EFFECT OF INDUSTRIAL POLLUTION ON THE BENTHIC COMMUNITIES OF A TROPICAL ESTUARY

THESIS SUBMITTED TO THE COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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This is to certify that this thesis is an authentic record of the work carried out by Mrs. K. Sarala Devi, M.Sc. under my supervision at the Regional Centre of the National Institute of Oceanography (C.S.I.R.), Cochin and that no part thereof has been presented for the award of any other degree.

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D E C L A R A T I O N

I hereby declare that the thesis entitled "Effect of Industrial Pollution on the Benthic Communities of a Tropical Estuary" is an authentic record of the work carried out by me at the Regional Centre of National Institute of Oceanography, Cochin-18 under the supervision of Dr. R.V. Unnithan, Assistant Director, and has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title or recognition.

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C O N T E N T S

P R E F A C E

Cochin backwaters, a tropical bar built estuary is well known for its prawn, molluscan and demersal fisheries. Also it formed the dumping area for sewage, retting of husks and discharge of effluents from industries located on either side of it. As a result, the fishery is being gradually dwindled year after year due to the lowering of the water qualities. Encouraged by the outcome of the earlier studies by Unnithan *et al*. (1975), Unnithan (1976), Vijayan *et al*. (1976), Sarala Devi *et al*. (1979) and the studies on organic pollution in the retting yards of this backwaters by Remani (1979), it was thought worth to undertake a comprehensive study on the effect of industrial pollution on the benthic community of this tropical estuary. An area extending over 21 km from the barmouth to Kalamassery (upstream of the industrial complex) was selected. Temporal and spatial variations taking place in 16 environmental parameters at 9 stations located along the area were monitored monthly, round the year during 1981, along with a survey of the benthic fauna. The observed variability however could not be adequately explained by the parameters studied. This is perhaps not surprising as the nature of pollution in the present area is inorganic from industrial effluents including toxic material that tend to have long term cumulative effects. Organic pollution on the other hand tends to generate a sequence of events wherein a few factors like enrichment and oxygen depletion etc. are 'key factors'. The monsoonal flow that flush the environment annually, rejuvenates the system so that long term observations take on a lot of significance and can augment or perhaps alter the present study. The thesis is presented in 5 chapters dealing with introduction, material and methods, results, discussion and summary in addition to the preface, acknowledgements, literature cited and an appendix of published papers.

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1. INTRODUCTION

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1.1. Studies on Estuaries:

Considerable amount of work on the physical, chemical, biological and other related aspects of various estuaries have appeared in the past eighty years, contributing significantly to an understanding of the various processes taking place in the estuarine environment.

Earlier reports on estuarims include studies on the South African estuaries by Day (1951 & 1967) and Day *et al*. (1952, 1954 & 1956); Australian estuaries by Rochford (1951) and Chesapeak Bay by Pritchard (1952 a, b; 1954 & 1956). Contribution on estuarine hydrography, circulation, fauna and their ecology have been attempted by Ketchum (1951 & 1954), Emery and Stevenson (1957), Hedgepeth (1957), Bowden (1960 & 1963), Jeffries (1962 a, b, c, d) and Odum (1971). Lauff (1967) has given the comprehensive account of the various aspects of estuarine research and management.

In India estuarine studies date back to the beginning of this century, Annandale (1907), Alcock (1911) and Kemp (1917) described the fauna of Gangetic Delta while Chilka

Lake was studied by Annandale and Kemp (1915) and Sewell (1924). The brackish water fauna of Madras area was studied by Panikkar and Aiyar (1937) and Panikkar (1951) reviewed the physiological adaptation of animals. Hydro-biological observations of Hoogly estuary have been made by Roy (1955); Dutta, Malhotra and Bose (1954), Bose (1956) and Saha, Gosh and Gopalakrishnan (1971). Godavary estuary has been studied in detail by Chandramohan (1963), and Chandramohan and Rao(1972). Work on Mahanadi estuary was carried out by Ray et al. (1981). Suspended matter from the Narmada and Tapti estuaries was studied by Bhaskaran et al. (1981). Vellar estuary is one of the best studied estuaries in the east coast. Investigations on various aspects of this estuary were made by Seshaiya (1959), Rangarajan (1959), Krishnamoorthy (1961), Ramamoorthy et al. (1965), Subbaraju and Krishnamoorthy (1972), Krishnamoorthy and Sundararaj (1973) and Devendran et al. (1974). Hydrography, circulation, phytoplankton, benthos and related aspects of Mandovi and Zuari estuarine systems of Goa have been studied by Das et al. (1972), Singbal (1973), Parulekar (1973), Parulekar et al. (1980), Cheriyan et al. (1974, 1975), Bhargava and Dwivedi (1974), Goswami and Singbal (1974), Goswami and Selvakumar (1977), Varma et al. (1975) and Selvakumar et al. (1980). Physical aspects of estuaries of Goa region were reviewed by Rao (1981).

Devassy *et al.* (1983) and Nair *et al.* (1980) have worked on phytoplankton and zooplankton of Goa estuaries. Bhat and Gupta (1980) and Nagarajaiah and Gupta (1983) have reported on the physical characters and distribution of meroplankton with reference to the hydrography of Netravathi estuary. Compiled information on the more recent works dealing with various aspects of estuarine biology has been given by Natarajan (1975) and Kurian (1977).

Kerala abounts in many estuaries along its coast line, but are the least explored scientifically. Some preliminary hydrobiological and planktonological investigations in the Korapuzha estuary were made by Suryanarayana Rao and George (1959) and George (1953 a, b). Murugan *et al.* (1980) studied the benthos of the Veli Lake. Mathew and Nair (1980) have worked on the phytoplankton of Ashtamudi estuary. Haridas (1982) made a detailed study of the zooplankton from 8 estuaries including Cochin backwaters along the Kerala coast. Sarala Devi *et al.* (1983) reported on the nutrient levels from 4 estuaries namely Mahe, Korapuzha, Kallai and Beypore along the north Kerala coast. Nair *et al.* (1983 & 1984 a, b, c) made extensive studies on different aspects of some of the backwaters of south Kerala.

Studies on Cochin Backwaters:

Cochin backwaters of Kerala is one of the better studied estuaries in India. General hydrographic studies of the estuary were made by Ramamirtham and Jayaraman (1963). Darbyshire (1967), Wellershaus (1974), Haridas et al. (1973) and Shynamma and Balakrishnan (1973). The tidal fluctuations were reported by George and ~~Krishnan~~ Kartha (1963) and Qasim and Gopinathan (1969); solar radiation by Qasim et al. (1968); nutrient distribution by Sankaranarayanan and Qasim (1969); Joseph (1974) and Manikoth and Salih (1974); silting by Gopinathan and Qasim (1971); sediments by Murthy and Veerayya (1972 a, b) and Veerayya and Murthy (1974); trace elements by Murthy and Veerayya (1981); phosphate regeneration by Reddy and Sankaranarayanan (1972) and nanoplankton by Qasim et al. (1974). Organic production and phytoplankton ecology and related aspects have been studied by Qasim and Reddy (1967), Qasim et al. (1969), Qasim (1970), and Devassy and Bhattathiri (1974).

Studies on the different aspects of zooplankton were made by several authors (George, 1958; Nair and Tranter, 1971; Wellershaus, 1974; Menon et al., 1971; Santhakumari and Vannucci, 1971; Nair, 1971, 1973; Srinivasan, 1971; Pillai and Pillai, 1973; Pillai et al., 1973; Madhupratap, 1978, 1979, 1980; Madhupratap et al., 1977 and Haridas, (1982). Benthic population studies of the estuary were attempted by Desai and Krishnan Kutty (1967 a, b), Damodaran (1973), Kurian (1974), Kurian *et al.* (1975), Devassy and Gopinathan (1970), Ansari (1977), Gopalakrishnan *et al.* (1977), Gopalakrishna Pillai (1978) and Nair *et al.* (1983).

1.2. Studies on benthos, its importance and biological aspects of pollution:

The pioneering work on benthos was by Peterson (1913) in Danish waters. In India the bottom fauna was first studied by Annandale (1907) and Annandale and Kemp (1915). Panikkar and Aiyar (1937) studied the bottom fauna of brackish waters of Madras. Seshappa (1953) and Kurian (1953) worked on the benthos of Malabar and Trivandrum coasts respectively. Balasubramanian (1961) studied the benthos of Vellar estuary. Rajan (1964) worked on the benthic fauna of Chilka Lake. Kurian (1967) has given an account of benthos of south west coast of India. Desai and Krishnan Kutty (1967 a) have studied the bottom fauna of the Cochin backwaters. Desai and Krishnan Kutty (1967 b) have also made a comparative study of marine and estuarine benthic fauna of nearshore region of the Arabian Sea.

Kurian (1972) has worked on the ecology of benthos of Cochin backwaters. Parulekar (1973) has studied the distribution of benthos in the inner shelf of central west coast of India. Damodaran (1973) worked on the benthos of mud banks of Kerala coast. Ansari (1974) has investigated the macrobenthic production in Vembanad Lake. Parulekar and Dwivedi (1974) have made investigation on the benthic population of estuarine region of Goa. Kurian et al. (1975) have studied the distribution of bottom fauna of Vembanad Lake. Harkrantra (1975) has made observations on the distribution of benthos of Kali estuary. Ansari (1977) and Pillai (1978) have studied the distribution of macrobenthos of the Cochin backwaters. Harkrantra et al. (1980) have worked on the benthos of shelf region along the west coast of India. Parulekar et al. (1980) have made observations on the benthic macrofaunal annual cycle of distribution, production and trophic relation in Goa estuaries. Murugan et al. (1980) studied the bottom fauna of Veli Lake. Parulekar et al. (1982) have given an account of the benthic production and assessment of demersal fishery resources of Indian seas. Divakaran et al. (1981) studied the benthos of Ashtamudi estuary, whereas the ecology and distribution of benthic fauna of Ashtamudi estuary was carried out by Nair et al. (1984 c). The benthic production of northern Vembanad Lake was studied by Anwar Bacha (1984).

Benthic production is of importance in assessing the biological productivity of an area. It is well recognised that the distribution and abundance of benthic animals of a region are directly related to the fisheries of that region. Benthos forming an important source of food for demersal fishes can be a good indicator of fish stocks. A knowledge of bottom community composition can help to solve problems relating to past communities and their habitats. Blegvad (1932), Jones (1956) and Sanders (1956) after carrying out intensive studies on the bottom fauna have revealed the importance of study of the bottom biomass in the evaluation of utilization of benthos as food for the higher carnivores and fishes. Damel and Mulicki (1954), Kurian (1971) and Savich (1972) have demonstrated a direct relationship between the demersal fish catch and abundance of bottom fauna. The data given by Prabhu and Dhavan (1974) for the demersal catch of Goa coast suggest that the major part of the trawl catch from 20 m depth consists of fishes feeding largely on benthos. The high average of macrobenthos (240 g/ml^2) contributed predominantly by polychaetes and bivalves appear to make an important contribution to the food of the fish of the shallow bays.

Until 1963, the study of marine bottom living animals and plants were primarily the province of basic research, but for some studies devoted to the productivity of bottom fishing grounds. Emphasis was placed on satisfying our own scientific curiosity as to life history studies of noncommercial bottom animals; physiology, composition and abundance of benthic communities. In the intervening years between 1963 and 1972 there has been a steady shift in the study of benthic communities from the basic to the applied aspects such as the effect of oil pollution on the benthic standing crops and productivity. The sand deposits, where oil accumulates, will have characteristic benthic assemblages which reveal how the sand got their direction to the ancient shoreline. Using these clues supplied by benthic animal studies, it has been possible to help discover new deposits of oil and gas (Parker, 1975).

Benthic populations are structural communities with numerous connecting links. Disruption of these communities by external stress like pollution, can affect the entire aquatic food web. Continuous discharge of industrial wastes into the aquatic environment endangers the safety of aquatic life and can reach the human body through the food chain. Although pollution may be caused by chemical or physical agencies it is essentially a biological phenomenon. Klein (1962) stated that after years of chemical and physical testing of river water the boards are today experiencing difficulties in the setting up of standards for effluents and it will only be in the light of biological surveys and tests that these standards can eventually be successfully determined. A knowledge of the biological aspects of pollution is not only of interest but also essential to study the problems of pollution in a given area. Biologists recognised the limitations of chemical and physical measurements of water quality and have searched for organisms which could serve as indicators of different degrees of pollution. Organisms particularly ~~those attached on~~ of the bottom inhabitants, are favoured by many, since they reflect the water condition not only at the time of sampling but for sometime past as well.

The changes brought about by the deposition of pollutants on the bottom greatly affect the bottom fauna and flora. Most of the bottom dwelling animals are detritus feeders. The role of predators declines as depth increases and detritus feeders and other bottom feeders become the predominant forms. Hence benthic fauna has a direct relationship with the type of the bottom and that the physical nature of the substratum act as a limiting factor to a considerable extent (Sanders, 1958). Benthos therefore may be treated as sensitive indicators of the conditions of accumulation of organic matter in sediments (Bordovskiy, 1964). Though extensive studies were made on benthos of different estuaries and shelf regions of India, very little information is available on the benthic fauna in relation to pollution. Dwivedi *et al.* (1975) have studied the macrobenthos of a sewage outfall at Goa. Work on the bioecology of the benthic fauna in the industrially and domestically polluted waters of Visakhapatnam Harbour was carried out by Ganapati and Raman (1976 a). An elaborate study of the benthic fauna of sewage and retting yard was made by Remani (1979) and Remani *et al.* (1983) reported on the indicator species of organic pollution in the Cochin backwaters.

Generally pollution affects stream community structure, predominantly by reducing species diversity. The elimination of nontolerant species is often accompanied by -

1. Increase in stream productivity of benthic invertebrates due to lack of predation and competition.
2. Changes and simplification in food chain and
3. In the case of organic pollution a seemingly inexhaustable allocthonous source of food for the remaining tolerant species.

1.3. Aspects of river pollution:

Eventhough a precise definition for river pollution is rather difficult, it may be defined as an undesirable change in its physical, chemical and biological properties leading to a lowering of water quality. Environmental contamination is an inevitable consequence of the activities of man and a natural phenomenon as well. Whether in an industrial society or in an agricultural society, placing waste material, partially used consumer goods and other byproducts, into the environment by man has characterised his activities. Along with the technological advancement and rapid industrialization, problem of pollution has increased considerably. World oceans have been considered inexhaustable in all their resources. But as a result of prolonged abuse and exploitation, this huge aqueous reservoir is under severe human impingement. The presnet amount of scientific endeavour, extended to this field in the last decade and a half, would avidly vouch for the decadent state of our environment. Not only are the estuary and nearshore areas subjected to severe stress but even the deep oceans show evidence of man's irrational behaviour. Contamination of environment is also a social problem which has created a new order of byproducts which increased in volume at a faster rate than population and has further been concentrated by our megapolitan tendencies. This has resulted in increasing contamination of the environment surrounding the habitats of man to the point where the self purification can no longer cope with, thus leading to pollution which has become a global problem today.

Pollutants can be in solid, liquid or gaseous state. As liquid it may contain dissolved materials or suspended matter as well as dissolved gases of a polluting character. The commonest form of pollution of serious concern to rivers however is of liquid nature which also include solid in suspension due to combined or independent discharge of sewage and industrial waste into the rivers and their tidal reaches. Industries are the worst polluting agencies as they draw water from rivers and throw back almost same quantity after loading it with waste and chemicals which causes severe pollution problems. Sewage is a cloudy dilute aqueous solution containing minerals and organic matter in many forms as large and small solid particles either as floating or in suspension as colloidal and pseudocolloidal dispersant. Sewage also contain living matter such as bacteria, viruses and protozoans. Among the industries the chemical industry is considered to be a major contributor to pollution of the environment. This industry produces many of the materials necessary for increasing agricultural products, raw materials for other industries and products for maintaining approved health and living standards. The rapid industrial expansion without adequate attention to raise the standard of human settlement has led to uncontrolled, unhygenic and insanitary environment in India.

India has a vast coastline with numerous rivers and estuaries periodically enriching the coastal waters with essential nutrients and minerals. Our coastal waters are very important nursery grounds for fishes and prawns and the growing pollution is apt to cause a decline of fisheries in our country. The means of controlling the pollution nuisance and hazards, to protect fishermen and consumers, are of vital importance for the continuing exploitation of the sea for commercial fisheries. Marine pollution is also a threat to tourist and recreation centres. Water, once polluted is not fit for drinking or any other use by man. Depending on the chemicals present in the effluent, it can produce food poisoning or skin infection. The pathogenic bacteria present in the polluted water can produce diseases like diarrhoea, dysentry, typhoid, gastroenteritis etc. Pollution particularly by large scale industrial dereliction and the indiscriminate discharge of waste are the obvious destroyer of our resources.

Due to their easy accessibility and consequent high human influences, rivers, estuaries and coastal areas are more susceptible to effects of pollution. Estuaries are the transition regions of fresh water streams to the tidal saline ocean. The flow in an estuary is affected by the conditions at both ends of this transitional zone and are modified by the configuration of the estuary, by winds and by point discharges. The augmentation of seaward flowing surface waters by the intrusion of sea water enhances the capacity of estuarine waters for transporting water. Man modifies the configuration of estuaries, the fresh water flows and waste discharges. These modifications affect the currents, suspended solid concentration, tides and dissolved materials in the estuary. All biota are subjected to these effects. It is evident that perturbation of any type, whether natural or man-made, may cause various shifts in kinds and number of species and relative sizes of population. This also affects the reproductive success, prey-predator relationship and various interactions between species.

Rivers, being often used as disposal areas for domestic and industrial wastes, estuaries act as transit area for pollutants on their way to marine environment. Hence it is important to consider effects of pollutants on the estuarine sediment, water and biota. A knowledge of the ecological requirements of aquatic organisms can be of considerable value in determining the changes that occur in aquatic habitat due to pollution. Pollutants may alter stream environment thereby affecting the aquatic life in a number of ways. These changes may include an increase in contents of dissolved nutrients, decrease or increase in amount of dissolved oxygen, increase in turbidity value or a change in the character of the stream bottom. The degree or extent of the effect of these changes on the aquatic life varies with type and amount of the pollutant and the character of the biota. For traditional fishing and for aquaculture in coastal waters the maintenance of water quality is of paramount importance. Thus a proper understanding of the environmental parameters and their effects on the biota is a pre-requisite in the management of any ecosystem.

India has several major riverine and estuarine systems. Along the east coast are the Hoogly, Mahanadi, Godavari, Krishna and Cauvery rivers and Pulikat and Chilka Lakes. On the west coast we have the Narmada, Tapti, Mandovi and Zuari rivers and Vembanad Lake. The Pulikat and Chilka Lakes of the east coast and Vembanad Lake of the west coast form large bodies of brackish water. Apart from these many riverlets creeks, and streams also contribute to the estuarine wealth of India.

The main water bodies of Kerala are 41 west flowing rivers which drain water into the Arabian Sea through the backwaters and 4 east flowing rivers. Major rivers of Kerala namely Chaliyar, Bharatapuzha, Chalakkudypuzha, Periyar, Pamba, Muvattupuzha, Kallada and Achancoil carry 4.056 million m^3 of water annually for discharge into Arabian Sea.

It has been estimated that 5 lakhs m^3 of trade effluents are being dumped into the rivers of the State every day (Jeysing, 1976). Indiscriminate discharge of trade effluents with high BOD, toxic chemicals and suspended solids has rendered, but for 6 rivers, all the rest unsuitable for fishing and recreation uses. In Kerala, for their daily requirements 85% of the people depend directly on water from rivers, ponds and wells.

The location of a chemical industry is always selected depending on the availability of reasonably good water for the process and the facilities for discharging waste water into the stream without inconveniencing other activities. Thus, river Chaliyar is polluted due to the discharge of pulp effluents of Gwaliyor Rayons silk manufacturing company whereas pollution in Chalakkudy river is due to the discharge of Madura Coats, Tapioca Starch Products and Paulson Distillery.

1.4. Pollution studies on estuaries in India:

While extensive work on hydrographical and biological aspects of different estuaries in India have been made by many authors, studies on pollution aspects have received very little attention. In the east coast, different aspects of pollution studies were made by David (1959) in Kulti, Gopalakrishnan et al. (1970) in Hoogly, and Ganapati and Chacko (1951), Ganapati and Raman (1973, 1976 a, b) in Visakhapatnam harbour. In Vellar estuary seasonal variations of carbon, nitrogen and phosphorous in the sediments were studied by Sivakumar et al. (1983) and effect of pesticides on phytoplankton production by Rajendran and Venugopalan (1973).

Along west coast of India, pollution studies were made by Zingde et al. (1979 a, b, c; 1980 a, b, c) who gave an account on water quality and effects of industrial waste disposal in River Par Mahim Creek Velsao and River Kolak in Bombay and River Dama Ganga in Gujarat. Desai (1971) discussed the problems of sewage and industrial waste discharges around Bombay waters. Dwivedi and Parulekar (1974) studied the effect of oil pollution along the Indian coastline. Benthic population of a sewage outfall in Panjim, Goa was worked out by Dwivedi et al. (1975). Monitoring of some environmental parameters at Zuari river was done by Desousa (1977). Monitoring studies of water and sediments of

Ulhas river, northeast Bombay was carried out by Shahu and Mukerjee (1983). Base line study of water quality of the river Narmada (Gujarat) was done by Zingde et al. (1981). Chaetognaths and copepods from the polluted and unpolluted zones of Bombay waters were compared by Nair et al. (1981) and Gajbee et al. (1981).

In Kerala, pollution studies were initiated by Unnithan et al. (1975). Unnithan (1976) discussed the problems of pollution in the backwaters of Kerala. Nair et al. (1976 a, b) have given an account of the problems of pesticide pollution in the Kuttanad area and the effect of pollutants on the algal production. Vijayan et al. (1976) discussed the effects of organic pollution on some hydrographic features of Cochin backwaters. Studies on the toxic effect of copper on the bivalve Villorita cyprinoides were carried out by Lakshmanan and Nambisan (1976). Indicator bacterial pollution in the Cochin backwaters was studied by Chandrika (1976) and Gore et al. (1979). Fish mortality from industrially polluted area of the Cochin backwater system was reported by Silas and Pillai (1976) and Unnithan et al. (1977). Gore and Unnithan (1977) worked on Thiobacilli from Cochin backwaters and their oxidation and corrosion activity. Sarala Devi et al. (1979) studied the hydrographic features and water quality of Cochin backwaters in relation to industrial pollution. Radhakrishnan et al.

(1979) have studied the microbial decomposition of the floating weed *Salvinia molesta* of Cochin backwaters. Studies on the effect of pollution with special reference to benthos were carried out by Remani (1979). The changes in ecology of the Cochin backwater system brought about by human activities were discussed by Qasim and Madhupratap (1979). Sediments of Cochin backwaters in relation to pollution have been investigated by Remani *et al.* (1980). Fish kill at Chitrapuzha was recorded by Venugopal *et al.* (1980). Remani *et al.* (1981) studied the sediment of a retting yard in Cochin backwaters. Trace metal level in the sediments of Cochin backwaters was studied by Venugopal *et al.* (1982). Indicator organisms of pollution of Cochin backwaters were studied by Remani *et al.* (1983). Seasonal variations in trace metal content in *Villorita cyprinoides*, *Meretrix casta* and *Perna viridis* were studied by Lakshmanan and Nambisan (1986). Rajendran and Kurian (1986) studied the metal concentration in the water, sediment and oysters in the Cochin backwaters. Environmental conditions of some paddy-cum-prawn culture fields from three areas of Cochin backwaters were studied by Nair *et al.* (1986). Cochin backwater system and the lower reaches of the river Periyar were studied in detail to assess the longitudinal extent of salt water intrusion into the system and its effect on the flushing of pollutants introduced by the industries by Sankaranarayanan *et al.* (1986).

1.5. Scope and purpose of study:

River Periyar receives effluents from a cluster of chemical and metallurgical industries located at Udyogamandal, and the Chitrapuzha is in receipt of the discharge of FACT Cochin Division and Cochin Oil Refinery at Ambalamedu. Effluents from all these factories reach the Vembanad Lake at the north and south limbs of the estuary respectively. Another factor of concern to industries and the residents of the area is the increase in salt content in the river water during dry months rendering it unfit for domestic water supply, irrigation and for any other purpose. The industries are trying to protect the water near their pumping stations in the river from contamination by intrusion of saline waters by providing bunds at suitable locations. Apart from this, Cochin backwaters is also subjected to the effects of organic pollution, caused by municipal sewage discharge, retting of coconut husks and discharges from food and marine products processing industries.

Cochin backwater is unique for its traditional prawn, clams and oysters fisheries. It is well recognised that the distribution and abundance of benthic animals are directly related to the fisheries of that region. The benthic biomass helps to evaluate their utilization as food for higher carnivores and demersal fishes (Blegvad, 1932; Sanders, 1956). Since benthic population are structural communities with numerous connecting links, disruption of these communities by external stresses like pollution can affect the entire aquatic food web. Abundance and diversity of biotic community in backwaters, are influenced by the interaction of a series of physico-chemical factors. Since the pollution effects are more conspicuous in the bottom, a qualitative and quantitative study of the bottom dwelling animals, sediment characteristics and the hydrographical features of the overlying water, will be useful to evaluate the extent of pollution effects in the system. Hence a detailed investigation on these aspects in areas of Cochin backwater around the industrial complex is attempted.

Cochin backwaters comprise an area continuously polluted from 3 major sources. They are the sewage pollution including land drainage from the surrounding localities, foul smelling stagnant waters from the retting grounds dotting the backwaters and the industrial effluents from Udyogmandal area. Sewage is a cloudy fluid arising out of domestic and industrial sources containing minerals and organic matter either in solution or having particles of solid matter floating or in suspension or in colloidal or in pseudocolloidal form in dispersion (Jhingran, 1976). Retting pollution is the result of pectinolytic activity of micro-organisms, especially bacteria and fungi, leading to liberation of large amounts of organic substances as tannin, fat, pentosan and pectin into the medium along with leaching of polyphenols.

Both the sewage and retting pollution also termed as organic pollution lead to oxygen depletion as a result of production of hydrogen sulphide and deposition of organic matter accelerated by higher temperature of premonsoon period. However Vijayan et al. (1976) found the sewage polluted areas never becoming depleted of oxygen permanently due to tidal mixing of the waters. But Remani (1979) found anoxic condition in the retting yard due to stagnation except during monsoon periods when rejuvenation took place to a certain extent. Remani also noted adverse pollution effects on the benthic fauna as reduced abundance and differences in the distribution of species according to their level of tolerance to polluted conditions.

However, the inorganic industrial pollution caused by the effluent discharhe around Udyogamandal area was unique ~~being inorganic~~ as it never amounted to organic pollution as earlier environmental studies neither indicated anoxic condition nor increase in organic matter contents.

Geomorphologically, the Cochin backwater system is believed to have originated in the 4th century A.D. and the Cochin gut was opened up as a result of the diversion for the Periyar river after the deluge in 1341 A.D. Recently this system has undergone the most serious anthropogenic environmental alterations, leading to an alarming rate of reduction in extent by about 35% as a result of construction of bunds and reclamation for agriculture, harbour and urban development. Since 1970 an area covering 176 hectares have been reclaimed for harbour and urban development. The existing geomorphological features of this estuarine sector brought about by natural and man-made alterations can be clearly seen in the Satellite imagery trace of the Land Sat France E 1202-04454 of the Eros Data Centre, USA reproduced by Mallik and Suchindran (1984). Also the siltations caused by river discharge and tidal influx has been a major factor contributing for the decrease in the depth of the backwaters. Studies on the sedimentation rate showed a deposit of 20 mm/year. Shell deposits at a depth of 2.5 to 5 metres indicated that the backwaters were deeper in the past. Thus the vertical and horizontal shrinkage of the estuary affected the carrying capacity of the system. The growing inflow of effluents from industrial, agricultural, domestic and retting sources compound its deterioration. Thus reclamation and siltation caused shrinkage which has affected the living resources.

The decreasing volume of backwaters and the limited exchange rate with the sea reduced the diluting capacity of the backwaters leading to mass mortality of benthic fauna and the fishes and prawns. Thus the physical alterations have also played their role in changing the abundance and composition of fauna and flora as is the case with the extinct estuarine crocodile *Crocodilus porosus* and dwindling of prawn fishery especially that of the fresh water giant prawn *Macrobrachium rosenbergi* and oyster and clam fisheries.

The series of earlier studies on the physico-chemical and biological processes of the backwater by Bristow (1938), Desai and Krishnan Kutty (1967), Qasim *et al*. (1968), Qasim and Gopinathan (1969), Sankaranarayanan and Qasim (1969), Nair and Tranter (1971), Madhupratap and Rao (1979), Haridas *et al*. (1973) etc. revealed the high life carrying capacity of this ecosystem as well as its problems and potentialities for development of fisheries.

But recent studies by Unnithan *et al*. (1975), Sarala Devi *et al*. (1979), Qasim and Madhupratap (1979), Gore *et al*. (1979) and Remani *et al*. (1979) have pointed out the rapid rate of environmental deterioration taking place in the backwaters.

Recognizing the importance of the significant role in the socio-economic and cultural aspects played by this part of Cochin backwaters in the life of Cochinites the need is felt to protect the backwaters considering its role as the most important coastal life support system and as an indispensible medium for the existence of various economically important marine as well as fresh water living resources. Hence the need was felt to suggest necessary control measures to maintain a healthy estuarine environment by studying the effect of various environmental parameters on the benthic fauna of this region.

With a view to understand the mechanism by which industrial effluents controlled/affected the abundance and distribution patterns of benthic fauna, the present investigation was taken up. Primarily it was thought that the toxic effect of pollutants from the effluents controlled the population of the benthic fauna of this region. Based on the earlier studies on the hydrographic features and water quality of Cochin backwaters, Sarala Devi et al. (1979) felt that pollution caused by the effluents from the different factories was largely localised one. They also noticed the stress diminishing gradually away from the discharge point towards both upstream and downstream. The accumulation of black suspended matter on the intertidal flora for about 1 km downstream was noteworthy during the study period. Similar type of suspended matter was also found in the sea-bottom sediment of the downstream station of discharge site. This may be contributed by the black effluent discharged from the FACT. The above factors prompted to study the area extensively.

Sankaranarayanan *et al.* (1986) also noticed a decreasing trend in pollution effects from the discharge site towards the estuarine mouth, which they attributed to the dilution of toxic effluents by the flushing mechanism, water currents and flow pattern.

In addition the need was felt to identify any species if found suitable as an indicator organism for the various industrial effluents discharged as noted by various workers.

So far no work has been undertaken on the benthic fauna of the area in and around the industrial belt at Eloor. The present work includes the species composition and distribution of macrofauna from 9 stations in Cochin backwaters, upstream and downstream of the effluent discharge site at Eloor. An attempt has also been made to correlate the different species with the environmental parameters studied from this area.

2. MATERIAL AND METHODS.

2. MATERIAL AND METHODS.

2.1. Area of Study:

The Cochin backwaters (9°58'N - 76°15'E) possessing a tidal area of approximately 300 m^2 are inter-connected by canals penetrating the mainland and encircling many islands in between. A channel of about 450 m wide forming the entrance to the Cochin harbour and another opening further north at Azhikode have linked the backwaters permanently with the Arabian Sea.

While Pamba, Meenachil and Muvattupuzha rivers emptied their water into the backwater system on its southern limb, only Periyar joined the northern limb. A number of chemical and metallurgical industries namely Fertilisers and Chemicals Travancore Ltd. (FACT), Travancore Cochin Chemicals (TCC), Indian Rare Earths (IRE), Cominco Binani, Periyar Chemicals, Hindustan Insecticides, Catalyst and Chemicals, Indian Aluminium Company are located at Udyogamandal. The effluents from these factories are regularly discharged into the river Periyar to be carried to the backwaters. Chitrapuzha, receiving effluents which contribute the major pollutants of the backwater from FACT Cochin Division at Ambalamedu, also joined the backwater.

The backwaters also received either directly or indirectly the sullage water and municipal sewage from the Cochin city. The total consumption of drinking water in this urban area was roughly 14 million gallons per day of which a high percentage joined the drainage and reached the backwaters through a net work of canals.

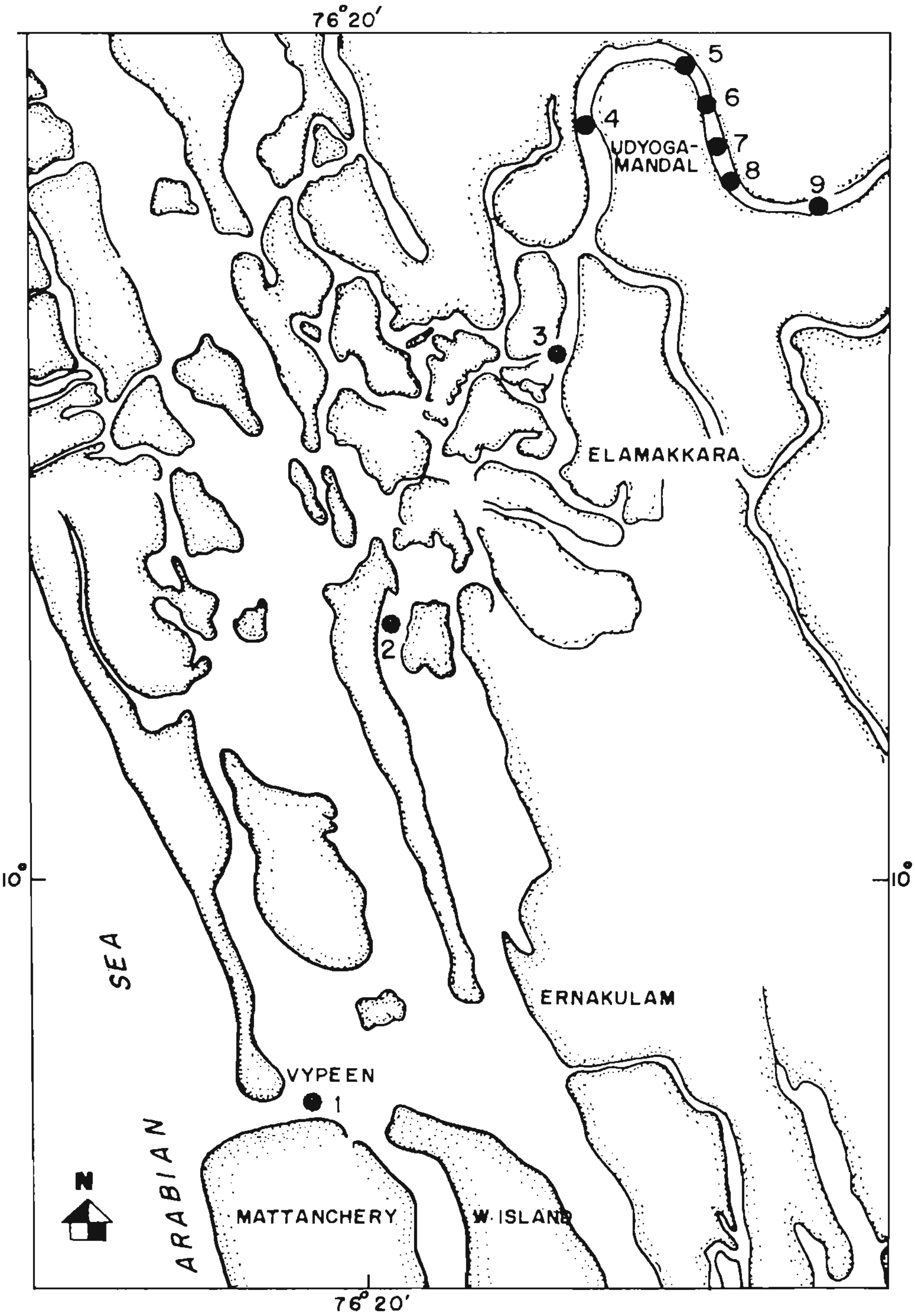
Monthly observations were made in the study area for one year in 1981. Nine stations were sampled from Barmouth to Kalamassery, covering 21 km upstream. The stations (Figs. 1 a & b) were located near barmouth (Stn. 1, 8 m), at Mulavukad (Stn. 2, 2 m), Varapuzha down (Stn. 3, 2.5 m), Varapuzha (Stn. 4, 5 m), near new Panchayath Jetty (Stn. 5, 2.5 m), old Panchayath Jetty down (Stn. 6, 2.5 m), old Panchayath Jetty (Stn. 7, 2.5 m), Eloor (Stn. 8, 3 m) and Kalamassery (Stn. 9, 4 m).

2.2. Material - Benthic fauna, sediments, water and effluent samples:

A total of 99 grab samples were collected to sort out benthic organisms, at the rate of 9 samples in each month, each sample representing one station. As a result 2.47 million specimens were available for the studies.

Grab samples were collected separately as above for sediment analysis and for estimation of organic carbon and grain size.

Fig. 1 a. Map showing locations of the nine stations in the Cochin Backwaters.



76°20'
5
6
4
7
UDYOGA-
MANDAL
8
9
3
ELAMAKKARA
2
10°
10°
SEA
ERNAKULAM
VYPEEN
1
ARABIAN
N
MATTANCHERY
W. ISLAND
76°20'

Fig. 1 a

Fig. 1 b. Chart showing the distance between the Stations and their depths.

STATION - 1 TO STATION - 9, 21 KM.

Distance	Station	Location	Depth
	Stn. 1	NEAR BARMOUTH	7 M. Depth
3·2 km			
	Stn. 2	MULAVUKAD	4 " "
6·8 km			
	Stn. 3	VARAPUZHA DOWN	3·5 " "
3·6 km			
	Stn. 4	VARAPUZHA	5 " "
4 km			
	Stn. 5	NEAR PANJAYAT JETTY	2·5 " "
1 km			
	Stn. 6	OLD PANJAYAT JETTY DOWN	2·5 " "
0·8 km			
	Stn. 7	OLD PANJAYAT JETTY	2·5 " "
0·2 km			
	Stn. 8	ELOOR	2·5 " "
1·5 km			
	Stn. 9	KALAMASSERY	4·5 " "

Fig. 1 b

Water retained in the grab, when it was brought on the deck, was also collected as "grab water" for analysis of nutrients, salinity, alkalinity and pH.

Water samples for analysis of physico-chemical variables were collected from the surface and bottom of each station. In all 198 water samples were collected during 11 months from the 9 stations.

However, effluent samples could be collected only during four months of February, April, July and August at the rate of 2 each from FACT and TCC and one each from other factories. Simultaneously samples were collected from an area 10 metres away from the effluent discharge points. Also source water samples were collected from Eloor Kadavu.

2.3. Methods - Measurement of variables:

2.3.1. Collection and treatment of biological data:

Benthos were collected using a Van Veen Grab (mouth area : 0.048 m^2). All organisms retained by a 0.5 mm mesh sieve (Birkett and McIntyre, 1971) were collected and preserved in 5% neutral formaline mixed with the rose bengal, for subsequent identification. The actual number of organisms counted were converted to number per m^2. The biomass values were expressed as wet weight in grams per m^2, (Shell on weight).

2.3.2. Sediment samples: Collection, treatment, grain size analysis and estimation of organic carbon:

Sediment samples also were collected using Van Veen Grab. The samples were dried in a hot air oven at 95°C. The percentage of sand, silt and clay portions of this dried material was determined by sieving through a net of 62 u mesh size and pipette methods (Krumbein and Petti John, 1938). Another portion was used for estimation of organic carbon, using the method of El Wakeel and Riley (1957).

2.3.3. Physico-Chemical methods of water and effluent analysis:

Water samples were collected from the surface using a clean bucket and bottom sampling was done by Meyer-type sampler. Water samples were analysed for the following parameters. While temperature and pH were measured on board, rest of the parameters were done in the laboratory. Dissolved oxygen was estimated by Winkler method (Strickland and Parsons, 1965), chemical oxygen demand by dichromate method (APHA, 1960) and chlorinity by Mohr Knudson method (Barnes, 1959), chloride corrections were made by multiplying the corresponding chloride values for salinity by a factor of 0.225. This factor was arrived at by estimating chloride interference for a series of sodium chloride solution with ferrous chloride contents ranging from 710 to 28400 mg/l. Suspended solids were determined by filtering water sample through a previously weighed millipore filter paper (Pore size - 0.45 μm), drying the residue to constant weight at 80° to 90°C and reweighing. The difference in weights indicated amount of solids. A known volume of water sample was filtered through GF/C paper for particulate matter and on drying to a constant weight at 80° to 90°C, particulate carbon was estimated by the method of El Wakeel and Riley (1957). Alkalinity was estimated by back titration method (APHA, 1960). Unseeded dilution method was used to find the BOD_5, of water samples and seeded dilution for effluents. Attenuation coefficient ('K' values) was calculated by using the formula $K = \frac{1.7}{D}$ (Qasim *et al.*, 1968).

Nutrients, like inorganic phosphates, nitrate, nitrite and ammonical nitrogen were estimated using the methods of Murphy and Riley (1962) for inorganic phosphate, Bendschneider and Robinson (1952) for nitrite, Morris and Riley (1963) for nitrate and Indophenol Blue method of Koroleff (1969) for ammonia.

Effluents were collected in glass bottles from the discharge points of the factories. Identical methodology as employed for water samples were used for effluent samples. However, for BOD_5 estimation seeded dilution method was used for effluents.

The period of study was divided into three seasons depending on the SW and NE monsoons (although this is somewhat arbitrary, since the onset of rainfall varies from year to year) into premonsoon (February to May), monsoon (June to October) and postmonsoon (November to January) seasons. Observations were not made during February due to technical reasons.

2.3.4. Statistical methods:

Interpretation of data was done using cluster and regression analysis after transforming the original data using the transformation $Y = \log_{10} (x + 1)$ (Colebrook, 1965). Coexistence of species was studied by Karl Pearson's correlation coefficient. The correlation between parameters, between species and that of species with parameters were calculated and the intergroup correlation matrix showing the relationship was formed and tested for significance (Fisher and Yates, 1963). A 16 parameters multiple regression model was fitted. But, due to the insufficiency of the sample size, only the 9 relatively important parameters were selected and a 9 parameter multiple regression model was fitted and it was tested for its significance in predicting abundance of species using Analysis of Variance technique (Snedecor and Cochran, 1967).

Single linkage cluster analysis was carried out using the correlation matrix for combining the species and also the parameters at various similarity levels. The results are given as dendrograms showing the clusters at various similarity levels.

Species diversity was studied using Fisher's species diversity index (α) and variance was studied by means of variance of α (Fisher et al., 1943). Diversity in the species distribution was also studied using Shannon-Wiener function (Monte Lloyd and Ghelardi, 1964). Equitability among the species was studied using Mac Arthur's coefficient of equitability (Monte Lloyd and Ghelardi, 1964).

3. RESULTS

3. RESULTS.

3.1. Physico-chemical investigations:

Emphasis was given to the grab water values as the study focused more on benthos.

3.1.1. Salinity (‰):

Salinity was estimated to ascertain its role in controlling the spatial and temporal distribution pattern of benthic fauna. Fig. 2 shows the salinities of the water column and grab water. Spatial (Stations 1-9) and temporal (January to December) studies indicated the following results. Spatial variation of salinity was very prominent in January with a high value of 28.3‰ at Station 1 falling steeply to less than 0.4 ‰ at Stations 6 - 9. A similar pattern of salinity distribution was found during November and December also. In November the peak value of 26.6 ‰ at Station 1 was reduced abruptly to less than 0.5 ‰ at Stations 5 to 9. Similarly in December the peak value was also reduced abruptly from 27.6 ‰ at Station 1 to lesser than 0.5 ‰ in Stations 7 to 9. During March the peak value of salinity (28.5 ‰) at Station 1 was reduced gradually until it reached 3.9 ‰ at Station 9.

Fig. 2. Distribution of salinity at the 9 stations during 1981.

