidae sp.	1.144	0	0.064	0.045	0	0.7	1.568	0.114	0.048	3.677
Nephtys sp.	0.446	0.339	0.058	0.055	0	0.854	0.181	0	0	0
Nereis sp.	0	0	0	0	0	0.092	0	0	0	0
Pectinaria sp	0	0	0	0	0	0	0	0	0	0 105
Polydora sp.	0	0	0	0	0	0	0.53	0	0	0
Prionospio sp.	0.428	0	0	0	0	0	0	0 256	0	0
Pulliella sp.	0	0.202	0	0	0	0	0	0	0	0
Siphanophanes sp.	0	0	0	0	0	0	0 192	0	0	0
Sternaspis sp.	0.008	0.012	0.042	0.042	0	0.023	0	0.08	0	0.022
Other groups										
Amphipoda	0.022	0	0	0	0	0	0	0	0 035	0 094
Bivalvia	0	0	0	0	0	0	0	0	0.586	2.059
Brachyura	0	0	0.0662	0.06	0	0	0	0.064	0	0.012
Gastropoda	1.39	0	1.338	1.3	0	6.041	0.162	0	0.168	0.278
Juvenile fish	0	0	0.522	0.52	0	0	0	2.314	0	0
Nematoda	0	0.028	0	0	0	0	0.004	0	0	0.044
Ophiuroidea	0.722	0	0	0	0	0	0.016	0	0	0
Palinuridae	0.13	0	0	0	0	0	0.068	0	0	0
Penaeidea	0	0	0.02	0.02	0	0	0.368	0	0.192	0.18
Sipuncula	0	0	0	0	0	0	0	0	0.034	0.064
Stomatopoda	0	0	0	0	0	0	0	0	2.232	0.72

Table 40. Biomass of infaunal macrobenthos obtained after trawling during July 2001 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0	0	0	0	0	0	0	0.018	0.011	0.011
Cirratulus sp.	0	0	0	0	0	0.265	0.242	0	0	0
Cossura sp.	0.2	0.2	0.038	0.046	0.036	0.051	0.02	0	0	0
Diopatra sp.	0	0	0	0	0	0	0	3.474	3.22	2.85
Dorvillea sp.	0	0	0	0	0	0	0	0.042	0	0
Euclymene sp.	0	0	0.02	0.016	0.015	0	0	0.046	0.05	0.05
Glycera sp.	0	0	0	0	0	0	0	0.094	0.09	0.09
Harmothoe sp.	0	0	0	0	0	0	0	0.008		0
Liomia sp.	0	0	0	0	0	0	0	0.022	0	0
Lumbrineries sp.	0.314	0.28	0.207	0.119	0.114	0.973	0.79	0.702	0.08	0.08
Magelonidae sp.	0.01	0.01	0.02	0.02	0.02	0	0	0	0	0
Nephtys sp.	0	0	0	0	0	0	0.206	0.963	0.012	0.012
Nereis sp.	0	0	0	0	0	0	0	0.504	0.0504	0.0423
Notomastus sp.	0	0	0	0	0	0	0	0		0
Onuphis sp.	0	0	0	0	0	0	0	0.074	0.068	0.068
Phylocapensis sp.	0	0	0	0	0	0	0		0	0
Prionospio sp.	0	0	0.06	0.016	0.015	0.23	0.183	1.981	1.45	1.45
Siphanophanes sp.	0	0	0	0		0	0	0	0	0
Sternaspis sp.	0.132	0.122	0.063	0.106	0.011	0.016	0.038	0.337	0.348	0.311
Streblosoma sp.	0	0	0	0	0	0	0	0.138	0.133	0.121
Other groups										
Holothuroidea	0	0	0	0	0	1.444	0	0	0	0
Palinuridae	0	0	0	0	0	0	0.112	0	0	0
Penaeidea	0	0	0	0	0	0	0	0.133	0	0
Sipunculidae	0	0	0	0	0	0	0	0.012	0	0