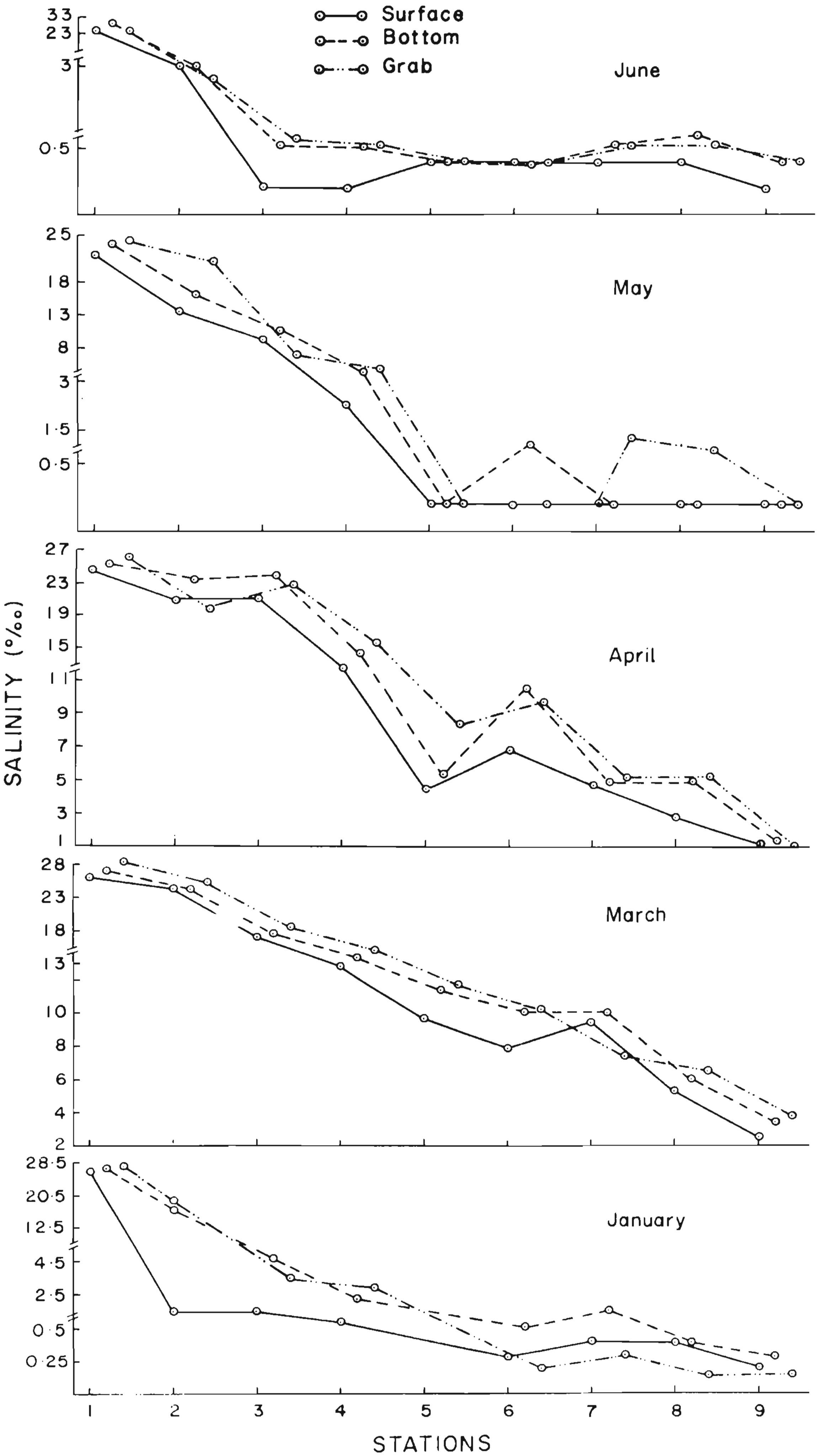
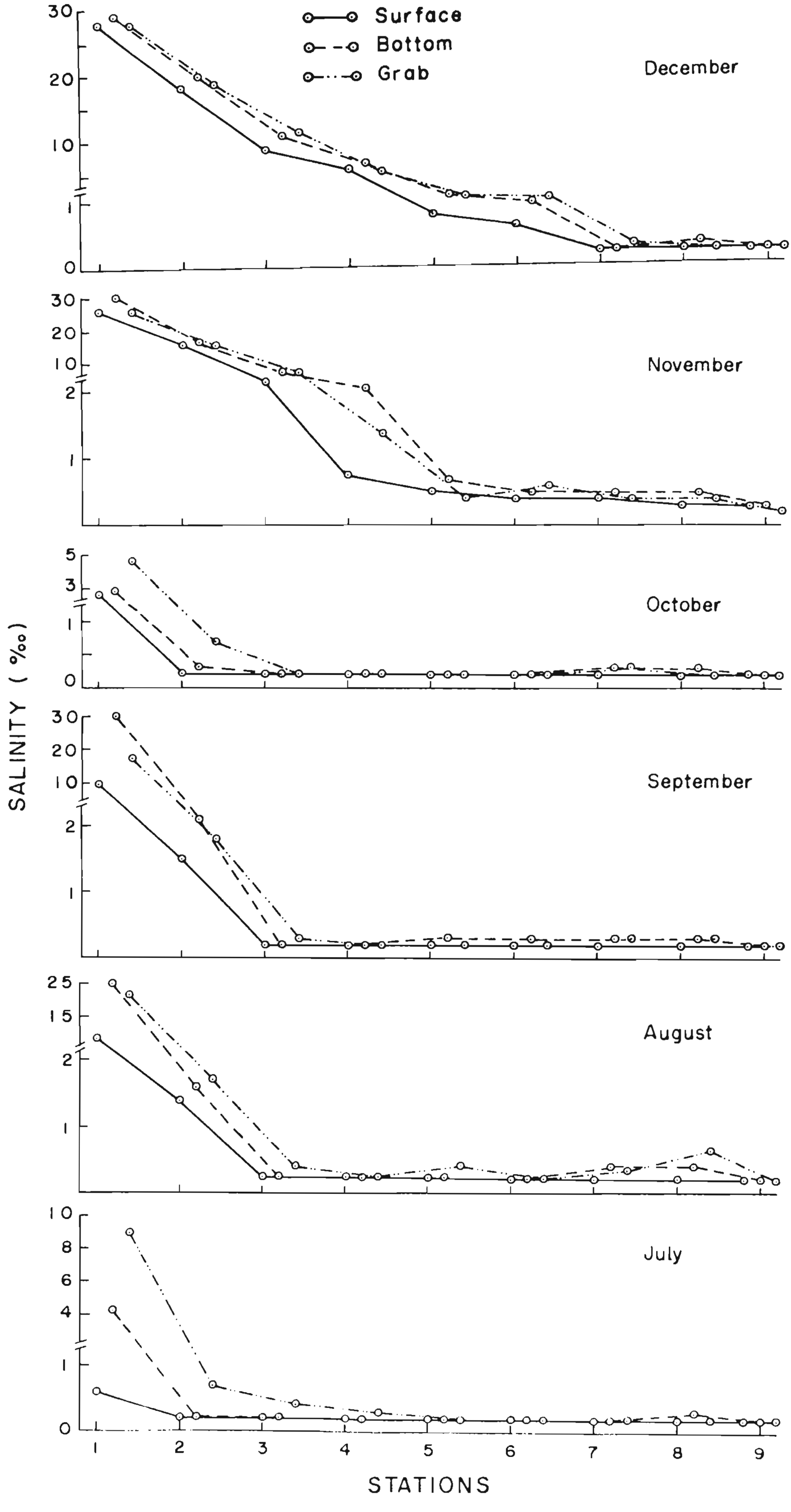

Surface
Bottom
Grab
June
May
April
March
January
SALINITY (‰)
STATIONS

Fig 2



Surface
Bottom
Grab
December
November
October
September
August
July
SALINITY (‰)
STATIONS
30
20
10
1
0
2
5
3
25
15
8
6
4
1
2
3
4
5
6
7
8
9

In April a similar fall in salinity from 26.9 ‰ at Station 1 to 5.3 ‰ at Station 8 was noticed as was seen during March. However, Station 9 had only 1 ‰ instead of 3.9 ‰ as in March. Salinity differences in May were more or less same as in January, with a peak value of 24.0 ‰ at Station 1 with a steep fall to 0.2 ‰ from Station 5 onwards. The spatial distribution pattern of salinity during the 5 months of June to October was more or less uniform with peak values, ranging from 4.6 to 24.3 ‰ at Station 1, which was reduced abruptly to very low values, of 0.7 ‰ to 2.6 ‰ at Station 2, thereafter maintaining very low values around 0.2 ‰ up to Station 9. The above results indicated the monsoonal effect during June to October when the outflow of fresh water was high. Thereafter as the monsoon flow started reducing, an increase in salt content could be seen during postmonsoon months. Subsequently with the incursion of more saline water, the salinity rose reaching a high value (3.9‰) even at Station 9 during March.

Spatial and temporal analysis of salinity variations at the surface and bottom of the water column indicated more or less same pattern of distribution in the grab, bottom and surface salinities. Stratification was noted during July to September at Station 1, the surface salinity values being considerably low compared to bottom values.

Temporal changes in salinity noted were as follows: Station 1 indicated an increase in salinity value from November (26.7 ‰) to March (28.5 ‰) and a fall to 8.9 ‰ in July, gradually reducting to 4.6 ‰ in October. Station 2 also showed a gradual increase in salinity from November to March, thereafter maintaining a steady value up to May, which was reduced abruptly up to a low value of 0.7 ‰ in October. But for the low value of 3.6 ‰ in January, Station 3 also exhibited an increase in salinity from November to April, thereafter reducing suddenly up to 0.2 ‰ in October. The above distribution pattern could be noticed at all stations from 4 to 9 eventhough the actual values varied. The general observation of very low saline water, except during March and April indicated the prevalence of fresh water from Station 2 onwards during June to October and from Station 5 onwards during November to January and in May.

3.1.2. Temperature (°C):

Temporal and spatial variations in temperature during January to December at Stations 1 to 9 are shown in Fig. 3.

Spatial variations in the surface and bottom temperature of the 9 stations were as follows: Eventhough at certain stations the surface temperatures exhibited higher values, in general the difference between surface and bottom temperature

Fig. 3. Distribution of temperature at the 9 stations during 1981.

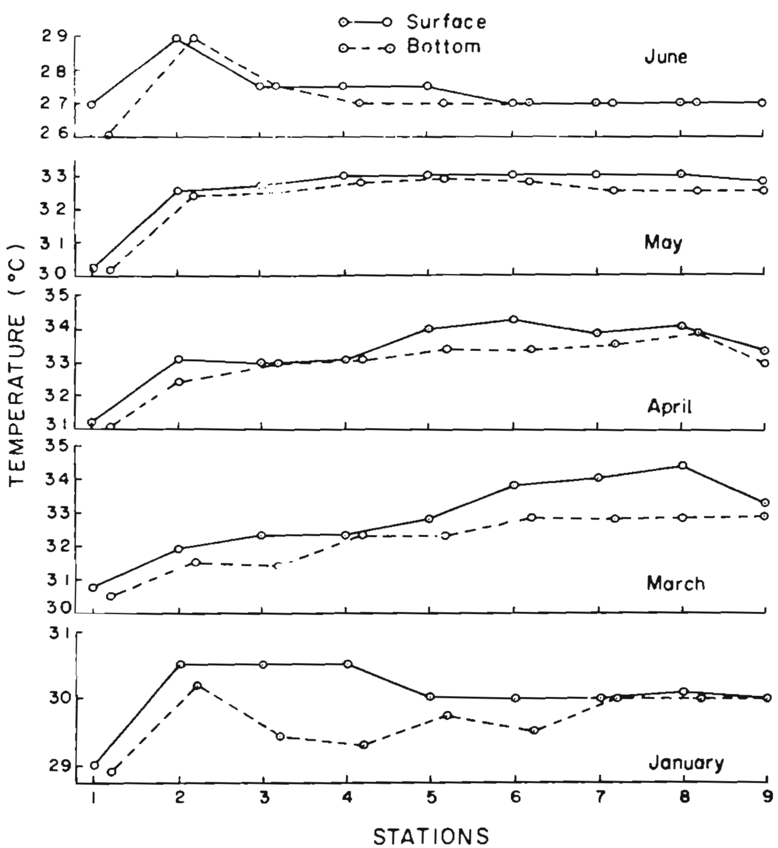

Surface
Bottom
June
May
April
March
January
TEMPERATURE (°C)
STATIONS

Fig 3

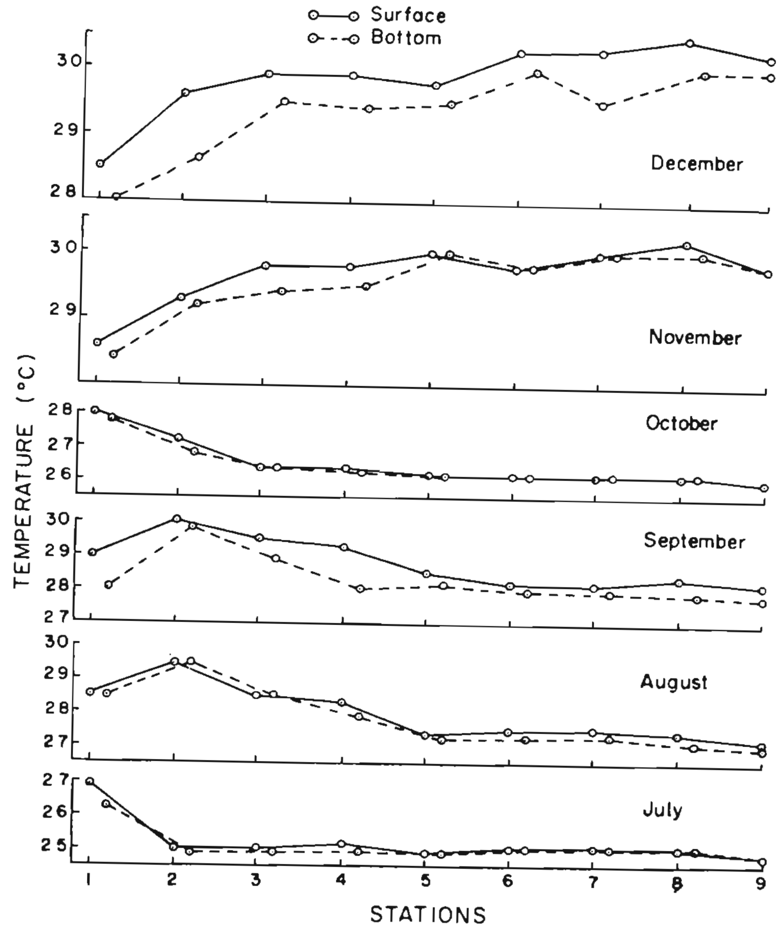

Surface
Bottom
December
November
October
September
August
July
TEMPERATURE (°C)
STATIONS

Fig. 3

were not well pronounced perhaps due to their shallow depths.

In January, but for a record of 29.0°C in Station 1 and a high value of 30.5°C in Stations 2, 3 and 4, rest of the stations registered a uniform temperature of 30°C. However bottom values ranged from 28.9°C to 30.2°C. Similarly November showed a temperature range varying from 29.3° to 30.2°C with the exemption of 28.6°C at Station 1 whereas bottom values ranged from 28.4° to 30.2°C. December, but for a low value of 28.5°C at Station 1, recorded temperatures ranging from 29.6°C to 30.5°C indicating a slight increase over that of November. The bottom temperature ranged between 28.0° and 30.0°C. Temperature variation during March, April and May followed the same pattern as compared to rest of the months probably due to a reduced river discharge. Thus the surface value during March, gradually increased from 30.8°C in Station 1 to 34.4°C in Station 8 with a fall in temperature to 33.3°C at Station 9. Similarly, the bottom temperature also varied between 30.5° and 32.9°C. More or less the same pattern of temperature increase was noted in April also with a low surface temperature value of 31.2°C in Station 1 and a high value of 34°C and 34.1°C at Stations 5 and 8 respectively. Bottom temperatures in April, ranged from 31° to 34°C. May recorded a general decrease in temperature compared to March and April, registering 30.3°C to 33.0°C at surface waters. Bottom water recorded a temperature range of 30.2° to 32.9°C. June to

October months, in general, registered a fall in temperature values compared to rest of the months due to high precipitation and out flow of river water. However, the temperature values registered a gradual increase at all stations from June to September. Thus June recorded identical surface and bottom temperature values at all the stations ranging from 26° to 29.0°C. July also showed an identical pattern with a temperature range of 24.5° to 27.0°C including surface and bottom values. August recorded a general increase in temperature over July. The surface and bottom temperature showed a variation from 27.1° to 29.5°C. Temperature values during September registered an increase over that of August ranging from 28.2° to 30.0° C, at the surface waters and from 28.0° to 29.8°C, at the bottom waters. October compared to September showed a general fall in temperature at all the stations. Thus the surface temperature ranged from 26° to 28.0°C and the bottom temperature from 26° to 27.8°C.

Temporal (monthly) variations of temperature at each station was as follows: At all stations, the comparatively low temperature recorded during June to October, showed an increase from November to January ascending further to higher values during March, April and May.

In general the spatial and temporal variations in temperature showed that the thermal structure was not affected by the high temperature (up to 40°C) of the discontinuous discharge of effluents. The higher volume of river water and fast flow during the monsoon season seems to absorb the excess heat introduced by the effluents effectively. Reduced river flow resulting in low replenishment and exchange of water along with the higher ambient heat seems to be responsible for the higher levels of temperature observed from March to May. These conditions effectively increase the capacity of the receiving waters to regulate and absorb the excess heat from the effluent.

3.1.3. Oxygen (ml/l):

Variations in oxygen content at the bottom and surface water of stations 1 to 9 during different months are depicted in Fig. 4.

Monthwise spatial analyses of oxygen contents of bottom water revealed following results. During January oxygen values showed a gradual increase from 4.3 ml/l at Station 1 to 5.3 ml/l at Stations 7, 8 and 9, but for a low value of 3.4 ml/l at Station 2. During March the comparatively low values of 2.2 to 2.85 ml/l at Stations 1 to 3 registered a gradual increase to 7.1 ml/l at Station 9 with the exception of 9.8 ml/l at Station 7. During April, but for high values at Station 1 (6.9 ml/l) and Station 4 (6.3 ml/l) rest of the stations registered an oxygen value ranging from 1.9 ml/l at Station 3 to 4.6 ml/l at Station 5. In May, but for Station 1

Fig. 4. Distribution of oxygen at the 9 stations during 1981.

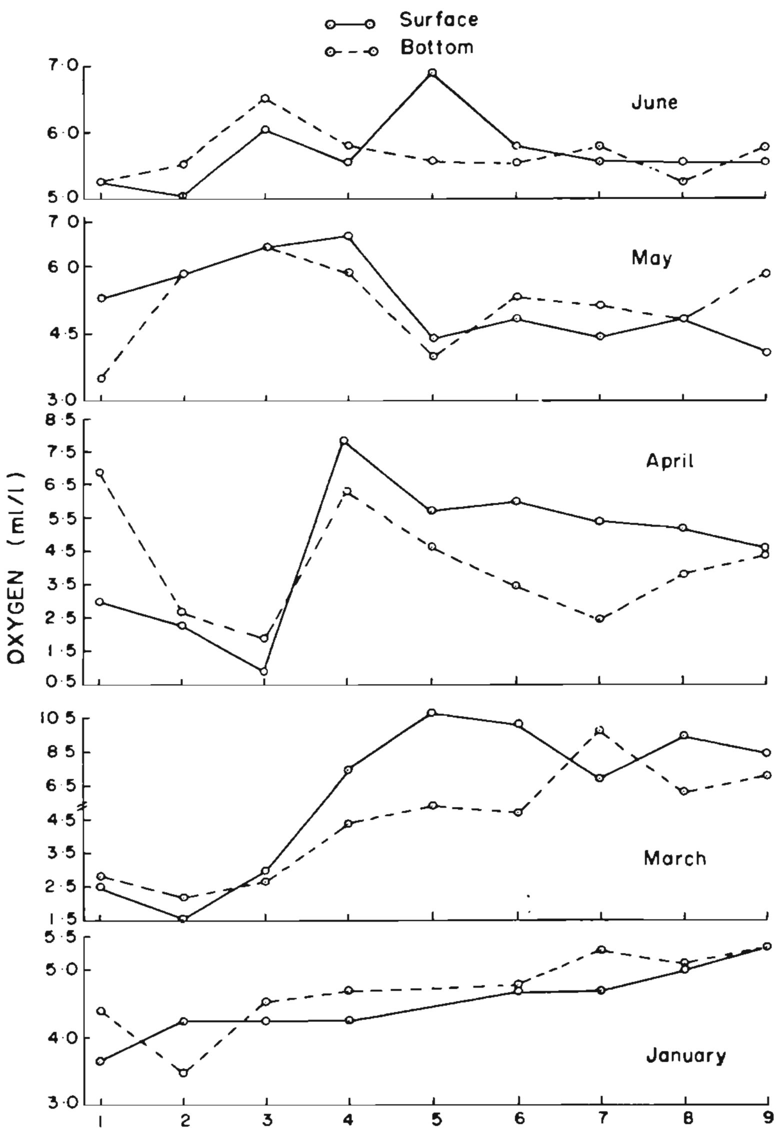

Surface
Bottom
June
May
April
March
January
OXYGEN (ml/l)
STATIONS

Fig. 4

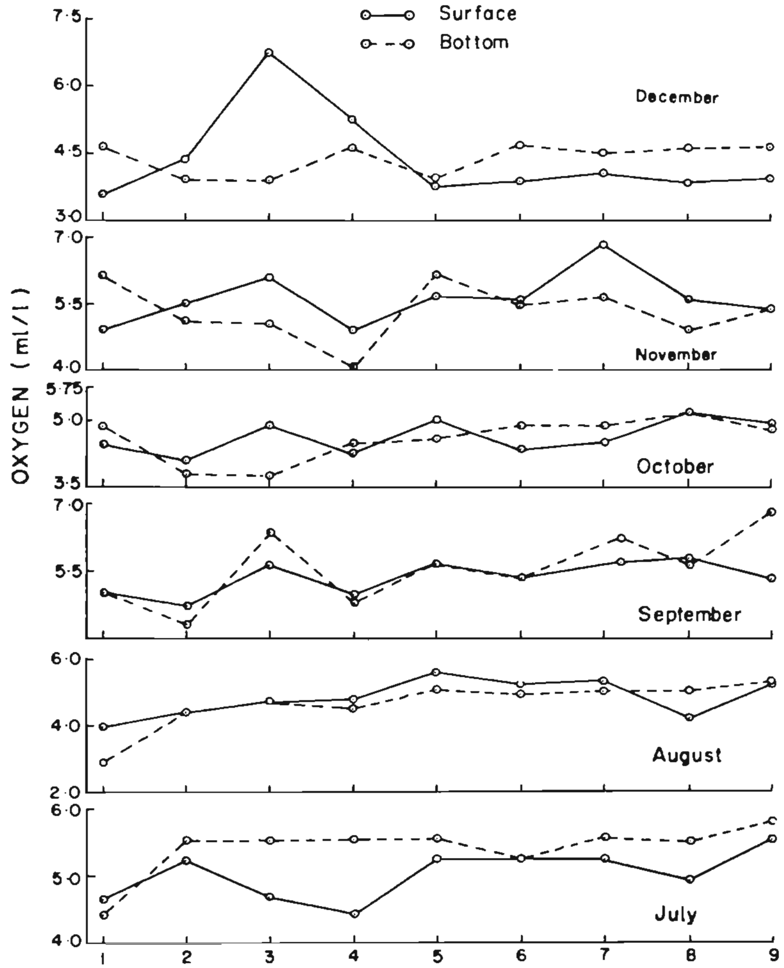

Surface
Bottom
December
November
October
September
August
July
OXYGEN (ml/l)
STATIONS

Fig 4

with 3.3 ml/l and Station 5 with 4.1 ml/l, rest of the stations recorded uniformly higher values ranging from 4.8 to 6.3 ml/l. In June and July the water had higher oxygen content ranging from 5.2 to 6.4 ml/l at all but Station 1 where it was only 4.4 ml/l in July. August also recorded uniform values ranging from 4.4 to 5.3 ml/l, but for a low value of 2.87 in Station 1. However, September registered an irregular pattern with values ranging from 4.6 to 6.9 ml/l. Oxygen values during October did not vary much from 4.0 to 5.3 ml/l. During November except 2 high values of 6.1 ml/l each at Stations 1 and 5 and a lower value of 4.1 ml/l at Station 4, rest of the stations registered values which ranged from 5.1 ml/l to 5.8 ml/l. December with an oxygen content ranging from 4.1 ml/l to 4.8 ml/l at all the stations registered uniformly moderate values.

The above results showed that the more or less uniform oxygen values in all months excepting in March, April and May are not affected by the discharge of industrial effluents. As such oxygen was not found to be a factor restricting the distribution of benthic fauna in the study area (Fig. 1).

In general, the oxygen content at surface waters followed more or less the same pattern as that of the bottom. Contrary to the general observations of higher oxygen content of the surface layer compared to that of the bottom, the difference was not considerable owing probably to the shallow depth in the study area and better mixing. However, with a few exceptions, oxygen content of bottom waters during January and July were found to be higher than than of surface waters.

Monthly analysis of oxygen data of bottom samples within each station revealed fluctuations in oxygen content due to the changes in the water flow. The temporal changes observed are as follows: At Station 1 the oxygen content fluctuated between 2.85 (March and August) and 6.9 ml/l (April). Stations 4, 5 and 6 showed uniform values ranging from 4.1 to 5.9 ml/l but for few values of 6.1 in November at Station 5, 6.3 in April at Station 4 and 3.5 ml/l at Station 6. At Station 7 except for the peak value of 9.8 ml/l in March and 6.2 ml/l in September and a very low value of 2.5 ml/l in April, other values ranged from 4.5 to 5.8 ml/l. Except for a high and a low value of 6.2 and 3.8 ml/l during March and April respectively, rest of the months registered more or less moderate oxygen values of 4.8 to 5.6 ml/l at Station 8. Station 9 recorded high values in all months ranging from 4.4 ml/l in April to 5.8 ml/l in June and July but for higher values of 7.1 and 6.9 ml/l in the months of March and September respectively.

The above observations also proved that even within each station the monthly variation in oxygen content are not to the extent as to redirect the distribution of benthic fauna.

3.1.4. BOD_5 values (mg/l):

Table 1 gives temporal and spatial distribution of the BOD_5 values of the surface, bottom and grab waters in Stations 1 to 9. Temporal variations are as follows: Grab water BOD_5 values at Station 1 fluctuated considerably between 6.7 mg/l in June and 165 mg/l in November. In general low values from January to June and an increasing trend from July to December were observed. BOD_5 recorded at the surface and bottom waters were very low ranging from 1 to 8.3 mg/l and 0 to 8.9 mg/l respectively. Station 2 also showed considerable fluctuations in grab water BOD_5 ranging from 6.1 mg/l in January and 9.4 mg/l in May, to 131.2 mg/l in November and 120.2 mg/l in December. In general, low values were recorded during January to June with an increasing trend from July to December. The BOD_5 of surface water varied from 1 to 14.3 mg/l while that of bottom water ranged between 0.6 and 5.6 mg/l. Grab water BOD_5 values at Station 3, but for their low values between 10.7 mg/l and 20.0 mg/l during March to May gradually increased reaching 148 and 120 mg/l during October and November respectively. The water column BOD_5 values ranged from 0.5 to 4.6 mg/l in surface waters while at the bottom it was 0.4 mg/l to 7.3 mg/l. Station 4, recorded grab water BOD_5 values of low order ranging from 12.0 to 42.4 mg/l during January to September, which rose to high values

Table 1. BOD_5 values (mg/l) of the Surface (S), Bottom (B) and Grab water (G) at Stations 1 - 9 during January to December, 1981.

Months / Stn. Nos.		J	M	A	M	J	J	A	S	O	N	D
	G	24.10	15.10	10.00	26.00	6.70	54.00	74.00	37.00	128.00	165.00	89.00
1	S	4.40	1.00	2.60	1.20	2.10	2.70	1.80	2.40	8.30	8.30	2.90
	B	8.90	0	3.50	1.18	1.20	4.40	0.48	0.90	5.60	5.50	2.90
	G	6.10	21.50	43.20	9.40	11.50	80.80	68.40	37.60	69.20	131.20	120.20
2	S	6.10	1.50	3.50	1.20	2.60	1.00	1.40	3.00	14.30	4.50	3.60
	B	-	2.00	0.90	1.20	2.00	0.60	3.10	3.00	4.50	4.50	5.60
	G	31.80	20.00	10.70	15.00	56.00	34.00	37.00	55.00	148.00	120.00	44.00
3	S	0.50	0.50	2.60	1.10	1.50	2.00	2.30	3.90	4.60	4.50	2.80
	B	5.20	-	5.30	0.40	2.30	2.10	1.40	2.60	7.30	7.30	4.40
	G	29.50	15.00	13.30	12.00	24.40	13.60	28.00	42.40	248.80	245.20	146.80
4	S	7.00	1.00	1.80	0.81	2.75	1.70	1.80	5.50	4.40	4.40	4.40
	B	16.50	0.50	4.40	0	2.10	0.70	2.30	1.70	5.70	5.70	7.80
	G	20.00	15.00	18.60	5.90	11.10	13.60	7.00	12.60	58.50	61.30	234.80
5	S	-	0.50	5.30	0.80	0	2.40	0.90	3.70	5.70	5.70	7.50
	B	-	0.50	3.50	3.10	2.20	2.00	1.30	5.80	2.80	2.80	5.10

Contd..

Table - 1 (Contd.)

Months / Stn. Nos.		J	M	A	M	J	J	A	S	O	N	D
	G	27.20	3.50	23.90	11.80	73.60	68.40	9.00	12.30	570.00	460.00	187.00
6	S	4.80	0.50	1.70	1.90	0.50	3.50	0.90	7.10	3.40	3.40	3.20
	B	2.60	1.50	7.10	-	2.50	1.30	0.90	2.30	7.40	7.30	3.20
	G	17.50	35.00	60.80	100.50	34.40	75.20	56.00	18.20	356.00	275.00	359.00
7	S	8.60	3.50	2.60	0.36	0.50	3.80	1.40	3.50	3.30	3.30	2.00
	B	6.90	2.00	4.30	1.50	1.60	3.80	6.10	4.40	2.20	2.10	1.50
	G	41.30	5.00	31.80	11.50	110.80	170.80	55.60	83.20	71.00	71.20	192.40
8	S	12.20	3.00	1.70	0.40	0.60	1.70	0.90	5.30	5.60	6.30	4.40
	B	7.50	1.50	3.50	0.40	0	2.40	0.90	3.90	2.50	2.50	1.30
	G	47.90	30.00	53.00	6.00	34.40	40.80	37.20	27.60	37.20	142.40	106.00
9	S	-	2.00	-	0.80	0.80	2.30	1.40	1.80	5.10	5.10	4.70
	B	4.30	-	1.70	0.50	2.20	2.70	0	1.70	3.60	3.50	3.40

of 146 to 248.8 mg/l during October to December. In general, BOD_5 values were low ranging from 0.81 to 7 mg/l for surface water and 0 to 7.8 mg/l for bottom water. Low BOD_5 values in the range of 5.9 to 20mg/l were recorded for grab water at Station 5 during January to September, thereafter the values recording a steep rise from 58.5 in October to 234.8 mg/l in December. The water column BOD_5 of this station was also low having a value of 0 to 7.5 mg/l for surface water and 0.5 to 5.8 mg/l for bottom water. The low BOD_5 values of grab water at Station 6, ranging from 3.5 in March to 27.2 in January, showed 2 peak values - one low peak from 68.4 to 73.6 during July/June and another high peak from 187 to 570 mg/l during December to October. BOD_5 in the water column did not show any such peaks. For surface water it ranged from 0.5 to 7.1 mg/l and for bottom water it was 0.9 to 7.4 mg/l. Station 7 recorded a gradual increase in grab water BOD_5 from 17.5 in January to 100.5 in April and then a fall to 18.2 in September followed by a sudden rise to 275 to 359 mg/l during October to December. But the water column BOD_5 did not show much fluctuation ranging only from 0.36 to 8.6 mg/l in surface water and 1.5 to 6.9 mg/l in bottom water. At Station 8 but for low values of 5 mg/l in March and 11.5 mg/l in May and peak values of 170.8 mg/l in July and 192.4 mg/l in December, grab water values in rest of the months ranged from 31.8 to 110.8 mg/l. The surface water BOD_5 ranged from 0.4 to 12.2 mg/l while that of bottom water ranged from nil to 7.5 mg/l. Grab water BOD_5 values at Station 9 except for a low value of 6 in May and peak values of 142.4 and 106 mg/l in November and December showed more or less uniform values in the range of 30.0 to 47.9 mg/l. As noted in the previous stations the surface water BOD_5 ranging from 0.8 to 5.1 mg/l and grab water BOD_5 ranging from nil to 4.3 mg/l did not show much change.

In spatial variations indicated very high values in grab water at all stations during October, November and December and comparatively low values were recorded during January to May. January to May registered grab water BOD_5 values fluctuating from 6.1 to 47.9 mg/l, 3 to 35 mg/l, 10 to 60.8 mg/l and 5.9 to 100.5 mg/l respectively. No pattern could be arrived at. In June it varied from 6.7 in Station 1 to 110.8 mg/l in Station 8 showing wide fluctuations from Station to Station. BOD_5 values in July varied between 13.6 in Station 4 and 170.8 mg/l in Station 8. August had values ranging from 7 to 74 mg/l whereas it was 12.3 to 83.2 mg/l in September. October, November and December recorded high values of 460 mg/l at Station 6 and 359 mg/l at Station 7 and low values of 37.2 mg/l at Station 9, 61.3 mg/l at Station 5 and 44 mg/l at Station 3. Comparatively very low BOD_5 values of nil to 16.5 mg/l were recorded for surface and bottom water samples during the entire period.

3.1.5. Chemical Oxygen Demand:

Table 2 gives the COD values as mg/l of water at the surface and bottom in each month at Stations 1 - 9.

Spatial variations noted were as follows: Almost 50% of the observations made failed to show any significant COD value. During January to May, COD showed patchy distribution only. Patches were noted in January at Stations 6 - 8, in March at Stations 1 - 4 and 8, in April at Stations 5, 6 and 8 and in May at Stations 5 - 9. From June to November COD was not recorded in Stations 1 and 2. At Stations 3 - 9 COD was of very negligible amount. However, two very high values were recorded, one in bottom water of Station 1 in June with 1669 mg/l and another in surface water of Station 3 in November (224 mg/l). December was the only month when high values of 917.13 mg/l and 1155 mg/l prevailed in surface waters of Stations 2 and 5. Likewise, bottom water of Stations 2 and 5 also showed high values ranging from 67 to 626 which was reduced to low values of 4.02 to 8.8 in Stations 6 - 9.

An analysis of temporal variations in each station indicated absence of COD in Stations 1 - 4 from January to May except March with high values, and in Stations 1 and 2 from July to November. High values occurred in Station 1 in June and Station 2 in December. In Stations 5 - 9, January to December registered extremely low values only, the exceptions

Table - 2. COD values (mg/1) of the Surface (S) and Bottom (B) water at Stations 1 - 9 during January to December, 1981.

Months		STATIONS								
		1	2	3	4	5	6	7	8	9
Jan.	S	0	0	0	0	-	5.70	15.20	4.70	0
	B	0	0	0	0	-	4.40	0	2.10	0
Mar.	S	525.00	241.00	141.60	283.60	0	0	0	64.40	53.87
	B	0	135.60	232.40	188.00	0	0	0	5.00	0
Apr.	S	0	0	0	0	107.00	92.00	0	108.00	0
	B	0	0	0	0	282.00	92.00	0	0	4.00
May	S	0	0	0	0	25.30	27.70	14.90	5.22	3.60
	B	0	0	0	0	12.70	0	1.46	5.21	1.65
Jun.	S	0	2.04	7.80	19.20	0.24	3.50	9.04	0	2.13
	B	1669.00	3.87	0	0	1.04	2.20	10.5	0	0
Jul.	S	0	0	0	3.47	4.50	3.30	1.70	0	0.10
	B	0	0	1.82	0	0.50	0.10	0.90	0.90	0

Contd...

Table - 2 (Contd.)

Months		STATIONS								
		1	2	3	4	5	6	7	8	9
Aug.	S	0	0	1.20	0	4.90	0	0	6.60	3.30
	B	0	0	2.07	862.00	7.80	12.10	7.60	3.50	1.90
Sept.	S	0	0	9.87	0	0.30	16.30	4.90	4.90	0
	B	0	0	1.93	1.07	0	16.70	3.63	3.63	0
Oct.	S	0	15.40	25.60	53.50	0	12.50	8.30	10.45	0
	B	0	0	16.83	11.30	11.83	15.40	5.12	5.90	2.24
Nov.	S	0	0	224.00	0	3.60	0.50	0.40	1.10	0
	B	0	0	0	0	0	0.90	0	0	0
Dec.	S	0	917.13	0	48.00	1155.00	0	7.03	1.14	0
	B	0	215.50	73.60	626.00	67.00	4.25	8.80	6.14	4.02

being April in Stations 5 and 8, and December in Station 5.

3.1.6. Alkalinity (mg $CaCo_3$/l):

The spatial and temporal distribution of alkalinity values from Stations 1 to 9 and during January to December are shown in Fig. 5.

The spatial variations indicated were as follows: January recorded peak surface water values of 31.64 mg/l and 34.1 mg/l in Stations 1 and 2 respectively, which was abruptly reduced to low values fluctuating between 5.72 and 17.16 mg/l at Stations 3 to 9. Bottom and grab water values followed same pattern but with a high peak value of 163.2 at Station 7 for grab water. March followed same pattern, with peak values of 98.46 and 121.62 for surface and grab water in Station 1 and another peak of 110 for grab water in Station 7 and 57.9 for bottom water at Station 8. Lowest values occurred at Stations 2 to 4. During April but for the higher values noted for surface, bottom and grab water at Stations 1 and 2, rest of the stations recorded reduced fluctuating values. Surface, bottom and grab water values were lowest with 5.2 each at Station 3 while high values of 45.6 for surface and 55.7 for bottom occurred at Station 1 and 55.7 for grab at Station 2 during May. While grab water

Fig. 5. Distribution of alkalinity at the 9 stations during 1981.

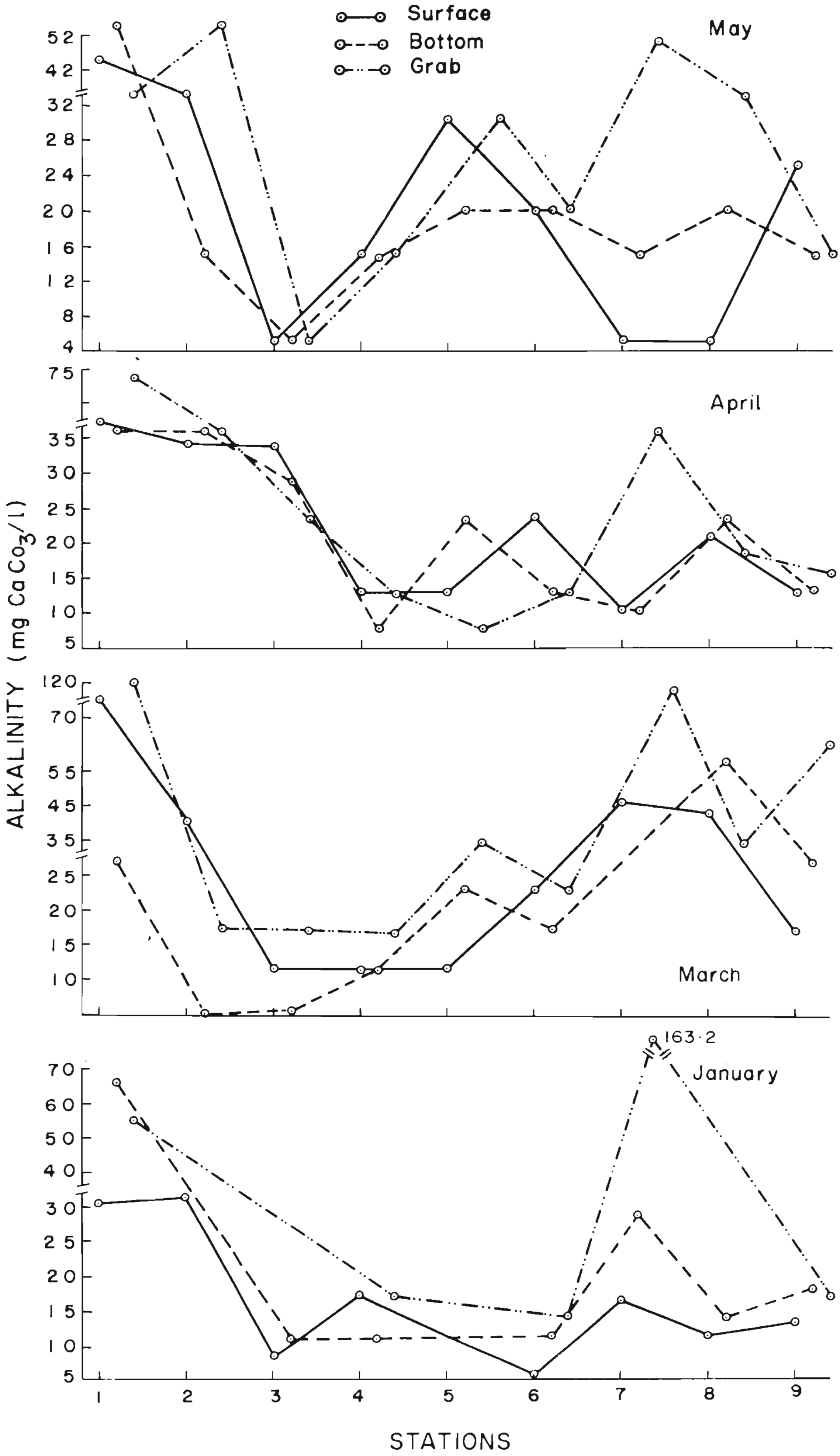

Surface
Bottom
Grab
May
April
March
January
163·2
ALKALINITY (mg CaCo$_3$/l)
52
42
32
28
24
20
16
12
8
4
75
35
30
25
20
15
10
5
120
70
55
45
35
25
20
15
10
70
60
50
40
30
25
20
15
10
5
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 5

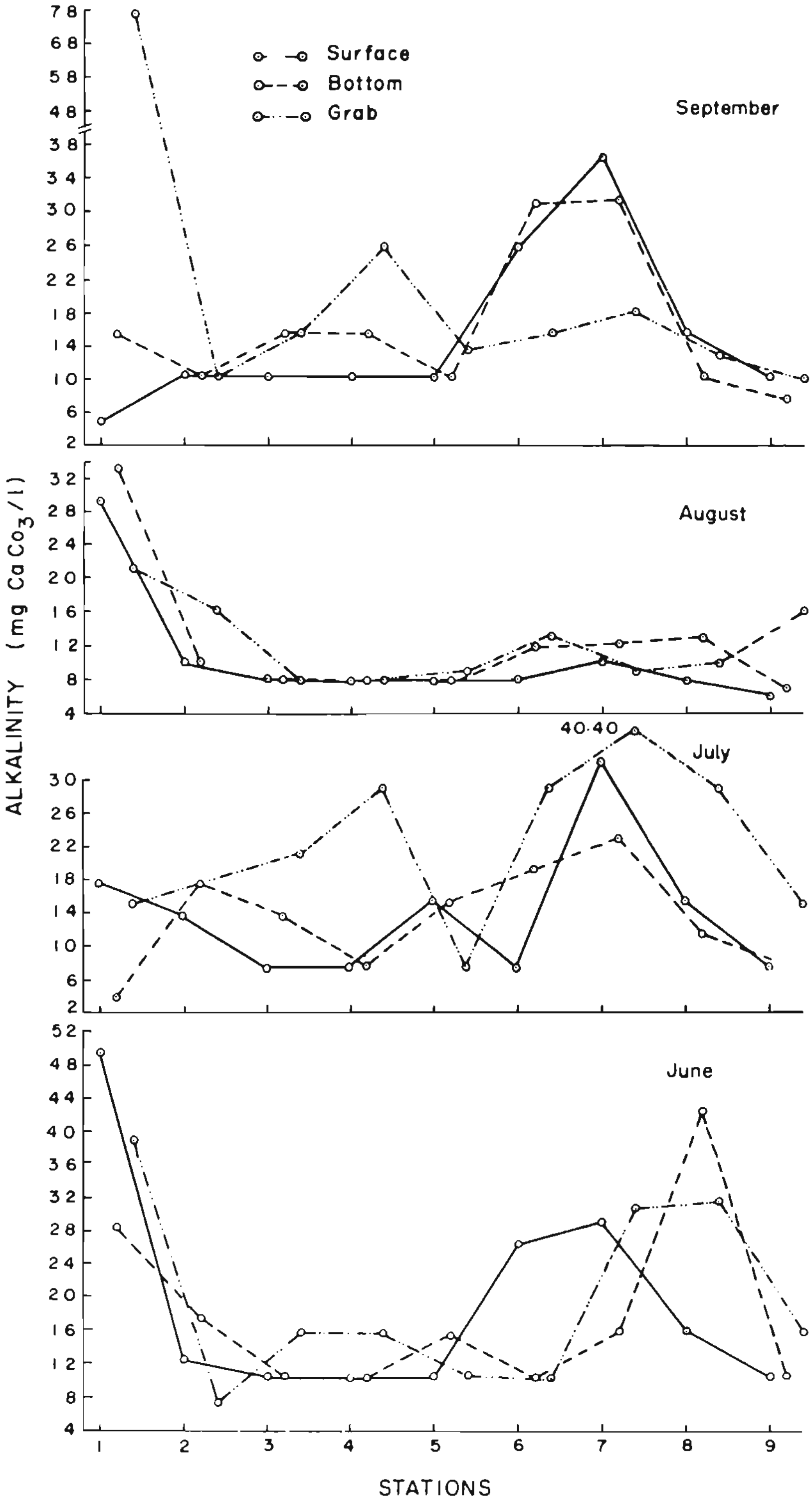

Surface
Bottom
Grab
September
August
July
June
40·40
ALKALINITY (mg CaCo3/l)
STATIONS

Fig 5

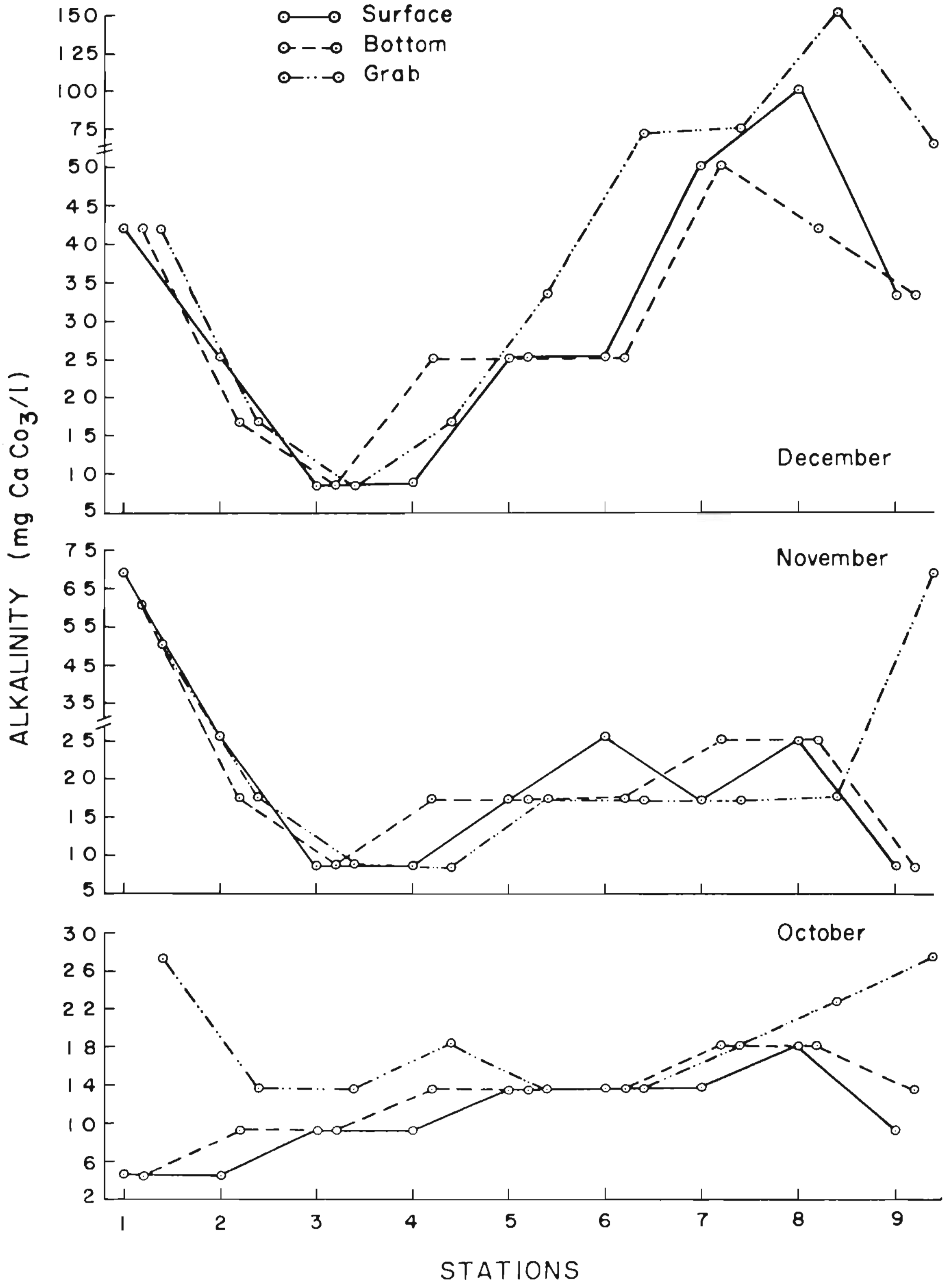

Surface
Bottom
Grab
ALKALINITY (mg Ca Co3/l)
December
November
October
150
125
100
75
50
45
40
35
30
25
20
15
10
5
75
65
55
45
35
25
20
15
10
5
30
26
22
18
14
10
6
2
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 5

showed a second peak at Station 7, the surface water touched lowest values of 5.2 each in Stations 7 and 8. June indicated low values at Stations 2 to 6 and 9 with highest values in Station 1 and high values in Stations 7 and 8. July with considerable fluctuations exhibited a gradual increase from Stations 1 to 7 with 30.56 and 40.4 for surface and grab water respectively at Station 7, thereafter decreasing to Stations 8 and 9 reaching values of 7.64, 7.64 and 15.28 for surface, bottom and grab water. August registered more or less uniform low values varying from 6.06 to 16.17 at Stations 2 to 9 and high values ranging from 21.24 - 33.37 at Station 1. Surface values of 10.39 in September at Stations 2 to 5 rose to 36.36 at Station 7 and again dropped to 10.39 in Station 9. Bottom water alkalinity values also exhibited similar pattern. However, the highest grab water value of 77.92 at Station 1 made an abrupt fall to 10.39 at Station 2 thereafter fluctuating between 10.39 and 25.97. Surface and bottom values in October showed only a gradual rise from the lowest 4.46 each in Station 1 to 18.24 each at Station 8. Grab water but for the peak values of 27.37 at Stations 1 and 9 did not show much of a variation at Stations 2 - 8. November as noted for April had peak values at Station 1 which were reduced to the lowest 8.7 at Stations 3, 4 and 9 and low 17.3 in Stations 7 and 8. December like May and September registered a reduction from high values of 42.01 at Station 1 to 8.43 at Station 3, thereafter increasing sharply to peak values of 100.84, 42.02 and 151.25 for surface, bottom and grab water respectively at Station 8 with a slight fall at Station 9.