Table 41. Biomass of infaunal macrobenthos obtained after trawling during September 2001 ($g.m^{-2}$)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0	0.004	0.008	0.008	0	0.002	0.002	0	0.193	0.18
Cirratulus sp.	0	0.002	0	0	0.002	0	0	0.13	0.002	0.002
Cossura sp.	0.041	0.08	0.012	0.015	0.056	0	0			
Diopatra sp.	0	0	0	0	0	0	0	0.47	1.07	0.98
Euclymene sp.	0	0	0	0	0.148	0	0	0	0	0
Harmothoe sp.	0	0	0	0	0	0	0	0	0.044	0.041
Liomia sp.	0	0	0	0	0	0	0	0	0.898	0
Lumbrineries sp.	0.303	0.833	0.079	0.385	0.564	0.472	0.42	2.232	1.86	1.45
Magelonidae sp.	0	0	0.082	0.018	0.04	0.034	0.03	0	0.047	0.031
Megalomma sp.	0	0.037	0	0	0	0	0	0	0	0
Nephtys sp.	0	0	0	0	0	0	0	0	0.869	0.88
Nereis sp.	0	0	0	0	0	0	0	0	0.144	0.13
Pectinaria capensis	0	0	0	0	0	0	0	0	0.008	0.007
Phyllodoce sp.	0	0	0	0	0	0	0	0.384	0	0
Prionospio sp.	0.004	0.046	0.082	0	0	0.045	0.036	2.04	2.297	2.13
Potamilla sp.	0	0	0	0	0	0	0	0	0.024	0.04
Sternaspis sp.	0	0.472	0	0.069	0	0.27	0.22	0	0	0
Syllis sp.	0	0	0	0	0	0	0	0	0.01	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0.028	0.004	0
Asteroidea	0	0	0	0	0	0	0	0	0.49	0.5
Bivalvia	0	0	0	0	0	24	0	0	0	0
Cephalopoda	0	0	0	0	0	0	0	12.302	0	0
Cumacea	0	0	0	0	0	0	0	0.01	0	0
Isopoda	0	0	0	0	0	0	0	0	0.122	0.11
Juvenile fish	0.196	7.88	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0.001	0
Penaeidea	0	0	0	0	0	0	0	0	0.624	0.06
Sea Anemone	0	0	0	0	0	7.84	0	0	0	0
Sipunculidae	0	0	0	0	0	0	0	0.102	0.687	1.3
Stomatopoda	0	0	0	0	0	0	0	0.478	0	0

Table 42. Biomass of infaunal macrobenthos obtained after trawling during November 2001 (g. m^{-2})

	A1	A2	A3	A4	A5	A6		A8	A9	A'
Polychaetes										
Amphicteis sp.	0	0	0	0	0	0	0	0	0.016	0
Ancistrosyllis sp.	0.002	0	0	0	0.009	0.018	0.148	0.128	0.358	0.264
Cirratulus sp.	0.012	0	0	0	0	0	0	0.041	0.032	0.042
Cossura sp.	0.093	0.099	0.04	0.03	0	0.38	0.041	0.004	0.002	0.008
Diopatra sp.	0	0	0	0	0	0	0	0	0.002	0
Dorvillea sp.	0	0	0	0	0	0	0	0	0.143	0.132
Euclymene sp.	0	0	0	0	0	0	0.123	0.284	0.108	0
Eunice sp.	0	0	0	0	0	0	0	0	0.041	0.041
Glycera sp.	0.012	0.012	0	0	0	0		0.254	0.006	0
Goniada sp.	0	0	0	0	0	0	0.226	0.185	0	0
Haploscoloplos sp.	0	0	0	0	0	0	0	0	0.026	0.03
Isolda sp.	0	0	0	0	0	0	0	0.004	0	0
Liomia sp.	0	0	0	0	0	0	0	0	0	0.04
Lumbrineries sp.	0.094	0.045	0	0.044	0.06	0.028	0.348	0.31	5.204	1.852
Magelonidae sp.	0	0	0	0	0	0	0.097	0.32	4.405	3.15
Nephtys sp.	0	0.394	0	0.272	0.23	0.137	0	0	0	0.073
Nereis sp.	0	0	0	0	0	0	0	0.008	0	0
Notomastus sp.	0	0	0	0.01	0	0	0.008	0	0	0
Pectinaria sp.	0	0	0	0	0	0	0	2.118	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0.014	0.02
Phyllodoce sp.	0	0	0	0	0	0	0	0	0.259	0.028
Prionospio sp.	0.002	0.002	0	0.002	0.069	0.058	0.07	0.008	0.28	1.12
Potamilla sp.	0	0	0	0	0	0	0.044	0	0	0
Pulliella sp.	0	0	0	0	0	0	0	0	0.002	0.002
Sternaspis sp.	0.022	0.034	0	0.012	0.062	0.166	0.099	0.016	0	0
Streblosoma sp.	0	0	0	0	0	0	0	0	0.002	0
Sabellaria sp.	0	0	0	0	0	0	0	0	0.012	0
Other groups										
Brachyura	0	0	0	0	0	0	0	0	0.18	
Penaeidea	0	0	0	0	0	0	0	0.31	0.102	0.289
Stomatopoda	0	0	0	0	0	0	0	0	0	2.65
Amphipoda	0	0.008	0	0	0	0	0	0.008	0.039	0.123
Juvenile fish	0		0	0	0	0	0	0	0	1.506
Bivalvia	0.145	0.122	0	0	0	0	1.822	0.034	0	0
Nematoda	0	0	0	0	0	0.001	0.002	0.002	0.006	0.003
Sipunculidae	0	0.05	0	0	0	0.028	0.044	0	0	0.026
Holothuroidea	0	0	0	0	0	0	0	0	0	0.024
Asteroidea	0	0	0	0	0	0	0	0.01	0	0
Bryozoa	0	0	0	0	0	0	0	0.002	0	0

Table 43. Biomass of infaunal macrobenthos obtained after trawling during January 2002 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Amphicteis sp.	0	0	0	0	0	0	0	0	0.002	0
Ancistrosyllis sp.	0	0	0	0	0	0	0	0	0.002	0
Aricidea sp.	0.011	0.01	0.006	0.002	0	0.008	0.002	0.016	0.002	0.076
Bhawania sp.	0	0	0	0	0	0	0	0	0	0.004
Cossura sp.	0.004	0	0.162	0	0.006	0	0.008	0.209	0.022	0.019
Diopatra sp.	0.064	0.035	0.009	0.007	0	0.199	0.004	0.226	0	0.114
Disoma sp.	0	0	0	0	0	0	0	0.084	0	0
Eunice sp.	0	0.108	0.044	0.074	0	0	0.126	0.092	0	0.058
Euprosine sp.	0	0	0	0	0	0	0.066	0	0.238	0.018
Goniada sp.	0.004	0.074	0	0	0.016	0	0.033	0.014	0.014	0
Harmothoe sp.	0	0	0	0	0.236	0	0	0	0	0
Johnstonia sp.	0	0	0	0	0	0	0	0.014	0	0
Liomia sp.	0	0	0	0	0	0	0	0.012	0	0
Magelonidae sp.	0.532	0.466	0.168	0.127	0.156	0.206	0.233	0.386	0.002	0.238
Malacoceros sp.	0	0	0.6	0	0	0	0	0.124	0	0
Maldanella sp.	0	0.038	0	0	0	0	0	0	0.01	1.936
Nereis sp.	0.008	0.088	0.224	0.306	0.032	0.34	0	0.378	0	0.122
Nichomache sp.	0	0	0	0	0	0	0	0	0	0.024
Nicolea sp.	0	0	0	0	0.124	0	0.022	0.032	0	0.018
Onuphis sp.	0.052	0.08	0	0	0	0	0	0.08	0	0
Ophelia sp.	0	0	0	0	0.02	0	0	0	0	0
Phalacrophorus sp.	0	0	0	0	0	0	0	0.026	0.024	0.046
Pherecardia sp.	0	0	0	0	0	0	8.522	0	0	0
Phyllodoce sp.	0	0	0	0	0	0	0.034	0	0	0
Phylocapensis sp.	0	0	0	0	0	0	0.168	0.024	0	0
Psedeurythoe sp.	0	0.098	0	0.002	0.099	0.023	0.022	0.07	0.078	0.027
Pulliella sp.	0	0	0	0	0	0	0	0.042	0	0
Streblosoma sp.	0.014	0.01	0.048	0.045	0.186	0.054	0	0.084	0	0
Terebellidae stroemi	0	0	0	0	0	0	0	0.766	0	0
Tharyx sp.	0	0	0	0	0	0	0.034	0.022	0	0.024
Trichobranchus sp.	0	0	0	0	0	0	0.166	0	0	0
Other groups										
Amphipoda	0	0	0	0	0	0	0	0	0	0.045
Brachyura	0	0.51	0	0	0	0	0	0	0	2.052
Holothuroidea	0	0	0	0	16.39	0	0	0	0	0
Juvenile fish	0	0	0	0	0.578	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0.002
Penaeidea	0	0	0	0	0	0	0.046	0	0	0
Sipunculidae	0	0	0	0	0.064	0.106	0.137	0.092	0.054	0.096
Sponges	0	0	0	0	0	0	0	57.876	0	0
Stomatopoda	0	0	0	0	0	0	0	0	0	2.116