Temperal variations noted in alkalinity were as follows: Station 1 recorded higher values (20) in all months except in July, October and September when it ranged between 4 and 15.88. Station 2 recorded low values except for January to May. Stations 3 and 4 registered lowest values in all months. But for May and December Station 5 also had low values. Except for January Station 6 showed an increase in values. Station 7 recorded peak values except at surface and bottom in January and April, surface value in May, bottom value in June, and all the three values in August, October and November, with certain exemptions. High values were noted in March, May, June, July and December whereas low values prevailed in April and August to November in the column and in grab water. Station 9 recorded uniformly low values except in grab water during March, surface water in May, grab water in August and October, November and December.

3.1.7. pH :

Variations in pH from Station to Station (spatial) and within each station (temporal) are shown in Fig. 6. pH values of grab water during January indicated a gradual reduction from Station 1 (7.8) to Station 9 (6.8), but for higher pH values of 7.4 and 7.8 at Stations 7 and 8 respectively. Bottom water registered a gradual reduction in pH from 7.95 in Station 1 to 6.4 at Station 7 with subsequent increase to 7.6 at Stations 8 and 9. Similarly the surface water too indicated a reduction from 7.9 at Station 1 to 6.4 at Station 8 followed by a rise to 7.6 at Station 9. During March except Station 7 with a pH of 7.1, grab water from the rest of the stations showed a reducing tendency from 7.5 at Station 1 to 5.6 at Station 9. Similar lowering in values from Stations 1 to 8 were noted for surface and bottom waters too. In effect an acidic nature prevailed from Stations 3 to 9. pH of grab, bottom and surface waters registered a fall during April from Stations 1 to 9 and was on the acidic side from Stations 4 to 9. During May except at Station 9 where pH values were low (6.1 to 6.5) alkaline values were recorded at Stations 1 to 8. June showed deviation from May with the grab water maintaining low pH values ranging from 5.5 to 5.8 at Stations 5, 6 and 7, rest of the stations showed pH values of 6.7 to 6.9. However,

Fig. 6. Distribution of pH at the 9 stations during 1981.

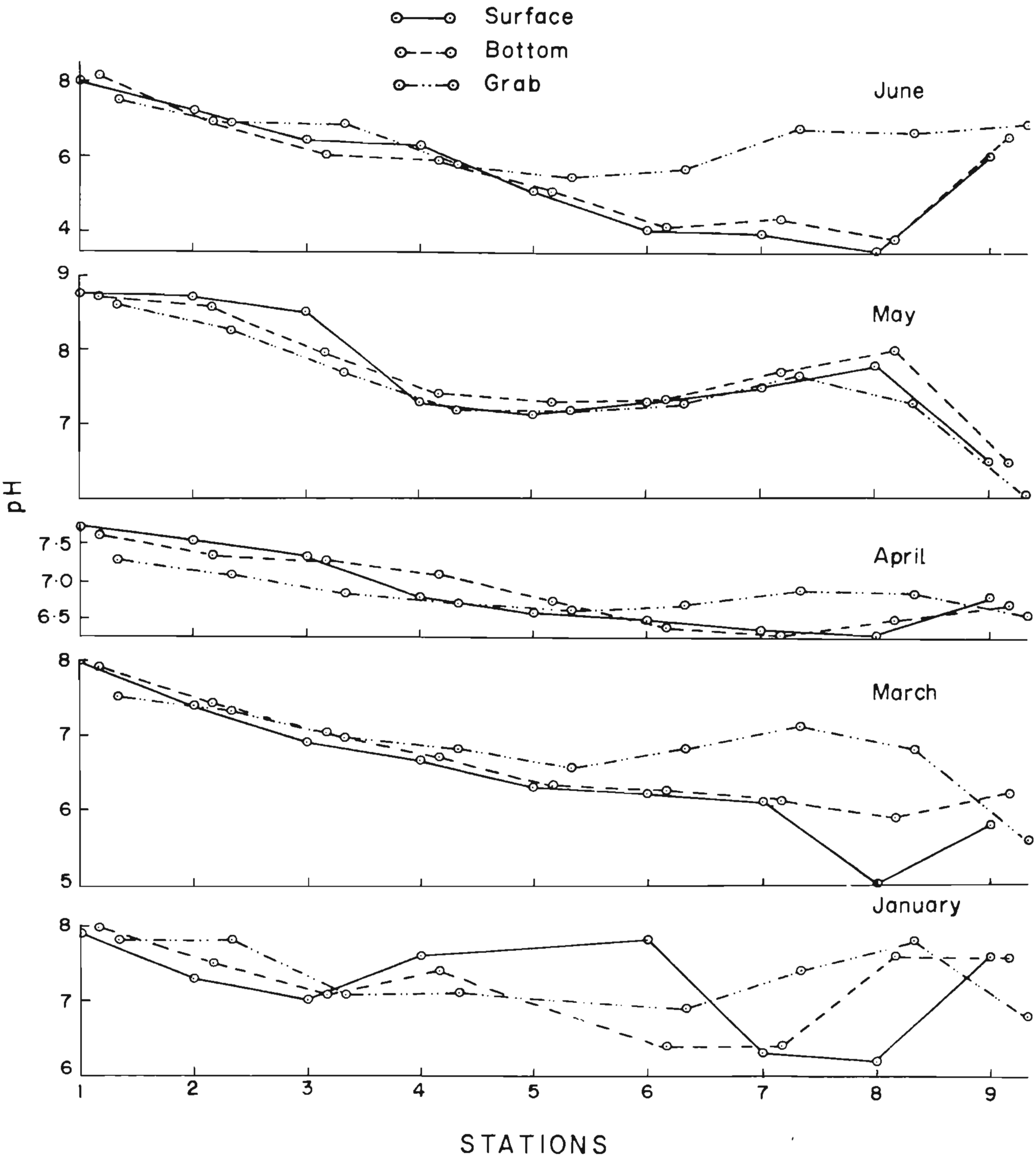
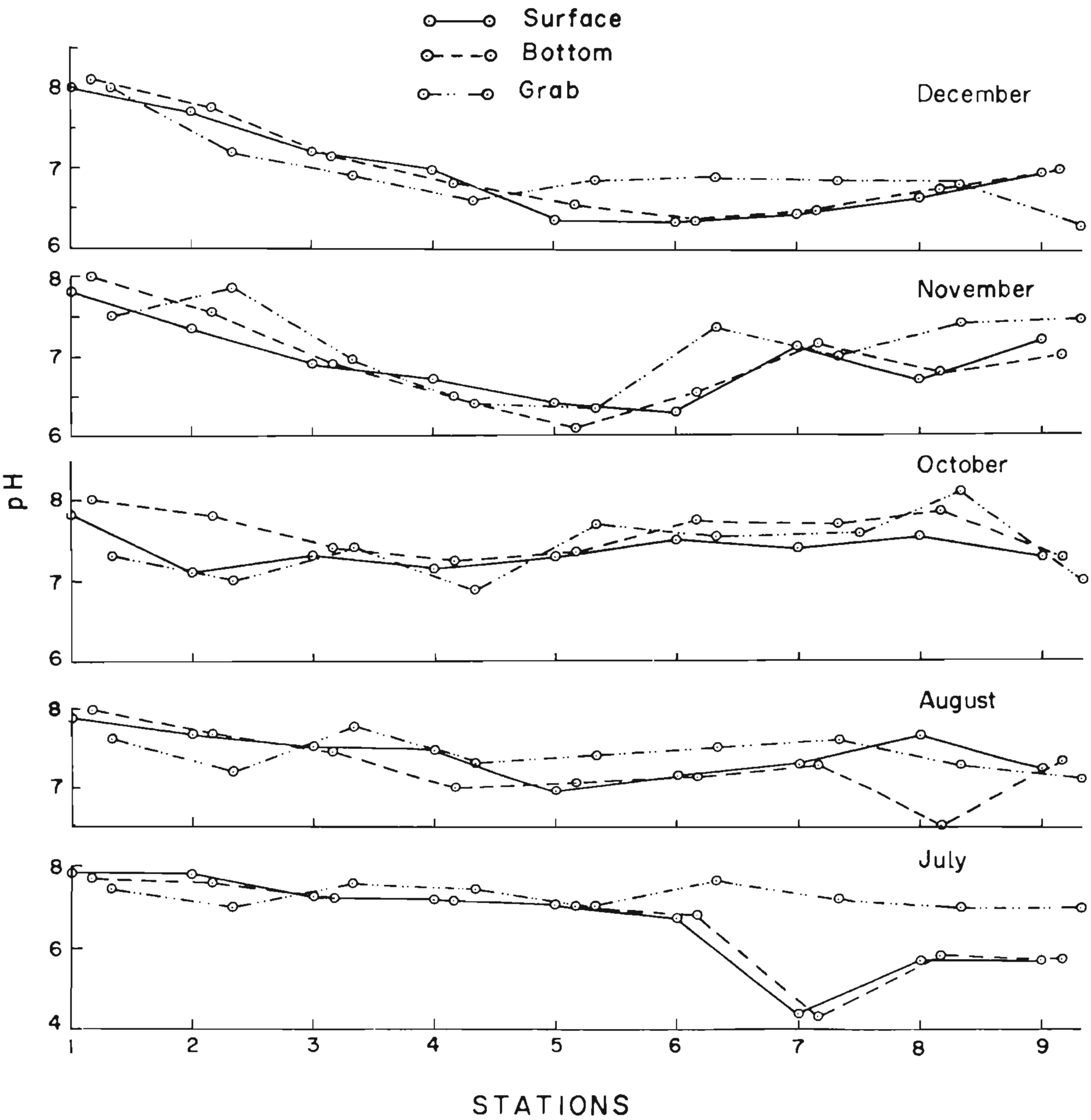

Surface
Bottom
Grab
June
May
April
March
January
pH
8
6
4
9
8
7
7·5
7·0
6·5
8
7
6
5
8
7
6
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 6


Surface
Bottom
Grab
December
November
October
August
July
pH
8
7
6
8
7
6
8
7
6
8
7
8
6
4
1
2
3
4
5
6
7
8
9
STATIONS
Fig. 6

pH of surface and bottom waters indicated a considerable reduction from Stations 1 to 8 with a rise at Station 9. In all an acidic pH was noted from Stations 3 to 9 especially in Stations 5 to 8. July registered a normal pH ranging from 7.05 to 7.7 for grab water whereas a range of 7.1 to 7.8 was maintained at Stations 1 to 5 in the surface and bottom waters. Stations 6 to 9 showed an acidic pH range of 4.35 to 5.9. August and September registered uniformly alkaline pH for the grab water and the entire water column. October recorded alkaline pH at Stations other than 3 to 6 and 8 where it was acidic. During November pH values were alkaline at Stations 1 to 3 whereas from Station 4 onwards it was acidic. Alkaline pH prevailed during December for grab, bottom and surface waters at Stations 1 to 3, whereas acidic pH varying between 6.3 and 7 was prevalent at Stations 4 to 9. In general, acidic water prevailed at Stations 4 to 9 except in May, August and September depending on the intensity of flow of the water. Grab water showed lesser variations in pH compared to bottom and surface waters.

Month-wise observations at each station (temporal) revealed that at Stations 1 to 3 high pH was maintained in all the months. However, at Stations 4 to 6 acidic pH was noted in the months except May and July to September. Stations 7 and 8 recorded low pH in all months except May, August and September. Station 9 recorded alkaline pH during January, June, August, September and October.

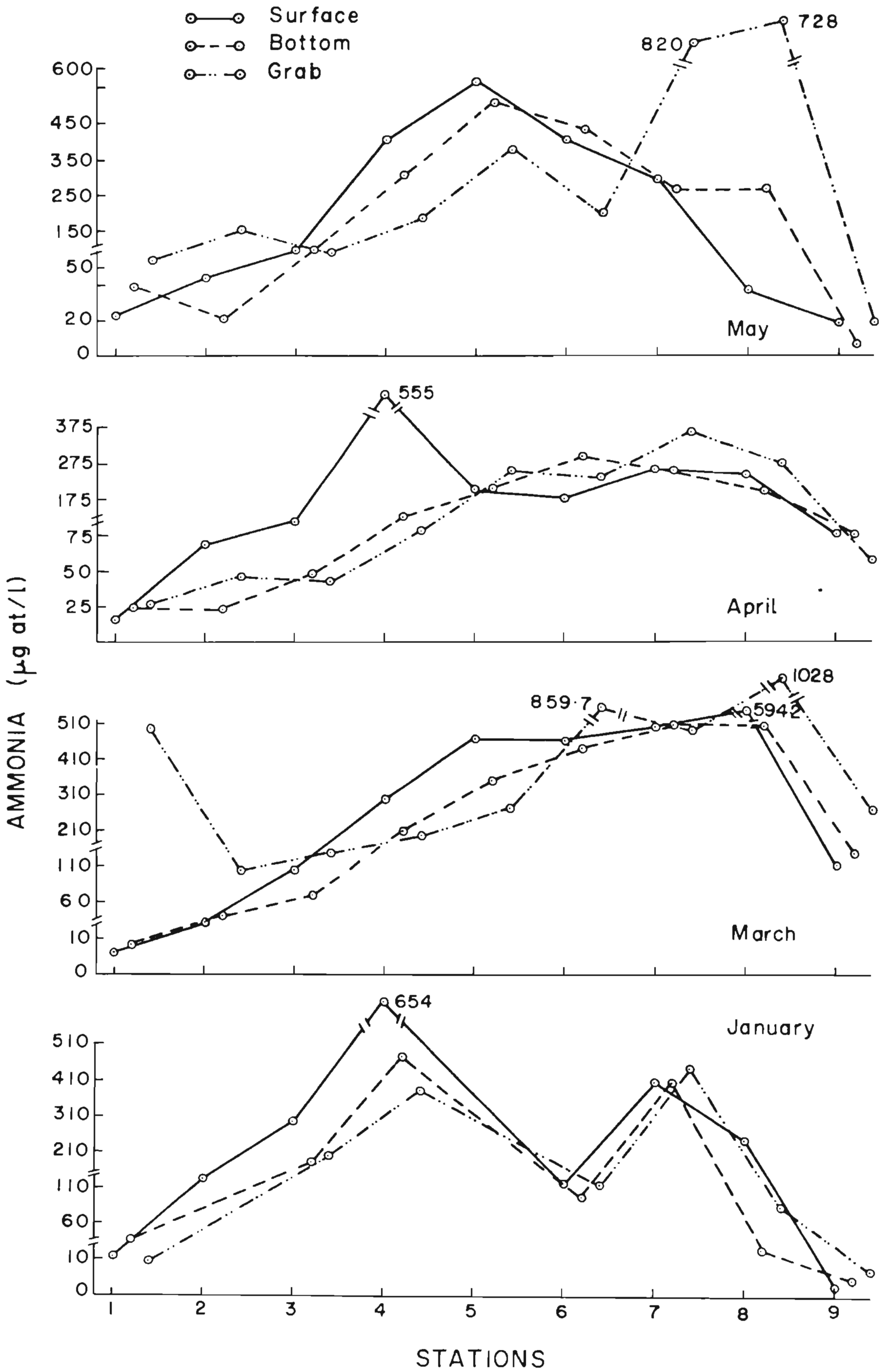
Thus pH was found to be an important factor in controlling the abundance of macrobenthos at the areas where industrial effluents were discharged.

3-1-8. Ammoniacal Nitrogen (ug-at/l):

The spatial and temporal distribution of Ammonia in the area of investigation during January to December at Stations 1 - 9 are shown in Fig. 7. Spatial distribution of ammonia at the surface, bottom and in grab water has been observed as follows:

January showed low values of 9.82 to 39.27 at Station 1 and very low values of 3.49 to 7.64 in Station 9. High values of 375.36 to 471.26 prevailed at Stations 4 and 7. Thus an irregular pattern was noted. In March, the very low surface (5.9) and bottom (8.01) values registered at Station 1 showed a sharp rise to 509.89 and 594.17 respectively at Station 8 thereafter following to a low value of 118.0 and 155.92 respectively at Station 9. The grab water value apart from Station 1 which had higher values also recorded an increase from 105.35 at Station 2 to a very high value of 1028.22 at Station 8. In April, low values at

Fig. 7. Distribution of ammoniacal nitrogen (ammonia) at the 9 stations during 1981.


Surface
Bottom
Grab
AMMONIA (µg at/l)
May
April
March
January
820
728
555
859·7
1028
5942
654
600
450
350
250
150
50
20
0
375
275
175
75
50
25
510
410
310
210
110
60
10
0
510
410
310
210
110
60
10
0
1
2
3
4
5
6
7
8
9
STATIONS
Fig. 7

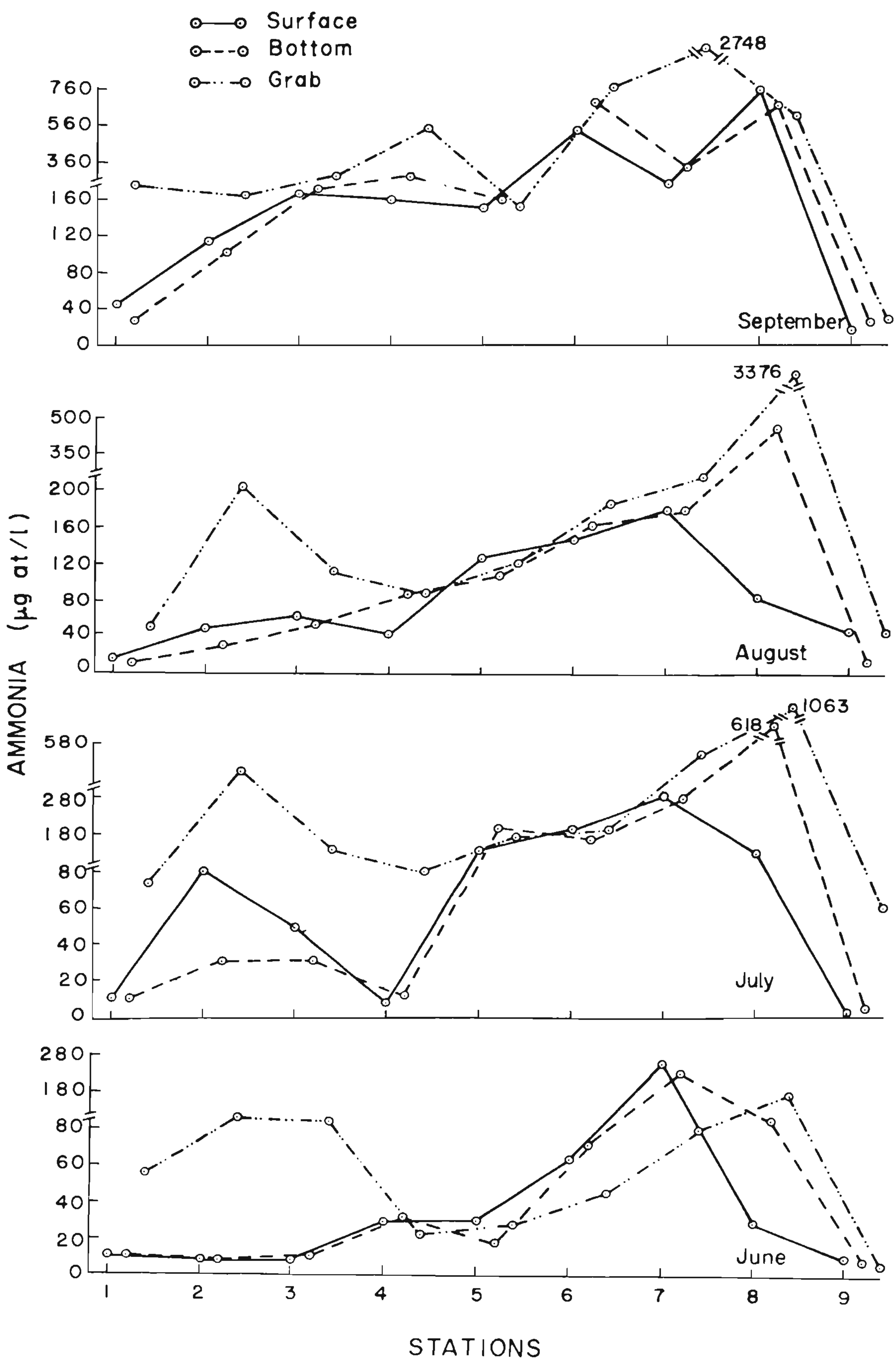
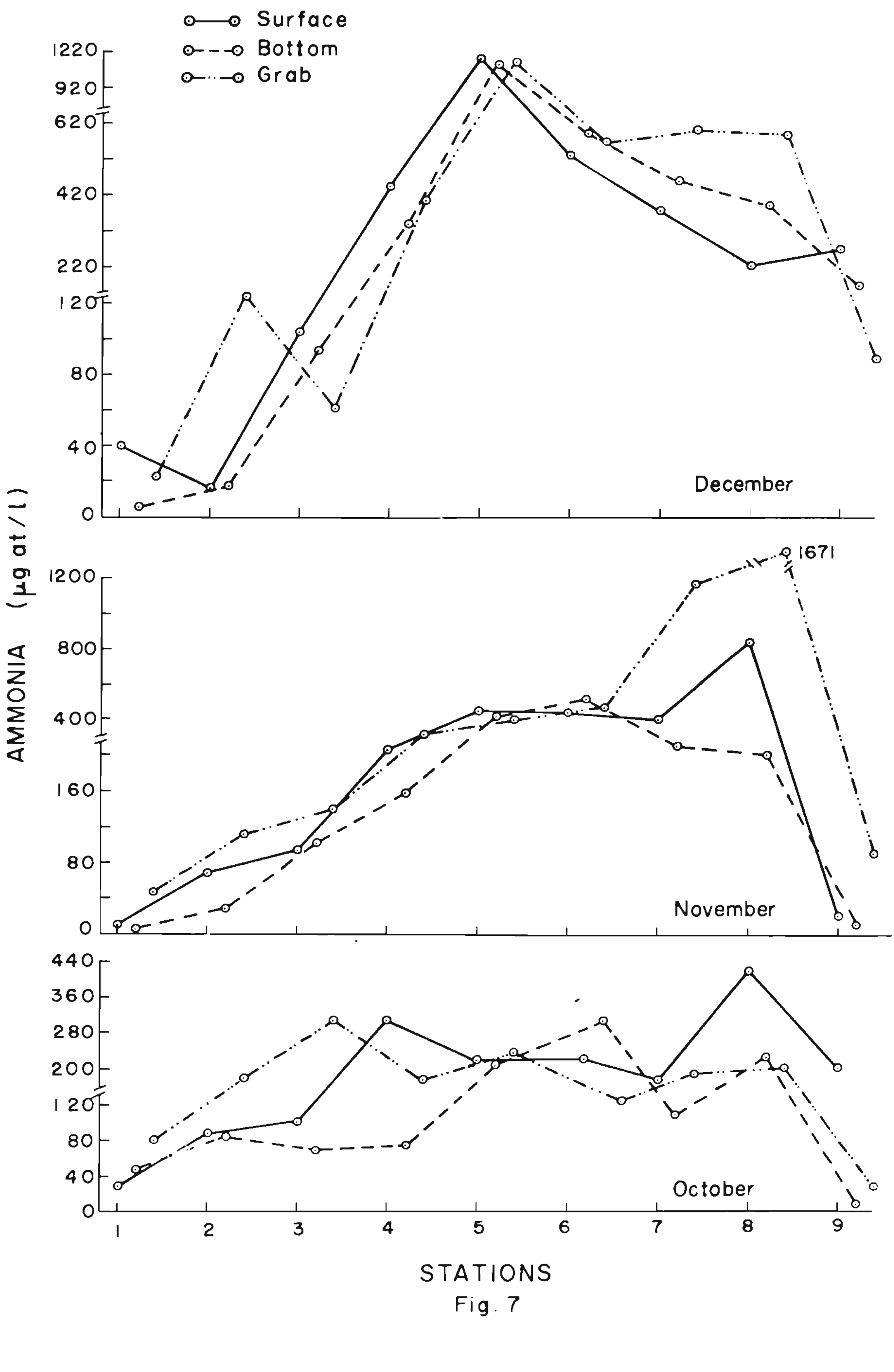

Surface
Bottom
Grab
2748
760
560
360
160
120
80
40
0
September
3376
500
350
200
160
120
80
40
0
August
618
1063
580
280
180
80
60
40
20
0
July
280
180
80
60
40
20
0
June
AMMONIA (µg at/l)
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 7



Surface
Bottom
Grab
1220
920
620
420
220
120
80
40
0
December
1671
1200
800
400
160
80
0
November
440
360
280
200
120
80
40
0
October
AMMONIA (μg at/l)
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 7

Stations 1, 2 and 3 showed a sharp increase to high values of 225.43 to 365.53 at Station 7 which got reduced to low values of 57.25 to 83.07 at Station 9. In May, low surface and bottom values at Stations 1, 2 and 3 ranging from 23.34 to 99.01 registered a steep rise to high values of 506.55 to 561.81 at Station 5, thereafter decreasing to low values of 6.91 to 18.42 at Station 9. The grab water values which fluctuated very much recorded an increase from Stations 1 to 7/8. June, in general, recorded low values. But for a peak value of 267.9 at Station 7, surface water at the rest of stations registered, low values of 9.21 to 64.47. Similarly, other than a peak value of 239.46 at Station 7 and 110.52 at Station 8, bottom water at the rest of the stations registered lower values of 9.21 to 73.68. However, ammonia content of grab water fluctuated from a low value of 6.91 to 180.52. July too indicated low contents of ammonia in the surface and bottom waters ranging from 7.84 to 11.31 at Station 1. Thereafter surface values rose to 294.0 at Station 7, with abrupt falls at Stations 4 and 9. Bottom values during this month rose to 617.7 at Station 8 with an abrupt fall to 5.64 at Station 9. However, grab water values fluctuated between 60.3 and 1063. In August the low surface and bottom values ranged from 11.78 to 62.81 at Stations 1 to 4. Then the surface value rose from 129.55 at Station 5, and 198.18 in Station 6 slowly getting reduced to

51.03 at Station 9. But bottom value rose from 109.92 at Station 5 to 466.79 at Station 8 followed by a steep fall to 15.71 at Station 9. Fluctuating grab water value made a sharp rise from 51.03 at Stations 1 and 9 to an unusually high value of 3376.14 at Station 8. Spatial distribution during September showed a low value of 45.08 at Station 1 for surface waters which increased up to a peak value of 762.94 at Station 8 and a sudden drop to 19.66 at Station 9. Likewise the low bottom value of 27.74 was raised to 679.71 at Station 8 and a steep fall to 27.74 in Station 9. Grab water recorded values ranging from 235.8 at Station 1 to 2748 at Station 7 dropping abruptly to 29.5 at Station 9. Surface water values in October too increased from the low value of 29.29 at Station 1 to 417.32 at Station 8 with low values at Stations 7 and 9. But the low bottom value of 47.6 at Station 1 showed a gradual rise to 307.5 at Station 6 followed by an abrupt fall to 9.15 at Station 9. However, grab water values fluctuated between 29.25 at Station 9 and 307.58 at Station 3. But for the low values at Station 9, the surface, bottom and grab water values during November showed a sharp rise from the low values in January to peak values of 844.82 for surface water at Station 8, 525.5 for bottom water at Station 6 and 1671.41 for grab water at Station 8. December recorded peak values of 1161.25, 1114.8 and 1138.03 respectively for surface, bottom and grab water at Station 5. Low values at Station 1 registered a steep rise to the peak value at Station 5 falling sharply at the next station and going down to lower values further upstream in December. In general low values were noted at Stations 1 to 4 and 9 and high values from Stations 5 to 8 in this month.

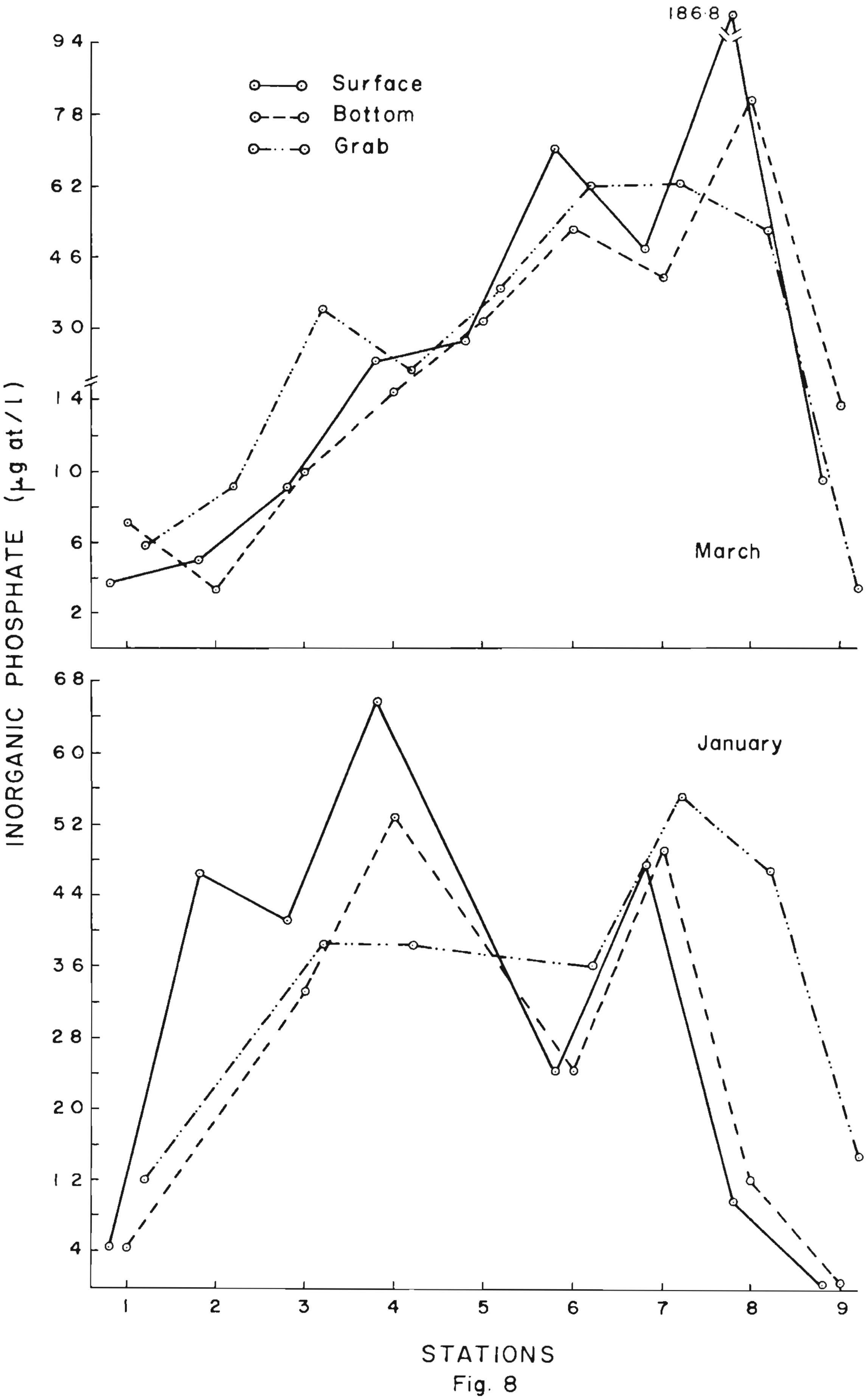
Temporal variations at Stations 1 to 9 during January to December were as follows: Station 1 during the 12 months, recorded low surface (5.01 to 45.08) and bottom (5.34 to 47.6) values, whereas grab water recorded higher values of 9.82 to 514.11. All the values showed considerable fluctuations. At Station 2, surface values varied from 9.21 to 135.21, bottom values from 9.21 to 100.54 and grab water values from 46.24 to 452.3 all variations being irregular. Similar irregular pattern of distribution of ammonia was recorded at all the stations. Values in general were high except for June when comparatively low values were obtained. Grab water values were of a higher order compared to the surface and bottom values.

3.1.9. Inorganic Phosphate (µg-at/l):

Phosphate content of water from surface, bottom and grab, at Stations 1 to 9 (spatial) during different months (temporal) are shown in Fig. 8.

Analysis of spatial variation of phosphate at Stations 1 - 9 during different months revealed the following: During January the lowest surface and bottom values of 0.82 each were noticed at Station 9 and 4.5 each at Station 1 and the peak value of 66.72 and 52.8 each at Station 4. Higher values prevailed from Stations 2 to 7. Similarly, grab water values ranged between 12.28 and 55.26 µg-at/l. A general increase, during March, from 3.75 to 186.8 for surface and from 7.06 to 80.95 for bottom waters was noticed at Stations 1 - 8. A similar increase was noticed for grab water from Stations 1 - 7. Low values were noticed for the surface, bottom and grab water at Station 9. During April, the surface, bottom and grab water values showed an increasing trend from Stations 1 to 6 and slightly fluctuating values were observed at Stations 7 and 8. Station 9, however, maintained low values. May recorded low phosphates content ranging from 0.77 to 13.55 at the surface, 1.55 to 15.49 at the bottom and 5.03 to 38.71 in the grab water. However, high values were of exemption at Station 7 and only for bottom water at Station 8.

Fig. 8. Distribution of inorganic phosphate at the 9 stations during the year 1981.



186·8
94
78
62
46
30
14
10
6
2
Surface
Bottom
Grab
March
68
60
52
44
36
28
20
12
4
January
INORGANIC PHOSPHATE (µg at/l)
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 8

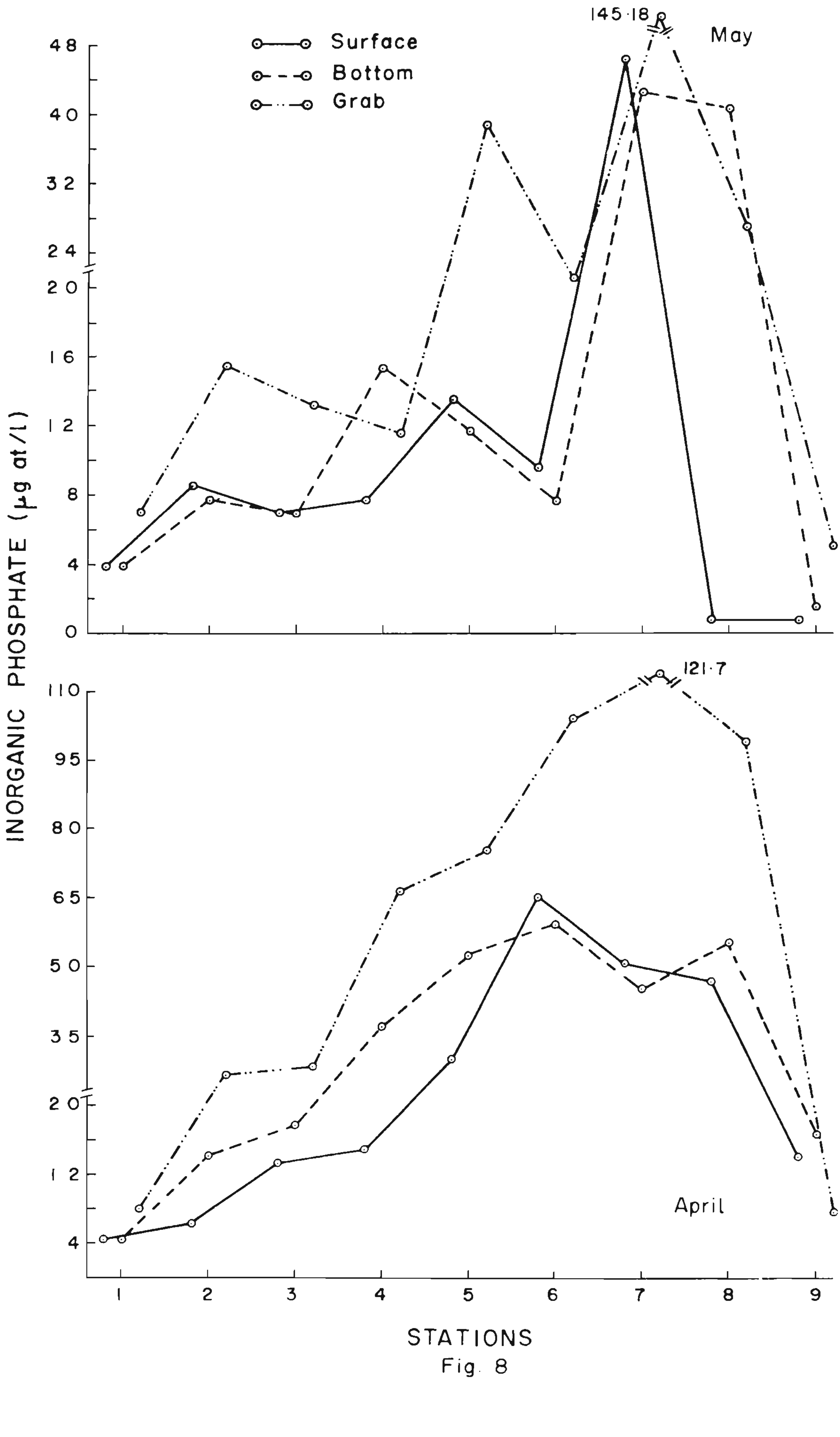
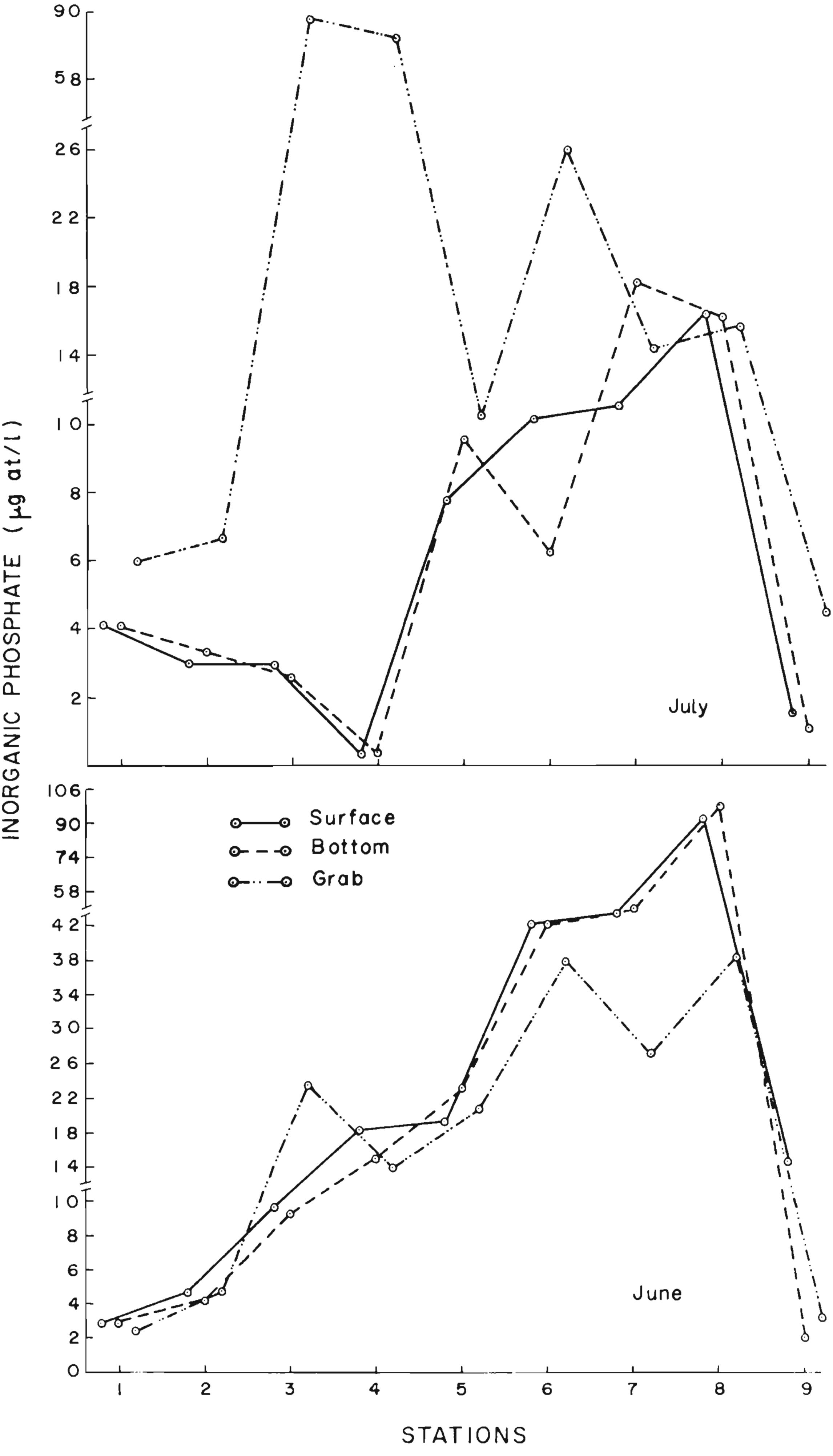
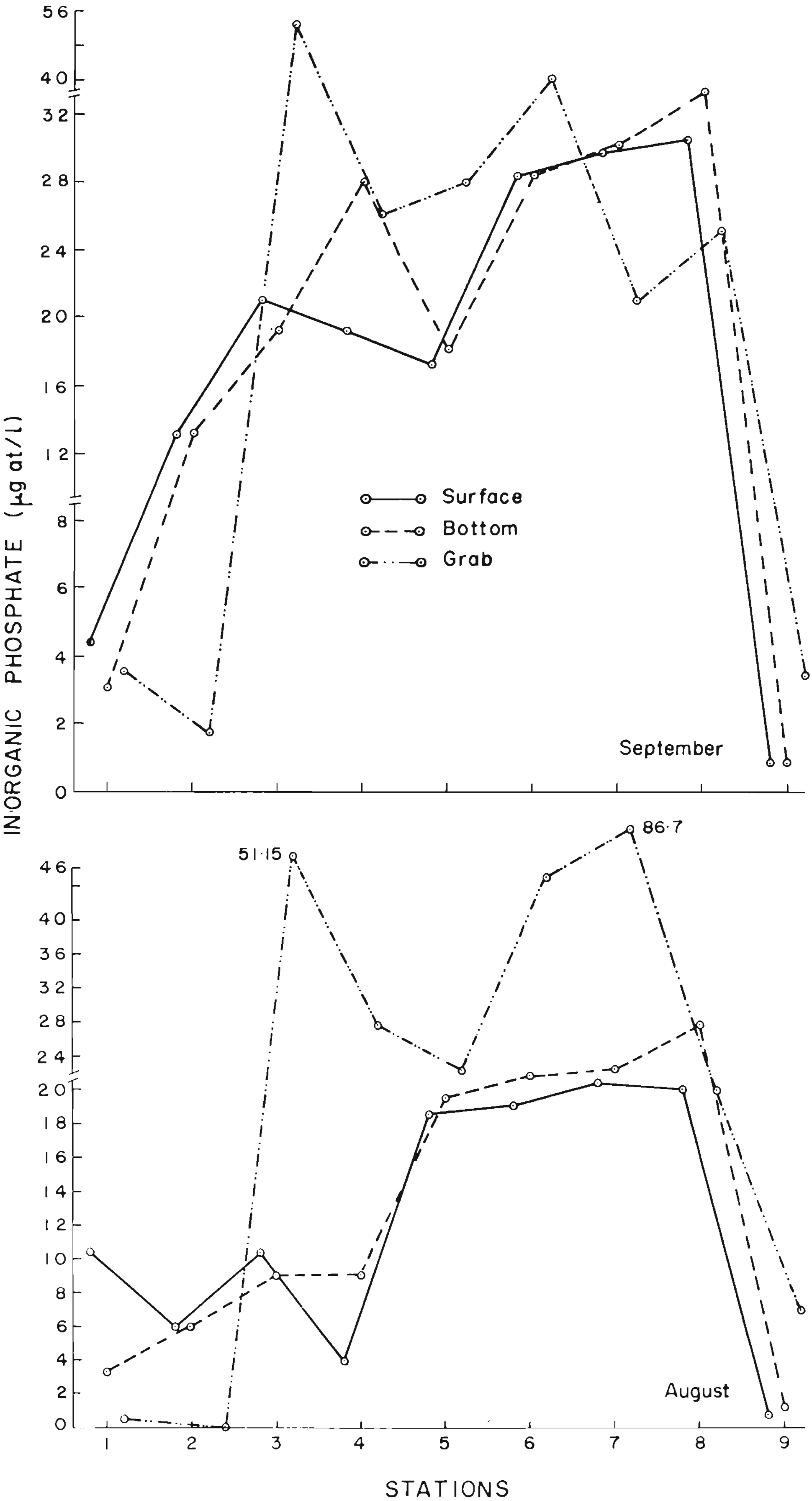