Table 44. Biomass of infaunal macrobenthos obtained after trawling during March 2002 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ampharete sp.	0	0	0	0	0	0	0	0	0.002	0
Ammotrypan sp.	0	0	0	0	0	0	0	0	0.002	0
Ancistrosyllis sp.	0.011	0.01	0.006	0.002	0	0.008	0.002	0.016	0.002	0.076
Aricidea sp.	0	0	0	0	0	0	0	0	0	0.004
Cirratulus sp.	0.004		0.162	0	0.006	0	0.008	0.209	0.022	0.019
Cossura sp.	0.052	0.066	0.005	0.007	0	0.164	0.004	0.018	0	0.114
Diopatra sp.	0	0	0	0	0	0	0.084	0.084	0	0
Euclymene sp.	0.12	0.108	0.044	0.074	0	0	0.126	0.092	0	0.058
Eunice sp.	0	0	0	0	0	0	0.066	0	0.238	0.018
Glycera sp.	0.004	0.074	0	0	0.016	0.015	0.033	0.014	0.014	0
Haploscoloplos sp.	0	0	0	0	0.236	0	0	0	0	0
Isolda sp.	0	0	0	0	0	0	0	0.014	0	0
Johnstonia sp.	0	0	0	0	0	0	0	0.012	0	0
Lumbrineries sp.	0.532	1.2	0.144	0.127	0.156	0.183	0.08	0.08	0.002	0.238
Magelonidae sp	0	0.038	0	0	0	0	0	0	0.39	4.75
Maldanella sp.	0	0	0.6	0.58	0	0	0	0.124	0	0
Nephtys sp.	0.008	0.088	0.224	0.306	0.032	0.32		0.378	0	0.122
Nereis sp.	0	0	0	0	0.124	0	0.022	0.032	0	0.018
Nicolea sp.	0	0	0	0	0	0	0	0	0	0.024
Notomastus sp.	0.052	0.08	0	0	0	0	0	0.08	0	0
Onuphis sp.	0	0	0	0	0.02	0.02	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0.026	0.024	0.046
Pectinaria sp.	0	0	0	0	0	0	8.522	0	0	0
Phyllocomus sp.	0	0	0	0	0	0	0.034	0	0	0
phyllodoce sp.	0	0	0	0	0	0	0.168	0.024	0	0
Prionospio sp.	0	0.098	0	0.002	0.099	0.023	0.022	0.07	0.078	0.027
Rhynchospio sp.	0	0	0	0	0	0	0	0.042	0	0
Sternaspis sp.	0.014	0.01	0.048	0.045	0.065	0.102	0	0.084	0	0
Syllis sp.	0	0	0	0	0	0	0.034	0.022	0	0.024
Terebellidae stroemi	0	0	0	0	0	0	0.166	0	0	0
Trichobranchus sp.	0	0	0	0	0	0	0	0.766	0	0
Other groups										
Brachyura	0	0.51	0	0	0	0	0	0	0	2.052
Penaeidea	0	0	0	0	0	0	0.046	0	0	0
Sponges	0	0	0	0	0	0	0	57.876	0	0
Stomatopoda	0	0	0	0	0	0	0	0	0	2.116
Amphipoda	0	0	0	0	0	0	0	0	0	0.045
Juvenile fish	0	0	0	0	0.578	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0.002
Sipunculidae	0	0	0	0	0.064	0.106	0.137	0.092	0.054	0.096
Holothuroidea	0	0	0	0	16.39	0	0	0	0	0

Table 45. Biomass of infaunal macrobenthos obtained after trawling during May 2002 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis	0.024	0.038	0	0.012	0	0	0.028	0.035	0.075	0.004
Aricidea	0	0	0	0	0	0	0	0.024	0.008	0
Cirratulus	0	0	0.576	0	0	0	0.194	0.002	0.008	0.008
Cossura	0.51	0.302	0.274	0.014	0.025	0.051	0	0.034	0.33	0.034
Diopatra	0	0.018	0	0	0	0	0	0	0	0
Dorvillea	0.002	0	0	0	0	0	0	0	0	0.032
Euclymene	0	1.05	0	0	0	0	0	0.024	0	0
Eunice	0	0	0	0	0	0	0	0	0	0.018
Glycera	0.002	0.212	0	0	0	0.002	0.124	0.134	0.192	0
Goniada	0.016	0	0	0	0	0	0	0	0	0
Heteromastus	0	0	0	0	0	0	0	1.33	0	0
Isolda	0	0	0	0	0	0	0.04	0	0	0
Lumbrineries	0.48	0.348	0.326	0.31	0.078	0.054	1.668	5.648	4.77	0.185
Magelonidae spp	0	0.237	0	0	0	0	0	0	17	1.463
Maldanella	0	0	0	0	0	0	0	0.124	0	0
Nephtys	0	0.056	0	0.696	0	0	0	0.102	0.002	0
Nereis	0	0	0	0	0	0	0.084	0.32	0.024	0.036
Nichomache		0	0	0	0	0	0	0	0	0
Notomastus	0.032	0	0	0.004	0.154	0.004	0.016	0	0	0.008
Paralacydonia	0	0	0	0	0.014	0	0.02	0	0.002	0.024
phyllodoce	0	0	0	0	0	0	0	0	0	0.05
Phylocapensis	0	0	0	0	0	0	0	0	0.027	0
Pilargia	0	0	0	0	0	0	0	0	0.526	0.003
Prionospio	0	0.958	0	0.002	0.038	0	0	0.037	0.026	0.042
Scoloplos	0	0	0	0	0	0	0.074	0	0.16	0
Sternaspis	0	0.435	0.188	0.272	0.182	0.016	0	0.009	0.046	0
Streblosoma	0	0	0	0	0	0.224	0	0	0	0
Other groups										
Brachyura	0	0	0	0	0	0	0	0	1.1	0.34
Penaeidea	0	0	0	0	0	0	0	0	0.086	0
Stomatopoda	0	0	0	0	0	0	4.422	0	0	10.56
Amphipoda	0	0	0	0	0	0	0	0	0.287	0
Juvenile fish	0	0	0	0	0.324	0	0	0	0	0
Bivalvia	0	0	0	0	0	0	0	1.49	0	0.339
Sipuncula	0.017	0.038	0.016	0	0	0	0.482	0.134	0.386	0