Surface
Bottom
Grab
May
145·18
121·7
April
INORGANIC PHOSPHATE (µg at/l)
48
40
32
24
20
16
12
8
4
0
110
95
80
65
50
35
20
12
4
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 8



INORGANIC PHOSPHATE (µg at/l)
90
58
26
22
18
14
10
8
6
4
2
July
106
90
74
58
42
38
34
30
26
22
18
14
10
8
6
4
2
0
Surface
Bottom
Grab
June
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 8



INORGANIC PHOSPHATE (μg at/l)
Surface
Bottom
Grab
September
August
51·15
86·7
STATIONS

Fig. 8

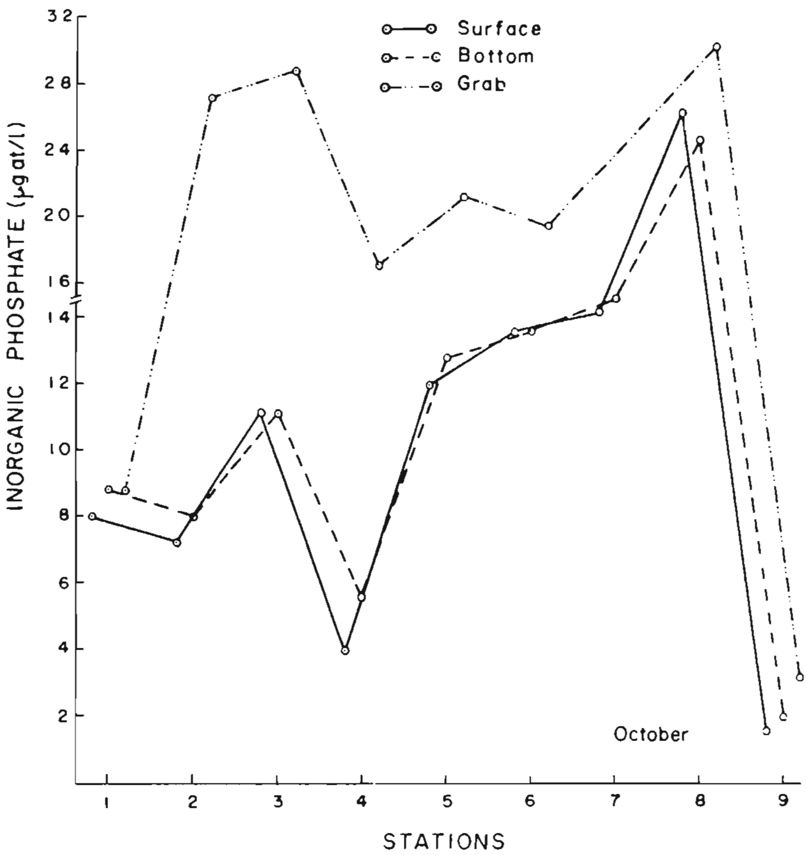

Surface
Bottom
Grab
INORGANIC PHOSPHATE (µg at/l)
32
28
24
20
16
14
12
10
8
6
4
2
October
1
2
3
4
5
6
7
8
9
STATIONS

Fig 8

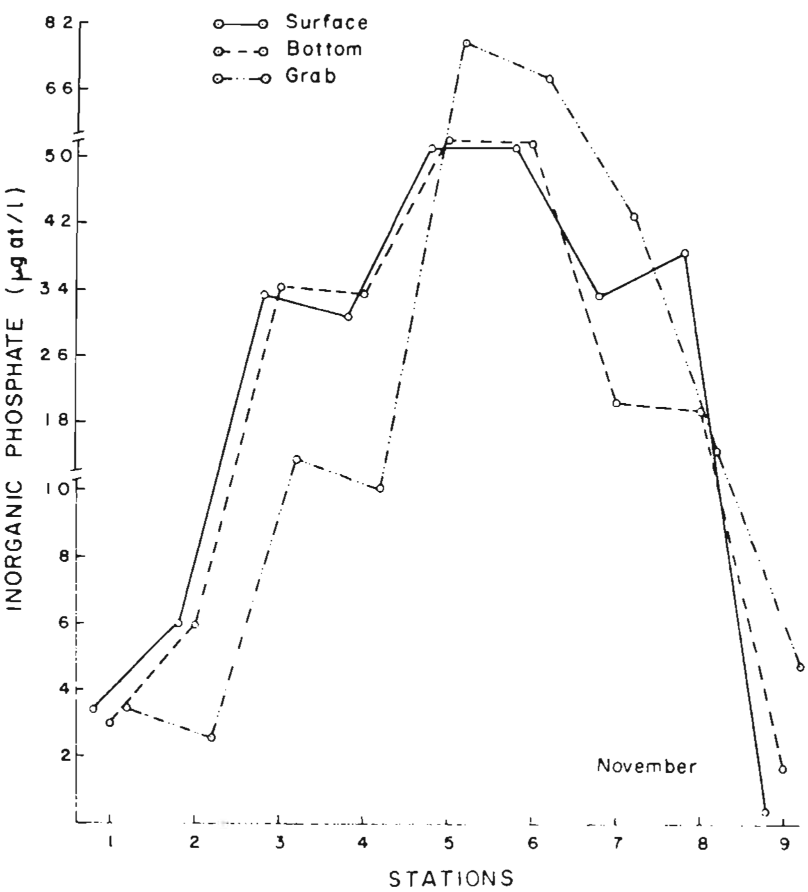
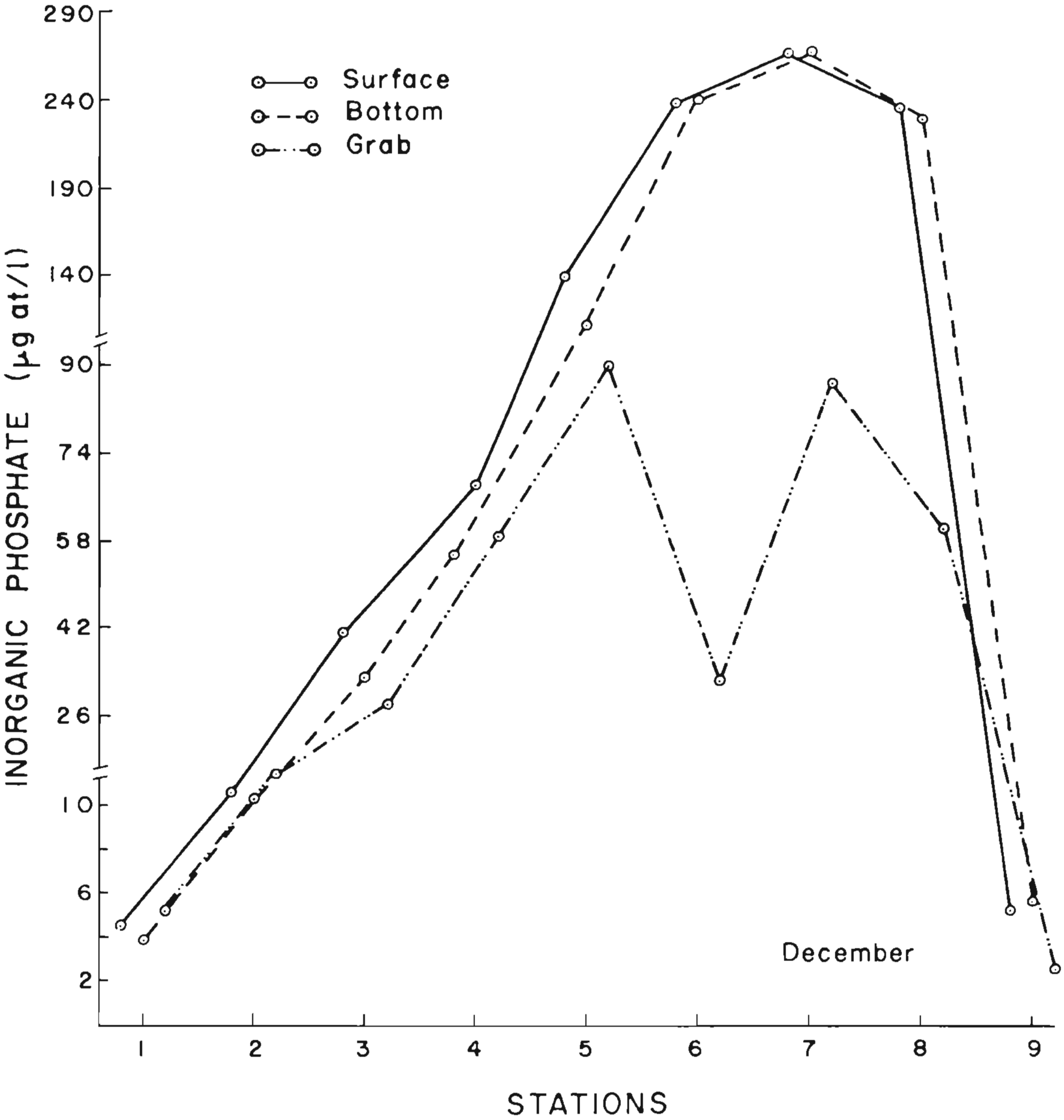

Surface
Bottom
Grab
INORGANIC PHOSPHATE (µg at/l)
82
66
50
42
34
26
18
10
8
6
4
2
November
1
2
3
4
5
6
7
8
9
STATIONS

Fig 8



Surface
Bottom
Grab
290
240
190
140
90
74
58
42
26
10
6
2
INORGANIC PHOSPHATE (µg at/l)
December
1
2
3
4
5
6
7
8
9
STATIONS

Fig.8

As noted for March and April values during June also showed a general increase from Stations 1 to 8, thereafter dropping to low levels at Station 9. Comparatively low values were registered during July, in the surface, bottom and grab water, the values ranging from 0.37 to 16.68, 0.37 to 18.54 and 4.45 to 26.69 respectively. However, the grab water phosphate content at Stations 3 and 4 was of a high order (77 to 86). August, similar to July, had fluctuating values of 0.87 to 20.81 at the surface, 1.3 to 27.74 at the bottom and nil to 27.74 in the grab water. But grab water values at Stations 3, 6 and 7 recorded high values. In general, values were on the increase from Stations 1 to 8. September too, as in July and August recorded moderate values with an increasing trend from Stations 1 to 8, the surface, bottom and grab water values ranging from 4.37 to 30.62, 3.1 to 38.49 and 1.75 to 53.37 respectively. October also followed the trend of increase from Stations 1 to 8, but for lower values at Station 4. November values varying from 3.45 to 52.66, 3.02 to 54.39 and 2.59 to 77.48 at the surface, bottom and grab water respectively exhibited an increasing trend up to Station 6 followed by a fall at Stations 7 and 8, and an abrupt drop at Station 9. Phosphate values in December recorded a sharp increase from Stations 1 to 8 in the surface, bottom and grab water values which ranged from 4.43 to 272.4, 3.9 to 276.85 and 5.32 to 93.91 respectively. Station 9 as in the case with the other months recorded low values of 2.66 to 3.76.

In general an increasing trend from Stations 1 to 8 and a sudden drop at Station 9 was noticed in all the months. Values fluctuated much at Station 1. Low values were noticed up to Station 6 in May, and up to Station 7 in October and at all Stations in July. Generally high values were noticed at Stations 6, 7 and 8 in all months.

Temporal variations showed uniformly lower values at Stations 1, 2 and 9. Station 3 recorded high values in January while only grab water gave high values in other months except November. Stations 4 to 8 were characterised by fluctuating high and low values from January to December.

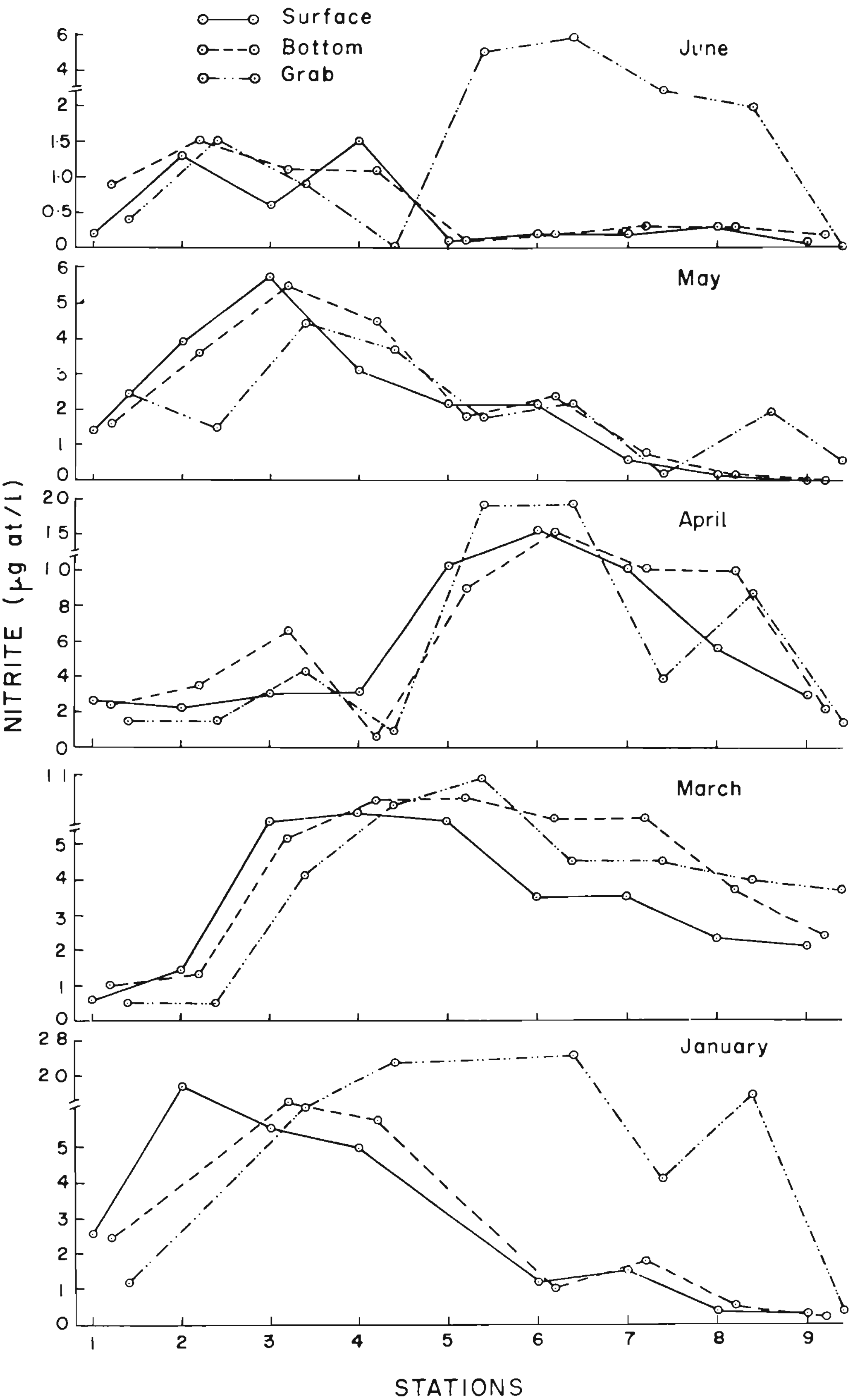
The results indicated the effect of monsoonal flow of water in the distribution of phosphate.

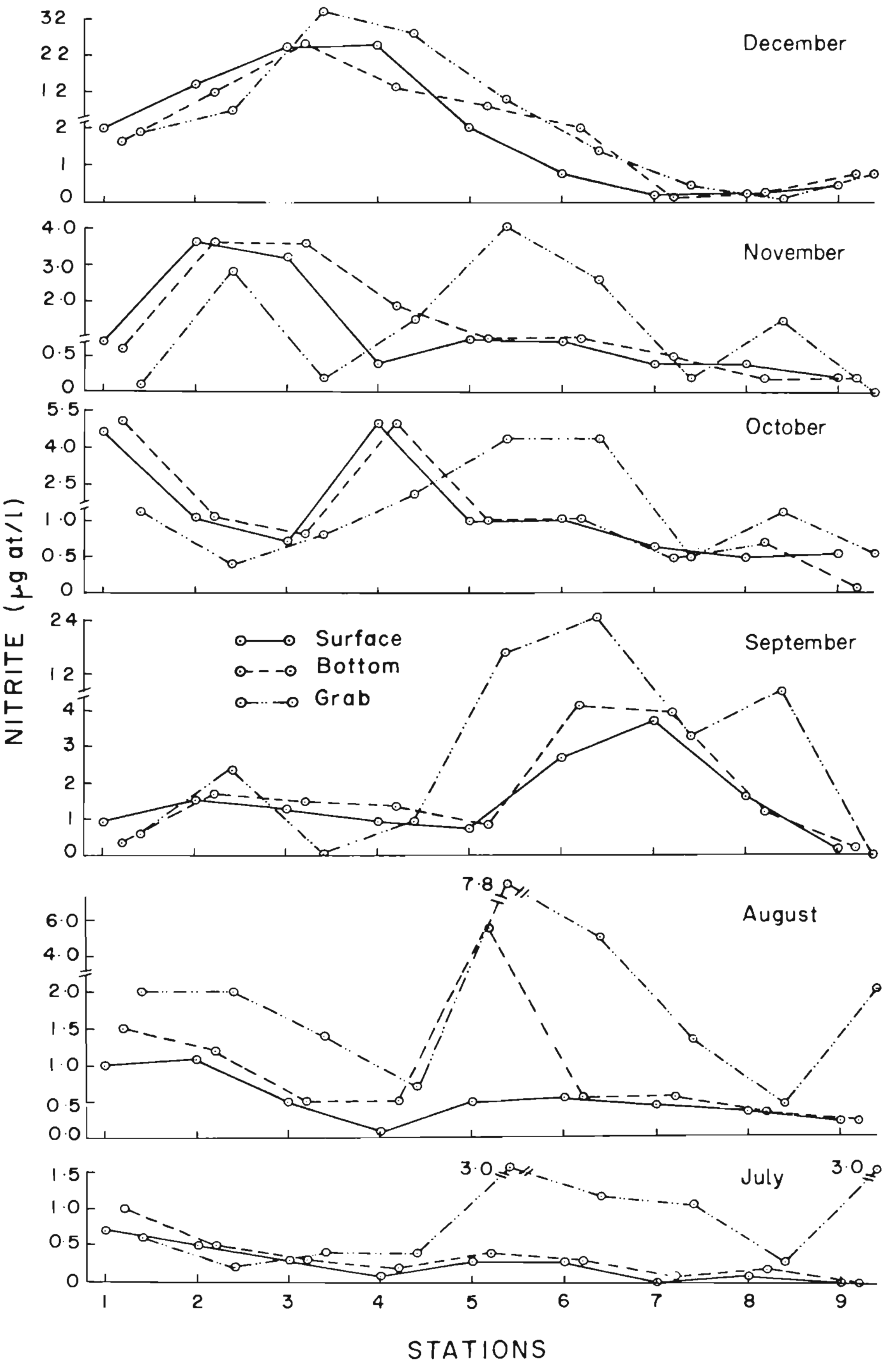
3.1.10. <u>Nitrite (µg-at/l)</u>:

Spatial and temporal variations of nitrite contents at the surface, bottom and in the grab water are illustrated in Fig. 9.

Spatial changes:- In January the surface and bottom water values recorded a fall from Stations 3/4 to 9, whereas the grab water values increased from Station 1 to Station 6,

Fig. 9. Distribution of nitrite at the 9 stations during 1981.


Surface
Bottom
Grab
June
May
April
March
January
NITRITE (µg at/l)
STATIONS
Fig. 9



December
November
October
September
August
July
Surface
Bottom
Grab
NITRITE (µg at/l)
STATIONS
7·8
3·0

Fig. 9

thereafter the lowest value of 0.43 at Station 9. During March, the surface, bottom and grab values recorded an increase in nitrite contents from the lowest values in Station 1 to high values in Station 5, thereafter falling to low values up to Station 9. April, registering low values up to Station 4 exhibited an increase at Stations 5, 6 and 7, which further declined to lower levels. During May the trend was different in that the low values from Station 1 rose to high values at Station 3 which progressively got reduced to nil values in the water column of Station 9. However, grab water values at Stations 8 and 9 showed slight increase. But for the high values at Stations 2, 3 and 4 uniformly very low values prevailed at the rest of the stations, in June. Grab water values however were high at Stations 5 - 8. Similar very low values prevailed during July and August, except for grab water in Stations 5 and 6. September, but for Stations 5 and 6 exhibited almost uniformly low values. Except for the low values at Station 3 and high values at Station 4, rest of the stations recorded a gradual reduction in nitrite content from Stations 1 - 9 during October. However, grab water registered high values at Stations 4 - 6. In November low surface and bottom values at Station 1 rose to high values at Stations 2 and 3 thereafter dropping towards very low values at Station 9. Grab water showed fluctuation between nil and 4.1. During

December nitrite contents were found increasing from Stations 1 to 3 followed by a gradual fall to very low values noted in Stations 6 to 9.

In general spatial distribution in the surface and bottom water revealed a gradual reduction in the nitrite content from Stations 3/5 towards Station 9. Very low to low values prevailed during June to November. High values were recorded only in grab water in most months in Stations 5 and 6.

Temporal changes - Nitrite values in surface waters of Station 1 varied from 0.21 to 4.41 and in bottom waters from 0.43 to 4.73 while that of grab water was 0.11 to 2.45. Low values of 0.21 to 1.02 were noted in June, July, September and November and peak values of 1.47 - 4.73 were recorded in October. Other months had moderate values ranging between 1.02 - 2.64. At Station 2, however, only July had low values of 0.21 to 0.33 and peak values were recorded in postmonsoon months of December and January (13.99 to 17.94). Rest of the months recorded comparatively higher values (1.13 to 3.92) than Station 1. Station 3 too had low values in July in addition to June, August, September and October. Peak values of 24.25 to 34.41 were recorded in December as at Station 2. In general Station 3 had low values during monsoon and high values during the postmonsoon months of December and January. Rest of the stations had values ranging between 3.04 and 6.79. June, July, August, September and November recorded low values at Station 4, similar to Station 3. While peak values of 10.44 to 23.13 occurred in the postmonsoon months of December and January except the lower values of 5.33 for surface water in January. Values in other months varied from 2.52 to 8.74. Station 5 had low nitrite values at the surface (0.11 to 0.97) and bottom waters (0.11 to 1.05) during June to November, whereas grab water showed 2.97 to 27.79. December, March and April recorded comparatively low values. Station 6 exhibited low values at the surface and bottom in contrast to high grab water values except during April when it was 15.61 to 19.86 respectively. A peak value of 24.38 was noted in the grab waters during January. Low values from 0.23 to 0.78 for surface and bottom waters were recorded from May to December except in October at Station 7 while values increased from January (1.52) to April (10.34). The gradual increase in surface and bottom water values from January to April at Station 8 was reduced abruptly to 0.20 in May which prevailed till December with slight alterations. Station 9 was unique with uniformly low values but for March and April.

Temporal variations in surface and bottom nitrite values revealed comparatively higher values during January to April/May followed by low to very low values up to December. At Stations 2 to 4 higher values occurred in October and December, also. Grab water was found to exhibit maximum fluctuation.

3.1.11. Nitrate (ug-at/l):

The spatial and temporal variations in nitrate contents were analysed and the results are shown in Fig. 10.

January indicated high values at Station 3 for bottom and grab and at Station 2 for surface water which gradually got reduced to the lowest values at Station 9. However, grab water maintained higher values at Stations 3, 4 and 6. The surface and bottom values in March increased from Stations 1 to 3 thereafter going gradually reducing to lower values towards Station 9, while grab water values rose from 23.01 to 140.36 at Station 4 thereafter lowering to 36.82 at Station 9. Nitrate content at Station 1 reached the peak values at Stations 3 and 4 followed by a gradual decrease towards Station 9 in April. May also showed a similar pattern with high values at Station 3, however, the fall in nitrate values was irregular. The surface and bottom values during June rose to the maximum of 32.3 / 34.0 at Station 8, with a slight fall in Station 9. But the grab water values fluctuated between 2.3 at Station 1 and 29.84 at Station 6. But for a higher value of 28.08 at Station 5 for surface water and low values of 7.12 and 8.85 in Stations 6 and 8 respectively for bottom water, rest of the stations during July did not have much of a variation. But grab water nitrate content increased from Stations 1 to 5 and then decreased towards Station 9. During August, surface

Fig. 10. Distribution of nitrate at the 9 stations during 1981.

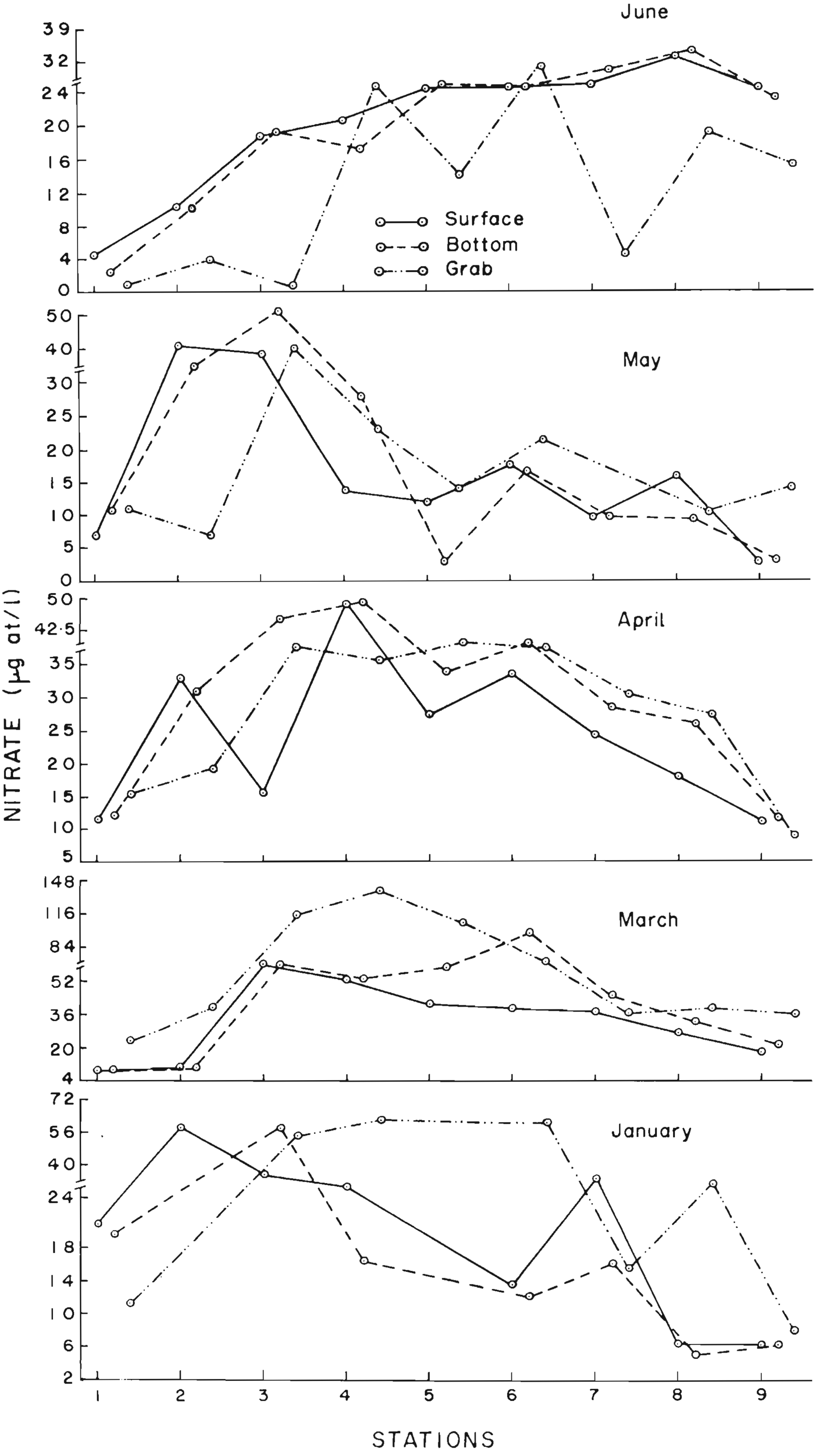
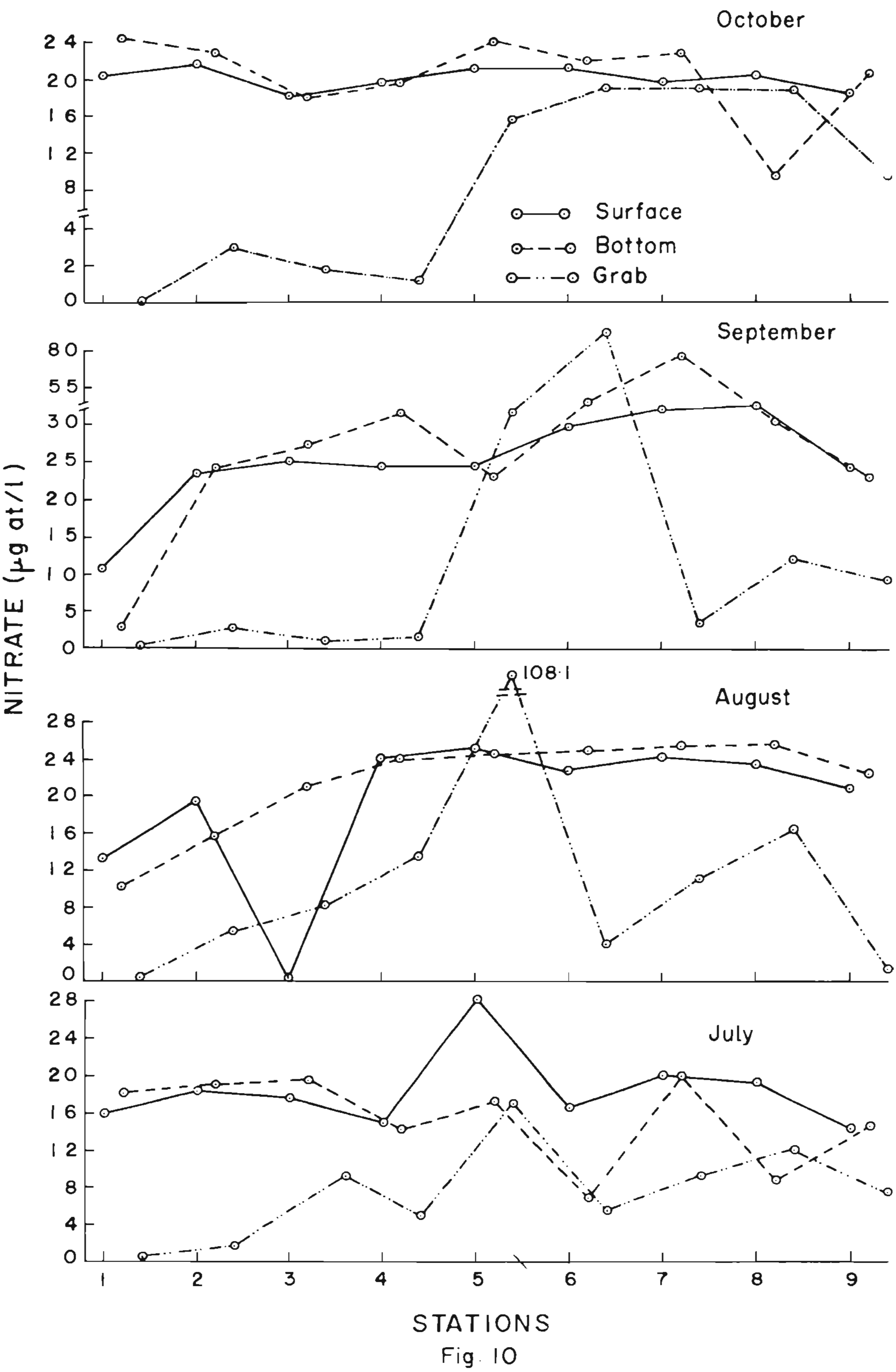

June
May
April
March
January
Surface
Bottom
Grab
NITRATE (µg at/l)
STATIONS

Fig. 10



October
Surface
Bottom
Grab
September
108·1
August
July
NITRATE (µg at/l)
STATIONS

Fig. 10

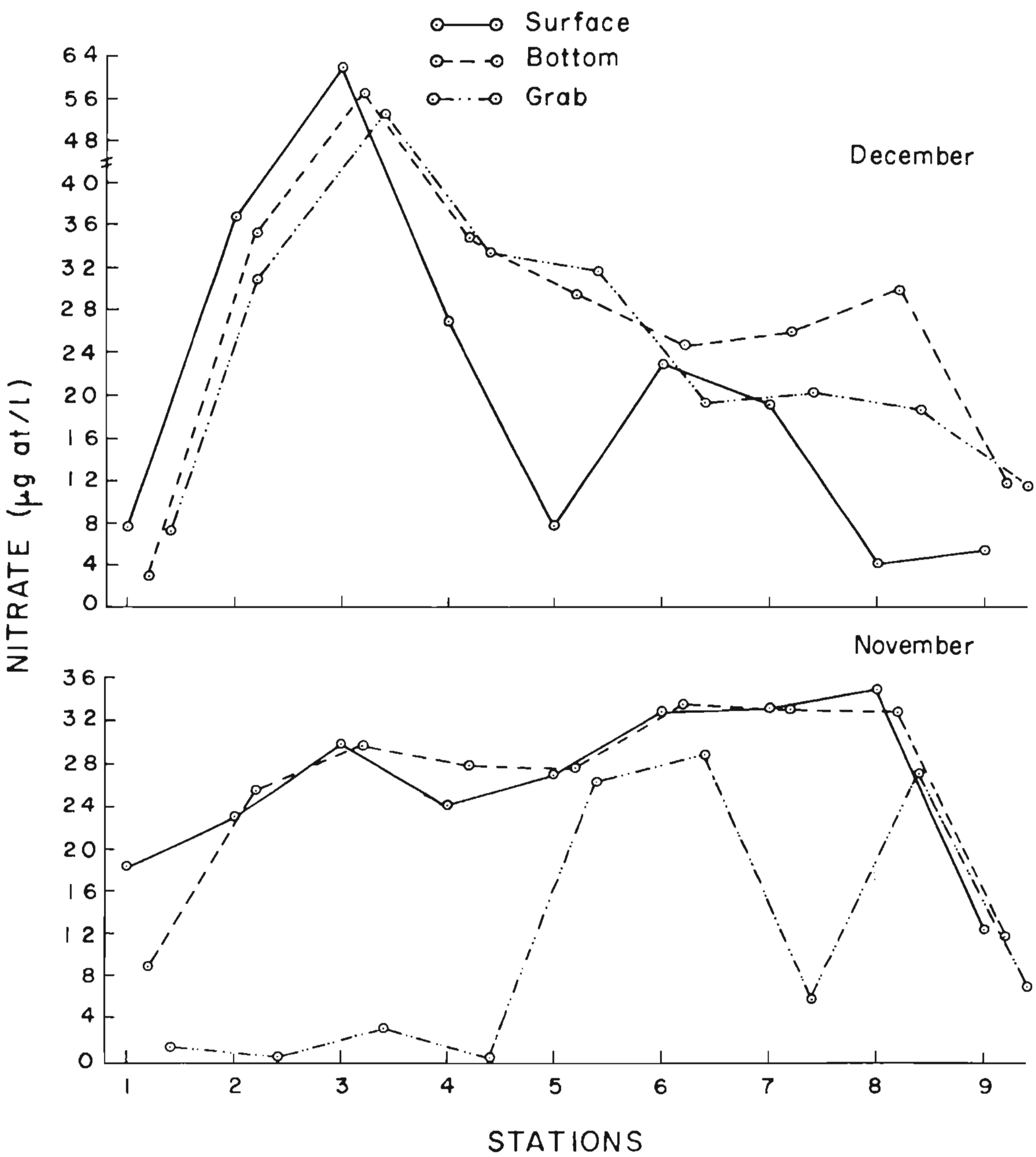

Surface
Bottom
Grab
December
November
NITRATE (μg at/l)
64
56
48
40
36
32
28
24
20
16
12
8
4
0
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 10

and bottom nitrate values gradually rose to a peak at Station 5 which was maintained at Stations 6 to 9. However, surface value at Station 3 registered a near zero value. Grab water nitrate value touched an unusual high value of 108.14 at Station 5 and was thereafter fluctuating. During September, except for the high values of 42.11 and 43.88 at Stations 7 and 8 respectively and the low value of 10.7 at Station 1, the surface values ranged between 23.57 and 29.7. Bottom values registered a steep rise from the low value of 2.78 at Station 1 to 77.57 at Station 7 and had reduced values at Stations 8 and 9. But for the unusually high values at Stations 5 and 6, other stations recorded very low values for grab water. During October, surface and bottom values at all stations maintained more or less same levels of nitrate. However, grab water values recorded lower values up to Station 4 and higher values from next station onwards. But for the low values at Station 9, surface and bottom waters in November maintained more or less uniform values from Stations 2 to 8. The very low grab water values of 0.31 to 3.10 at Stations 1 to 4 shot up to high values at Stations 5, 6 and 8 during this month. Surface, bottom and grab water values during December exhibited an increase from Stations 1 to 3 thereafter recording a fall in values to Station 9.

In general, spatial variations were more or less same at Stations 1 and 9. Initially the values rose from Stations 1 to 3 in all months thereafter either declining as in premonsoon or maintaining the values as in monsoon months. Grab water exhibited the maximum fluctuations with the highest and lowest values.

Temporal variations noted from January to December at Stations 1 to 9 revealed the following: At Station 1 the surface values fluctuated from 4.53 in June to 20.87 in January/October. Bottom values ranged from 2.6 / 2.73 / 2.98 in June / September / December respectively to 29.37 in October. Grab water which recorded very low values of 0.1 to 0.65 during July to November rose to a peak value of 23.01 in March. Station 2 recorded an abrupt fall in grab water value from 39.12 in the premonsoon months to 1.96 in July and then to 0.31 in November, followed by a sudden spurt to 30.82 in December. Fluctuations at the surface and bottom were quite similar at this station throughout the year. Station 3 registered comparatively higher values in all months with the lowest values in July, 17.48 for the surface water and 19.58 for the bottom water. However, the grab water showed very low nitrate content from June to November. At Station 4, nitrate values of surface waters fluctuated much from 53.03 in March to 13.98 in May. Bottom water values also varied from 14.23 in July to 55.28 in March.

The highest degree of variations occurred in the grab water which varied from 0.42 in November to 140.36 in March. Nitrate content in surface water of Station 5, varied from 7.91 in December, to 40.27 in March whereas bottom water values ranged from 12.9 in May to 66.73 in March. However, grab water values ranged from 14.16 in May to 108.15 in March/August. At Station 6, variations in the surface contents of nitrate was less, compared to the bottom. A range of 13.48 in January to 40.34 in March was noted. Values at the bottom varied considerably from 9.12 in July to 82.34 in March. Similar wide fluctuation was noted in grab water too from 4.0 / 5.5 in August / July to 123.66 in September. Fluctuations in surface water values of Station 7, recorded a low value of 9.75 in May and a high value of 42.11 in September. Bottom values showed the lowest value of 9.75 in May and a high value of 77.57 in September whereas lowest value for grab water (0.32) was in May and the highest value of 36.82 in March. Station 8, too with fluctuations from January to December registered a low surface content of 4.20 in December rising to a high nitrate content of 35.10 in November while bottom values ranged from the low value of 5.21 in January to 34.0 in June; the grab water content registered an increase from 9.44 in October to 39.12 in March. Highly fluctuating nitrate content values were noted at Station 9 also. The surface value ranged from its low value of 3.15 in May to high value of 25.24 in June whereas the bottom values exhibited a range of 3.3 in May to 23.05 in September. However, grab water values ranged from 1.33 in August to 36.82 in March. In general temporal fluctuations were considerably high within each station.

3.1.12. Suspended solids (Particulate matter) (mg/l):

Fig. 11 shows the spatial and temporal distribution of suspended solids at the different stations during the year. Spatial variations at Stations 1 to 9 during January to December showed the following results. During January apart from high values of 128 at Station 3 and 41.5 at Station 8, surface water at rest of the stations recorded values decreasing from 27.14 at Station 1 to 3.67 at Station 6 followed by a slight increase to 5.67 at Station 9. Bottom water except for Stations 8 and 9, showed an increase in values compared to surface waters. But for Stations 3 and 8, with high values of 150 and 65 respectively and Station 9 with a low value of 9, surface water from the rest of the stations during March showed a gradual increase from 11.5 at Station 1 to 18.6 at Station 7. Bottom values too more or less followed the pattern at the surface. Surface and bottom water values during April had a similar course as in

March with high values of 165 and 256.7 at Station 3 and 42.3 and 45.8 respectively at Station 8. During June except for the high values of 152.3 and 252.5 and 30.8 at Stations 1, 3 and 8 for surface waters, rest of the stations had low values ranging from 2.43 to 13.47. Bottom values also followed same pattern with higher values compared to surface waters except for Stations 3 and 8 where it was less and Station 9 which recorded a high value of 52.7. July recorded a different pattern of distribution of suspended solids in the surface and bottom waters with uniformly high values ranging from 60.75 to 75.7 for the surface and 67.52 to 138.0 for the bottom at all stations except 2 and 8 where low values of 26.7 and 10.5 respectively for surface and 37.5 and 10.5 respectively for bottom waters were recorded. August with a high content of suspended solid of 126 at Station 3 in the surface water showed a lesser content at other stations ranging from 5.84 to 41.5. However, bottom water indicated a high amount (231) at Station 1 and a uniformly low amount of 18.2 to 43.3 in the bottom waters of other stations. Surface waters, during September, recorded low values of 4.56 to 23.86 except at Station 3 having a high content of 150.6. At the sametime bottom water registered values ranging between 7.11 and 56.67. Compared to surface values the bottom water of Station 3 had only a low value of 51.8. October, too registered low values at the surface, ranging from 12.0 to 27.4 with the exception of 93.3 at Station 3.

However, bottom water recorded high values of 82.14 to 85.4 at Stations 2 and 9 respectively, the other stations having values ranging from 14.02 to 57.6. November, as in the case with January, March and April registered high values of 174.0 and 80.0 for surface and bottom respectively and 92.6 and 36.0 at Station 8 for surface and bottom waters respectively. Values for other stations ranged from 2.3 to 21.0 for surface and from 2.1 to 29.0 for bottom waters. December too registered a pattern similar to November, recording high values at Stations 1, 2, 3 and 8 for surface and bottom waters.

Studies on temporal variations, at Stations 1 to 9 revealed uniformly high values in all months at Stations 3 and 8. Surface waters had suspended solids ranging from 63.0 to 252.5 and bottom water from 24.8 to 256.6 at Station 3, whereas at Station 8, corresponding values were 10.55 to 92.5 and 10.57 to 71.11. The occurrence of high values during June and August at Station 1 during July at Stations 4 to 7 was a special feature.

3.1.13. Particulate organic carbon (mg/l):

Spatial and temporal variations of particulate organic carbon are shown in Fig. 11. Variations on particulate organic carbon did not necessarily conform to the pattern of distribution of suspended solids, eventhough estimation of POC were made from the latter.

Spatial distribution: - During January, the surface values ranged from 0.26 to 1.68, while the bottom values from 0.5 to 1.58 but for a single value of 6.04 at Station 1. March, displayed an increase with surface values, ranging from 0.7 to 5.33 and bottom values from 0.9 to 4.7. April, registered surface water values ranging from 0.6 to 3.35 and bottom water values ranging from 1.02 to 2.76. June recorded higher values of 8.02 and 7.8 for surface and bottom waters respectively. Stations 2 to 9 recorded low values of 0.26 to 1.18 at the surface and 1.76 to 3.61 at the bottom. Comparatively high values were noticed in July, at Stations 3 to 9 ranging from 2.62 to 4.03 at the surface and 3.28 to 6.05 at the bottom. Low values of 1.26 to 2.95 were noted at Stations 1 and 2. August registered low surface values ranging between 0.63 and 2.42 and higher bottom values in the range of 1 to 8.48 except at Station 1 which had a stray peak value of 15.8. September, showed low surface and bottom values, ranging from 0.39 to 1.76 and 0.7 to 2.27 respectivel

Fig. 11. Distribution of suspended solids and particulate organic carbon at the 9 stations during 1981.