Table 48. Biomass of infaunal macrobenthos obtained after trawling during July 2002 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ampharete sp.	0	0	0	0	0	0	0	0	0	0.168
Ancistrosyllis sp.	0.008	0	0	0	0	0.002	0.002	0.106	0.071	0.104
Aricidea sp.	0	0	0	0	0	0.056	0.071	0.777	0.074	0.124
Bhawania sp.	0	0	0	0	0	0	0	0	0.034	0
Cirratulus sp.	0	0	0	0	0	0	0.088	0.063	0.062	0.101
Cossura sp.	0.312	0.012	0.067	0.051	0.138	0.176	0	0	0	0.021
Dorvillea sp.	0	0	0	0	0	0	0	0	0	0.006
Euclymene sp.	5.278	0.804	0	0	0.268	0.026	0.241	0.292	0	0
Glycera sp.	0	0	0	0	0	0	0	0	0	0.05
Heteromastus sp.	0	0	0	0	0	0	0	0	0.142	0
Lepidonotus sp.	0	0	0	0	0	0	0	0	0.014	0
Lumbrineries sp.	1.2	0.126	0.406	0.555	0.183	0.107	0.06	0.006	0.15	0.197
Magelonidae sp.	0	0	0	0	0	0	0.034	0	4.72	0.303
Melinna sp.	0	0	0	0	0	0	0	0	0.616	0
Nephtys sp.	0	0	0	0	0	0.234	0	0	0	0
Nereis sp.	0	0.084	0	0	0	0	0.168	0.132	0.651	0.172
Notomastus sp.	0.298	0	0	0	0	0.532	0	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0.036	0.048	0
Pectinaria sp.	0	0	0	0	0	0	0	0	0	10.87
Polycirrus sp.	0	0	0	0	0	0	0	0	0.61	0
Prionospio sp.	0.18	0.002	0.002	0	0.152	0	0.361	0.106	0.142	0.349
Sternaspis sp.	1.34	0	0.097	0.093	0	0.008	0	0	0.826	0.038
Syllis sp.	0	0	0	0	0	0	0.006	0.024	0.048	0.138
Terebellidae stroemi	0	0	0	0	0	0	0	0	0.642	0
Other groups										
Stomatopoda	0	0	0	0	0	0	0.068	1.135	0	0
Amphipoda	0	0	0	0	0	0	0.02	0	0	0.082
Sipunculidae	0	0	0	0	0	0	0.194	0.364	0.261	0.054
Asteroidea	4.708	4.417	0	0	0	0	0	0	0	0

Table 47 Biomass of infaunal macrobenthos obtained after trawling during September 2002 (g. m^{-2})

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis	0	0	0	0	0.002	0	0	0	0	0.008
Aricidea	0	0	0	0	0	0	0.056	0.168	0	0
Cirratulus	0.358	0	0	0	0	0	0	0.096	0	0.141
Cossura	0.01	0.014	0.005	0.006	0.002	0.19	0.008		0	0
Diopatra	0	0	0	0	0	0	0	0.412	0	0
Euclymene	0	0	1.6	0	0	0	0	0.357	0	0
Loandalia	0	0	0	0	0	0	0.008	0	0	0
Lumbrineries	0.416	0.003	0.021	0.025	0	0.33	0	0	0	0.098
Magelonidae spp	0	0	0	0	0.002	0.002	0	4.536	0	9.156
Nereis	0	0	0	0	0	0	0	0.207	0.064	0.085
Notomastus	0.01	0	0.106	0	0	0.012	0	0	0	0
Paralacydonia	0	0	0	0	0	0	0	0.061	0	0
Prionospio	0	0	0	0	0	0.002	0	0.03	0	0
Scoloplos	0	0	0	0	0	0	0	0.158	0	0
Sternaspis	0.037	0	0	0.036	0.006	0.012	0	0.186	0	0
Other groups										
Penaeidea	0	0	0	0	0	0	0	0	0	1.102
Palinuridae	0	0	0	0	0	0	0	0	0	
Stomatopoda	0	0	0	0	0	0	0	0	0	
Isopoda	0	0	0	0	0.024	0	0	0	0	0.02
Amphipoda	0	0	0	0	0	0	0	0	0.076	0.156
Amphioxus	0	0	0	0	0	0	0	0.012	0	0
Juvenile fish	0	0	0	0	0	0	0	0	0	4.976
Bivalvia	0	0	0	0	0	0	0	0	0	0.824
Sipuncula	0	0	0.038	0.006	0.012	0	0.072	0	0	0
Prawn larvae	0	0	0	0	0	0	0	0	0.954	0

Table 48. Biomass of infaunal macrobenthos obtained after trawling during November 2002 ($g.m^{-2}$)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Polychaetes										
Ancistrosyllis sp.	0.16	0.226	0	0.018	0.002	0.007	0.214	0.012	0.026	0.206
Aricidea sp.	0	0.004	0	0	0.024	0.024	0.861	0	0.078	0.032
Bhawania sp.	0	0	0	0	0	0	0	0	0	0.022
Cirratulus sp.	0	0	0	0	0.004	0.002	0.414	0.044	0.02	0.034
Cossura sp.	0.055	0.126	0.038	0.045	0.01	0.002	0.146	0	0	0.002
Disoma sp.	0.048	1.746	0	0	0	0	0	0.098	0	0
Euclymene sp.	0	0	0	0.93	0.02	0	0.997	0.09	0	0
Glycera sp.	0	0	0	0	0.004	0.004	0.007	0.51	0.07	0.092
Glyphanostomum sp.	0	0	0	0	0	0	0	0	0	
Goniada sp.	0	0	0	0	0	0	0	0	0	0.01
Isolda sp.	0	0	0	0	0	0	2.41	0	0	0
Lumbrineries sp.	0.19	0.382	0.002	0.225	0.008	0.15	0.264	0.214	7.2	1.226
Magelonidae sp.	0	0	0	0	0.016	0.006	1.406	0	0.554	0.555
Nephtys sp.	0	0	0	0	0.222	0.002	0	0	0	0
Nereis sp.	0	0.004	0	0	0	0	0.054	0	0	0.006
Notomastus sp.	0	0	0	0	0	0.042	0.098	0	0	0
Paralacydonia sp.	0	0	0	0	0	0	0	0	0.012	0.026
Phyllodoce sp.	0	0	0	0	0	0	0.027	0.872	0.174	0
Prionospio sp.	0	0	0	0	0	0.094	0.24	0.17	0	0
Sternaspi sp	0.002	0.12	0	0.04	0.209	0.158	0.009	0.002	0	0
Syllis sp.	0	0	0	0	0	0	0.012	0.006	0	0
Terebellidae stroemi	0	0	0	0	0	0	0.016	0	0.096	0.104
Other groups										
Brachyura	0	0	0	0	0	0	0	0	0.71	0
Penaeidea	0	0	0	0	0	0	0	0	0.21	0
Palinuridae	0	0	0	0	0	0	0	0		0
Stomatopoda	0	0	0	0	0	0	0	0	0.966	0
Isopoda	0	0	0	0	0	0	0	0	0	0.002
Amphipoda	0	0	0	0	0	0	0	0.002	0.062	0.086
Juvenile fish	0	0	0	0	0.19	0	0	0	0	0
Sipuncula	0	0	0	0	0.014	0.01	0.024	0	0.13	0.098
Asteroidea	0	0	0	0	0	0	0	0	0	0.088
Amphioxus	0	0	0	0	0	0	0.01	0.002	0	0.022

Table 49. Results of two- way ANOVA on polychaete abundance (no. m^{-2}) obtained before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	1.82E+08	11	16538901	3.775555	0.000157	1.886683
Stations	46787442	9	5198605	1.186755	0.311893	1.975806
Error	4.34E+08	99	4380522			
Total	6.62E+08	119				

Table 50. Results of two- way ANOVA on polychaete abundance (no. m¯2) obtained after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	3.66E+08	11	33287461	2.914566	0.002276	1.886683
Stations	1.78E+08	9	19765764	1.73064	0.09187	1.975806
Error	1.13E+09	99	11421071			
Total	1.67E+09	119				

Table 51. Results of two- way ANOVA on polychaete biomass (g.m^{-2}) obtained before trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	259.6918	11	23.60834	1.569195	0.119721	1.886683
Stations	367.8307	9	40.87007	2.716545	0.007156	1.975806
Error	1489.443	99	15.04487			
Total	2116.965	119				

Table 52. Results of two- way ANOVA on polychaete biomass (g.m¯2) obtained after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Months	939.1021	11	85.37292	1.453678	0.161496	1.886683
Stations	1059.32	9	117.7023	2.004163	0.046531	1.975806
Error	5814.161	99	58.7289			
Total	7812.583	119				