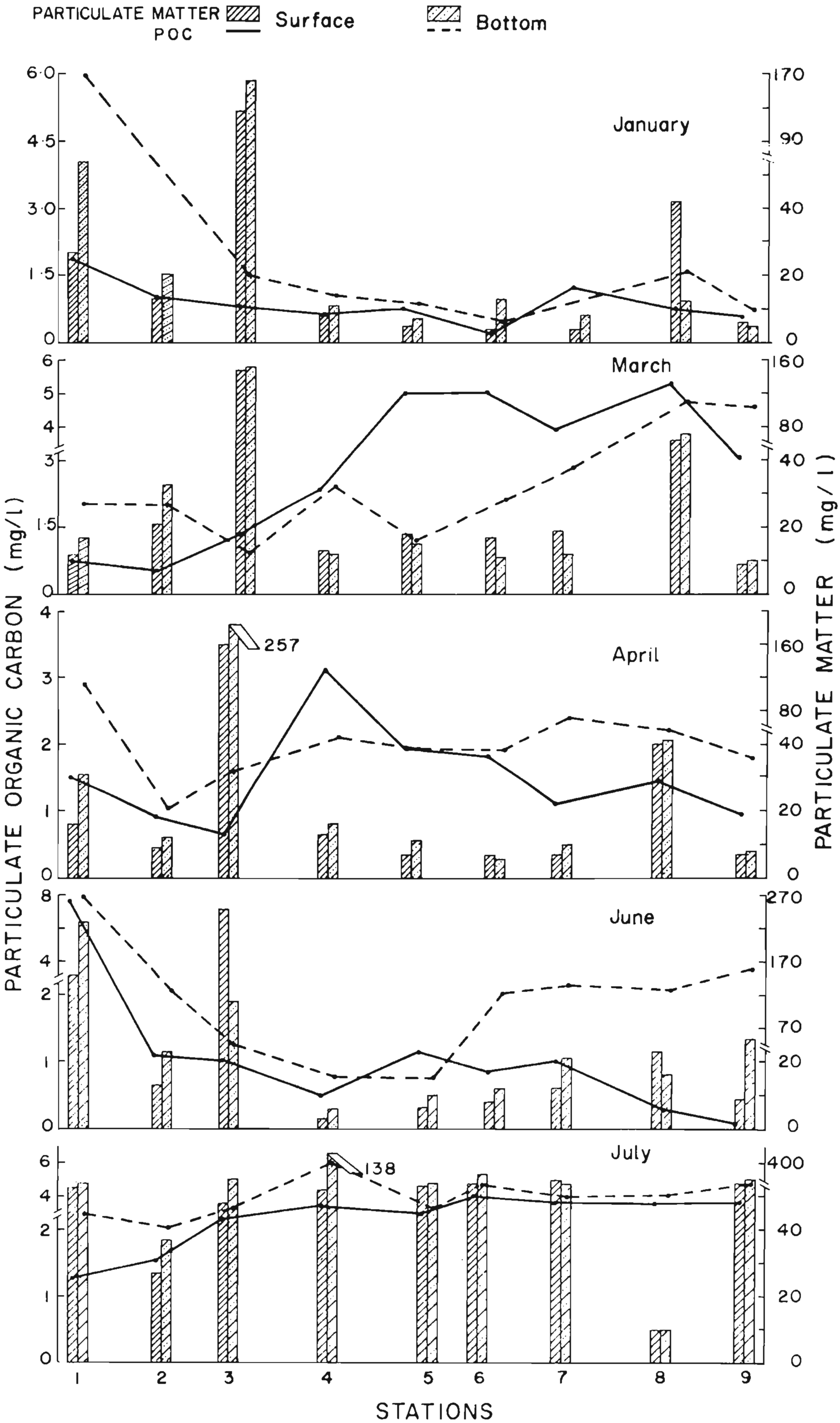

PARTICULATE MATTER
POC
Surface
Bottom
January
March
April
June
July
257
138
PARTICULATE ORGANIC CARBON (mg/l)
PARTICULATE MATTER (mg/l)
STATIONS

Fig. 11

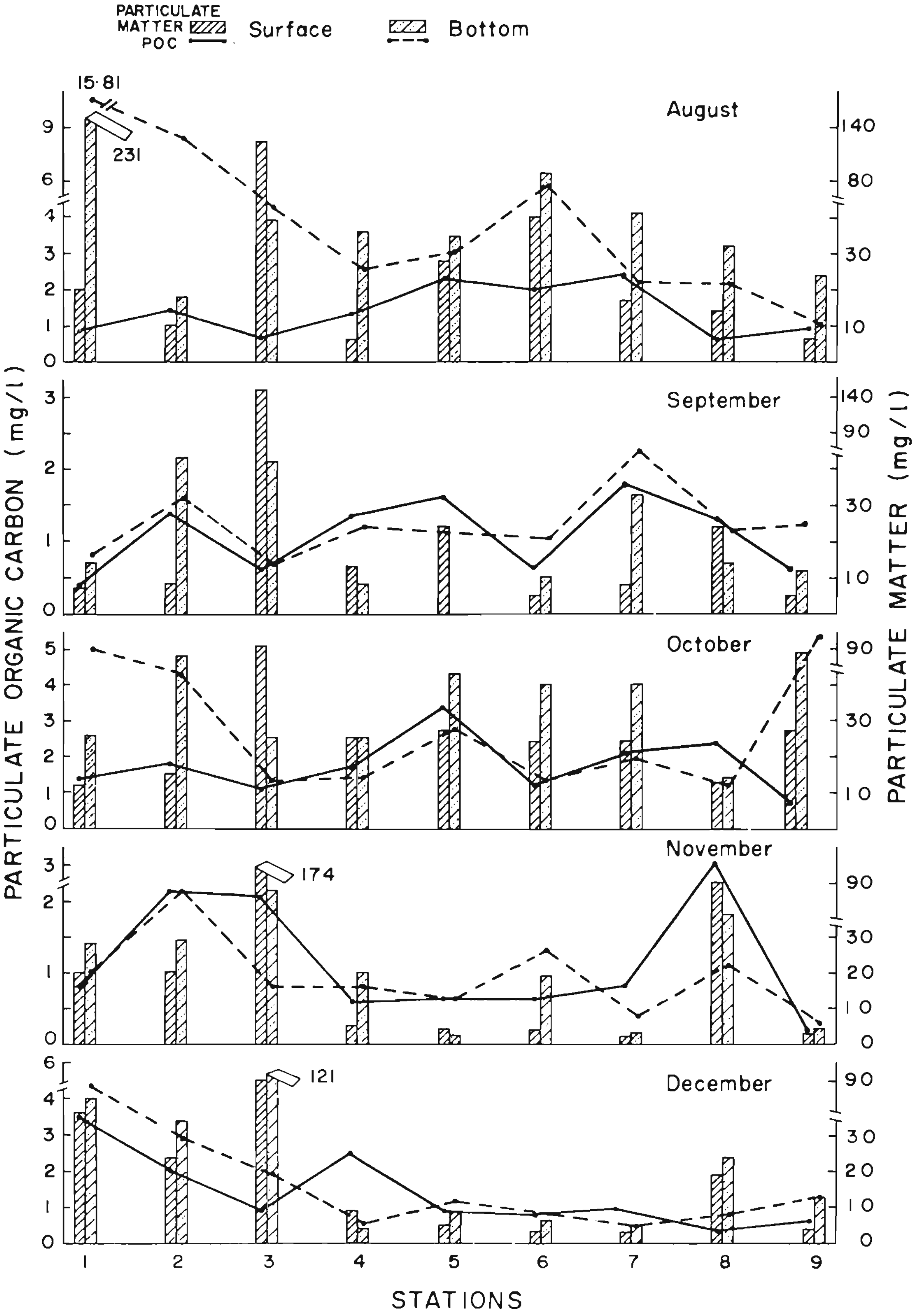

PARTICULATE MATTER
POC
Surface
Bottom
15·81
231
August
September
October
November
174
December
121
PARTICULATE ORGANIC CARBON (mg/l)
PARTICULATE MATTER (mg/l)
STATIONS

Fig. 11

Whereas, low surface values of 0.77 to 3.44 prevailed in October, bottom values remained at slightly elevated levels between 1.18 and 2.7 at all stations except at Stations 1, 2 and 9 with high bottom values of 5.0, 4.3 and 5.5 respectively. November, too recorded low surface values of 0.6 to 2.3 from Stations 1 to 9, except at Station 8 which recorded 3.1, whereas bottom water values varied from 0.32 to 2.3. In December, except, Stations 1 and 2 which recorded higher values, other stations recorded surface water values ranging from 0.39 to 2.5 and bottom water values of 0.45 to 1.9.

Stationwise analysis to locate monthly variations at each station could not bring out any fixed pattern.

3.1.14. Attenuation co-efficient/"K" value:

This was measured at all the 9 stations during January to December and values are shown in Table 3.

"K" values were highly correlated with that of particulate matter present. Spatial distribution of "K" values revealed an increase, except at Station 9, from 1.36 at Station 1 to 3.0 at Stations 7 and 8. During March, low values of 1.5 were noted at Stations 3, 4 and 6 and 1.88 at Station 9, whereas high values of 3.33 to 3.75 were noted for the rest of the Stations. "K" values fluctuated irregularly

Table - 3. Attenuation coefficient ("K" values) during the months of January to December, 1981 at Stations 1 - 9.

Months Station Nos.	J	M	A	M	J	J	A	S	O	N	D
1	1.36	3.15	2.14	4.29	7.50	10.0	5.00	2.50	5.00	3.00	1.20
2	1.88	3.33	1.88	3.75	2.50	7.5	3.75	2.14	5.00	3.00	1.50
3	1.60	1.50	2.50	3.75	2.01	15.0	2.50	1.88	6.00	2.50	1.50
4	1.66	1.50	2.50	2.50	2.15	15.0	2.50	3.00	6.00	1.50	1.50
5	2.14	3.75	1.88	2.00	1.88	15.0	3.33	3.00	7.50	1.20	2.50
6	2.50	1.50	3.00	2.14	1.88	15.0	3.75	2.50	7.50	1.20	2.50
7	3.00	3.75	2.50	2.31	3.00	15.0	3.75	3.00	7.50	1.20	2.00
8	3.00	3.75	2.50	2.31	2.50	15.0	3.75	5.00	7.50	1.88	2.40
9	1.66	1.88	1.88	1.88	2.50	15.0	3.33	2.14	7.50	1.15	1.88

between 1.88 and 3.00 during April. A gradual reduction from 4.29 to 1.88 was noticed from Stations 1 to 9 during May. But for the high value of 7.5 at Station 1, it fluctuated between 1.88 and 3.00 at other stations in June, as was seen in April. July, as such recorded very high values of 10 and 7.5 at Stations 1 and 2 and 15 in Stations 3 - 9. Uniformly moderate values ranging from 2.5 to 5 were registered in August and 1.88 to 5.00 in September. As recorded in July, increasingly high values were noted during October with 5.0 at Stations 1 and 2, 6.0 at Stations 3 and 4 and 7.5 at Stations 5 to 9. In contrast to earlier months, November values indicated a decreasing trend from 3.0 at Station 1 to 1.15 at Station 9. The reverse was the case in December when the value of 1.2 at Station 1 gradually increased to 2.4 at Station 8 with a fall to 1.88 in Station 9.

Temporal distribution:- Stations 1 and 2 had values of 3.75 to 10.0 during May to August and in October. Stations 3 - 7 showed high values during July (15.0) and October 6.0 to 7.5. Station 8 showed comparatively high values during July to October (15.0 - 7.5). Station 9 recorded lower values in all months except in July (15.0), August (3.33) and October (7.5). Monthly variations in "K" value at each station indicated peak value in July and a high value in October. In general, monsoon months exhibited high values, postmonsoon low values and premonsoon months moderate values.

3.1.15. <u>Sediment characteristics:</u>

During the present study, area-wise and monthly variations, in colour and texture of the sediments were noted. These changes were largely brought about by variations in the grain size and state of oxidation of organic matter. Fig. 12 depicts, the monthly variations in the percentage contribution of sand, silt and clay and organic carbon content of the sediments, at Stations 1 to 9 estimated during the period of investigation. Table 4 gives the type of texture of the sediment at the nine stations studied.

The colour of the sediment, varied from greyish black at Stations 1 and 2 to brownish at Station 3, black at Stations 4 to 8 and reddish brown at Station 9.

<u>Temporal variation in the texture of the sediment:</u> At Station 1, except in December, rest of the months had sediment predominated by clay portion, forming 46 to 59 %, followed by 22.5 to 39.6 percent silt. In December the proportion of clay : sand : silt was 28 : 43 : 29. The substratum, at Station 2 showed a different combination i.e. clayey from January to April and in July, November and December. Rest of the months namely May, June and August to October showed a clayey silt combination. Substratum, at Station 3, also exhibited monthly variations as in

Station 2. January to May and December had a sandy bottom with sand content varying from 63 to 97 percent. Also, sand predominated in August and October, with 42 to 48 percent. During, June, July and September with a silt content of 44 to 49 percent, it was clayey silt, whereas sand and clay content was in the proportion of 40 : 45 in November. 88 percent sand formed the substratum in December. Stations 4, 5 and 6 had substratum predominated by sand in all, but for 5 months. Sandy portion at Station 4 varied from 60 to 99 percent except in November where it was only 38 percent. Station 5 was characterised by a very high sand content varying from 92 to 99.8 percent except in April (75%). At Station 6, too, the substratum was dominated by sand comprising of 91 to 99.4 percent, during March to June, September and October whereas in December it was 74 percent. However, during January, July, August and November, silty portion dominated. Stations 7 and 8 were unique to possess a substratum dominated by silt, varying in composition from 45 to 72 percent at Station 7 and 44 to 82 at Station 8, except for August at Station 7 and May and August in Station 8. Station 9 also had a substratum composed mainly of sand varying from 88 percent in January to 40 percent in December in a decreasing order, in addition to clay from January to April and silt from June to December.

<u>Spatial variation</u>: At each station monthly pattern of sediment variation was controlled by monsoon and other man made effects. In January, Stations 1 to 9 showed a change from silty clay at Stations 1 and 2 to sandy sediment at Stations 3 to 5, followed by silty sediment at Stations 6, 7 and 8 and was again sandy at Station 9. During March, the silty sediment at Station 6 was replaced by sandy sediment. April showed no change from that of March. During May, Station 2 had dominance of silt instead of clay. Similar changes from silty to clayey at Station 8 and sandy to silty at Station 9 were also observed. In June, at Station 3, sand was replaced by silt. July, exhibited more changes probably due to monsoon effects having silt replaced by clay at Station 2 and sand by silt at Stations 4 and 6. August, too showed changes in sediment nature from silt to sand at Stations 3 and 7 and silt to clay at Station 8. The pronounced change noticed in September, was at Station 6 where silt was replaced by sand whereas in October, at Station 3, dominance of silt was changed to sand. November, brought about changes at Station 2, by replacing silt by clay, at Station 3 sand by clay and at Station 6 sand by silt. December showed a replacement of the clay sediment at Station 3 by sand and, at Station 6 the silt by sand. In general, drastic changes were noted during monsoon months and the least changes in post and premonsoon months. Stations 1 and 5 remained devoid of any major changes, having clayey bottom except in December at Station 1 and predominance of sand at

Station 5. Stations 2, 3 and 6 were the most affected.

Table - 4. Texture of the sediments at Stations 1 to 9 during January to December, 1981.

Months	STATIONS								
	1	2	3	4	5	6	7	8	9
Jan.	B	B	G	G	G	A	F	F	G
Mar.	D	D	G	G	G	G	A	A	G
Apr.	D	B	G	G	E	G	F	F	E
May	D	F	C	G	E	G	F	B	F
Jun.	D	F	F	G	G	G	F	F	C
Jul.	D	D	F	A	G	F	A	F	C
Aug.	D	F	E	E	G	F	E	D	E
Sept.	D	F	F	G	G	G	F	E	E
Oct.	D	F	C	G	G	G	F	E	C
Nov.	D	B	B	C	G	F	D	B	E
Dec.	C	D	G	G	G	E	F	G	E

A - Sandy silt; B - Sandy clay; C - Silty sand;
D - Silty clay; E - Clayey sand; F - Clayey silt;
G - Sandy.

3.1.16. Organic carbon (mg/g):

Organic carbon, present in the substratum exhibited considerable spatial and temporal variations according to the nature of the sediment. Thus considerable variations were noted at Stations 1 to 9 and within stations in time as shown in Fig. 12.

Temporal variations: Station 1, showed an organic carbon content varying from 8.36 in July to 23.63 in May with a mean value of 10.49. In general, a gradual decreasing trend from premonsoon to postmonsoon was noted from January to December but for a peak value of 23.63 in May. Station 2 recorded values varying from 3.66 in April to 22.05 in May with a mean value of 16.96. In general, apart from the low value of 3.66 in April rest of the months had an organic content of 13.5 to 22.05. At Station 3 values ranged from 7.04 in April to 27.18 in July with an average of 16.42. In general the organic carbon gradually rose from January to September thereafter declining to 13.57 in December. More or less the above pattern was followed in Station 4 where the January value gradually rose to a peak value of 23.66 in July and August which fall to 5.33 in December. The values ranged from 4.83 in June to 23.6 in August with a mean value of 14.68. Except for the January and March values, Station 5 showed gradual decrease from April/May to November/December. Organic carbon varied

Fig. 12. Organic carbon and grain size in the sediment at the 9 stations during 1981.

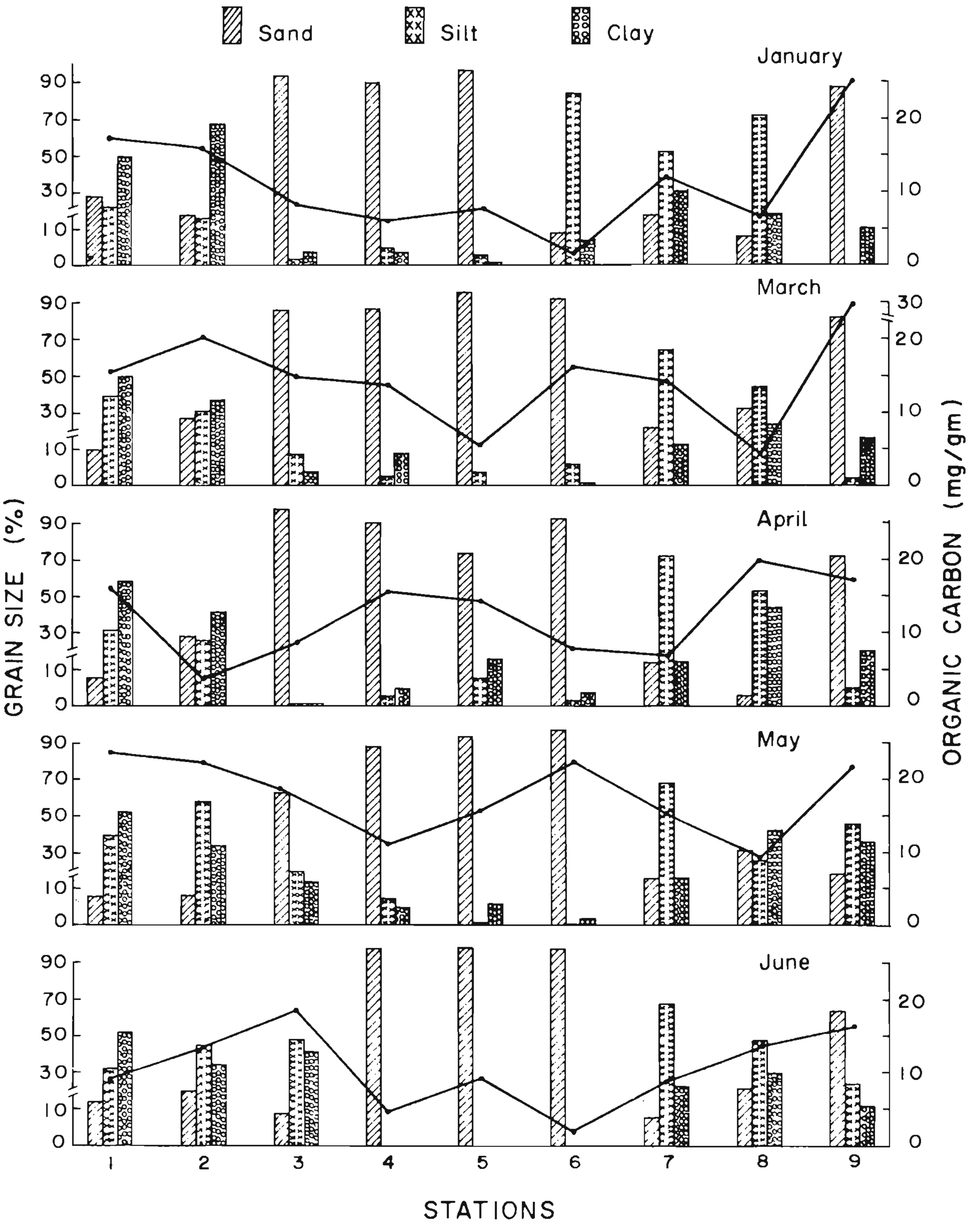
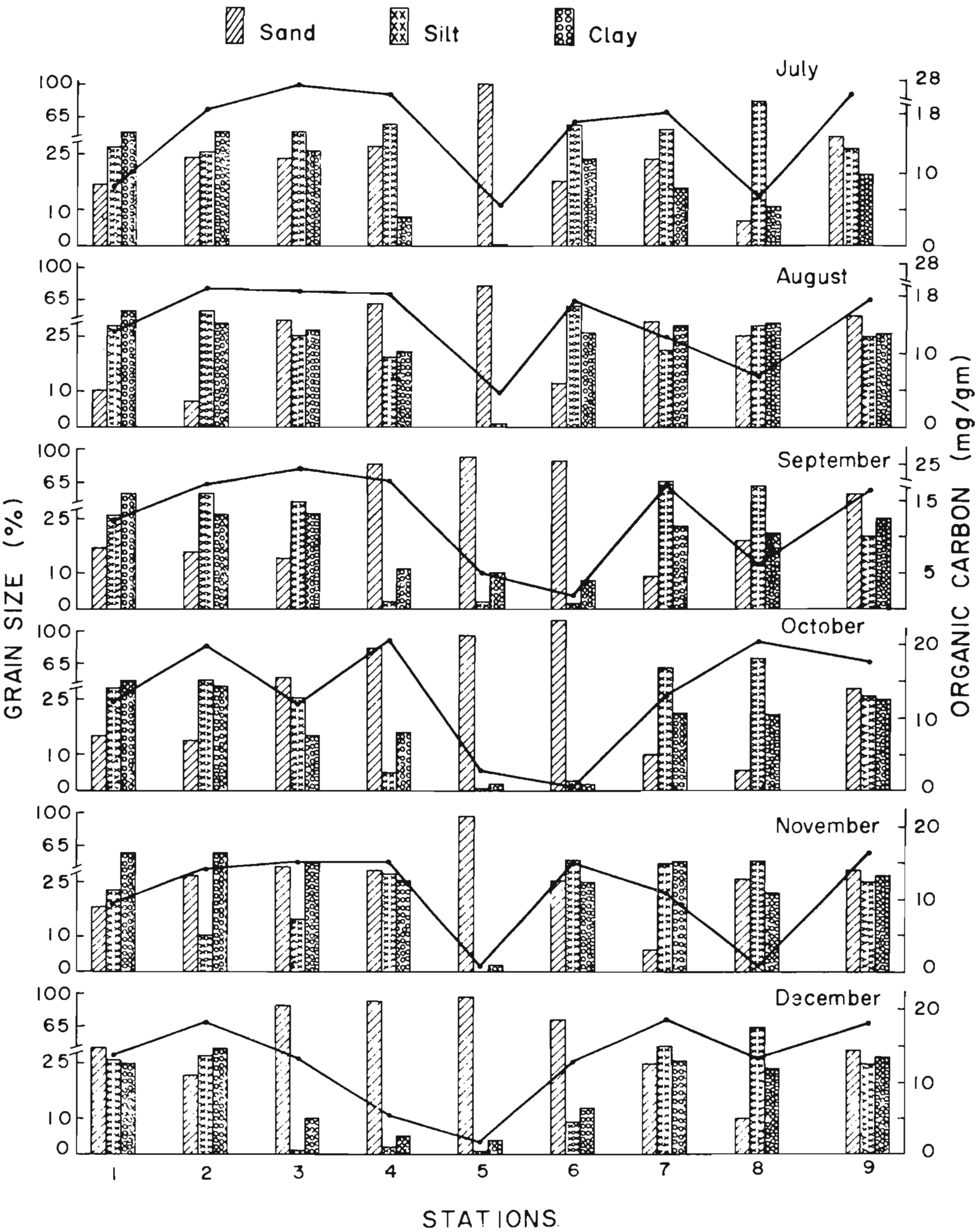

Sand
Silt
Clay
January
March
April
May
June
GRAIN SIZE (%)
ORGANIC CARBON (mg/gm)
90
70
50
30
10
0
30
20
10
0
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 12



Sand
Silt
Clay
July
August
September
October
November
December
GRAIN SIZE (%)
ORGANIC CARBON (mg/gm)
100
65
25
10
0
28
18
10
0
25
15
5
20
1
2
3
4
5
6
7
8
9
STATIONS

Fig. 12

from 1.4 in November to 15.56 in May with an average of 6.8. The substratum at Station 6, showed an organic carbon content varying from a low value of 1.19 in October to 22.31 in May with an average of 10.61. In general month to month variations showed an irregular pattern. Organic carbon at Station 7 varied from 6.78 in April to 18.65 in July with an average value of 13.39. Monthly fluctuations were high. Station 8 with a low organic carbon content of 1.62 in November and a peak value of 20.76 in October had an average value of 9.87, exhibiting considerable fluctuation between very high and low values. Sediments at Station 9 had very high values ranging between 16.55 in November and 29.6 in March with a mean value of 20.08. Spatial variations exhibited fluctuating values during premonsoon period. During monsoon season the values showed an increasing trend from Stations 1 to 4. Thereafter the values fluctuated. The lowest values were noted at Station 5 and the highest at Station 9.

On the whole temporal variations were considerably high. While very high values prevailed at Station 9, lower values occurred at Station 5. Fluctuations were more at Stations 6, 7 and 8. Stations 3 and 4 showed an increase in value up to postmonsoon. Spatial distribution showed uniformly high values in all months at Station 9 and low values at Station 5. In general, considerable fluctuations were noted from station to station.

3.1.17. Effluent characteristics:

The major portion of the industrial waste waters produced in the study area of the river Periyar, amounting to 260 million litres per day, are generated from a number of large industries i.e. those producing more than 1,000 litres per day. Of these 180 million litres are discharged into the river Periyar and 78 million let out to Chitrapuzha and 2 million on the land (KSPCB, 1982).

The factories included - 1) Fertilizers and Chemicals Travancore Ltd., 2) Travancore Cochin Chemicals, 3) Hindustan Insecticides, 4) Indian Rare Earths Ltd., 5) Cominco Binani Zinc Ltd., 6) Indian Aluminium Company Ltd., 7) Premier Tyres Ltd., 8) Tata Oil Mills Ltd., 9) Periyar Chemicals, 10) United Catalysts & Chemicals, 11) Milma Diary and 12) Travancore Chemical Manufacturing Company Ltd.

The major pollutants identified from the above effluents are - 1) Free ammonia, 2) Ammoniacal nitrogen, 3) pH, 4) BOD, 5) COD and 6) Suspended solids.

The details of waste water/effluent flow from the 7 factories and water from one control site (upstream of the industrial belt) at Eloor Kadavu are given in Table 5. The effluent characteristics analysed included, ammoniacal nitrogen, inorganic phosphate, nitrite, nitrate, alkalinity, pH, chlorinity, dissolved oxygen, BOD_5, dichromate COD, temperature and suspended solids. The table also gives the details of the above parameters, with respect to the water samples collected from a distance of 10 metres away from the discharge point of each effluent in order to locate immediate fate of the effluent. The results of a similar analysis carried out in February 1977 (Sarala Devi et al., 1979) are given in Table 6, along with the details from the Kerala State Pollution Control Board (KSPCB, 1982)in Table 7 for purpose of comparison. The details available from KSPCB (1982) on industrial waste water discharges into the river in litres/year, and suspended solids, BOD_5, COD, average pH, and other relevant data in tonnes/year are shown in Table 8.

Variations in different parameters during the period of study as given in Table 5 are: Ammonia content discharged as effluent varied, from 6.2 µg-at/l (Periyar Chemicals) to 157.5 µg-at/l (FACT black) in February, from 7.19 (TCC) to 8033.4 (FACT black) in April, 3.77 (TCC) to 2657.3 µg-at/l (FACT white) in July and from 6.95 (TCC II) to 413.2 µg-at/l (FACT white) in August indicating considerable fluctuations in the amount of ammonia released. However, the water collected 10 m away showed a range of 14.39 (Cominco Binani Ltd.) to 172.77 (IRE) in February, 14.39 (Cominco Binani Ltd.) to 899.3 (FACT black) in April, 3.77 (Periyar Chemicals) to

508.8 (FACT white) in July and 10.42 (Catalyst) to 138.9 (IRE) in August. In all no correlation could be noticed between undiluted and diluted effluents. The ammonia content from effluents collected in 1977 however recorded only very low values of 0.12 (Periyar Chemicals) to 3 µg-at/l (FACT) only while the water samples from upstream had only 0.03 µg-at/l. The control station from Eloor Kadavu during the present study had ammonia content ranging from nil to 46.9, showing highly irregular pattern. The above analysis revealed wide fluctuations in the ammonia content of the study area depending on various factors as tidal effects and monsoonal water flow pattern. It is worth recollecting that the accepted value of ammonia as per Environmental Protection Agency (1971) is 2.5 ppm. KSPCB (1980) noted ammoniacal nitrogen content fluctuating between 0.3 and 46 µg-at/l at Eloor area during their pollution monitering studies.

Inorganic phosphate contents of the effluents varied from 2.56 (TCC I) to 107.14 µg-at/l (FACT black) in February, 1.37 µg-at/l (Periyar Chemicals) to 1628.5 (FACT white) in April, 0.37 µg-at/l (TCC I) to 3926.2 (FACT white) in July and 0.92 (Periyar Chemicals) to 22.9 µg-at/l (IRE) in August. However, often the phosphate contents of waters collected 10 metres away from the discharge point showed considerable high/low values. February with nil to 93.4, April with 2.4 to 1628.5, July with 1.48 to 1111.2 and August with 0.92 to 76.12 µg-at/l. The control water from Eloor Kadavu showed a phosphate value ranging from 0.62 to 11.3 only. During pollution monitoring studies conducted by KSPCB (1980) at Eloor area, phosphate values were found varying from 0.6 to 15.8 mgm/l in the effluents. Thus depending on tidal and monsoonal flow pattern and local condition, phosphate values showed a highly irregular pattern.

Nitrite contents recorded low values, but for 110.69 µg-at/l recorded in effluents from Catalysts in July. During February the effluents had a nitrite content of nil in TCC II to 7.42 in TCC I. Nitrite values in April varied from nil (TCC II) to 4.3 µg-at/l (Catalyst) in July from nil (TCC II) to 110.69 (Catalyst) µg-at/l and in August from nil (TCC II) to 9.18 (FACT white). The control station at Eloor Kadavu also noted a nitrite content of 0.09 to 19.1 µg-at/l. Water samples collected from areas 10 metres away from the effluent discharge had nitrite contents varying from nil (TCC II) to 29.06 (Periyar Chemicals).

Analysis of nitrate, during 4 months, of the effluents discharged from 8 factories indicated higher values than nitrite. The values fluctuated between nil (TCC II) and 57.82 (Catalyst) in February, nil (TCC II) and 25.4 (FACT black) in April, 1.6 (Periyar Chemicals) and 503.1 (Catalyst) in July and nil (Cominco) and 51.72 (Periyar Chemicals) in August. The nitrate content, from waters sampled from 10 m downstream the discharge point, showed in general lower values.

The upstream water at Eloor Kadavu recorded nitrate values ranging from 5.61 to 19.1 µg-at/l.

BOD_5 values varied, from nil to 18.8 mg/l (IRE effluent) during February, nil to 18.5 (IRE) in July and 1.7 (FACT white) to 7.4 (TCC I) during August. Effluents collected from same factory in 1977 showed BOD_5 values ranging from 1.3 (Zinc Smelsters) to 51.3 (Periyar Chemicals), while the water samples from upstream had a BOD_5 value of 9. Eloor Kadavu recorded a BOD value of 3.78 to 7.69. BOD_5 values were in general quite variable probably due to the relative toxic effect on bacterial flora. KSPCB (1980) recorded BOD_5 values of 0.8 to 5.8. According to Environmental Status Report of KSPCB (1982) the industrial waste discharged from 10 industries had a BOD_5 values ranging from 0.279 to 12.75 mg/l.

COD in general is indicative of oxygen demand. Earlier studies on effluents in 1977 (Sarala Devi et al., 1979) showed COD up to 4400 mg/l for effluents from Periyar Chemicals, which produced organic chemicals. During the present study however, COD for effluents from Periyar Chemicals, flustuated between 133.4 and 887.0 only. COD values for effluents from other 7 factories ranged between nil and 17800 (Distillery effluent). According to Environmental Status Report published by KSPCB (1982), COD of effluents from 10 industries ranged from 2.89 to 558.2 tonnes/year.

Effluents ranged from poorly to well oxygenated condition as noted earlier by Sarala Devi et al. (1979). While dissolved oxygen content varied from < 0.05 to 4.5 ml/l for effluents from various factories in 1977, during the present study also similar variations were observed. Dissolved oxygen in the effluents ranged from 0.64 to 4.08 ml/l in February, nil to 4.87 ml/l in April, nil to 7.86 in July and nil to 5.26 in August. While the source water during the present study showed a range of 4.3 to 5.42 ml/l, the upstream water during earlier studies recorded up to 6.9 ml/l. The oxygen content of water sampled, 10 m away from the effluent discharge site, recorded in general higher values ranging from 2.98 to 5.96 ml/l. Monitoring studies by KSPCB (1980) showed Eloor area of Periyar having dissolved oxygen content of 2.2 to 8.7 mg/l.

While alkalinity values of the effluents from 7 factories in 1977 fluctuated between 10.8 and 195.8 mg $CaCo_3$/l, during the present analysis of effluents from 7 factories registered variations from 4.9 to 793.6 mg $CaCo_3$/l. Alkalinity varied from 4.9 to 500.8 during February, 9.2 to 588.5 during April, 10.91 to 793.6 during July and 10.05 to 179.6 during August. Effluents, from Catalysts and Distillery factory showed high alkalinity values. Water samples collected from 10 m away from discharge point also recorded varying alkalinity content. It varied from 4.8 to 76.2 mg $CaCo_3$/l during February, 1.84

to 43.7 during April, 1.79 to 166.0 during July and 5.03 to 159.0 mg $CaCo_3$/l during August. Source water alkalinity ranged from 4.9 to 15.15 in the Eloor Kadavu.

pH also varied considerably in association with alkalinity. pH measurements of the effluents from 7 factories varied from 2.1 to 11.2 in February, 3.05 to 11.8 in April, 2.4 to 11.1 in July and 2.8 to 12.3 in August. Both the high and low pH were contributed by TCC I and TCC II effluents. Catalyst and Chemicals also showed high pH. Similar pH measurements done in 1977 however recorded a low variation (2 to 8). pH measurements on water samples collected from 10 metres away from the effluents discharge site, also showed wide variations in pH values (3.55 to 9.9). pH of 10 m down from discharge site varied from 5.95 to 9.2 during February, 6 to 9 in April, 6.0 to 9.9 in July and 3.55 to 9.2 in August. This indicated considerable reduction in the acidity and alkalinity of water. pH of the source water varied from 6.25 to 7.4. The reported value of pH by KSPCB (1982) indicated lowest pH of 2.8 at Eloor area rising up to 7.9. According to Environmental Status Report of KSPCB (1982) pH value of effluents from 10 industries ranged from 3.9 to 12.0.

Effluents, from the 7 factories, had higher temperature than the ambient temperature. Temperature variations recorded were from 33.2° to 45°C in February, 33.6° to 43.2°C in April, 29.5° to 43.2°C in July and 27° to 36°C in August. Similar higher temperatures were noted during 1979 for the effluents from 7 factories. However, water samples collected from 10 m away showed only low changes. The ambient temperature changed from 32.2° to 37°C in February, 33° to 34°C in April, 26.6° to 39.5°C in July and 25.5° to 30.2°C in August. The temperature of the Eloor Kadavu water also exhibited similar variations from 25.3° to 33.2°C.

Compared to the earlier observations on chlorinity of effluents discharged from factories, the present values were very high. While values in 1977 ranged from 50 to 310 ppm, during the present study, it varied from 260 to 3,470 in February, 75 to 6,990 in April, 90 to 2,060 in July and 50 to 920 in August. However, water samples collected from 10 m down from the discharge point showed lower values. Chlorinity ranged from 125 to 2,780 in February, 75 to 175 in April, 100 to 460 ppm in July and 50 to 720 ppm in August. Chlorinity of the source water at Eloor Kadavu varied from 100 to 460 ppm, while KSPCB (1982) noted chloride values ranging from 12 to 9,500 mg/l.

Compared to the present results, suspended solids were found lower in the effluents analysed in 1977 from the same area and from the same factories. Suspended load varied from lowest value of 8 in the effluents from Cominco Binani to the highest value of 264 mg/l in the effluents of Periyar Chemicals.

During the present study, suspended particles ranged from 8 to 140 mg/l in April, 14.29 to 6,040 in July and 16 to 315 mg/l in August. The peak value of 17,333 mg/l was observed in the effluents from a distillery. Water samples from 10 m down recorded very low values probably due to fluctuation of organic particles. The values varied from 4.0 to 50 mg/l in April, 24 to 352 mg/l in July and 5 to 120 mg/l in August. The source water from Eloor Kadavu had a suspended load of 4 to 22 mg/l. According to the environmental status report (KSPCB, 1982) the total dissolved solids content of the water in the backwater comes down to 160 mg/l, during monsoon, from values as high as 53,750 mg/l during summer season. The suspended load of effluents from 10 industries ranged from 377 to 1,336.06 tonnes/year. The above observations clearly indicated an irregular source of supply of suspended load from various factories into the receiving waters through the effluents. However, the initial concentration was found undergoing substantial dilutions in the receiving waters. However, the values encountered in the water indicated the addition of pollutants from other sources as well.

Table - 5. Effluent Characteristics.

	Temperature				Chlorinity				Dissolved Oxygen			
	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.
Eloor Kadavu.	32.0	33.2	26.6	25.3	460	100	100	210	4.50	4.30	5.40	4.70
Periyar Chemicals.	38.5	34.3	30.5	32.2	260	6990	150	210	0.64	-	3.25	2.02
Down.	32.2	33.0	28.6	30.0	665	75	100	210	-	3.43	5.69	3.03
Catalyst.	44.1	43.2	43.2	31.3	1135	200	410	100	4.08	3.61	5.96	3.03
Down.	32.5	33.3	27.1	26.1	720	95	150	720	-	3.25	5.96	5.04
Cominco Binani.	35.1	33.6	31.6	-	285	75	150	-	3.48	-	1.61	-
Down.	33.1	33.2	-	-	125	175	-	-	5.80	-	-	-
TCC I.	33.2	35.5	31.2	29.8	645	1940	2060	100	3.68	0	7.86	0
Down.	33.4	33.7	28.0	26.9	955	150	460	210	-	4.06	5.96	0
TCC II.	-	-	29.5	29.3	-	-	90	920	-	-	0	5.05
Down.	-	-	-	25.7	-	-	-	100	-	-	-	5.05
IRE.	38.0	40.5	30.2	36.0	3470	120	210	50	3.52	4.87	4.07	3.84
Down.	33.6	33.3	-	27.6	2780	100	-	100	-	2.98	-	4.85
FACT (White).	37.6	40.2	42.0	27.0	485	150	210	50	2.88	4.78	4.34	5.26
Down.	34.4	34.0	39.5	25.7	-	120	150	50	-	3.79	5.15	5.26
FACT (Black).	45.0	38.3	37.1	29.8	1290	260	150	100	3.36	1.71	4.61	0
Down.	37.0	33.5	33.3	25.5	1230	100	100	50	-	3.97	4.88	4.65
Distillery.			39.2				800				-	

Contd...

Table - 5 (Contd.)

	BOD				COD				pH			
	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.
Eloor Kadavu.	7.69	-	3.78	4.59	108.40	21.60	3.33	24.20	6.25	5.50	6.40	7.40
Periyar Chemicals.	Nil	-	6.10	2.90	627.50	887.80	193.74	133.40	3.80	3.35	3.30	8.70
Down.	30.35	-	-	-	82.88	9.50	32.30	4.02	6.50	6.00	6.10	6.70
Catalyst.	Nil	-	4.50	6.00	343.40	21.04	28.12	28.60	8.30	11.80	10.90	12.30
Down.	6.20	-	-	-	256.98	189.40	1.03	10.56	6.32	6.50	9.10	8.10
Cominco Binani.	3.50	-	16.10	-	43.40	186.50	28.10	-	2.10	5.90	6.50	-
Down.	5.80	-	-	-	6.31	104.83	-	-	6.10	6.10	-	-
TCC I.	Nil	-	6.00	7.40	22.70	348.00	393.33	82.60	11.20	11.30	11.10	11.50
Down.	3.07	-	8.80	14.50	173.38	24.19	70.00	44.64	9.20	9.00	9.90	9.20
TCC II.	Nil	-	7.10	6.00	-	-	23.30	49.50	-	-	2.40	2.80
Down.	-	-	-	-	-	-	-	32.60	-	-	-	3.55
IRE.	18.80	-	18.50	17.40	820.50	68.50	82.50	45.32	8.40	7.00	7.00	7.10
Down.	3.13	-	-	-	134.20	14.10	-	26.40	7.60	7.80	-	8.00
FACT (White)	-	-	Nil	1.70	115.60	2.10	6.19	40.62	9.30	3.05	5.90	7.90
Down.	-	-	-	-	-	20.72	15.12	30.96	-	6.75	8.30	7.80
FACT (Black).	1.70	-	2.75	5.80	190.60	25.50	1.55	11.16	6.60	9.40	6.00	9.00
Down.	2.77	-	9.10	29.10	138.80	2.10	1.03	-	5.95	7.80	6.00	8.30
Distillery.			-				178.00				3.90	

Contd...

Table - 5 (Contd.)

	Suspended load				Alkalinity				Ammonia			
	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.
Eloor Kadavu.	-	4.0	22.0	13.33	4.9	-	15.15	10.05	46.96	0	3.77	27.80
Periyar Chemicals	-	52.0	14.29	145.00	500.8	9.20	10.91	106.30	6.20	21.58	58.42	29.52
Down.	-	33.0	31.43	13.33	9.8	9.20	1.79	62.70	77.08	-	3.77	24.31
Catalyst.	-	57.14	12.00	193.33	32.3	588.50	793.60	179.60	51.38	875.30	2318.00	211.82
Down.	-	4.00	24.00	16.00	4.8	13.00	15.30	5.03	86.82	95.70	490.00	10.42
Cominco Binani.	20.69	24.00	32.00	-	4.9	579.00	131.30	-	40.77	35.97	11.31	-
Down.	4.00	8.00	-	-	-	1.84	-	-	14.39	14.39	0	-
TCC I.	-	140.00	1312.50	315.00	368.8	195.50	490.00	332.00	19.49	7.19	3.77	20.84
Down.	-	42.86	352.00	120.00	76.2	21.00	166.00	159.00	154.16	182.25	71.61	107.65
TCC II.	-	-	24.02	103.33	-	-	707.00	125.80	-	-	15.07	6.95
Down.	-	-	-	13.33	-	-	-	25.10	-	-	-	10.42
IRE	-	8.00	24.00	16.00	7.8	32.00	20.20	20.08	123.15	419.65	113.10	131.90
Down.	-	4.00	-	10.00	29.4	25.00	-	70.28	172.77	358.10	-	138.90
FACT (White)	-	548.00	6040.00	280.00	105.8	9.20	570.00	220.80	32.78	3860.90	2657.30	413.20
Down.	-	50.00	76.00	5.00	0	43.70	15.30	14.10	-	54.00	508.80	107.70
FACT (Black)	-	50.00	36.00	40.00	58.80	257.00	141.40	41.60	157.70	8033.40	467.40	326.40
Down.	-	20.00	35.00	15.00	44.10	32.00	101.00	14.20	148.85	899.30	301.50	131.90
Distillery.			17333				1333					11.30

Contd..

Table - 5 (Contd.)

	Inorganic Phosphate				Nitrite				Nitrate			
	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.	Feb.	Apr.	Jul.	Aug.
Eloor Kadavu.	11.31	1.37	1.85	0.62	1.39	0.09	0.11	19.10	5.61	7.00	19.10	10.01
Periyar Chemicals	6.00	1.37	5.19	0.92	5.80	0.37	1.80	4.81	1.30	0	1.60	51.72
Down.	22.30	2.74	1.48	0.92	1.86	0.09	0.11	29.06	12.61	7.71	18.26	37.54
Catalyst.	8.50	4.11	2.59	7.03	1.97	4.30	110.69	1.24	57.82	10.82	503.10	22.52
Down.	22.39.	2.40	3.70	0.92	1.62	0.19	3.37	0	18.04	11.30	31.04	51.72
Cominco Binani.	27.09	13.03	3.70	-	1.86	2.23	0.67	-	0	14.02	23.88	0
Down.	8.91	7.89	-	-	0.56	0.19	-	-	6.16	10.50	-	-
TCC I.	2.56	-	0.37	7.03	7.42	0.65	0.42	0.62	44.50	15.77	34.39	22.52
Down.	66.87	106.80	33.34	76.12	0	0.09	0.22	0	20.85	9.65	21.97	2.50
TCC II.	-	-	1.85	3.97	0	0	0	0	0	0	0.11	12.93
Down.	-	-	-	2.14	-	-	0	0	0	0	-	2.50
IRE.	86.60	212.60	148.20	22.90	6.03	4.18	1.91	0.31	25.23	19.27	152.83	5.84
Down.	93.40	36.40	-	15.60	2.78	0.93	-	0.62	17.34	12.26	-	4.17
FACT (White)	27.40	1628.50	3926.20	37.60	1.16	1.58	3.15	9.18	26.98	18.40	29.45	9.18
Down.	-	60.20	296.30	13.76	-	0.46	1.35	7.93	0	13.10	88.10	7.93
FACT (Black).	107.14	65.14	1444.56	19.26	3.94	2.13	1.24	2.47	33.49	25.40	36.93	5.84
Down.	61.71	1628.50	1111.20	11.92	3.48	0.65	1.01	0.93	37.49	14.20	33.43	22.94
Distillery.			99.30				2.02				5.45	

Table - 6. Effluent characteristics as studied by Sarala Devi *et al.* (1979).

Source of Effluent	Temp. (°C)	Chlorinity (ppm)	pH	Diss. Oxygen (ml/l)	Alkalinity (mg $CaCo_3$/l)	Suspended solids (mg/l)	Permanganate consumed (mg/l)	COD Dichromate (mg/l)	BOD_5 (mg/l)	Ammonia (ppm)	Colour of effluents
Periyar Chemicals	33.9	200	8	1.8	117.0	264	51.3	4400	51.3	0.12	Orange
Catalysts & Chem. India Ltd.	43.9	310	6	1.4	16.4	184	7.67	20	14.3	2.76	Brown
Cominco Binani Zinc Smelters(1)	35.5	300	2	0.05	195.8	8	11.93	50	1.3	0.15	Colourless.
Bleach Smelters (2)	32.2	50	2	4.5	157.7	16	6.67	10	-	1.1	-do-
Indian Rare Earths Ltd.	36.0	50	6	4.2	10.8	18	12.67	20	6.3	1.86	-do-
FACT	30.2	50	6	4.4	16.3	12.5	14.00	30	5.3	3.00	Light grey.
TCC	31.0	150	7	4.3	16.4	50	14.67	190	-	0.18	Colourless
Water Sample Upstream	29.5	50	6.5	6.9	18.0	8	5.30	20	9.0	0.03	-do-

Table - 7. Effluent characteristics as studied by KSPCB, 1982.

Monitoring Station Location	pH		BOD_5 (mg/l)		Total Diss. solids (mg/l)		Dissolv. Oxygen (mg/l)		Total ammoniacal nitrogen		Chlorides (mg/l)		Phosphates (mg/l)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Eloor	2.9	7.9	0.8	5.8	665	16855	2.2	8.7	0.3	46.0	12.0	9500	0.60	15.8

Table - 8. Details of waste discharges into the river Periyar as revealed by KSPCB, 1982.

List of industries discharging more than 1000 l/day.	Waste water flow from the industry 1000000 l/year (Not seasonal)	Suspended solids Tonnes/year	BOD Tonnes/year	COD Tonnes/year	pH Average	And other relevant parameters Tonnes/year
Travancore Rayons Limited.	5360.70	332.47	187.61	717.46	5.21	-
Indian Aluminium Company Ltd.	4110.00	102.75	12.74	170.98	5.90	-
Travancore Cochin Chemicals.	3504.00	327.82	-	220.84	7.40 - 9.40	
Fertilizers and Chemicals Travancore Ltd.	20658.00	1336.06	-	558.20	5.78 - 7.62	F-250, P_2O_4-736, Free ammonia-658, Amm.N_2 -2512.
Indian Rare Earths Ltd.	705.10	11.97	-	38.67	3.9 - 12.00	P_2O_4 - 73.
Hindustan Insecticides.	65.60	2.04	-	5.20	4.13	Insecticide (not measured)
Periyar Chemicals.	43.20	11.67	10.48	48.65	5.60	-
United Catalysts.	126.00	57.45	2.27	17.15	7.62	Zinc - 2.450.
Cominco Binani Zinc Ltd.	844.98	7.604	-	-	-	-
Travancore Chemical Manufacturing Co.	239.08	2.418	1.088	11.715	6.93 - 7.05	Zinc - 0.145.
Milma Diary.	16.43	0.377	0.279	2.89	7.35	-

3.2. Biological investigations - Spatial and temporal distribution patterns:

3.2.1. Faunal composition and abundance (Figs. 13 & 14):

Station 1: (Tables 9 and 10 a).

Amphipods numbering 20,36,402 were found to be the most dominant group constituting 96.4 % of the benthic community with a mean value of 1,85,155 /m^2. This high numerical abundance was mainly due to their high density during the months from July to November, with a maximum of 18,38,637 /m^2 in the month of August. Numerical abundance showed considerably low values during April (28/m^2) and December (42/m^2). Seasonal variation revealed a mean high intensity of 3,94,387/m^2 during monsoon which was abruptly reduced to 20,035/m^2 in postmonsoon culminating in 1,554/m^2 during premonsoon.

Isopods numbering 41,466/m^2 representing 1.96% was the second dominant group of benthos with a monthly mean value of 3,769/m^2. Their high numerical abundance was due to their occurrence in large numbers (22,574/m^2 and 17,084/m^2) during July and August respectively. Rest of the months recorded comparatively low values ranging from 56/m^2 in January to 889/m^2 in November. However, they were totally absent in December and only 14/m^2 were present in April and June. Seasonal variation indicated the mean high values of

Fig. 13. Distribution of total number of benthos at 9 stations during 1981.

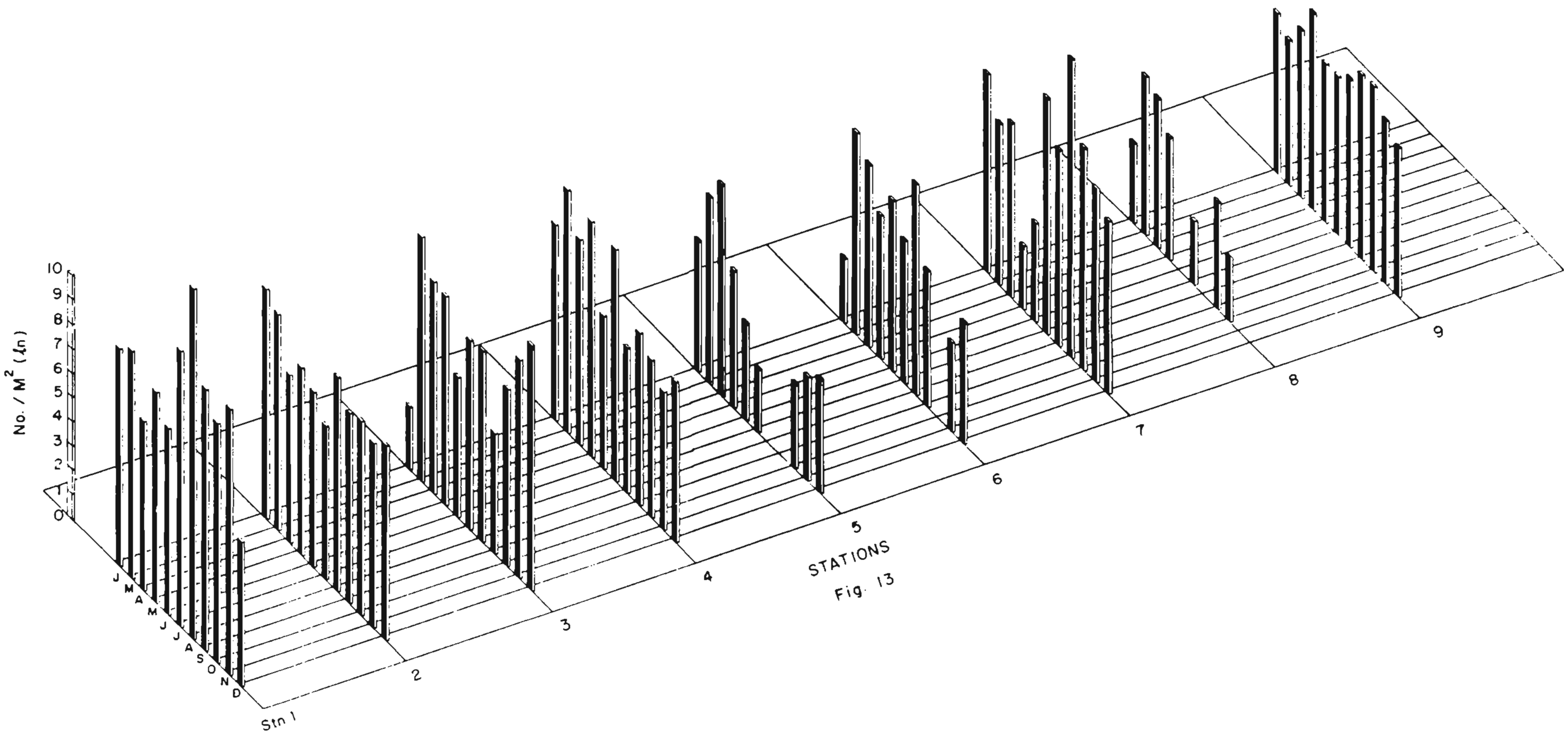


Fig. 13

Fig. 14. % Distribution of major groups of benthos at 9 stations during 1981.

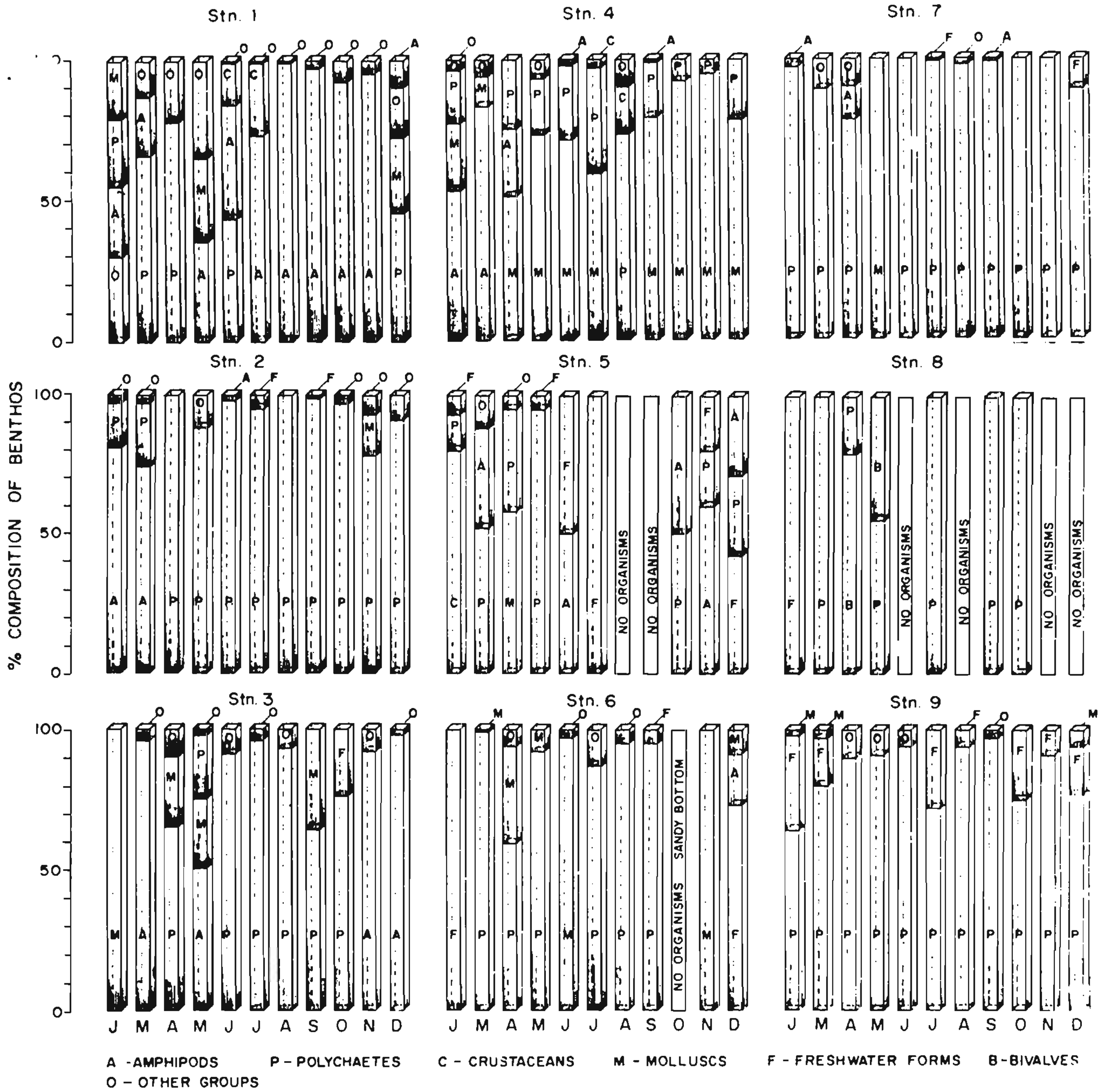

Stn. 1
Stn. 4
Stn. 7
Stn. 2
Stn. 5
Stn. 8
Stn. 3
Stn. 6
Stn. 9
% COMPOSITION OF BENTHOS
NO ORGANISMS
SANDY BOTTOM
J M A M J J A S O N D
A -AMPHIPODS
P - POLYCHAETES
C - CRUSTACEANS
M - MOLLUSCS
F - FRESHWATER FORMS
B - BIVALVES
O - OTHER GROUPS

Fig. 14

8,048/m^2 during monsoon which was reduced to 315/m^2 during postmonsoon, and a low value of 93/m^2 during premonsoon.

Polychaetes numbering 20,759 comprising only 0.98% was the third abundant group of benthos with a mean value of 1,892/m^2. March and August contributed higher abundance of 7,762/m^2 and 4,483/m^2 respectively compared to the very low value of 182/m^2 in December. Other months showed moderate values ranging between 571/m^2 and 2,024/m^2. The mean high value of 3,074/m^2 during the premonsoon got reduced to 1,700/m^2 in the monsoon and 1,032/m^2 during the postmonsoon.

Next in abundance was molluscs numbering 4,817 comprising only 0.22% of benthos, with a monthly mean value of 438/m^2. May with 1,835/m^2 and January with 1,752/m^2 were the months of abundance. Molluscs were not present in August and 14/m^2 each were present in June and July. Rest of the months had moderate values ranging from 56 to 445/m^2. Seasonal variations indicated very low value of 31/m^2 during monsoon which increased to 774/m^2 during postmonsoon and 780/m^2 in premonsoon.

Tanaidaceans numbering 4,073 forming 0.19% of the benthos ranked 5th in abundance with a monthly mean value of 370/m^2. Their numerical abundance was due to high values of 2,210/m^2 in August and 764/m^2 in July.

While April recorded total absence, moderate values of 333 and 445 were recorded during the months of June and

November respectively. Rest of the months had low values ranging from $14/m^2$ to $97/m^2$. Seasonal variation recorded mean high value of $686/m^2$ in monsoon followed by $171/m^2$ in the postmonsoon and $42/m^2$ in the premonsoon.

Sea anemones numbering 3,684 forming 0.17% of benthos ranked 6th in abundance with a monthly mean of $331/m^2$. Higher densities occurred in January ($2,168/m^2$) and May ($1,376/m^2$). During the monsoon months (June-October) they were totally absent. The rest of the months values were very low ranging between 14 and $56/m^2$. The density of $477/m^2$ during the premonsoon showed a substantial increase and reached $730/m^2$ during the postmonsoon while they were totally absent during monsoon.

Miscellaneous groups consisting of Echinoderm larvae, Fish larvae, Nematoda, Sipunculids etc. were identified from Station 1 numbering 1170 comprising 0.05% recorded a monthly mean of $106/m^2$. But for the high numerical abundance of 237 and $835/m^2$ in January and March respectively and their total absence in the months from June to September, the rest of the months yielded very low numbers of benthos ranging from 14 to $42/m^2$. Seasonal variations showed their mean $297/m^2$ of high abundance in the premonsoon following very low value of $3/m^2$ and $88/m^2$ during the monsoon and the post-monsoon respectively.

Other crustaceans comprising of 1) decapods including crab megalopa, 2) *Acetes* sp., 3) *Alphid* sp., 4) *Balanus* sp. and 5) insect larva numbering 293 formed 0.01% of benthos having a monthly mean of $28/m^2$. But for a numerical abundance of $139/m^2$ noticed in November and total absence during June, August, September and December. Rest of the months had only low abundance ranging from 14 to $42/m^2$. Seasonal values showed a mean high value of $51/m^2$ during the postmonsoon followed by $32/m^2$ during the premonsoon and $11/m^2$ in the monsoon.

Table - 9. Total number of specimens, numerical abundance and percentage occurrence of different groups of benthic fauna at Stations 1-9.

Stn. Nos.	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%
1	21,13,366	20,36,402	96.40	20,759	0.98	41,466	1.96	4,073	0.19
2	41,576	15,317	36.84	24,651	59.29	241	0.58	140	0.34
3	74,450	57,278	76,93	12,205	16.40	390	0.52	111	0.15
4	58,682	19,392	33.04	11,680	19.90	501	0.85	42	0.07
5	8,429	1,143	13.56	3,616	42.89	-	-	-	-
6	15,852	182	1.15	13,526	85.30	14	0.09	14	0.09
7	2,26,939	627	0.28	2,26,083	99.60	-	-	-	-
8	1,405	-	-	947	67.40	-	-	-	-
9	13,010	-	-	11,229	86.30	-	-	-	-

Contd....

Table - 9 (Contd.)

Stn. Nos.	Other Crustaceans		Sea anemones		Molluscs		Other groups	
	Nos.	%	Nos.	%	Nos.	%	Nos.	%
1	293	0.01	3,684	0.17	4,817	0.22	1,170	0.05
2	334	0.80	-	-	669	1.61	224	0.54
3	431	0.58	-	-	3,979	5.30	56	0.08
4	168	0.29	-	-	26,898	45.80	-	-
5	293	3.48	-	-	3,377	40.10	-	-
6	167	1.05	-	-	1,949	12.30	-	-
7	84	0.04	-	-	140	0.06	-	-
8	28	1.99	-	-	430	30.60	-	-
9	1,585	12.18	-	-	196	1.50	-	-

Table - 10 a. Numerical abundance and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 1.

Months	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%
January	8,378	2,058	24.56	2,024	24.16	56	0.67	56	0.67
March	11,831	2,496	21.09	7,762	65.61	181	1.53	56	0.47
April	1,147	28	2.44	890	77.59	14	1.22	-	-
May	6,076	2,140	35 .22	571	9.39	84	1.38	70	1.15
June	2,309	946	40.97	1,002	43.39	14	0.60	333	14.42
July	89,323	64,746	72.49	1,141	1.27	22,574	25.27	764	0.86
August	18,62,428	18,38,637	98.72	4,483	0.24	17,084	0.92	2,210	0.12
September	49,092	47,816	97.40	1,025	2.09	153	0.31	28	0.06
October	21,436	19,794	92.34	849	3.96	417	1.95	97	0.45
November	60,940	58,006	95.19	890	1.46	889	1.46	445	0.73
December	405	42	10.37	182	44.94	-	-	14	3.45
Premonsoon	6,351	1,554	24.49	3,074	48.40	93	1.46	42	0.66
Monsoon	4,04,917	3,94,387	97.39	1,700	0.42	8,048	1.98	686	0.17
Postmonsoon	23,241	20,035	86.21	1,032	4.45	315	1.35	171	0.85
Monthly Average	1,92,124	1,85,155	96.37	1,892	0.98	3,769	1.96	370	0.19

Contd....

Table - 10 a (Contd.)

Months	Other Crustaceans		Sea anemones		Molluscs		Other Groups	
	Nos.	%	Nos.	%	Nos.	%	Nos.	%
January	14	0.16	2,168	25.87	1,752	20.90	237	2.82
March	42	0.35	14	0.12	375	3.17	835	7.06
April	42	3.64	42	3.66	131	11.42	14	1.22
May	14	0.23	1,376	22.65	1,835	30.20	42	0.69
June	-	-	-	-	14	0.61	-	-
July	28	0.03	-	-	14	0.02	-	-
August	-	-	-	-	-	-	-	-
September	-	-	-	-	56	0.11	-	-
October	28	0.13	-	-	70	0.32	14	0.07
November	139	0.23	56	0.09	445	0.73	14	0.02
December	-	-	28	6.91	125	30.80	14	3.45
Premonsoon	32	0.51	477	7.51	780	12.28	297	4.68
Monsoon	11	0.002	-	-	31	0.01	3	0.001
Postmonsoon	51	0.25	750	3.23	774	3.33	88	0.38
Monthly average	28	0.01	331	0.17	438	0.23	438	0.006

<u>Station 2:</u> (Tables 9 & 10 b):

Polychaetes were the dominant group at this Station with 24,651 comprising 59.29 percent of benthic fauna with an average of 2,241/m^2. The low numerical abundance of 528/m^2 recorded in July shot up to 6,532/m^2 in August, thereafter maintaining a range of 1,029 to 2,990 during the rest of the months. Seasonal average showed their mean higher abundance of 2,758/m^2 in the monsoon which was reduced to 2,104/m^2 in the postmonsoon and 1,507/m^2 in the premonsoon.

Second in abundance were amphipods numbering 15,317 forming 36.84% with a monthly mean of 1,397/m^2. Monthly variations indicated a very high concentrations of amphipods numbering 9,864/m^2 in January and 5,254/m^2 in March. In the rest of the year presence was noted only in May, June and November and that too in numbers ranging between 14 and 139/m^2. Seasonal variation exhibited a very low occurrence of 3/m^2 in the monsoon, an increase to 1,797/m^2 during the premonsoon and to considerably higher mean value of 3,320/m^2 during the postmonsoon.

Mollusca ranked 3rd in abundance with 669 comprising 1.61% and had a mean monthly value of 61/m^2. Monthly occurrence showed their total absence in the months March to September. They made their appearance in October in fair numbers (70/m^2)rose to much higher values in November (279/m^2), were still abundant in December (209/m^2), but declined to much lower numbers in January (111/m^2). Seasonal variations registered an increase from the mean monsoon value of 14/m^2 to 209/m^2 during the postmonsoon and thence to a total absence during the premonsoon.

Other crustaceans consisting of decapods, cumacea, chironomed larvae, tanytarsus, plectrocnemia and insect larvae numbering 334 forming 0.8 percent were 4th in abundance, having a monthly mean of 30/m^2. Monthly variation showed their high numerical abundance of 208/m^2 in January. But for their total absence in the months of April, June, October and November, rest of the months had a range of 14 to 42/m^2. Seasonal average indicated a higher mean value of 74/m^2 during the postmonsoon which was reduced to 11/m^2 and 19/m^2 during the monsoon and premonsoon respectively.

Isopods numbering 241 comprising 0.58 percent of benthic fauna had a monthly average of 5/m^2. Their presence occurred only in the months of January (56/m^2), March (157/m^2) and May (28/m^2).

Miscellaneous group (Sipunculids, Nematode, Echinoderms, Flatworm and Fish larvae) ranking 6th in abundance (224) found 0.54 percent with a monthly mean of 19/m^2. Monthly occurrence indicated their total absence in April, August and September, and low abundance ranging from 14 to 42 during rest of the months. Seasonal average with a high value of $37/m^2$ during the postmonsoon was reduced to $19/m^2$ and $8/m^2$ during the premonsoon and monsoon respectively.

Tanaidaceans, the least represented group in this Station had only 140 numbers forming 0.34 percent with a monthly mean value of $13/m^2$. They were totally absent from April to October and in December. They were present in low numbers of 14 to $70/m^2$ in the months of November, January, March and May. Mean seasonal value of $28/m^2$ during postmonsoon was reduced to $8/m^2$ and $18/m^2$ during the monsoon and premonsoon respectively.

Table - 10 b. Numerical abundance and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 2.

Months	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans		Other Crustaceans		Molluscs		Other Groups	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%
January	12,241	9,864	80.58	1,989	15.50	56	0.45	70	0.19	208	1.69	111	0.91	28	0.28
March	7,079	5,252	74.19	1,600	22.60	157	2.21	-	-	14	0.19	-	-	42	0.59
April	1,029	-	-	1,029	100.00	-	-	-	-	-	-	-	-	-	-
May	2,159	139	6.44	1,894	87.70	28	1.29	42	1.95	42	1.95	-	-	14	0.65
June	1,279	14	1.09	1,251	97.81	-	-	-	-	-	-	-	-	14	1.09
July	556	-	-	528	94.96	-	-	-	-	14	2.52	-	-	28	2.52
August	6,546	-	-	6,532	99.8	-	-	-	-	14	0.21	-	-	-	-
September	2,517	-	-	2,489	98.88	-	-	-	-	28	1.11	-	-	-	-
October	3,074	-	-	2,990	97.27	-	-	-	-	-	-	70	2.28	14	0.46
November	1,962	98	4.99	1,529	77.93	-	-	14	0.71	-	-	279	14.22	42	2.14
December	3,060	-	-	2,795	91.33	-	-	-	-	14	0.46	209	6.83	42	1.37
<u>Seasonal av.</u>															
Premonsoon	3,422	1,797	0.10	1,507	28.54	62	1.06	19	0.37	19	1.17	-	-	19	0.37
Monsoon	2,794	3	1.95	2,758	98.71	-	-	8	0.28	11	0.39	14	0.50	8	0.28
Postmonsoon	5,754	3,320	37.02	2,104	86.10	19	0.33	28	0.27	74	0.28	200	9.77	37	1.67
Monthly average	3,773	1,397	37.02	2,241	59.13	5	0.13	13	0.34	30	0.79	61	1.61	19	0.50

Station 3: (Tables 9 & 10 c).

Amphipods numbering 57,278 comprised 76.93 percent of benthic fauna with a monthly mean of 4,633/m^2. Majority of amphipods were collected during March (22,193/m^2) and December (24,631/m^2). High monthly values were noted in April (362/m^2), May (2,697/m^2) and November (7,367/m^2) while July, September and October did not have any amphipods, in June and August they were recorded very low number of 14/m^2. Mean seasonal variations indicated highest abundance of 10,666/m^2 during the postmonsoon which declined to a low 8,417/m^2 during the premonsoon, terminating in a sharp decline to only 6/m^2 during monsoon.

Polychaetes numbered second in abundance with 12,205 comprised 16.4% resulting in a monthly mean value of 1,109/m^2. But for January, polychaetes were seen in all months with higher density which ranged from 1,140/m^2 to 3,768/m^2 in the months of April, May, July, August and October. Representation during the rest of the months was low to the counts of 56/m^2 in December, 98/m^2 in September, 164/m^2 in March and 292/m^2 in June. Seasonal variations in mean values showed comparables counts (1,714/m^2) during the premonsoon and 1,267/m^2 in the monsoon with a sharp fall to 241/m^2 during postmonsoon.

Molluscs the third major component of the fauna of the station numbering 3,979 formed 5.3% with a mean of 357/m^2. Monthly variations revealed their total absence during June, July and October. Large numbers were collected in April (1,460/m^2) and May (1,335/m^2). Medium counts of 170, 375 and 487/m^2 were noticed in the months of August, December and March respectively. Low values of 14 - 56/m^2 were recorded during January, September and November. Mean seasonal variations indicated low values of 45/m^2 during the monsoon which was raised to 139/m^2 during the post-monsoon and then to a high value of 1,094/m^2 during the premonsoon.

Other crustaceans consisting of Cumacea, Chironomid larvae, Tanytarus sp., Plectrocnemia sp. and Ephydra sp. ranked 4th in abundance with 431 numbers realised 0.58 percent and a mean monthly value of 39/m^2. Of this a maximum of 361/m^2 was present in October. Much lower numbers of 14 - 28/m^2, were seen during May to August and were totally absent during the rest of the months. Seasonal mean intensity showed their rare occurrence of 5/m^2 during the premonsoon, a maximum of 83/m^2 during the monsoon and total absence during postmonsoon.

Isopods numbering 390 ranked 5th in abundance representing 0.52 percent of benthos, with a mean monthly count of 35/m^2. Monthly distribution showed their absence in all months but for their presence in March, April and July with

209, 153 and 28 respectively. Mean seasonal density indicated their high population of $121/m^2$ during premonsoon which abruptly declined to $6/m^2$ during the monsoon and total absence during the postmonsoon.

Tanaidaceans, numbering 111 i.e. 15% of benthic fauna were collected only in the month of May. Miscellaneous groups consisting of sipunculids, nematodes, flat worms and fish larvae numbering 56 represented 0.08% of benthic fauna. Monthly distribution recorded their presence in April and July $28/m^2$ each.

Table - 10 c. Numerical abundance (No./m^2) and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 3.

Months	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans		Other Crustaceans		Molluscs		Other Groups	
		Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%	Nos.	%
January	14	-	-	-	-	-	-	-	-	-	-	14	100.0	-	-
March	23,056	22,193	96.26	164	0.71	209	0.91	-	-	-	-	487	2.11	-	-
April	5,771	362	6.27	3,768	65.29	153	2.65	-	-	-	-	1,460	25.29	28	0.48
May	5,367	2,697	50.25	1,210	22.55	-	-	111	2.07	14	0.26	1,335	24.87	-	-
June	320	14	4.38	292	91.25	-	-	-	-	14	4.38	-	-	-	-
July	2,391	-	-	2,293	95.90	28	1.17	-	-	28	1.17	-	-	28	1.17
August	2,714	14	0.52	2,516	92.70	-	-	-	-	14	0.52	170	6.26	-	-
September	154	-	-	98	63.64	-	-	-	-	-	-	56	36.36	-	-
October	1,501	-	-	1,140	75.95	-	-	-	-	361	24.05	-	-	-	-
November	8,063	7,367	91.37	668	8.28	-	-	-	-	-	-	28	0.35	-	-
December	25,062	24,631	98.28	56	0.22	-	-	-	-	-	-	375	1.49	-	-
Premonsoon	11,398	8,417	73.80	1,714	15.00	121	1.06	28	0.32	5	0.03	1,094	9.63	9	0.08
Monsoon	1,415	6	0.42	1,267	89.47	6	0.42	-	-	83	5.86	45	3.17	6	0.42
Postmonsoon	11,046	10,066	96.60	241	2.18	-	-	-	-	-	-	139	1.21	-	-
Monthly average.	6,765	4,633	68.50	1,109	16.39	35	0.51	10	0.14	39	0.57	357	5.27	5	0.07

Station 4: (Tables 9 & 10 d).

The most important component of the fauna of this station was molluscs numbering 26,898 comprising of 45.8% with a monthly mean value of 2,453/m^2. Monthly variation in numerical abundance revealed a maximum of 11,426/m^2 in May and a minimum of 14/m^2 in August, the rest of the months having a range of 278/m^2 to 7,509/m^2. Seasonal averages indicated a progressive fall from 5,310/m^2 during the premonsoon to 1,891/m^2 during the monsoon and to 531/m^2 during the postmonsoon.

Second in abundance were amphipods numbering 19,392 forming 33.04 percent with an average value of 1,761/m^2. Monthly variation in abundance indicated a very high peak of 16,569/m^2 in March compared to low values of 1,610/m^2 in January and 1,070/m^2 in April followed by a sharp fall from 70/m^2 in May to 28/m^2 in July and 14/m^2 in June, August and subsequent absence in the rest of the months. Mean seasonal counts of amphipods showed a low occurrence of 56/m^2 during the monsoon which rose to 537/m^2 during the postmonsoon and 5,903/m^2 during the premonsoon.

Polychaetes numbering 11,680 comprising 19.9 percent with a monthly mean count of 1,038/m^2 ranked third in numerical abundance. Their monthly variation indicated high values of 1,099 to 4,592/m^2 during March, April, May and July. Moderate values of 140 to 626/m^2 prevailed in January, June, August, September and November. Very low values 56 and 14/m^2 were noted in October and November. Seasonal average counts showed high numerical incidence of 1,761/m^2 during the premonsoon, which was reduced to 1,066/m^2 during the monsoon and a sharp fall to 269/m^2 during the post-monsoon.

Isopods numbering 501 comprising 0.85 percent were noted only during three months i.e. January (14/m^2), July (417/m^2) and August (70/m^2).

Other crustaceans - Decapoda, Megalopa larvae, Cumacea, Chironomid larvae - numbering 168 forming 0.29% were noticed only in three months at very low counts of 126/m^2 in January, 28/m^2 in March and 14/m^2 in April.

The least represented were Tanaidaceans numbering 42 comprising of 0.07% were noted at low counts of 14 each in January, April and May.

Table - 10 d. Numerical abundance (No./m^2) and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 4.

Month	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans		Other Crustaceans		Molluscs	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
January	3,109	1,610	51.78	626	20.13	14	0.45	14	0.45	126	4.05	719	23.12
March	20,003	16,509	82.83	1,196	5.98	-	-	-	-	28	0.14	2,210	11.04
April	4,491	1,070	23.82	1,099	24.47	-	-	14	0.31	14	0.31	2,294	51.07
May	14,498	70	0.48	2,988	20.60	-	-	14	0.09	-	-	11,426	78.81
June	557	14	2.51	140	25.13	-	-	-	-	-	-	375	67.32
July	12,518	28	5.70	4,592	36.68	417	3.33	-	-	-	-	7,509	59.98
August	488	14	1.16	306	62.70	70	14.34	-	-	-	-	14	2.86
September	1,211	-	-	237	19.57	-	-	-	-	-	-	946	78.11
October	668	-	-	56	8.38	-	-	-	-	-	-	612	91.61
November	292	-	-	14	4.79	-	-	-	-	-	-	278	95.20
December	766	-	-	168	21.90	-	-	-	-	-	-	598	78.06
<u>Seasonal av.</u>													
Premonsoon	12,997	5,903	45.41	1,761	13.54	-	-	-	-	14	0.11	5,310	40.85
Monsoon	3,088	56	1.81	1,066	34.52	97	3.14	-	-	-	-	1,891	61.23
Postmonsoon	1,389	537	38.70	269	15.05	5	0.36	5	0.36	42	3.02	531	38.23
Monthly av.	5,327	1,761	33.10	1,038	19.48	46	0.86	11	0.21	15	0.28	2,453	46.05

Station 5: (Tables 9 & 10 e).

Polychaetes numbering 3,616 were the most dominant faunal group of this station. They formed 42.89% of benthos with a monthly average of $319/m^2$. Their monthly distribution showed a high abundance of $1,071/m^2$ in March, $2,099/m^2$ in April and a moderate value of $250/m^2$ in May. They were totally absent from June to September, but were present in negligible numbers from October to January. Seasonal values showed their rare presence of $3/m^2$ during monsoon which rose to $23/m^2$ during postmonsoon and reached the maximum of $1,140/m^2$ during premonsoon.

Second in abundance was molluscs with 3,377 forming 40.1% of benthic fauna. Monthwise distribution revealed, their occurrence only in March ($112/m^2$) and April ($3,265/m^2$).

Amphipods ranked third with 1,143 forming 13.56 percent of benthic fauna. Their monthly average showed $90/m^2$. Monthwise distribution revealed high population of $736/m^2$ in March and $139/m^2$ in April and their total absence in the month of January, May, July, August and September. Low counts ranging from 14 to 42 were observed during the months of June, October, November and December. Mean seasonal variation indicated very low counts ($9/m^2$) during the monsoon, which was raised to $28/m^2$ during the postmonsoon reaching a peak of $291/m^2$ during the premonsoon.

Other crustaceans (consisting of Decapoda, insect larvae, Chironomid larvae, Tanytarsus sp., Cricotopus sylvestris, Simulium sp.) together constituted a population density of 293 forming 3.48% and ranked 4th in abundance with a mean monthly count of $49/m^2$. Majoroty of these were recorded in January ($181/m^2$), March ($143/m^2$) and April ($97/m^2$). Very low population counts of 14 to $42/m^2$ were observed from May to July and November and December. But August, September and October did not record any of them. Seasonal averages recorded very low counts of $9/m^2$ during the monsoon followed by $79/m^2$ in the postmonsoon and a high count of $84/m^2$ during the premonsoon.

Table - 10 e. Numerical abundance (No./m^2) and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 5.

Months	Total number of specimens	Amphipods		Polychaetes		Other Crustaceans		Molluscs	
		No.	%	No.	%	No.	%	No.	%
January	209	-	-	28	13.39	181	86.60	-	-
March	2,062	736	35.69	1,071	51.94	143	6.94	112	5.43
April	5,600	139	2.48	2,099	37.48	97	1.74	3,265	58.30
May	264	-	-	250	94.69	14	5.31	-	-
June	56	28	50.00	-	-	28	50,00	-	-
July	14	-	-	-	-	14	100.00	-	-
August	-	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-	-
October	28	14	50,00	14	50.00	-	-	-	-
November	70	42	60,00	14	20,00	14	20.00	-	-
December	98	28	28.57	28	28.57	42	42.85	-	-
Premonsoon	2,642	291	11,01	1,140	43.15	84	3.20	1,225	46.40
Monsoon	20	9	45,00	3	15,00	9	45.00	-	-
Postmonsoon	126	28	22,20	23	18.30	79	62.70	-	-
Monthly av.	764	90	11,80	319	41.80	49	6.40	111	14.50

Station 6: (Tables 9 & 10 f).

Polychaetes numbering 13,526 was the most abundant group forming 85.3% of benthic fauna, with a monthly average count of 957/m^2. Distribution on a monthly basis revealed a high population of 3,447/m^2 in March, 1,043/m^2 in April and 5,171/m^2 in August. Moderate values of 306/m^2 and 278/m^2 were noted in May and July respectively, whereas June and September recorded low values of 14/m^2 and 83/m^2 respectively. They were totally absent from October to January. Seasonal average showed more or less same count of 1,598/m^2, 1,145/m^2 and 1,052/m^2 during premonsoon, monsoon and postmonsoon respectively.

Second in abundance were molluscs numbering 1949 comprising 12.3% with a monthly mean count of 180/m^2. Monthwise distribution recorded their total absence during January, July, September and October, low occurrence of 14 to 42/m^2 in the months of March, May and December and high density of 209, 641 and 1015/m^2 in August, April and June respectively. Seasonal averages indicated high premonsoonal 232/m^2 and monsoonal (250/m^2) abundance compared to the low value of 19/m^2 during the postmonsoon.

Amphipods ranking 3rd in numerical abundance had only 182 specimens forming 1.15%. They were present only in 4 months i.e. April ($84/m^2$), July ($28/m^2$), August ($42/m^2$) and December ($28/m^2$). Compared to the monsoon ($14/m^2$) and the postmonsoon ($9/m^2$) the premonsoon showed a mean count of $28/m^2$.

Tanaidaceans numbering only 14 constituting 0.09 % of benthos were present only in April.

Similarly isopods also numbering only 14 constituted 0.09 percent of benthos were recorded in August only.

Other Crustaceans (unidentified crustacean larvae, Anatopynia sp., Ephydra sp., Bezzia sp.) numbering 167 formed 1.05 percent of benthic fauna. Monthly distribution values revealed high incidence of $111/m^2$ in December and very low counts of $14/m^2$ in January, June, July and September. Rest of the months were totally devoid of above groups.

Table - 10 f. Numerical abundance (No./m^2) and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 6.

Months	Total number of specimens	Amphipods		Polychaetes		Isopods		Tanaidaceans		Other Crustaceans		Molluscs	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
January	14	-	-	-	-	-	-	-	-	14	100.0	-	-
March	3,475	-	-	3,447	99.19	-	-	-	-	-	-	28	0.81
April	1,782	84	4.71	1,043	60.10	-	-	14	0.78	-	-	641	35.97
May	334	-	-	306	91.62	-	-	-	-	-	-	28	8.38
June	1,043	-	-	14	1.34	-	-	-	-	14	1.34	1,015	97.32
July	320	28	8.75	278	86.88	-	-	-	-	14	4.38	-	-
August	5,436	42	0.77	5,171	95.13	14	0.25	-	-	-	-	209	3.84
September	97	-	-	83	85.56	-	-	-	-	14	5.04	-	-
October	-	-	-	-	-	-	-	-	-	-	-	-	-
November	1,083	-	-	1,043	96.30	-	-	-	-	-	-	42	1.00
December	2,266	28	18.3	2,113	93.20	-	-	-	-	111	72.55	14	9.15
Premonsoon	1,863	28	1.5	1,598	85.80	-	-	5	0.27	-	-	232	12.45
Monsoon	1,415	14	0.99	1,145	80.90	3	0.21	-	-	8	0.56	250	17.67
Postmonsoon	1,121	9	0.80	1,052	93.80	-	-	-	-	42	3.75	19	1.69
Monthly av.	1,171	14	1.19	957	81.70	1	0.08	1	0.08	15	1.28	180	15.40

<u>Station 7</u>: (Tables 9 & 10 g).

Polychaetes were the most abundant numbering 2,24,800 amounting to 99.6% of benthos and showing a monthly mean value of 20,556/m^2. Their distribution on a monthly basis recorded their total absence in May and low numerical count of 56/m^2 in June. Almost all the polychaetes (1,90,667/m^2) were present in September. A high count of 14,499/m^2 was noted in July. Rest of the months showed a low range of count of 657 to 9,146/m^2. Seasonal mean counts indicated their profound abundance during the monsoon 43,474/m^2 compared to low incidence of 2,375/m^2 in the postmonsoon and 538/m^2 during the premonsoon.

Second in abundance were amphipods numbering 627/m^2 comprising 0.28% with an average monthly value of 57/m^2. Monthly distribution revealed their presence in only 5 months, January, March, April, August and September in small counts of 28 to 306/m^2. Seasonal mean counts showed a more or less uniform distribution of 65/67/m^2 in both the premonsoon and monsoon periods whereas the postmonsoon recorded low density (32/m^2).

Molluscs ranked third in abundance numbering 140 comprising 0.06%. They were recorded in only three months, March, April and May, during the premonsoon with 42, 84 and 14/m^2 respectively.

Other crustaceans consisting of insect larvae, Chironomid larvae, Diamesa sp., Anatopynia sp. ranked 4th in abundance with 84 specimens comprising 0.4% of benthos. Their presence was recorded in all the seasons, but was restricted to the four different months, of April ($42/m^2$), July ($14/m^2$), August ($14/m^2$) and December ($14/m^2$).

Table - 10 g. Numerical abundance and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 7.

Months	Total number of specimens	Amphipods		Polychaetes		Other Crustaceans		Molluscs	
		No./m^2	%	No./m^2	%	No./m^2	%	No./m^2	%
January	3,344	97	2.90	3,247	97.09	-	-	-	-
March	741	42	5.67	657	88.66	-	-	42	5.66
April	1,239	154	12.43	959	77.40	42	3.39	84	6.78
May	14	-	-	-	-	-	-	14	100.00
June	56	-	-	56	100.0	-	-	-	-
July	14,513	-	-	14,499	99.90	14	0.96	-	-
August	3,045	28	0.92	3,003	98.62	14	0.46	-	-
September	1,90,973	306	0.16	1,90,667	99.84	-	-	-	-
October	9,146	-	-	9,146	100.00	-	-	-	-
November	2,850	-	-	2,850	100.00	-	-	-	-
December	1,154	-	-	1,029	89.17	-	-	-	-
Premonsoon	665	65	5.47	538	91.09	14	0.75	46	2.86
Monsoon	43,547	67	0.15	43,474	99.83	6	0.01	-	-
Postmonsoon	2,449	32	--	2,375	96.90	5	3.15	-	-
Monthly av.	20,643	57	0.28	20,556	99.58	18	0.09	13	0.06

Station 8: (Table 10 h).

This station situated near the effluent discharge points in the industrial complex was characterised by low population and counts of benthic fauna. As such a total number of 1405 specimens were encountered. Among these polychaetes numbering 947 comprising 67.4% with a monthly mean of $86/m^2$ were the dominant group. Monthly variation showed their maximum ($653/m^2$) during March followed by low counts of $98/m^2$ in April and $84/m^2$ in May and September. Very low counts of $14/m^2$ were noted in the months of July and October. Their total absence during rest of the months is noteworthy. Mean seasonal counts indicated their dominance ($278/m^2$) during the premonsoon, an abrupt fall to $22/m^2$ during the monsoon and their total absence during the postmonsoon.

Molluscs numbering 430 comprising 30.6% ranking 2nd in abundance were present only during April ($360/m^2$) and May ($70/m^2$).

The only other group present in the station was Chironomid crustaceans which are considered as indicators of pollution. In all 28 of them were collected during January.

Table - 10 h. Numerical abundance and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 8.

Months	Total number of specimens	Polychaetes		Other Crustaceans		Molluscs	
		No./m^2	%	No./m^2	%	No./m^2	%
January	28	-	-	28	100.0	-	-
March	653	653	100.00	-	-	-	-
April	458	98	21.39	-	-	360	78.6
May	159	84	54.55	-	-	70	45.5
June	-	-	-	-	-	-	-
July	14	14	100.00	-	-	-	-
August	-	-	-	-	-	-	-
September	84	84	100.00	-	-	-	-
October	14	14	100.00	-	-	-	-
November	-	-	-	-	-	-	-
December	-	-	-	-	-	-	-
Premonsoon	423	278	64.00	-	-	143	-
Monsoon	22	22	100.00	-	-	-	-
Postmonsoon	9	-	-	9	100.0	-	-
Monthly av.	128	86	67.18	3	2.3	39	30.5

Station 9: (Table 10 i).

Benthic fauna of this station consisted of only three groups viz. Polychaetes, Crustaceans and Molluscs.

Polychaetes numbering 11,229 comprising of 86.3% with a monthly average of 1,018/m^2 formed the dominant group. But for a peak value of 2,968/m^2 in May and moderate values of 1,961/m^2 in September and 1,557/m^2 in October, rest of the months had a low range of 320/m^2 to 890/m^2. Seasonal averages indicated premonsoon and monsoon counts of 1,389 and 1,110/m^2 with a fall to 491/m^2 during the postmonsoon.

Second in abundance was other Crustaceans consisting of insect larvae, unidentified crustacean larvae, Diamesa sp., Chironomid larvae, Anatopynia sp., Plectrocnemia sp., Baetis sp. May fly larvae, Tanytarsus sp., water beetle, Ephydra sp., and Platymbus sp., a total population of 1,585 comprising of 12.18% with a mean monthly count of 143/m^2. But for a peak value of 501/m^2 in October, moderate values of 265/m^2 in May and 204/m^2 in July, rest of the months showed a population range of 28 to 70/m^2. Seasonal averages indicated values of 70 and 121/m^2 during the premonsoon and the monsoon and a slight increase to 163/m^2 in the postmonsoon.

The least represented fauna of this station, the molluscs numbering 196 comprised of 1.5% of benthos. But for their absence in the months of July, August, October and November, their representation was low ranging from 14 to 56/m^2.

Table - 10 i. Numerical abundance and percentage occurrence of different groups of benthic fauna during January to December and premonsoon, monsoon and postmonsoon periods at Station 9.

Months	Total number of specimens	Polychaetes		Other Crustaceans		Molluscs	
		No./m^2	%	No./m^2	%	No./m^2	%
January	696	445	63.90	237	34.05	14	2.01
March	421	337	80.05	70	16.70	14	3.33
April	947	863	91.12	28	2.95	56	5.83
May	3,275	2,968	90.63	265	8.09	42	1.28
June	709	653	92.10	28	3.94	28	3.94
July	693	489	70.56	204	29.43	-	-
August	946	890	94.08	56	5.92	-	-
September	2,031	1,961	96.56	56	2.76	14	0.68
October	2,058	1,557	75.66	501	24.34	-	-
November	780	710	91.03	70	8.97	-	-
December	418	320	76.56	70	16.75	28	6.66
Premonsoon	1,547	1,389	86.20	70	11.43	37	2.39
Monsoon	1,281	1,110	86.65	121	12.72	8	0.62
Postmonsoon	631	491	85.97	163	11.69	14	2.34
Monthly av.	1,178	1,013	86.42	125	12.14	18	1.53

3.2.2. Species Composition and Abundance:

Table 11a indicates distribution of different species of benthic organisms showing total number of specimen, frequency of occurrence, percentage frequency and seasonal averages with range.

Station 1:

Six species of amphipods *Corophium triaenonyx*, *Quadrivisio bengalensis*, *Grandidierella gilesi*, *Grandidierella bonnieri*, *Melita zeylanica* and *Eriopisa chilkensis* belonging to the family Gammaridae were identified. Rest of the amphipods belonged to the family Caprillidae. Eventhough *C. triaenonyx* and *Q. bengalensis* were present throughout the year only the former numbering 18,00,777 dominated by contributing 88.42% of the amphipod fauna. A maximum number of 16,46,317/m^2 was collected in August and the lowest counts of 14/m^2 were noted in April and December. Seasonal mean distribution showed a peak occurrence of 3,54,372/m^2 during the monsoon which declined to 9,209/m^2 during the postmonsoon and to a very low count of 428/m^2 during the premonsoon. *Q. bengalensis* numbering 1,85,625 constituted 9.11% having a maximum of 1,69,955/m^2 in August and minimum of 14/m^2 during April and December. This species with a peak abundance of 35,306/m^2 during the monsoon suddenly declined to 2,238/m^2 in postmonsoon and a very low count of 794/m^2 during the premonsoon.

G. gilesi with 42,200 specimens present in 7 months and *G. bonnieri* with 7,143 specimens in 6 months forming 2.07 and 0.35 percent respectively, were found in all the seasons. Their maximum numbers were 21,739/m^2 in August and 5,777/m^2 in November respectively and had low respective densities of 209/m^2 in January and 84/m^2 in May. *G. gilesi* numbering 182/m^2 during the premonsoon increased to 4,512/m^2 during monsoon reaching a high value of 6,296/m^2 during the post-monsoon. *G. bonnieri* with a low population density of 140/m^2 and 153/m^2 during the premonsoon and the monsoon respectively reached the high value of 1,986/m^2 during the postmonsoon.