Table 53. Results of one- way ANOVA on Shannon diversity on polychaete abundance before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00857	1	0.00857	0.244181	0.627178	4.413863
Within Groups	0.631777	18	0.035099			
Total	0.640348	19				

Table 54. Results of one- way ANOVA on Pielou's eveness on polychaete abundance before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000984	1	0.000984	0.086198	0.772426	4.413863
Within Groups	0.205539	18	0.011419			
Total	0.206524	19				

Table 55. Results of one- way ANOVA on richness on polychaete abundance before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.063364	1	0.063364	1.509526	0.235034	4.413863
Within Groups	0.755565	18	0.041976			
Total	0.818929	19				

Table 56. Results of one- way ANOVA on Simpson's diversity on polychaete abundance before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000818	1	0.000818	0.111596	0.742195	4.413863
Within Groups	0.131972	18	0.007332			
Total	0.132791	19				

Table 57 Results of one- way ANOVA on Shannons's diversity on polychate biomass before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.029447	1	0.029447	1.124686	0.302935	4.413863
Within Groups	0.471282	18	0.026182			
Total	0.500729	19				

Table 58. Results of one- way ANOVA on Pielou's eveness on polychate biomass before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000657	1	0.000657	0.089075	0.768774	4.413863
Within Groups	0.132841	18	0.00738			
Total	0.133498	19				

Table 59. Results of one- way ANOVA on richness on polychate biomass before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2194.22	1	2194.22	1.781487	0.198605	4.413863
Within Groups	22170.22	18	1231.679			
Total	24364.44	19				

Table 60. Results of one- way ANOVA on Simpson's diversity on polychate biomass before and after trawling

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.100494	1	5.100494	0.330689	0.572372	4.413863
Within Groups	277.6291	18	15.42384			
Total	282.7296	19				

Appendix VII

A. Papers published

1. **Thomas, J.V.** and Kurup, B.M. 2001. On the emergence of a Non-edible swarming crab Charybdis (Goniohellenus) smithii Macleay in the trawl fishing grounds of Kerala: a case of ecosystem overfishing. In Goddard, S., Al-Oufi, H, McIlwain, J. and Claereboudt, M. (Eds.) Proceedings of first international conference on Fisheries, Aquaculture and Environment in the northwest Indian Ocean. Sultan Qaboos University, Muscat, Sultanate of Oman. In Vol.2: 68-75.

B. Papers accepted

1. **Thomas, J.V.** and Kurup, B.M. 2003. Padal fishery – A unique fishing method in Ashtamudy estuary of Kerala (South India). NAGA ICLARM Journal Malaysia (in press).
2. Premlal.P, **Joice.V.Thomas** and B.M.Kurup 2000. Observations on the trawl catch composition of FORV Sagar Sampada with special reference to bycatch and discards. In Proceedings of the International Symposium on fisheries and Aquaculture in the tropics, Sultan Quaboos university, Sultanate of Oman. 16-24th Feb 2002. Vol III (in Press).
3. Madhusoodana Kurup, B., Premlal. P., **Joice V. Thomas** and Vijay Anand. 2003. Status of bottom trawl discrds along coastal waters

of Kerala. Journal of Marine Biological Association of India (in press).

C. Papers communicated

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. **Joice.V.Thomas**, Premlal.P and Kurup, B.M. 1999. Recent technological advancements in the Ring seine fishery of Kerala coast. Paper communicated to Infofish International, Malaysia
3. **Joice.V.Thomas** 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 (JMBA).
4. **Joice.V.Thomas** 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 (JMBA).
5. **Joice.V.Thomas** and Madhusoodana Kurup 2002. Immediate effect of bottom trawling on nutrients with special reference to nitrite and phosphate along the inshore waters of Kerala. Paper

presented at the Sixth Asian Fisheries Forum, conducted at CIFE, Mumbai, 16 – 20th December 2002.

6. Sreedevi, C., **Joice V. Thomas** and B. Madhusoodana Kurup. 2002. Temporal and spatial variations in meiofaunal polychaete assemblages at 0-50m along Cochin waters, Kerala. Indian Journal of Fisheries.