M. zelanica numbering 1,056 (0.05%) was present during 2 months only with 222/m^2 in July and 834/m^2 in November. *E. chilkensis* numbering 70 comprising 0.003% was present only in July with 56/m^2 and August with 14/m^2. Caprillids numbering 112 and 0.005 percent of amphipods were recorded during January and May.

Of the 25 species of polychaetes identified listed in Table 11 a not a single species was present throughout the year.

Diopatra neapolitana the most abundant species numbering 3,027 was noted in all months except in December, with a maximum of 751/m^2 in June and a minimum of 14/m^2 in January and November.

Heteromastides bifidus numbering 5,387 was present during 8 months with a maximum of 3,148/m^2 in August and a minimum of 14/m^2 in July and October. *Prionospio polybranchiata* numbering 2,239 and *Pista indica* numbering 1,724 occurred in 7 months each with maximum counts of 543/m^2 in September and 445/m^2 in March respectively. Lowest counts of *P. polybranchiata* (14/m^2) was noted in May and December and that of *P. indica* in May (14/m^2). *Ancistrosyllis constricta* numbering 480 was noticed during 6 months with a maximum of 167/m^2 in March and a minimum of 14/m^2 in April. *Lumbriconereis notocirrata*, *Eunice tubifex* and *Goniada emerita* numbering 559, 167, and 209 respectively were collected during 5 months each. They recorded counts of 337/m^2 in March, 111/m^2 in March and 83/m^2 in September respectively. All the three showed their minimum counts of 14/m^2, in December. *Glycera convoluta*, *Prionospio pinnata* and *Paraheteromastus tenuis* numbering 364/m^2, 417/m^2 and 585/m^2 respectively were present only four months each. *Lumbriconereis simplex* represented by 4,463 and *Lycastis indica* with 376 were noted during 3 months each.

Four species namely *Glycera alba*, *Dendronereis aestuarina*, *Perinereis cavifrons* and *Heteromastus similis* numbering 125, 126, 70 and 111 respectively were observed during 2 months each. Rest of the polychaete species namely, *Nephthys polybranchia*, *N. oligobranchia*, *Notopygos* sp., *Odontosyllis gravelyi*, *Owenia* sp., *Serpula vermicularis*, *Sthenelais boa* and *Sabellidae* sp. were recorded only once each during the period of study. But for Nephthys oligobranchia with 111, Sthenelais boa with 778, and Sabellidae sp. with 222, all others showed lowest counts of $14/m^2$ each. Of the 25 species seasonal variation studies revealed presence of nine of them during all the three seasons, 3 in the pre- and post- monsoon and one in the premonsoon and monsoon one in the monsoon and postmonsoon. Rest of the 11 species were observed in one season each namely 4 in premonsoon, 3 in the monsoon and 4 in the postmonsoon. In all 17 species were recorded during the premonsoon, 15 in the monsoon and 17 in the postmonsoon.

Molluscan fauna comprised of five species of bivalves namely Modiolus striatulus, Paphia papilliens, Pandora flexosa and Meritrix casta and the gastropod Littorina littorina and an unidentified gastropod. M. striatulus numbering 3,634 was recorded in five months with a maximum density of $1,738/m^2$ in January and a minimum of $14/m^2$ in March. Seasonal distribution indicated a high density of $599/m^2$ in the premonsoon and $625/m^2$ in the postmonsoon and absence in the monsoon.

P. flexosa numbering 279 was present in six months with a maximum density of $70/m^2$ in October and a minimum of $14/m^2$ in January, April and May. Their seasonal densities were $46/m^2$, $14/m^2$ and $23/m^2$ during premonsoon, monsoon and postmonsoon respectively.

Paphia papilliona found in only three months were represented by 56 specimens showed a maximum of 28/m^2 in March and a minimum of 14/m^2 in June and December.

Arca species numbering 389 were observed in March (222/m^2) and October (167/m^2).

M. casta numbering 14/m^2 occurred only in July.

L. littorina numbering 375 were recorded during two months of May (153/m^2) and November (222/m^2). The unidentified gastropod numbering 56 was recorded only in September.

Isopods were represented by two species namely Cirrolinia fluviatilis and Anthurid sp., the former numbering 41,243 were collected in 9 months. A maximum of 22,574/m^2 was noticed in July and a minimum of 14/m^2 in April, June and October, the latter numbering 153 collected only in May (14/m^2) and September (139/m^2).

Tanaidaceans represented by Apseudes chilkensis and Apseudes gymnophobium. A. chilkensis numbering 3,850 was collected during 8 months the maximum number being 2,210/m^2 in August and minimum 28/m^2 in January. A. gymnophobium 222 in number were present in 7 months showing their maximum of 28/m^2 in January and September and minimum of 14/m^2 during October to December.

Fish larvae numbering 70 were recorded during 4 months, with a maximum of 28/m^2 in May and minimum 14/m^2 in January.

Echinoderm larvae numbering 167 also were recorded in four months with a maximum of 83/m^2 in January and minimum of 14/m^2 in March and December.

Nematodes with a high abundance of 751 were found in 3 months only with 723/m^2 in March and 14/m^2 each in May and October.

Sipunculids numbering 196 were from two months of January (140/m^2) and March (56/m^2).

Other crustaceans comprised of decapods _Acetes_ sp., _Alpheid_ sp., _Balanus_ sp. and insect larvae. Of these decapods numbering 167 had their peak occurrence of 125/m^2 in November and the lowest 14/m^2 in January, May and September. _Balanus_ sp. numbering 56 was noticed during March (42/m^2) and October (14/m^2). 14 specimens of _Acetes_ sp. were collected in November, 28 specimens of insect larvae and _Alpheids_ sp. were seen during April and July respectively.

Table - 11 a. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station-1.

AMPHIPODA

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months	Min. No./ Months
Corophium triaenonyx	18,00,777	11	88.42	428	3,54,372	9,209	16,46,317 (Aug.)	14 (Apr., Dec.)
Quadrivisio bengalensis	1,85,625	11	9.11	794	35,306	2,238	1,69,955 (Aug.)	14 (Apr., Dec.)
Grandidierella gilesi	42,200	7	2.07	182	4,512	6,296	21,739 (Aug.)	209 (Jan.)
G. bonnieri	7,143	6	0.35	140	153	1,986	5,777 (Nov.)	85 (May)
Melita zeylanica	1,056	2	0.05	-	222 (Jul.)	834 (Nov.)	-	-
Eriopisa chilkensis	70	2	0.003	-	56 (Jul.) 14 (Aug.)	-	-	-
Caprillidae	112	2	0.005	84 (Jan.) 28 (May)	-	-	-	-

Contd...

Table - 11 a (Contd.)

POLYCHAETA

Species	Total number of specimens	Frequency of occurrence.No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Diopatra neapolitana	3027	10	14.58	144	366	5	751(Jun)	14 (Jan., Nov.)
Heteromastus bifidus	5387	8	25.95	560	646	157	3148 (Aug.)	14 (Jul., Oct.)
Prionospio polybranchiata	2239	7	10.79	5	387	5	543 (Sept.)	14 (May, Dec.)
Pista indica	1724	7	8.30	153	-	107	445(Mar)	14 (May)
Ancistrosyllis constricta	480	6	2.30	79	-	81	167(Mar)	14 (Apr.)
Lumbriconereis notocirrata	559	5	2.70	140	25	5	337(Mar)	14 (Dec.)
Eunice tubifex	167	5	0.80	41	3	9	111(Mar)	14 (Jan., Jul., Dec.)
Goniada emerita	209	5	1.00	18	25	14	83(Sept.)	14 (Dec.)
Paraheteromastus tenuis	585	4	2.80	60	81	-	320(Sept)	14 (May)
Prionospio pinnata	417	4	2.00	30	39	30	153(Jun.)	42 (Jul.)

Contd...

Table - 11 a (Contd.)

POLYCHAETA (Contd.)

Species	Total number of specimens	Frequency of occurrence.No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Glycera convoluta	364	4	1.75	98	-	23	280(Mar)	14 (Apr., Dec.)
Lumbriconereis simplex	4463	3	21.50	3781 (Mar.)	56 (Aug.)	626 (Jan.)	-	-
Lycastis indica	376	3	1.80	278 (Mar.)	56 (Aug.)	42 (Jan.)	—	-
Glycera alba	125	2	0.60	-	97(Jun.) 28(Oct.)	-	-	-
Dendronereis aestuarina	126	2	0.60	-	112 (Aug.) 14 (Sept)	-	-	-
Heteromastus similis	111	2	0.50	-	28 (Oct)	83(Jan)	-	-
Perinereis cavifrons	70	2	0.30	-	-	14(Jan) 56(Dec)	-	-
Sthenelais boa	778	1	3.70	778(Mar)	-	-	-	-
Sabellidae	222	1	1.07	222(Mar)	-	-	-	-
Nephthys oligobranchia	111	1	0.53	-	111(Aug)	-	-	-
N. polybranchia	14	1	0.07	-	-	14(Jan)	-	-

Contd...

Table - 11 a (Contd.)

POLYCHAETA (Contd.)

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months	Min. No./ Months
Notopygos sp.	14	1	0.07	-	-	14 (Jan.)	-	-
Odontosyllis gravelyi	14	1	0.07	14 (Mar.)	-	-	-	-
Owenia sp.	14	1	0.07	14 (Mar.)	-	-	-	-
Serpula vermicularis	14	1	0.07	-	-	14 (Dec.)	-	-
ISOPODA								
Cirrolinia fluviatilis	41243	9	99.60	88	8021	315	22574 (Jul.)	14 (Apr., Jun., Oct.)
Anthuridae	153	2	0.40	14 (May)	139 (Sept)	-	-	-
TANAIDACEA								
Apseudes chilkensis	3850	8	94.52	42	653	157	2210 (Aug.)	28 (Jan.)
A. gymnophobium	222	7	5.48	38	14	19	28 (Jan., Sept.)	14 (Oct., Nov., Dec.)

Contd....

Table - 11 a (Contd.)

MOLLUSCA

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Pandora flexosa	279	6	5.79	46	14	23	70(Oct)	14 (Jan., Apr., May)
Modiolus striatulus	3634	5	75.40	599	-	625	1738 (Jan.)	14 (Mar.)
Paphia papillions	56	3	1.45	28(Mar)	14(Jun)	14(Dec.)	-	-
Arca sp.	389	2	8.07	222(Mar)	167(Oct)	-	-	-
Meritrix casta	14	1	0.29	-	14(Jul.)	-	-	-
Littorina littorina	375	2	7.78	153(May)	-	222(Nov.)	-	-
Gastropod (Unidentified)	56	1	1.17	-	56(Sept.)	-	-	-
MINOR GROUPS (CRUSTACEA)								
Decapoda	167	4	52.21	5	3	41	125(Nov)	14 (Jan., May, Sept)
Balanus	56	2	19.10	42(Mar)	14((ct)	-	-	-
Insect larva	28	1	9.60	28(Apr)	-	-	-	-
Alpheids	28	1	9.60	-	28(Jul.)	-	-	-
Acetes sp.	14	1	4.80	-	-	14(Nov)	-	-

Contd...

Table - 11 a (Contd.)

MINOR GROUPS (MISCELLANEOUS)

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months	Min. No./ Months
Echinoderm larvae	167	4	14.30	23	-	32	83(Jan)	14 (Mar., Dec.)
Fish larvae	70	4	6.00	9	-	9	28(May)	14 (Jan.)
Nematoda	751	3	64.20	723 (Mar) 14 (May)	14(Oct)	-	-	-
Sipunculoida	196	2	16.70	140 (Jan) 56 (Mar)	-	-	-	-
Sea anemone	3684	6	100.00	477	-	750	2168 (Jan)	14 (Mar)

Station 2: (Table 11 b).

Nineteen species of polychaetes were identified from this station. Of these only 3 species namely Heteromastides bifidus, Prionospio polybranchiata and Lycastis indica were present during 10 months of the year and Nephthys polybranchia and Owenia sp. during 4 months each.

Among the rest 12 species 2, 7 and 3 were identified from 3, 2 and 1 month respectively.

Seasonal distribution studies showed presence of 5 species namely Heteromastides bifidus, Prionospio polybranchiata, Dendronereis aestuarina, Lycastis indica and Paraheteromastus tenuis throughout the observation period. Four species namely Nephthys polybranchia, Owenia sp., Ancistrosyllis constricta, and Glycera convoluta were encountered during the premonsoon and postmonsoon months. Capitella capitata and Heteromastus similis were noticed during the monsoon and the postmonsoon. Perinereis cavifrons and Glycera alba were collected during pre- and post- monsoon periods. Aphroditidae, Eunice tubifex and Goniada emerita were available during the premonsoon period only, while Diopatra neapolitana was collected only during monsoon period. Lumbriconereis notocirrata was noticed only during the postmonsoon.

Population density indicated *H. bifidus* with 15,901 numbers as the most abundant species whereas *E. tubifex* with 14 specimens was found to be the least. Rest of the 17 species showed density variation from 28 to 3,460.

H. bifidus numbering 15,901 being present in all months except in April had their mean peak occurrence of 2,355/m^2 during the monsoon which was reduced to 968/m^2 during the postmonsoon and 407/m^2 during premonsoon. Monthly distribution showed their peak value of 6,074/m^2 in August and the lowest of 125/m^2 in May.

P. polybranchiata, even though present in 10 months showed reduced numerical abundance of 3,460. The high mean value of 690/m^2 during the postmonsoon was reduced to 228/m^2 during the monsoon and 83/m^2 during the premonsoon. Monthly variation showed a high value of 778/m^2 in November and low value of 42/m^2 in September.

L. indica also present during 10 months with a total of 946 specimens had their peak of 375/m^2 in May and the lowest values of 14/m^2 in September. Seasonal distribution indicates a low density of 53/m^2 in the monsoon which gradually increased to 78/m^2 during the postmonsoon followed by 148 specimens/m^2 during the premonsoon.

D. aestuarina present during 8 months numbering 1,432 had their peak occurrence of 959/m^2 in April and lowest count of 14/m^2 in November. Seasonal distribution revealed their high count of 356/m^2 during the premonsoon with a sudden fall to 33/m^2 during the monsoon and 65/m^2 in the postmonsoon.

P. tenuis numbering 389 was present during only 5 months. A peak value of 222/m^2 was in November and the lowest of 14/m^2 on September. Seasonal distribution showed the lowest premonsoonal count of 9/m^2 being raised to 25/m^2 during monsoon and a sudden spurt to 78/m^2 during the postmonsoon.

Of the 208 specimens of N. polybranchia collected in 4 months a maximum of 139/m^2 belonged to May and the minimum of 14/m^2 in December. Seasonal variations showed their total absence in monsoon, low occurrence of 19/m^2 during the postmonsoon and 38/m^2 during the premonsoon.

A total of 140 specimens of Owenia sp. were collected during 4 months with a peak of 70/m^2 in April and low value of 14/m^2 in June and December. 19/m^2 specimens were collected during the postmonsoon and 18/m^2 during the premonsoon and their absence during monsoon was noted.

112 specimens of G. convoluta were collected in the 3 months of May (14/m^2), November (42/m^2) and December (56/m^2).

Similarly A. constricta also was present in three months of May (348/m^2), March (28/m^2) and November (28/m^2) yielding a total of 404 specimens. Following seven species were present during only 2 months each. They are Aphroditid sp. in March (681/m^2) and May (14/m^2), C. capitata in August (42/m^2) and January (28/m^2), D. neapolitana in September (195/m^2)

and October (70/m^2), *G. alba* in January (56/m^2) and in May (42/m^2), *H. similis* in January (195/m^2) and October (42/m^2), *Pista indica* in January (28/m^2) and December (14/m^2) and *Perinereis cavifrons* in January (83/m^2) and in March (70/m^2).

Three species collected only once during the study period are - *E. tubifex* (14/m^2) in March, *G. emerita* (28/m^2) in March and *L. notocirrata* (56/m^2) in December.

Five species of Gammaridae namely *Corophium triaenonyx*, *Quadrivisio bengalensis*, *Grandidierella gilesi*, *G. bonnieri* and *Melita zeylanica* were identified from this station. *G. gilesi* numbering 5,543 was found during 4 months with a peak density of 4,834/m^2 in March and the lowest of 14/m^2 in May. This species which formed 36.19 % of amphipod population, was the dominant one. Their seasonal distribution indicated a spurt to 1,616/m^2 during the premonsoon from a meagre 231/m^2 during the postmonsoon and total absence during monsoon.

Q. bengalensis numbering 4,184 constituting 27.32 percent of the amphipods was also present during 4 months with a peak value of 3,988/m^2 in January and the lowest count of 58/m^2 in November. This species absent during the monsoon appeared in high densities of 1,334/m^2 in the postmonsoon which decreased to 60/m^2 in the premonsoon.

C. *triasnonyx* and *O. bonnieri* which formed 34.12% and 0.82 % respectively were present only during 3 months each. Of the total 5,227 *C. triasnonyx* identified 5,143/m^2 were in January, 70/m^2 from March and 14/m^2 in June. Similarly of the 126 *O. bonnieri* 56 each belonged to January and March and the rest 14 to May.

M. zeylanica numbering 195 constituting only 1.27 % of amphipods was observed in March (167/m^2) and in May and January (14/m^2) each.

Species belonging to Caprillidae constituted only 0.27 percent. They showed their presence only once (March, 42/m^2).

Among the amphipods *Q. bengalensis* and *G. gilesi* were collected during the pre- and post- monsoon periods, whereas *C. triasnonyx* was present during all the three periods. *O. bonnieri*, *M. zeylanica* and Caprillidae were found during the premonsoon. All the 6 species were present during the premonsoon, whereas only *C. triasnonyx* extended its presence to monsoon also. All the 6 species except *Caprillid* sp. were also noticed during postmonsoon.

Molluscan fauna was sorted out into 4 species of bivalves and 2 species of gastropods. Of these one was present during 3 months, two during 2 months each three in one month each. But for *Pandora flexosa* the others were noted during the postmonsoon.

Villorita cyprinoides numbering 334 constituting 49.93 % of the molluscs were seen in the months i.e. January (111/m^2), November (209/m^2) and 14/m^2 in December.

Paphia papilliona numbering 84 and forming 12.58 % of molluscs, was collected in November (70/m^2) and December (14/m^2)

42 specimens of *P. flexosa* were collected in October which formed 6.27 percent of the molluscs.

While *Littorina littorina* was present in December, the other gastropod (unidentified) was noted in September (28/m^2) and December (42/m^2). They constituted 10.46 percent of mollusc *Cirrolinia fluviatilis* numbering 42 formed 17.4 percent of the isopods whereas *Anthuridae* numbering 199 formed 82.6 percent. While the former was noticed during January (42/m^2) the latter was collected in the months of March (157/m^2), January (14/m^2), and May (28/m^2).

Tanaidaceans included *Apseudes chilkensis* and *Apseudes gymnophobium*. *A. chilkensis* numbering 112 forming 80 % of the tanaidaceans was present during 4 months with a maximum number of 56/m^2 in January and a minimum of 14/m^2 in March. *A. gymnophobium* which constituted 20% of the tanaidaceans occurred only during 2 months with 14 specimens/m^2 each (January and May).

Among the minor groups namely decapods, Cumacea, chironomid larvae, *Tanytarsus* sp., *Plectrocnemia* sp. and insect larvae, except the first one all were collected just once. *Tanytarsus* sp. numbering 14, insect larvae 14 and *Plectrocnemia* sp. 194 were obtained in January only, whereas 14 specimens of Cumacea and 28 specimens of *Chironomids* sp. were recorded in March and September respectively. Of the 70 specimens of decapod collected 42 were in December and 28 in November.

14 Fish larvae were present in October, July (14) and December (28) shared the flat worm numbers (42).

Nematodes numbering 56 were noticed in March (28), June (14) and July (14). Sipunculids numbering 70 were seen in January (14/m^2); May (14/m^2) and 42/m^2 in November. Echinoderm numbering 42 were observed in March, July and December in equal numbers.

Table - 11 b. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 2.

AMPHIPODA

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Quadrivisio bengalensis	4184	4	27.32	60	-	1334	3948 (Jan.)	58 (Nov.)
Grandidierella gilesi	5543	4	36.19	1616	-	231	4834 (Mar.)	14 (May)
Corophium triaenonyx.	5227	3	34.12	70 (Mar.)	14(Jun)	5143 (Jan.)	-	-
Grandidierella bonnieri	126	3	0.82	56(Mar) 14(May)	-	56(Jan)	-	-
Melita zeylanica	195	3	1.27	167(Mar) 14(May)	-	14(Jan.)	-	-
Caprillidae	42	1	0.27	42(Mar.)	-	-	-	-

Contd....

Table - 11 b. (Contd.)

MOLLUSCA

Species	Total number of specimens	Frequency of occurrence.No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Villorita cyprinoides	334	3	49.93	-	-	111(Jan.) 209(Nov.) 14 (Dec.)	-	-
Paphia papillions	84	2	12.55	-	-	70 (Nov.) 14 (Dec.)	-	-
Arca sp.	125	1	18.68	-	-	125(Dec.)	-	-
Pandora flexosa.	42	1	6.27	-	42(Oct)	-	-	-
Gastropod (unidentified)	70	2	10.46	-	28(Sept)	42(Dec.)	-	-
Littorina littorina	14	1	2.09	-	-	14 (Dec.)	-	-

Contd....

Table - 11 b. (Contd.)

POLYCHAETA

Species	Total number of specimens	Frequency of occurrence.No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months
Heteromastides bifidus	19801	10	64.50	407	2355	968	6074 (Aug.)	125 (May)
Prionospio polybranchiata	3460	10	14.00	83	228	690	778 (Nov.)	42 (Sept.)
Lycastis indica	946	10	3.83	148	53	78	375 (May.)	14 (Sept.)
Dendronereis aestuarina	1432	8	5.81	356	33	65	959 (Apr.)	14 (Nov.)
Paraheteromastus tenuis	389	5	1.58	9	25	78	222 (Nov.)	14 (Sept.)
Nephthys polybranchia	208	4	0.84	38	-	19	139 (May.)	14 (Dec.)
Owenia sp.	140	4	0.57	18	-	19	70 (Apr.)	14 (Jun., Dec.)
Ancistrosyllis constricta	404	3	1.60	28 (Mar.) 348 (May)	-	28 (Nov.)	-	-
Glycera convoluta	112	3	0.45	14 (May)	-	42 (Nov.) 56 (Dec.)	-	-

Contd...

Table - 11 b. (Contd.)

POLYCHAETA (Contd.)

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months	Min.No./ Months.
Aphroditidae	695	2	2.81	681 (Mar.) 14 (May)	-	-	-	-
Diopatra neapolitana	265	2	1.07	-	195(Sept) 70(Oct)	-	-	-
Heteromastus similis	237	2	0.95	-	42(Oct)	195(Jan)	-	-
Perinereis cavifrons	153	2	0.62	70(Mar)	-	83(Jan)	-	-
Glycera alba	98	2	0.39	42(May)	-	56(Jan)	-	-
Capitella capitata	70	2	0.28	-	42(Aug)	28(Jan)	-	-
Pista indica	28	2	0.17	-	-	28(Jan) 14(Dec)	-	-
Lumbriconereis notocirrata	56	1	0.22	-	-	56(Dec)	-	-
Goniada emerita	28	1	0.11	28(Mar)	-	-	-	-
Eunice tubifex	14	1	0.06	14(Mar)	-	-	-	-

Contd...

Table - 11 b. (Contd.)

MINOR GROUPS (CRUSTACEA)

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Decapoda	70	2	20.95	-	-	28 (Nov.) 42 (Dec.)	-	-
Plectrocnemia sp.	194	1	58.10	-	-	194 (Jan.)	-	-
Chironomid larvae	28	1	8.38	-	28 (Sept)	-	-	-
Cumacea	14	1	4.19	14 (Mar)	-	-	-	-
Tanytarsus sp.	14	1	4.19	-	-	14 (Jan.)	-	-
Insect larvae	14	1	4.19	-	-	14 (Jan.)	-	-

MINOR GROUPS (MISCELLANEOUS)

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Sipunculoida	70	3	31.30	14 (May)	-	14 (Jan.) 42 (Nov.)	-	-
Nematoda	56	3	25.00	28 (Mar)	14 (Jun)	-	-	-
Echinoderm larvae	42	3	18.80	14 (Mar)	14 (Jul)	14 (Dec.)	-	-
Flat worm	42	2	18.8	-	14 (Jul)	28 (Dec.)	-	-
Fish larvae	14	1	6.25	-	14 (Oct)	-	-	-

Contd...

Table - 11 b. (Contd.)

ISOPODA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Anthuridae	199	3	82.60	157 (Mar.) 28 (May)	-	14 (Jan.)	-	-
Cirrolinia fluviatilis	42	1	17.40	-	-	42 (Jan.)	-	-
TANAIDACEA								
Apseudes chilkensis	112	4	80.00	28	-	7	56(Jan)	14 (Mar)
A. gymnophobium	28	2	20.00	14 (May)	-	14 (Jan)	-	-

Station 3: (Table 11 c).

Four species of Gammarids namely Corophium triaenonyx, Quadrivisio bengalensis, Grandidierella gilesi and Melita zeylanica and one Caprillid sp. were encountered in this Station. Of these C. triaenonyx numbering 25,558 and forming 44.62 percent of the amphipods had a maximum number of 19,553/m in March and a minimum of 42/m^2 in May. Its presence was noticed in 4 months only. This species not recorded during the monsoon indicated an increase in population from a postmonsoon value of 1,946/m^2 to 6,573/m^2 during the premonsoon.

Q. bengalensis being present in 6 months had a count of 10,508 (18.35%). Their maximum of 4,309/m^2 was noted in November with the lowest density of 14/m^2 in April and in June. Higher counts of 2,567/m^2 during the postmonsoon declined suddenly to 937/m^2 during the pre-monsoon and 3/m^2 in the monsoon.

G. gilesi numbering 19,877 forming 34.7% of amphipods, was present in 5 months and had a maximum of 14,734/m^2 in December and a minimum of 14/m^2 in August.

This also indicated a higher value of 5,931/m^2 during the postmonsoon an abrupt fall to 690/m^2 during the pre-monsoon and to 3/m^2 in the monsoon.

The 4th species M. zeylanica numbering 320 occurred in only in the months of April (42/m^2) and March (278/m^2).

Caprillid sp. numbering 1,015 was present in 4 months, with a peak of 667/m^2 in December and a low value of 28/m^2 in August. This also followed the same seasonal pattern as the above 4 species with a high postmonsoon count of 222/m^2 reduced to 107/m^2 in the premonsoon and 5/m^2 in the monsoon.

Polychaetes comprised of 10 species. Of these one species each was present during 10, 8, 5 and 3 months; whereas 2 species each occurred in 7 and 2 months. Two species were collected one month each.

Of these eight species namely Dendronereis aestuarina, Lycastis indica, Heteromastides bifidus, Prionospio polybranchiata, Paraheteromastus tenuis, Perinereis cavifrons, Glycera convoluta and Eunice tubifex were present during the premonsoon. Monsoon periods had the first 6 species and Capitella capitata whereas the postmonsoon recorded the first 5 species and Owenia sp.

Five species were noticed during all the three seasons. Seasonal variations indicated the presence of one species during the premonsoon and the monsoon, 2 species during the premonsoon and one species each during the monsoon and the postmonsoon.

D. aestuarina numbering 4,296 were present in 10 months with a peak of 2,266/m^2 in April and low density of 14/m^2 in October. Seasonal variations indicated a gradual reduction from 815/m^2 during the premonsoon to 306/m^2 during the monsoon and 79/m^2 during the postmonsoon.

L. indica present in 8 months, numbering 1,753 showed its maximum occurrence of 709/m^2 in October and minimum of 14/m^2 in November with a seasonal variation showing gradual increase from the postmonsoon (5/m^2) to the premonsoon (70/m^2) and spurt in the monsoon (306/m^2).

H. bifidus numbering 4,490 and forming 36.79% of polychaete was present during 7 months with a high density of 1,279/m^2 in August and low density of 56/m^2 in March. Seasonal changes showed gradual increase from postmonsoon (97/m^2) to premonsoon (528/m^2) and monsoon (523/m^2).

P. polybranchiata also was present in 7 months, comprised of 8.46 % of the polychaetes and with a total of 1,043 specimens. A maximum of 375/m^2 in March and low count of 14/m^2 in October was noticed. Seasonal variations showed a progressive reduction from the premonsoon 204/m^2 to the monsoon 64/m^2 and the postmonsoon 37/m^2.

P. tenuis occurring in 5 months had a total of 472 specimens and formed only 3.87 percent of the polychaetes. It's peak was found in July (222/m^2) and the lowest number (14/m^2) in May. Seasonal distribution showed a gradual increase from the postmonsoon, 9/m^2 to the premonsoon 42/m^2 and the monsoon 64/m^2.

P. cavifrons numbering 98 specimens and forming only 0.8% of polychaete population occurred in April with 42/m^2 and September and October with 28/m^2 each.

56 specimens of *C. capitata* which formed only 0.46 percent polychaete were present in August and September with 14 specimens/m^2 each.

C. convoluta was also present in 2 months (April and May) with 14 specimens/m^2 each. This formed only 0.22% of the polychaetes.

Fourteen specimens each of *Owenia* sp. and *E. tubifex* were obtained from November and April respectively. This formed 0.11 percent of polychaete population.

Molluscan fauna was represented by 3 bivalves and one gastropod species *Villorita cyprinoides* numbering 1,799 and forming 44.7 percent of molluscs, were collected in 6 months with a peak occurrence of 876/m^2 in January. Seasonal changes indicated a very low monsoonal density of 3/m^2 raising to a postmonsoon value of 47/m^2 and an abrupt spurt to 528/m^2 during premonsoon.

Pandora flexosa with 1,738 specimens formed 43.68% of benthos were recorded in 5 months. It showed a peak value of 709/m^2 in April and minimum count of 28/m^2 in December. This species was not recorded during the monsoon. 130 specimens/m^2 were present during the postmonsoon which spurt up to 449/m^2 during the premonsoon.

Modiolus striatulus numbering 42 was present in April 28/m^2 and August with 14/m^2 and formed only 1.05 % of molluscs.

The gastropod Littorina littorina was present in 5 months and formed 10.85 % of molluscs. Of the 432 specimens maximum of 306/m^2 was found in May and the minimum of 14/m^2 in April and December.

Seasonal variation showed similar trend during premonsoon and postmonsoon numbering 37 specimens/m^2 each which reduced to 17/m^2 during monsoon.

Two species of isopods, Anthurid sp. and Cirolinia fluviatilis were identified. 14 specimens, of C. fluviatilis were collected inJuly and Anthurida sp. numbering 376 from 3 months i.e. March (209/m^2), April (153/m^2) and July (14/m^2).

Tanaidacean represented by one species Apseudes chilkensis numbering 111 was recorded in May.

Cumacea numbering 14 was present in March. Tanytarsus sp. Plectroenemia sp. and Ephydra sp. numbering 14/m^2 each were collected, the ~~first~~ that in August, and the latter two in July.

Chironomid larvae numbering 375 occurred in September with 361/m^2 and July with 14/m^2.

Sipunculids and nematodes numbering 14/m^2 each were collected in April while first worms and fish larvae numbering 14/m^2 each were noticed in July.

Table - 11 c. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 3.

AMPHIPODA

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Quadrivisio bengalensis	10508	6	18.35	937	3	2567	4309 (Nov.)	14 (Apr., Jun.)
Grandidierella gilesi	19877	5	34.70	690	3	5931	14734 (Dec.)	14 (Aug.)
Corophium triaenonyx	25558	4	44.62	6573	-	1946	19553 (Mar.)	42 (May)
Caprillidae	1015	4	1.77	107	5	222	667(Dec)	28 (Aug.)
Melita zeylanica	320	2	0.56	278(Mar.) 42 (Apr.)	-	-	-	-

Contd...

Table - 11 c. (Contd.)

POLYCHAETA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Dendronereis aestuarina	4296	10	35.19	815	306	79	2266 (Apr.)	14 (Oct.)
Lycastis indica	1753	8	14.36	70	306	5	709 (Oct)	14 (Nov.)
Heteromastides bifidus	4490	7	36.79	528	523	97	1279 (Aug)	56 (Mar.)
Prionospio polybranchiata	1043	7	8.46	204	64	37	375 (Mar)	14 (Oct.)
Paraheteromastus tenuis	472	5	3.87	42	64	9	222 (Jul)	14 (May)
Perinereis cavifrons	98	3	0.80	42 (Apr)	28 (Sept., Oct.)	-	-	-
Capitella capitata	56	2	0.46	-	42 (Aug.) 14 (Sept.)	-	-	-
Glycera convoluta	28	2	0.22	14 (Apr) 14 (May)	-	-	-	-
Owenia sp.	14	1	0.11	-	-	14 (Nov)	-	-
Eunice tubifex	14	1	0.11	14 (Apr)	-	-	-	-

Contd...

Table - 11 c. (Contd.)

ISOPODA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Anthuridae	376	3	96.40	209 (Mar.) 153 (Apr.)	14 (Jul)	-	-	-
Cirrolinia fluviatilis	14	1	3.59	-	14 (Jul)	-	-	-
TANAIDACEA								
Apseudes chilkensis	11	1	100.00	111 (May)	-	-	-	-
MOLLUSCA								
Villorita cyprinoides	1799	6	44.70	528	3	47	876 (May)	14 (Jan)
Pendora flexosa	1738	5	43.68	449	-	130	709 (Apr)	28 (Dec)
Modiolus striatulus	42	2	1.05	28 (Apr)	14 (Aug)	-	-	-
Littorina littorina	432	5	10.85	37	17	37	306 (May)	14 (Apr. & Dec.)

Contd...

Table - 11 c. (Contd.)

MINOR GROUPS (CRUSTACEA)

Species	Total number of specimens	Frequency of occurrence.No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Chironomid larvae	375	2	85.60	-	361(Sept) 14(Jul.)	-	-	-
Cumacea	14	1	3.20	14 (Mar.)	-	-	-	-
Tanytarsus sp.	14	1	3.20	-	14(Aug.)	-	-	-
Plectrocnemia sp.	14	1	3.20	-	14(Jul.)	-	-	-
Ephydra sp.	14	1	3.20	-	14(Jul.)	-	-	-

MINOR GROUP (MISCELLANEOUS)

Species	Total number of specimens	Frequency of occurrence.No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Sipunculoida	14	1	25.00	14 (Apr.)	-	-	-	-
Nematoda	14	1	25.00	14 (Apr.)	-	-	-	-
Flat worms	14	1	25.00	-	14 (Jul.)	-	-	-
Fish larvae	14	1	25.00	-	14 (Jul.)	-	-	-

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Station 4: (Table 11 d).

Five species of Gammaridae namely *Corophium triaenonyx*, *Quadrivisio bengalensis* and *Grandidierella gilesi*, *Eriopisa chilkensis*, *Melita zeylanica* and one *Caprillid* sp. were encountered of which *C. triaenonyx* and *G. gilesi* formed 56.19 and 35.69 percent of amphipods while *Q. bengalensis* constituted 6.31 percent, and *E. chilkensis* and *M. zeylanica* formed 0.07 percent each.

Of the 6 species only *Q. bengalensis* occurred during 6 months, *C. triaenonyx* and *G. gilesi* and caprillidae occurred 3 months each, *Eriopisa chilkensis* and *Melita zeylanica* in only one month each. Except *Q. bengalensis* which was present during the monsoon period also all the above 6 species were recorded only during premonsoon and postmonsoon periods. *Q. bengalensis* numbering 1,224 forming 6.3 percent of amphipods were recorded during six months, with their peak number of $737/m^2$ in January and low count of $14/m^2$ in June. Seasonal variations indicated high density during the postmonsoon ($245/m^2$) with a gradual reduction to $143/m^2$ during the pre-monsoon and an abrupt fall to $5/m^2$ during the monsoon.

C. triaenonyx with a high density of 10,898 was prêsent only during 3 months with a peak abundance of $10,217/m^2$ in March and a value of $14/m^2$ in January. This species being absent in the monsoon recorded a low density of 5/m^2 in postmonsoon which raised to an average of 3,628/m^2 in the premonsoon.

G. gilesi also with a high density of 6,922 (35.69%) was present during 3 months showing a peak number of 6,338/m^2 in March and a low density of 28/m^2 in April. Being absent during monsoon, premonsoon and postmonsoon showed an average of 2,122/m^2 and 185/m^2 respectively.

E. chilkensis and M. zeylanica numbering 14/m^2 each were recorded during January and March respectively.

Caprillid sp. with 320 specimens present in 3 months showed a peak number of 278/m^2 in January and low value of 14/m^2 in May.

Eight species of polychaetes namely Dendronereis aestuarina, Prionospio polybranchiata, Lycastis indica, Heteromastides bifidus, Paraheteromastus tenuis, Heteromastus similis, Owenia sp. and Eunice tubifex were encountered. The dominant species P. tenuis formed 40.67 % of polychaetes and the second dominant species P. polybranchiata formed 27.24 %. D. aestuarina and H. bifidus formed 10.14 and 10.36 percent. The three namely H. similus, Owenia sp. and E. tubifex formed 0.12 percent each of the polychaete population.

Of the eight polychaete species D. aestuarina was recorded in 9 months, P. polybranchiata in 8 months, Lycastis indica in 7 months, H. bifidus in 6 months, P. tenuis in 4 months and H. similis, Owenia sp. and E. tubifex in one month each.

Seasonal variations indicated presence of the first 4 species in the 3 seasons whereas P. tenuis was present during the premonsoon and the monsoon, H. similis, E. tubifex and Owenia sp. occurred during the postmonsoon. D. aestuarina with a density of 1,184 present in 9 months showed a peak density of $431/m^2$ in May and low density of $28/m^2$ in March and December. Seasonal variation indicated a low density of $61/m^2$ during the monsoon $116/m^2$ during the postmonsoon and $176/m^2$ during premonsoon.

P. polybranchiata numbering 3,182 specimens having present in 8 months with a peak density of $1,168/m^2$ in March and low density of $14/m^2$ in August. Seasonal variation showed a peak value of $917/m^2$ during the premonsoon with an abrupt fall to $31/m^2$ during the monsoon and $93/m^2$ during the postmonsoon.

L. indica present in 7 months had 377 specimens with a peak value of $97/m^2$ in September and $14/m^2$ in April.

Seasonal variation indicated a high value of $50/m^2$ during the monsoon. Gradually declined to $19/m^2$ during the post-monsoon leading to $23/m^2$ during the premonsoon.

H. bifidus with 1,210 specimens present in 6 months showed a peak value of $459/m^2$ in July and $14/m^2$ in April.

Seasonal variation indicated a low value of $14/m^2$ during the postmonsoon short up to $153/m^2$ during the premonsoon and $141/m^2$ during the monsoon.

Eventhough *P. tenuis* present in only 4 months was represented by 5685 specimens, with a maximum of $4,239/m^2$ in July and a minimum of 14 specimens/m^2 in September.

Seasonal variation indicated a total absence during the postmonsoon with $477/m^2$ during premonsoon and $850/m^2$ during the monsoon.

H. similis, *Owenia* sp. and *E. tubifex* with 14 specimens each were recorded once was during the postmonsoon.

Molluscs comprised of 2 species of bivalves and one of gastropod, occurred in all the three seasons. *Pandora flexosa* present during the pre- and post- monsoon only.

Villorita cyprinoides collected during 10 months had 20,618 specimens with their peak occurrence of $9,299/m^2$ in May and lowest in January ($28/m^2$). Seasonal variations showed a gradual fall from the premonsoon value of $3,720/m^2$ to the monsoon value of $1,774/m^2$ followed by an abrupt fall to the postmonsoon $194/m^2$.

Littorina littorina was present in 7 months consisting of 3,448 specimens/m^2 with a high value of $2,113/m^2$ in May and a minimum of $14/m^2$ during January and March. Seasonal averages indicated a sudden reduction from $978/m^2$ during premonsoon to $100/m^2$ during monsoon and a low density of $5/m^2$ during postmonsoon.

Isopod fauna represented by Anthurid sp. comprising of 501 specimens was present only in 3 months with a range of $14/m^2$ in January and $417/m^2$ in July. Their total absence during the premonsoon was followed by a low value of $3/m^2$ during the postmonsoon which rose to $97/m^2$ during the monsoon.

Tanaidaceans also represented by a lone species Apseudes gymnophobium were present in three months of January, April and May with 14 specimens per unit area each.

Among other crustaceans 70 specimens of decapods were recorded in January. Cumacea numbering $84/m^2$ were present - in January ($56/m^2$) and March ($28/m^2$) during the premonsoon. Fourteen specimens of Chineremid larvae were noted in April.

Table - 11 d. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrencce, percentage frequency and seasonal averages at Station 4.

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
AMPHIPODA								
Quadrivisio bengalensis	1224	6	6.31	143	5	245	737 (Jan)	14 (Jun.)
Corophium triaenonyx	10898	3	56.19	3628	-	5	10217 (Mar)	14 (Jan.)
Grandidierella gilesi	6922	3	35.69	2122	-	185	6338 (Mar.)	28 (Apr.)
Caprillidae	320	3	1.65	28 (Apr) 14 (May)	-	278 (Jan)	-	-
Ericopisa chilkensis	14	1	0.07	-	-	114 (Jan.)	-	-
Melita zeylanica	14	1	0.07	14 (Mar)	-	-	-	-
POLYCHAETA								
Dendronereis aestuarina	1184	9	10.14	176	61	116	431 (May)	28 (Mar., Dec.)
Prionospio polybranchiata	3182	8	27.24	917	31	93	1168 (Mar.)	14 (Aug.)
Lycastis indica	377	7	3.22	23	50	19	97(Sept)	14 (Apr)
Heteromastides bifidus	1210	6	10.36	153	141	14	459(Jul)	14 (Apr)
Paraheteromastus tenuis	5685	4	40.67	477	850	-	4239(Jul)	14 (Sept)

Contd...

Table - 11 d. (Contd.)

POLYCHAETA (Contd.)

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Heteromastus similis	14	1	0.12	-	-	14 (Jan.)	-	-
Owenia sp.	14	1	0.12	-	-	14 (Nov)	-	-
Eunice tubifex	14	1	0.12	-	-	14 (Jan.)	-	-
ISOPODA								
Anthuridae	501	3	100.00	-	417(Jul) 70(Aug)	14 (Jan.)	-	-
TANAIDACEA								
Apseudes gymnophobium	42	3	100.00	14(Apr) 14(May)	-	14(Jan.)	-	-
MINOR GROUPS (CRUSTACEA)								
Cumacea	84	2	50.00	28(Mar)	-	56(Jan.)	-	-
Decapoda	70	1	41.65	-	-	70(Jan.)	-	-
Chironomid	14	1	8.33	14(Apr)	-	-	-	-
MOLLUSCA								
Villorita cyprinoides	20618	10	76.65	3720	1774	194	9299(May)	28(Jan.)
Pandora flexosa	2832	5	10.52	611	—	225	1404(Mar)	14(May)
Littorina littorina	3448	7	12.80	978	100	5	2113(May)	14(Jan. Mar.)

Station 5: (Table 11 e).

Amphipod fauna consisted of 6 species namely Quadrivisio bengalensis, Grandidierella gilesi, Melita zeylanica, Eriopisa chilkensis, Corophium triaenonyx and Caprillid sp. All species were present during the premonsoon whereas Q. bengalensis occurred in all the 3 seasons and G. gilesi extended its presence to the postmonsoon also.

Q. bengalensis comprising of 306 specimens were recorded in 5 months with a peak occurrence of 250/m^2 in March and low occurrence of 14/m^2 each during April, October and December. Seasonal variations showed its abundance during the premonsoon 88/m^2 with an abrupt fall to 8/m^2 in the monsoon and 5/m^2 in the postmonsoon. G. gilesi numbering 430 specimens were present in 3 months with a peak of 305/m^2 in March and a low count of 111/m^2 in April. Being totally absent during the monsoon the postmonsoon value of 5/m^2 suddenly increased to 139/m^2 in the premonsoon. M. zeylanica forming 111 specimens was recorded in March (97/m^2) and April (14/m^2). E. chilkensis and C. triaenonyx were found to occur only each during March with 28 specimens/m^2 each.

A total of 240 specimens of Caprillid sp. were present in March and April, numbering 143/m^2 and 97/m^2 respectively.

Polychaetes comprised of 7 species namely Dendronereis aestuarina, Paraheteromastus tenuis, Capitella capitata, Prionospio polybranchiata, Heteromastides bifidus, Lycastis indica and Talehsapia annandalei.

Of these P. tenuis was found during the three seasons whereas H. bifidus was found during the premonsoon and monsoon periods. D. aestuarina and P. polybranchiata were noticed in the premonsoon monyhs only. C. capitata was noticed during the monsoon and the postmonsoon periods whereas L. indica and T. annandalei numbering 28/m^2 and 14/m^2 were recorded in January and November respectively.

Molluscs were represented by 3 species namely Villorita cyprinoides, Pandora flexosa and Littorina littorina numbering 429 was collected in March (42/m^2), and April (387/m^2).

Decapoda numbering 181 were found in January (167/m^2) and December (14/m^2). Twenty eight insect larvae were recorded in 2 months, 14/m^2 each in June and December.

Fourteen Chironomid larvae were collected in January.

Tanytarsus sp. numbering 28 was present only in December.

Fourteen specimens of Cricotopus sylvestris and 28 specimens of Simulium sp. were recorded in May and January respectively.

Table - 11 e. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 5.

AMPHIPODA

Species	Total number of specimens	Frequency of occurrency. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Quadrivisio bengalensis	306	5	26.80	88	8	5	250(Mar.)	14(Apr., Oct.,Dec.)
Grandidierella gilesi	430	3	37.62	139	-	5	305(Mar.)	111(Apr.)
Caprillidae	240	2	20.99	143 (Mar.) 97 (Apr.)	-	-	-	-
Melita zeylanica	111	2	9.71	97 (Mar.) 14 (Apr.)	-	-	-	-
Ericopisa chilkensis	28	1	2.45	28 (Mar.)	-	-	-	-
Corophium triaenonyx	28	1	2.45	28 (Mar.)	-	-	-	-
POLYCHAETA								
Dendronereis aestuarina	3100	3	85.70	834 (Mar.) 2016 (Apr.) 250 (May)	-	-	-	-
Paraheteromastus tenuis	84	3	2.33	28 (Mar.)	14 (Jun)	42(Nov.)	-	-
Capitella capitata	42	3	1.16	-	14 (Aug) 14 (Oct)	14(Dec.)	-	-
Prionospio polybranchiata	250	2	7.33	167 (Mar) 83 (Apr)	-	-	-	-
Heteromastides bifidus	84	2	2.33	70 (Mar)	14 (Oct)	-	-	-
Lycastis indica	28	1	0.78	-	-	28(Jan.)	-	-
[illegible]	14	1	0.38	-	-	14(Nov)	-	-

Table - 11 e. (Contd.)

MOLLUSCA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Pandora flexosa	429	2	12.70	42 (Mar) 387 (Apr)	-	-	-	-
Villorita cyprinoides	56	1	1.66	56 (Apr)	-	-	-	-
Littorina littorina	2892	2	85.63	70 (Mar) 2822 (Apr)	-	-	-	-
MINOR GROUPS (CRUSTACEA)								
Decapoda	181	2	61.80	-	-	167 (Jan) 14 (Dec)	-	-
Insect larvae	28	2	9.60	-	14(Jul)	14 (Dec)	-	-
Tanytarsus sp.	28	1	9.60	-	-	28 (Dec)	-	-
Simulium sp.	28	1	9.60	-	-	28 (Jan)	-	-
Cricotopus sylvestris	14	1	4.80	14 (May)	-	-	-	-
Chironomid larvae	14	1	4.80	-	-	14 (Jan)	-	-

Station 6: (Table 11 f).

Capitella capitata, the most dominant polychaeta species numbering 8,369 were collected in 6 months with their peak value of 5,046/m^2 in August and low value of 28/m^2 in July. Seasonal variation showed the low occurrence of 18/m^2 during the premonsoon which increased to 1,031/m^2 during the monsoon and 1,052/m^2 during the postmonsoon.

Next in abundance was Dendronereis aestuarina numbering 4,712 spread over in 5 months with a peak value of 3,447/m^2 in April and the lowest value of 14/m^2 in May and June. Seasonal fluctuations indicated their absence during the postmonsoon, a low value of 53/m^2 during the monsoon which rose to 1,482/m^2 during the premonsoon.

Forty two Lycastis indica and 139 Heteromastides bifidus were observed in 2 months each, April (28/m^2) and May (14/m^2) accounted for the former while August (125/m^2) and May (14/m^2) had the latter.

Prionospio polybranchiata numbering 264 was recorded only in May.

Amphipods were represented by 3 species namely, Quadrivisio bengalensis, Grandidierella gilesi and Caprillid sp. They were present in 3, 2 and 1 month respectively. While Q. bengalensis numbering 112 was present in April (70/m^2), July (14/m^2) and December (28/m^2), Caprillid sp. numbering

56 was recorded in July ($14/m^2$) and August ($42/m^2$). G. gilesi numbering ($14/m^2$) was seen only in April.

Molluscs comprised of 2 species of bivalve namely Villorita cyprinoides and Pandora flexosa. P. flexosa with high numerical occurrence of 1,587 was noticed during 5 months, with a maximum of $1,015/m^2$ in July and a minimum of $28/m^2$ in May. They were present throughout the year showing the lowest value of $14/m^2$ during the postmonsoon which raised to $111/m^2$ during the premonsoon and showed a further increase to $242/m^2$ during the monsoon.

V. cyprinoides numbering 363 was collected only in 3 months with a peak of $334/m^2$ in April and $14/m^2$ each in March and August. In addition to the above 1,271 numbers of empty shells also were sorted out along with 2,502 empty shells of Littorina littorina.

Fourteen specimens of isopods represented by a lone anthurid species was present in August. Similarly 14 tanaidaceans belonging to one species, Apseudes gymnophobium, were noted in April.

Rest of the 4 species from this station were of riverine forms.

Twenty eight unidentified worms, $14/m^2$ each were observed i July and June; while 111 specimens of Anatopynia sp. was found in December, 14 specimens of Enhydra sp. was present in January and 14 of Bezzia sp. in July.

Table - 11 f. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 6.

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
AMPHIPODA								
Quadrivisio bengalensis	112	3	61.50	70(Jul)	14(Jul)	28(Dec.)	-	-
Caprillidae	56	2	30.80	-	14(Jul) 42(Aug)	-	-	-
Grandidierella gilesi	14	1	7.69	14(Apr)	-	-	-	-
POLYCHAETA								
Capitella capitata	8369	6	61.87	18	1031	1052	5046(Aug)	28(Jul)
Dendronereis aestuarina	4712	5	34.80	1482	53	-	3447(Apr)	14(May, Jun.)
Heteromastides bifidus	139	2	1.03	14(May)	125(Aug)	-	-	-
Lycastis indica	42	2	0.31	28(Apr) 14(May)	-	-	-	-
Prionospio polybranchiata	264	1	1.95	264(May)	-	-	-	-

Contd...

Table - 11 f. (Contd.)

Species	Total number of specimens	Frequency of occurrence.No. of Months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
ISOPODA								
Anthuridae	14	1	100.00	-	14(Aug)	-	-	-
TANAIDACEA								
Apseudus gymnophobium	14	1	100.00	14(Apr)	-	-	-	-
MOLLUSCA								
Pandora flexosa	1587	5	81.40	111	242	14	1015(Jul)	28(May)
Villorita cyprinoides	363	3	18.60	14(Mar) 334(Apr)	14(Aug)	-	-	-
MINOR GROUPS (CRUSTACEA)								
Unidentified	28	2	17.00	-	14(Jun) 14(Jul)	-	-	-
Anatopynia sp.	111	1	66.50	-	-	111(Dec)	-	-
Ephydra sp.	14	1	8.38	-	-	14(Jan.)	-	-
Bezzia sp.	14	1	8.38	-	14(Jul)	-	-	-

Station 7: (Table 11 g).

Station 7 comprised ~~of~~ 16 species, 4 species of amphipods, 7 of polychaetes, one each of molluscs, insect larvae, chironomid larvae, Diamesa and Anatopynia. Their numerical abundance indicated a very high occurrence of Capitella capitata with 2,22,738 specimens being present over 8 months. Of the rest of the species Dendronereis aestuarina was seen in 5 months, Quadrivisio bengalensis and Pandora flexosa in 3 months each, Caprillidae, Prionospio polybranchiata, Lycastis indica and Heteromastides bifidus in 2 months each. But for D. aestuarina with 1,546 specimens, rest of the 14 species were recorded only in few numbers.

While only C. capitata was present during the entire period, 10 species were found only in one season and rest of 5 in 2 seasons each. Whereas 8 and 10 species were found during the premonsoon and monsoon period, the postmonsoon had only 4 species.

C. capitata was observed in 8 months with a peak value of 1,90,639 in September and a lowest value of 28 in June. Seasonal variations showed a high value of 43,446/m^2 during the monsoon, a low value of 1,911/m^2 during the postmonsoon, which suddenly dropped to the lowest value of 14/m^2 during the premonsoon.

Next in abundance was D. aestuarina with 1,546 specimens collected during 5 months with a peak value of $959/m^2$ in April and a low number of $14/m^2$ in August. Seasonal variation indicated high numerical abundance of $492/m^2$ during the pre-monsoon followed by an abrupt fall to $14/m^2$ during the monsoon and total absence during the postmonsoon. January and March recorded 28 specimens/m^2 of P. polybranchiata. L. indica numbering 28 was noticed in the month of March ($14/m^2$) and August ($14/m^2$). H. bifidus numbering 84 was also present in the 2 months of March ($6/m^2$) and September ($28/m^2$).

Nais sp. and P. tenuis were present only in one month each, January ($334/m^2$) and June ($14/m^2$) respectively.

Of the four species of amphipods, Q. bengalensis numbering 196 was recorded in the months of March ($14/m^2$), April ($154/m^2$) and August ($28/m^2$). Caprillidae numbering 111 were present in January ($97/m^2$) and March ($14/m^2$) respectively.

306 specimens of C. triaenonyx were recorded in September whereas 14 specimens of E. chilkensis were collected in March.

Among molluscs only the bivalve species P. flexosa numbering 140 was collected in 3 months, i.e. March ($42/m^2$), April ($84/m^2$) and May ($14/m^2$). However empty shells of Littorina littorina numbering 3,914 were also noted.

Insect larvae, Chironomid larvae, Diamesa sp. and Anatopynia sp. were collected only once during the period, insect larvae in April ($42/m^2$) and the other three in August ($14/m^2$) each.

Table - 11 g. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 7.

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
AMPHIPODA								
Quadrivisio bengalensis	196	3	31.30	14 (Mar.) 154 (Apr.)	28 (Aug)	-	-	-
Caprillidae	111	2	17.70	14 (Mar.)	-	97 (Jan.)	-	-
Corophium triaenonyx	306	1	48.80	-	306 (Sept)	-	-	-
Ericoisa chilkensis	14	1	2.23	14 (Mar.)	-	-	-	-
POLYCHAETES								
Capitella capitata	222738	8	99.08	14	43446	1911	190639 (Sept.)	28 (Jun.)
Dendronereis aestuarina	1546	5	0.68	492	14	-	959 Apr.)	14 (Aug.)
Heteromastides bifidus	84	2	0.04	56 (Mar.)	28 (Sept.)	-	-	-
Prionospio polybranchiata	56	2	0.02	28 (Mar.)	-	28 (Jan.)	-	-
Lycastis indica	28	2	0.01	14 (Mar.)	14 (Aug.)	-	-	-
Nais sp.	334	1	0.15	-	-	334 (Jan.)	-	-
Paraheteromastus tenuis	14	1	0.005	-	14 (Jun.)	-	-	-

Contd...

Table - 11 g. (Contd.)

MOLLUSCS

Species	Total number of specimens	Frequency of occurrence.No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Pandora flexosa	140	3	100.0	42(Mar.) 84(Apr.) 14(May)	-	-	-	-
MINOR GROUPS (CRUSTACEA)								
Insect larva	42	1	100.0	42(Apr.)	-	-	-	-
Chironomid larvae	14	1	100.0	-	14(Aug.)	-	-	-
Diamesa sp.	14	1	100.0	-	14(Aug.)	-	-	-
Anatopynia sp.	14	1	100.0	-	14(Aug.)	-	-	-

Station 8: (Table 11 h).

Station 8 located near the effluent discharge site had 6 species only, namely *Dendronereis aestuarina*, *Lycastis indica*, *Paraheteromastus tenuis*, *Talehsapia annandalei*, chironomid larva and *Pandora flexosa*. Of these two species were present in three months each and the rest 3 in one month each. While only *L. indica* was recorded during the premonsoon and the monsoon, *P. tenuis* and *T. annandalei* were present only in the monsoon. No fauna was observed during postmonsoon. *D. aestuarina* numbering 807 was observed in the 3 months of March (653/m^2), April (98/m^2) and May (56/m^2).

L. indica also was present during 3 months with 28, 14 and 70 specimens/m^2 in May, July and September respectively. *P. tenuis* and *T. annandalei* (14/m^2) each were noted in October. A total of 28 chironomid larvae were collected in January. The only bivalve species *Pandora flexosa* numbering 430 was obtained in April (360/m^2) and May (70/m^2). Empty shells of gastropods (682), of *Villorita cyprinoides* (42) and of *Pandora flexosa* (111) were also observed.

Table - 11 h. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 8.

POLYCHAETA

Species	Total number of specimens	Frequency of occurrence, No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Dendronereis aestuarina	807	3	85.20	653(Mar.) 98(Apr.) 56(May)	-	-	-	-
Lycastis indica	112	3	11.80	28(May)	14(Jul) 70(Sept.)	-	--	-
Paraheteromastus tenuis	14	1	1.47	-	14(Oct.)	-	-	-
Talehsapia annandalei	14	1	1.47	-	14(Oct.)	-	-	-
MINOR GROUP								
Chironomid larva	28	1	100.00	-	-	28(Jan.)	-	--
MOLLUSCS								
Pandora flexosa	430	2	100.00	360(Apr.) 70(May)	-	-	-	-

Station 9: (Table 11 i).

A total of 21 species, 6 of polychaetes, 3 of molluscs and 12 of minor groups were present at Station 9. Of these *Lycastis indica*, *Capitella capitata*, *Dendronereis aestuarina*, , *Villorita cyprinoides*, *Anatopynia* sp. and *Plectrocnemia* sp. were noted in 10, 7, 6, 6, 5 and 4 months respectively. Three species were present in 3 months each whereas 5 species were present in 2 months each and the rest 7 species in one month each.

While 2 species were present during the 3 seasons, 10 species in 2 seasons each and 9 species were present during one season only.

But for the high numerical abundance of *L. indica* numbering 6,634 and *D. aestuarina* numbering 2,351 rest of 19 species occurred in low densities only.

The most abundant species *L. indica* totalling 6,534 being present in 10 months indicates a peak of 1,613/m^2 in April and 14/m^2 in January.

Seasonal fluctuation showed a monsoon value of 136/m^2 gradually increasing to 204/m^2 and 714/m^2 during the post-monsoon and premonsoon respectively. Next in abundance was *D. aestuarina* with 2,351 specimens collected over six months with a peak value of 1,335/m^2 in May and a low value of 42/m^2 in June.

C. capitata with a total of 863 specimens from 7 months indicated a peak value of $389/m^2$ in January and a low value of $14/m^2$ in August, October and December. Seasonal variations indicated their absence during the Premonsoon and mean values of $80/m^2$, and $153/m^2$ during the monsoon and the postmonsoon respectively.

Paraheteromastus tenuis with 404 specimens was present only in the months of June and November with 70 $specimens/m^2$ each and December with $264/m^2$. Lumbriconereis pseudobifilaria and Nais sp. were noticed only once each in June and July respectively.

Among molluscs, Villorita cyprinoides numbering 84 was recorded in 6 months with 14 specimens each representing all the seasons. Batissa sp. and gastropods numbering 42 and 70 each were observed in two months each in May, June, April and December respectively.

168 specimens of Anatopynia sp. were recorded in 5 months with a maximum of $56/m^2$ in January and $14/m^2$ in October. All the 663 specimens of Plectrocnemia sp. were recorded during the four monsoon months with a peak occurrence of $445/m^2$ in October. Of the 362 Diamesa sp. recorded $14/m^2$, $195/m^2$ and $133/m^2$ were collected ~~from~~ in April, May and January respectively. Insect larvae numbering 70 were present in June, July and November. Tanytarsus sp., water beetles, and Enhydrus sp. numbering 112, 84 and 42 respectively were recorded from two months each. Chironomid larvae, Baetis sp., May fly larvae, Platambus sp. and an unidentified worm were collected during one month each.

Table - 11 i. Distribution of different species of benthic organisms showing total number of specimens, frequency of occurrence, percentage frequency and seasonal averages at Station 9.

POLYCHAETA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Lycastis indica	6634	10	64.50	714	136	204	1613(Apr)	14(Jan.)
Capitella capitata	863	7	8.40	-	80	153	389(Jan)	14(Aug., Oct., Dec.)
Dendronereis aestuarina	2351	6	22.60	556	136	-	1335(May)	42(Jun.)
Paraheteromastus tenuis	404	3	4.20	-	70(Jun.)	70(Nov.) 264(Dec.)	-	-
Lumbriconereis pseudobifilaris	83	1	0.74	-	83(Jun.)	-	-	-
Nais sp.	14	1	0.12	-	14(Jul.)	-	-	-

MOLLUSCA

Species	Total number of specimens	Frequency of occurrence. No. of months.	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max.No./ Months.	Min.No./ Months.
Villorita cyprinoides	84	6	42.85	10	5	7	14 in all months	
Batissa sp.	42	2	22.10	28(May)	14(Jun)	-	-	-
Gastropoda (unidentified)	70	2	36.84	56(Apr.)	-	14(Dec.)	-	-

Contd..

Table - 11 i. (Contd.)

MINOR GROUPS (CRUSTACEA)

Species	Total number of specimens	Frequency of occurrence. No. of months	% Frequency	Premonsoon average	Monsoon average	Postmonsoon average	Max. No./ Months.	Min. No./ Months.
Anatopynia sp.	168	5	10.60	-	8	42	56(Jan.)	14(Oct.)
Plectrocnemia sp.	663	4	41.80	-	133	-	445(Oct.)	56(Aug.)
Diamesa sp.	362	3	22.80	14(Apr.) 195(May)	-	13(Jan)	-	-
Insect larvae	70	3	4.41	-	14(Jun.) 14(Jul.)	42(Nov.)	-	-
Tanytarsus sp.	112	2	7.06	70(Mar)	-	42(Nov.)	-	-
Water beetle.	84	2	5.29	14(Jan.) 70(May)	-	-	-	-
Ephdra sp.	42	2	2.65	14(Apr)	25(Jul.)	-	-	-
Chironomid larvae	14	1	0.88	14(Apr)	-	-	-	-
Baetis sp.	14	1	0.88	-	14(Jun.)	-	-	-
May fly larvae	14	1	0.88	-	14(Jul.)	-	-	-
Platambus sp.	28	1	1.77	-	-	28(Dec.)	-	-
Unidentified worms	14	1	0.88	-	-	14(Jan.)	-	-

3.3. Statistical inferences from cluster and regression analysis.

At Station 1 the most abundant species was *Corophium triaenonyx*. The least abundant and comparatively homogeneous species were *Notopygos* sp., *Odontosyllis gravelyi*, *Nephthys polybranchia*, *Owenia* sp., *Serpula vermicularis*, *Acetes* sp., Crab megalopa and *Meritrix casta*. The most variable or least consistent species was *Grandidierella bonnieri*. Nearly 7.91% of the species correlation was found significantly positive. The groups like nematodes, sipunculids, echinoderms, fish larvae and polychaete species *Glycera convoluta* were found coexisting with almost all other species (Table 12 a), since they preferred a common environment. From dendrogram studies (Fig. 15 a) at 5% level of significance 9 major clusters of species with maximum affinity and 3 major clusters of environmental parameters (Fig. 16 a) with maximum affinity were identified. 4.2% of the species (Table 13 a) were found to have very significant positive correlations with different environmental parameters. The 9 parameters which were found to be relatively important based on multiple regression analysis ranked in the order nitrate > ammonia > 'K' factor > nitrite > suspended solids > sand > organic carbon in sediments > salinity > oxygen. But these alone are not able to predict the abundance as the regression model fitted was not found to be significant.

However, including the interaction effects of the significantly correlated parameter clusters like (1) temperature and organic carbon, (2) pH and nitrite and (3) suspended solid and organic carbon with the above, the abundance could be predicted.

<u>Multiple regression analysis</u>:

Table - 12 a. Showing the species with significant correlation (Significant at 5% level - (P $\leq$0.05) in Barmouth (Station 1).

With	species	1	-	4, 5, 10, 12, 15, 16, 36, 43, 45, 50.
"	"	2	-	32, 49, 51, 52.
"	"	3	-	16, 45, 46, 49, 52.
"	"	4	-	5, 10, 12, 13, 15, 16, 36, 43, 45, 50.
"	"	5	-	12, 13, 15, 16, 20, 25, 36, 50.
"	"	6	-	9, 26, 27.
"	"	7	-	29, 30, 37, 40, 48.
"	"	8	-	32, 51, 52.
"	"	9	-	20, 26, 27.
"	"	10	-	16, 25, 50.
"	"	12	-	51, 52.
"	"	14	-	35.
"	"	15	-	25, 36, 44, 50.
"	"	16	-	25, 36, 44, 50.
"	"	18	-	45.
"	"	20	-	28, 29, 45.

Contd...

Table - 12 a. (Contd.)

With species	21	-	35.
" "	23	-	53.
" "	25	-	36, 43, 45, 50.
" "	26	-	27.
" "	28	-	33, 34.
" "	29	-	39, 45.
" "	30	-	37, 40.
" "	31	-	34, 38, 46.
" "	32	-	42, 49, 53.
" "	33	-	34.
" "	35	-	47.
" "	36	-	44, 50.
" "	37	-	39, 48.
" "	38	-	46.
" "	39	-	40, 48.
" "	40	-	48.
" "	41	-	56.
" "	42	-	49, 52, 35.
" "	44	-	45.
" "	48	-	53.
" "	49	-	53.
" "	51	-	52.

Number denotes species name as in the list.

Table - 13 a. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 1.

With	Temperature	- 22.
With	Salinity	- 3, 17 (-ve), 19 (-ve).
With	Oxygen	- 13 (-ve), 20 (-ve), 41, 5 (-ve), 28 (-ve)
With	pH	- 23, 42, 48, 49.
With	BOD_5	- 42 (-ve).
With	'K' factor	- 11, 31, 33, 34, 38, 46.
With	Phosphate	- 6 (-ve), 18 (-ve), 22, 32, 42, 48 (-ve), 49.
With	Nitrite	- 42.
With	Nitrate	- 11, 47.
With	Ammonia	- 4, 5, 15, 21, 25, 36, 50.
With	Sand	- 11 (-ve), 24.
With	Silt	- 11, 13.
With	Clay	- 24 (-ve).
With	Organic carbon	- 23, 32, 42, 49, 52.

Number denotes species name as in the list.

List of Species for Station 1.

Sl.No.	Name of species
1	*Sthenelais boa*.
2	*Ancistrosyllis constricta*.
3	*Lycastis indica*.
4	*Dendronereis aestuarina*.
5	*Perinereis cavifrons*.
6	*Nephthys oligobranchia*.
7	*Eunice tubifex*.
8	*Diopatra neapolitana*.
9	*Lumbriconereis simplex*.
10	*Lumbriconereis notocirrata*.
11	*Goniada emerita*.
12	*Glycera alba*.
13	*Glycera convoluta*.
14	*Prionospio polybranchiata*.
15	*Prionospio pinnata*.
16	*Heteromastus similis*.
17	*Heteromastides bifidus*.
18	*Paraheteromastus tenuis*.
19	*Pista indica*.
20	Sabellidae.
21	*Corophium triaenonyx*.
22	*Quadrivisio bengalensis*.
23	*Grandidierella gilesi*.
24	*Grandidierella bonnieri*.
25	*Melita zeylanica*.
26	*Eriopisa chilkensis*.

Contd...

List of Species for Station 1. (Contd.).

Sl.No.	Name of Species.
27	Caprillidae.
28	Tanaidaceans (both species).
29	*Cirrolinia fluviatilis*.
30	Anthuridae.
31	*Balanus* sp.
32	*Alpheid* sp.
33	Decapods.
34	Insect larvae.
35	*Modiolus striatulus*.
36	*Paphia papillions*.
37	*Pandora flexosa*.
38	*Arca* sp.
39	Gastropods (unidentified).
40	*Littorina littorina*.
41	Sea anemone.
42	Nematodes.
43	Sipunculoidea.
44	Echinoderms.
45	Fish larvae.

At Station 2 the most abundant species was Heteromastides bifidus and the least abundant and comparatively homogeneous species were Cumacea, Tanytarsus sp., insect larvae, Littorina littorina, fish larvae and polychaeta species Eunice tubifex and Pista indica while least consistent species was Grandidierella gilesi. 9.1% of the correlation between species were significantly positive. The species Ancistrosyllis constricta, Perinereis cavifrons, Goniada emerita, Heteromastus similis, Corophium triaenonyx, Quadrivisio bengalensis and Aphroditids were found preferring almost the same physical environment (Table 12 b) indicated by significantly positive correlation. Dendrogram studies (Figs.15 b and 16 b) have shown 9 major clusters of species and 4 major clusters of environmental parameters having great affinity at 5% level. Correlation studies of species (Table 13 b) with environmental parameters showed different species having specific affinities with different parameters (nearly 5.56% of the correlations were significantly positive). The relatively important 9 parameters, based on multiple regression analysis, were ranked as nitrate > salinity > 'K' factor > organic matter > oxygen > suspended solids > phosphate > ammonia > sand. Salinity being the second important parameter, the benthos at Station 2 were of marine nature. These 9 important parameters alone were not able to predict the abundance of benthos in this station as regression model fitted was not found to be significant. However, including the interaction effects of the significantly correlated parameter clusters like (1) BOD and suspended solids, (2) temperature and salinity, (3) 'K' factor and ammonia and (4) phosphate and nitrate along with the above parameters could predict the abundance of benthos in this station.

Table - 12 b. Showing the species with significant correlation (significant at 5% level - (P - < 0.05) in Station 2.

With	species	1	2, 6, 7, 8, 12, 29, 49.
"	"	2	3, 6, 7, 8, 29, 49.
"	"	3	6, 29.
"	"	4	48.
"	"	5	20, 21, 22, 23, 24.
"	"	6	7, 8, 12, 13.
"	"	7	49.
"	"	8	29, 49.
"	"	9	31.
"	"	10	28, 38, 39, 42.
"	"	11	21, 24, 25, 28, 41.
"	"	12	29.
"	"	13	18, 37, 38, 40.
"	"	15	20, 21, 27, 33, 34.
"	"	17	37.
"	"	18	38, 39, 42.
"	"	20	21, 22, 23, 26, 27, 33, 34.
"	"	22	30, 28.
"	"	23	26, 27, 28.
"	"	24	25, 28, 30, 41.
"	"	25	28, 41.
"	"	26	33, 34, 43.

Contd...

Table - 12 b. (Contd.)

With species	28	-	30, 41.
" "	30	-	41.
" "	36	-	43.
" "	37	-	43.
" "	38	-	39, 40, 42.
" "	39	-	40.
" "	40	-	42.

Number indicates species name as in the list.

Table - 13 b. Showing the species with significant correlation with parameters at 5% level P - <0.05 at Station 2.

With salinity	-	26.
" Oxygen	-	4 (-ve), 5 (-ve), 11 (-ve), 25 (-ve), 30 (-ve).
" pH	-	1, 2, 3 (-ve), 6, 7, 8, 12, 29.
" 'K' values	-	4 (-ve), 32.
" Suspended solids.	-	39.
" Particulate organic matter	-	16.
" Phosphate	-	15, 27, 33, 34.
" Nitrite	-	10, 18, 38, 39, 42.
" Nitrate	-	4, 5, 20, 22, 23, 27, 33, 34 (-ve), 38, 42.
" Ammonia	-	4 (-ve), 19 (-ve), 23, 32.
" Sand	-	19, 29 (-ve).
" Silt	-	36 (-ve), 37 (-ve), 43 (-ve).
" Clay	-	21, 27, 33, 34, 36.
" Organic carbon	-	3, 4 (-ve), 16, 19 (-ve).

Number indicates species name as in the list.

List of Species for Station 2.

Sl.No.	Name of Species
1	Aphroditidae.
2	*Ancistrosyllis constricta*.
3	*Lycastis indica*.
4	*Dendronereis aestuarina*.
5	*Perinereis cavifrons*.
6	*Nephthys polybranchia*.
7	*Capitella capitata*.
8	*Eunice tubifex*.
9	*Diopatra neapolitana*.
10	*Lumbriconereis notocirrata*.
11	*Goniada emerita*.
12	*Glycera alba*.
13	*Glycera convoluta*.
14	*Prionospio polybranchiata*.
15	*Heteromastus similis*.
16	*Heteromastides bifidus*.
17	*Paraheteromastus tenuis*.
18	*Pista indica*.
19	*Owenia* sp.
20	*Corophium triaenonyx*.
21	*Quadrivisio bengalensis*.
22	*Grandidierella gilesi*.
23	*Grandidierella bonnieri*.
24	*Melita zeylanica*.
25	Caprillidae.

Contd...

List of Species for Station 2. (Contd.)

Sl.No.	Name of Species
26	Tanaidaceans (both species).
27	*Cirrolinia fluviatilis*.
28	Anthuridae.
29	Decapoda.
30	Cumacea.
31	Chironomid larvae.
32	*Tanytarsus* sp.
33	Plectrocnemia.
34	Insect larvae.
35	*Pandora flexosa*.
36	*Villorita cyprinoides*.
37	*Paphia papillions*.
38	*Arca* sp.
39	Gastropoda (unidentified).
40	*Littorina littorina*.
41	Nematodes.
42	Flat worms.
43	Sipunculoidea.
44	Echinoderms.
45	Fish larvae.

At Station 3, the abundant species was Corophium triaenonyx and the least abundant and comparatively homogeneous species were Eunice tubifex, Owenia sp., Cirrolinia fluviatilis, Cumacea, Tanytarsus sp., Plectrocnemia sp., Ephydra, Sipunculids, nematodes and flat worms. Nearly 6.65% of the correlation between species were significantly positive. Only 3 species namely Glycera convoluta, Pandora flexosa and and Nematod sp. were found correlated with (Table 12 c) certain other benthos. Significant positive (6.7% and negative (6.31%) correlation noted between environmental parameters and species showed the conditions at Station 3 (Table 13 c) neither highly favourable nor damaging for the benthic fauna. From dendrogram studies (Fig. 15 c) 5 major clusters of species and 5 major clusters of parameters (Fig. 16 c) having great affinity at 5% level were found. Relative importance of the 9 parameters based on multiple regression analysis were ranked as salinity > nitrate > oxygen > nitrite > 'K' factor > organic matter > ammonia > sediment > BOD. As in Station 2 salinity was found to be the most important parameter. Here also, including the interaction effects of the significantly correlated parameter clusters like (1) temperature, salinity, nitrate and sand, (2) pH and suspended solids, (3) 'K' factor and organic matter, (4) BOD and ammonia and (5) oxygen, 'K' factor, clay and organic carbon along with the 9 important parameters alone could predict the abundance of benthos.

Table - 12 e. Showing the species with significant correlation (significant at 5% level $P < 0.05$) in Station 3.

With	species	3	-	8, 9, 26.
"	"	4	-	5, 29.
"	"	5	-	6, 18, 26.
"	"	6	-	7, 16, 20, 25, 28, 29.
"	"	7	-	8.
"	"	8	-	9.
"	"	11	-	12, 13, 14, 24.
"	"	12	-	13, 24.
"	"	14	-	18, 24.
"	"	15	-	24.
"	"	16	-	25, 27.
"	"	18	-	28, 29.
"	"	19	-	27.
"	"	25	-	27.
"	"	26	-	28, 29.

Number denotes species name as in the list.

Table - 13 e. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 3.

With temperature	-	1 (-ve), 6, 23 (-ve), 24, 25, 30(-ve)
" salinity	-	2 (-ve), 11, 12, 14, 15, 18 (-ve), 24, 31 (-ve).
" pH	-	2.
" oxygen	-	5 (-ve), 14 (-ve), 15 (-ve), 18 (-ve), 24 (-ve), 28 (-ve), 29 (-ve).
" BOD_5	-	6 (-ve), 25 (-ve).
" 'K' factor	-	23, 30.
" suspended solids	-	2,22, 31.
" particulate organic matter	-	1, 9, 23, 30.
" phosphate	-	1, 12 (-ve), 23, 30, 31.
" nitrite	-	2 (-ve), 15, 31.
" nitrate	-	2 (-ve), 11, 14, 15, 24.
" ammonia	-	5 (-ve), 6 (-ve), 15 (-ve), 24 (-ve), 26, 28 (-ve), 29 (-ve).
" sand	-	15, 17 (-ve), 21 (-ve), 24.
" silt	-	2, 15 (-ve), 24 (-ve).
" clay	-	15 (-ve), 18 (-ve), 24 (-ve).
" organic carbon	-	2.

Number denotes species name as in the list.

List of Species for Station 3.

Sl.No.	Name of Species.
1	*Talehsapia annandalei*.
2	*Lycastis indica*.
3	*Dendronereis aestuarina*.
4	*Perinereis cavifrons*.
5	*Eunice tubifex*.
6	*Glycera convoluta*.
7	*Prionospio polybranchiata*.
8	*Heteromastides bifidus*.
9	*Paraheteromastus tenuis*.
10	*Owenia* sp.
11	*Corophium triaenonyx*.
12	*Quadrivisio bengalensis*.
13	*Grandidierella gilesi*.
14	*Melita zeylanica*.
15	Caprillidae.
16	Tanaidaceans (both species).
17	*Cirrolinia fluviatilis*.
18	Anthuridae.
19	Cumacea.
20	Chinoromid larvae.
21	*Tanytarsus* sp.
22	*Plectrocnemia* sp.
23	Ephydra.
24	*Pandora flexosa*.
25	*Villorita cyprinoides*.
26	*Modiolus striatulus*.
27	*Litterina littorina*.
28	Sipunculoidea.
29	Nematodes.
30	Flat worms.
31	Fish larvae.

At Station 4 the most abundant species was _Villorita cyprinoides_ and the least abundant and homogeneous species were _Eunice tubifex_, _Heteromastus similis_, _Owenia_ sp., _Eriopisa chilkensis_, _Melita zeylanica_, megalopa larvae and chironomid larvae. The least consistent species was _Corophium triaenonyx_. 15.63% of species correlations were highly positive (Table 12 d). Similarly 8.85% of species were found to be positively correlated (Table 13 d) with different environmental parameters too. Dendrogram studies showed 5 major clusters among species (Fig. 15 d) having maximum affinity at 5% level and 4 major clusters among 16 environmental parameters (Fig. 16 d) with high affinity at 5% level. The 9 relatively important parameters, based on multiple regression analysis, were ranked as salinity > organic matter > 'K' factor > BOD > suspended solids > nitrate > silt > clay > temperature. Salinity was found to be the most important factor. In this station, the abundance of benthos could be predicted only when the interaction effects of the significantly correlated parameter clusters like (1) organic carbon, suspended solids and organic matter, (2) BOD and 'K' factor, (3) temperature and salinity and (4) oxygen and nitrate were considered along with the 9 important parameters.

Table - 12 d. Showing the species with significant correlation (significant at 5% level - $P < 0.05$) in Station 4.

With species	1	-	7, 8, 17.
" "	2	-	23.
" "	3	-	11, 16.
" "	4	-	11, 15, 18, 20.
" "	5	-	10, 12, 16, 22.
" "	6	-	11, 15, 18, 20.
" "	7	-	8, 17.
" "	8	-	23, 24.
" "	10	-	12, 14, 22.
" "	11	-	13, 15, 16, 18, 19.
" "	12	-	14, 20, 22, 23.
" "	13	-	15, 18, 20.
" "	15	-	16, 18, 19, 20.
" "	20	-	18, 19, 22, 23.

Number denotes species name as in the list.

Table - 13 d. Showing the species with significant correlation with parameters at 5% level - P.<0.05 at Station 4.

With temperature	-	5,10, 16, 22.
" salinity	-	5, 7, 10, 22.
" oxygen	-	23.
" pH	-	7, 17.
" BOD_5	-	3 (-ve), 5 (-ve), 24 (-ve).
" 'K' factor	-	1, 8, 17.
" suspended solids	-	1, 17.
" phosphate	-	1, 17.
" nitrite	-	4, 6, 13, 18, 19, 20, 22.
" nitrate	-	5, 10, 12, 14, 20, 22.
" sand	-	1 (-ve), 17 (-ve).
" silt	-	1, 17.
" clay	-	9.
" organic carbon	-	22 (-ve).

Number denotes species name as in the list.

List of Species for Station 4.

Sl.No.	Name of Species.
1	*Talehsapia annandalei*.
2	*Lycastis indica*.
3	*Dendronereis aestuarina*.
4	*Eunice tubifex*.
5	*Prionospio polybranchiata*.
6	*Heteromastus similis*.
7	*Heteromastides bifidus*.
8	*Paraheteromastus tenuis*.
9	*Owenia* sp.
10	*Corophium triaenonyx*.
11	*Quadrivisio bengalensis*.
12	*Grandidierella gilesi*.
13	*Eriopisa chilkensis*.
14	*Melita zeylanica*.
15	Caprillidae.
16	*Apseudes gymnophobium*.
17	Anthuridae.
18	Decapoda.
19	Megalopa larva.
20	Cumacea.
21	Chironomid larvae.
22	*Pandora flexosa*.
23	*Villorita cyprinoides*.
24	*Littorina littorina*.

At Station 5 the most abundant and the least consistent species was *Dendronereis aestuarina*. The least abundant and comparatively homogeneous species were *Talehsapia annandalei*, chironomid larvae and *Cricotopus sylvestris*. 17.75% of the correlations were highly significantly positive. Correlations of *D. aestuarina*, *Prionospio polybranchiata* and *Heteromastides bifidus* with other species were prominent. Also, *Melita zeylanica*, *Ericthonius chilkensis*, Caprillidae, *Pandora flexosa*, *Villorita cyprinoides* and *Littorina littorina* showed highly positive correlations with most of the species (Table 12 e). From dendrogram studies 4 major clusters of benthic species (Fig. 15 e) having great affinity at 5% level and 4 major clusters of parameters too (Fig. 16 e) with great affinity at 5% level were identified. Species - parameters correlations (Table 13 e) showed 2.2% of the species being positively significantly correlated with parameters. The relative 9 important parameters, based on multiple regression analysis, were ranked as oxygen > phosphate > sand > clay > nitrate > nitrite > BOD > suspended solids > temperature. Strangely, salinity did not figure among the ranking probably suggesting that the benthic fauna at Station 5 was not at all controlled by salinity.

The above mentioned 9 important parameters alone could not predict the abundance of benthos at this station, as the regression model fitted was not found to be significant. However including the interaction effects of the significantly correlated parameter clusters like (1) light, suspended solids and organic matter (2) nitrite and nitrate, (3) pH and phosphate and (4) silt and clay along with the above parameters, the abundance of parameters could be predicted.

Table - 12 e. Showing the species with significant correlation (significant at 5% level - $P < 0.05$) in Station 5.

With	species	1	-	7.
"	"	2	-	4.
"	"	3	-	5, 10, 13, 20, 21, 22.
"	"	5	-	6, 8, 9, 10, 11, 12, 13, 20, 22.
"	"	6	-	8, 9, 10, 11, 12, 13.
"	"	8	-	9, 10, 11.
"	"	9	-	10, 11, 12, 13.
"	"	10	-	11, 12, 13.
"	"	12	-	13.
"	"	13	-	20, 21, 22.
"	"	14	-	15.
"	"	20	-	21, 22.
"	"	21	-	22.

Number denotes species name as in the list.

Table - 13 e. Showing the species with significant correlation with parameters at 5% level - P. < 0.05 at Station 5.

With salinity	-	3, 5, 6, 8, 9, 10, 11, 12, 20, 22.
" oxygen	-	7 (-ve), 19 (-ve).
" pH	-	4, 17.
" BOD_5	-	4, 17.
" ammonia	-	4, 17.
" sand	-	18 (-ve).
" silt	-	5 (-ve), 10 (-ve), 11 (-ve) 13 (-ve).
" organic carbon	-	8, 12.

Number denotes species name as in the list.

List of Species for Station 5.

Sl.No.	Name of Species.
1	*Talehsapia annandalei*.
2	*Lycastis indica*.
3	*Dendronereis aestuarina*.
4	*Lumbriconereis simplex*.
5	*Prionospio polybranchiata*.
6	*Heteromastides bifidus*.
7	*Paraheteromastus tenuis*.
8	*Corophium triaenonyx*.
9	*Quadrivisio bengalensis*.
10	*Grandidierella gilesi*.
11	*Melita zeylanica*.
12	*Eriopisa chilkensis*.
13	Caprillidae.
14	Decapoda.
15	Chironomid larvae.
16	Insect larvae.
17	*Tanytarsus* sp.
18	*Cricotopus sylvestris*.
19	Simulium.
20	*Pandora flexosa*.
21	*Villorita cyprinoides*.
22	*Litterina litterina*.

At Station 6 the most abundant and least consistent species was *Capitella capitata* and the least abundant and comparatively homogeneous species were *Grandidierella gilesi*, *Apseudes gymnophobium*, *Anthuridae* sp., *Ephydra* sp. and *Bezzia* sp. About 10% of the correlations between species were significantly positive. Of these species *G. gilesi*, Caprillidae, *A. gymnophobium*, Anthuridae and *Villorita cyprinoides* were the frequently occurring ones with positive correlations (Table 12 f). Also, positive correlations were noted among species - parameter correlations (Table 13 f). Dendrogram studies revealed high affinity with 2 clusters of species (Fig. 15 f) and 4 clusters of environmental parameters (Fig. 16 f). The nine relatively important parameters based on multiple regression analysis were salinity $>$ BOD $>$ organic carbon $>$ silt $>$ clay $>$ 'K' factor $>$ nitrate $>$ oxygen $>$ suspended solids. Salinity was found to be the most important factor. Here also the interaction effects of the significantly correlated parameter clusters like (1) 'K' factor, suspended solids, and organic matter, (2) silt and clay, (3) nitrite and nitrate and (4) salinity and phosphate along with the 9 important parameters alone could predict the abundance of benthos.

Table - 12 f. Showing the species with significant correlation (significant at 5% level - P $<$0.05)in Station 6.

With species		1	-	7, 9, 16.
"	"	4	-	5.
"	"	5	-	8, 10.
"	"	6	-	7, 9, 10.
"	"	7	-	16.
"	"	8	-	10.
"	"	9	-	16.

Number denotes name of the species as inthe list.

Table - 13 f. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 6.

With temperature	-	1.
" salinity	-	2, 7, 9, 16.
" oxygen	-	1 (-ve), 6 (-ve), 7 (-ve), 9 (-ve), 16 (-ve).
" pH	-	5 (-ve).
" 'K' factor	-	14.
" suspended solids	-	8, 14.
" particulate organic matter	-	8.
" phosphate	-	7, 9, 16.
" nitrate	-	8 (-ve).
" clay	-	8.
" sand	-	8 (-ve).

Number denotes name of the species as in the list.

List of Species for Station 6.

Sl.No.	Name of species.
1	*Lycastis indica*.
2	*Dendronereis aestuarina*.
3	*Prionospio polybranchiata*.
4	*Heteromastides bifidus*.
5	*Capitellidae* sp.
6	*Quadrivisio bengalensis*.
7	*Grandidierella gilesi*.
8	Caprillidae.
9	*Apseudes gymnophobium*.
10	Anthuridae.
11	Crustacean larvae.
12	Anatopynia.
13	Ephydra.
14	Bezzia.
15	*Pandora flexosa*.
16	*Villorita cyprinoides*.

At Station 7 the most abundant species was *Capitella capitata* and the least abundant and comparatively homogeneous species were *Paraheteromastus tenuis*, *Eriopisa chilkensis* and *Dianema* sp. The least consistent species was *Dendronereis aestuarina*. Significant positive correlations (Table 12 g) among 10.31% were noted. Of these species *E. chilkensis*, *Anatopynia*, Caprillidae and insect larvae were very significant. From dendrogram, 4 major clusters (Fig. 15 g) having great affinity at 5% level among benthic fauna and 2 clusters among parameters (Fig. 16 g) were identified. Also 6.64% of species (Table 13 g) were found significantly positively correlated with the environmental parameters. The 9 important parameters based on multiple regression analysis were ranked as salinity > silt > nitrate > 'K' factor > sand > phosphate > oxygen > BOD > ammonia. As these parameters alone could not predict the abundance of benthos in this station also, the interaction effects of the significantly correlated parameters clusters like temperature and phosphate and that of 'K' factor, suspended solids, and organic matter were also considered and found effective.

Table - 12 g. Showing the species with significant correlation (significant at 5% level - $P < 0.05$) in Station 7.

With	species	1	-	10.
"	"	2	-	9, 13, 15.
"	"	3	-	4, 11.
"	"	4	-	10, 11.
"	"	5	-	10.
"	"	7	-	8.
"	"	9	-	13, 15.
"	"	13	-	15.

Number denotes name of the species as in the list.

Table - 13 g. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 7.

With temperature	-	15.
" salinity	-	2, 9, 10, 15.
" oxygen	-	5, 10, 13 (-ve).
" BOD_5	-	13 (-ve).
" 'K' factor	-	6, 14.
" suspended solids	-	6, 14.
" phosphate	-	4.
" nitrite	-	2, 14.
" nitrate	-	10.
" ammonia	-	7, 8.
" clay	-	2 (-ve), 15 (-ve).

Number denotes name of the species as in the list.

List of Species for Station 7.

Sl.No.	Name of species
1	*Lycastis indica*.
2	*Dendronereis aestuarina*.
3	*Nais* sp.
4	*Prionospio polybranchiata*.
5	*Heteromastides bifidus*.
6	*Paraheteromastus tenuis*.
7	*Capitella capitata*.
8	*Corophium triaenonyx*.
9	*Quadrivisio bengalensis*.
10	*Eriopisa chilkensis*.
11	Caprillidae.
12	Chironomid larvae.
13	Insect larvae.
14	Diamesa.
15	Anatopynia.

At Station 8 the most abundant and least consistent species was Dendronereis aestuarina. The least abundant and comparatively homogeneous species was Paraheteromastus tenuis. Only Lycastis indica and P. tenuis were significantly positively correlated (Table 12 h). 6.25% of the benthic species were found positively significantly correlated with environmental parameters (Table 13 h). Dendrograms indicated presence of only 1 cluster (Fig. 15 h) with high affinity with each other namely Lycastis indica and Paraheteromastus tenuis. But dendrogram showing grouping of parameters indicated 4 major clusters (Fig. 16 h) with great affinity. The ranking of the 9 parameters based on multiple regression analysis were nitrite > oxygen > salinity > phosphate > nitrate > 'K' factor > BOD > temperature > sediment. The significantly correlated parameter clusters, whose interaction effects were also considered, along with the above 9 parameters, for predicting the abundance of benthos at this station were (1) 'K' factor and suspended solids, (2) phosphate and organic carbon, (3) temperature and salinity and (4) BOD and silt.

Table - 12 h. Showing the species with significant correlation (significant at 5% level - $P < 0.05$) in Station 8.

With species	2	-	4.

Number denotes name of the species as in the list.

Table - 13 h. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 8.

With temperature	-	3, 6.
" salinity	-	3.
" oxygen	-	6 (-ve).
" pH	-	4.
" BOD_5	-	3.
" nitrite	-	5.
" clay	-	6.

Number denotes name of the species as in the list.

List of Species for Station 8.

Sl.No.	Name of species.
1	*Talehsapia annandalei*.
2	*Lycastis indica*.
3	*Dendronereis aestuarina*.
4	*Paraheteromastus tenuis*.
5	Chironomid larvae.
6	*Pandora flexosa*.

At Station 9 the most abundant and least consistent species was *Lycastis indica*. The least abundant and comparatively homogeneously distributed species were *Nais* sp., Crustacean larvae, *Baetis* sp., may fly larva and *Platambus* sp. Nearly 6.06% of the correlation between species positively significant (Table 12 i). Correlations of species Anatopynia, Ephydra and Platumbus with a few other species were very high. From dendrogram 7 major clusters of species with maximum affinity at 5% level were located (Fig. 15 i). But only 3 major clusters of parameters (Fig. 16 i) were obtained from the dendrogram. Some of the benthic species (11.93%) were found highly correlated with various enviromental parameters (Table 13 i). The 9 relatively important parameters, based on multiple regression analysis, were ranked as salinity > silt > BOD > nitrite > nitrate > 'K' factor > ammonia > suspended solids > oxygen. Here also, the interaction effects of the significantly correlated parameter clusters like (1) salinity, nitrite and ammonia, (2) 'K' factor, suspended solids and organic matter and (3) silt and clay, along with 9 parameters alone could predict the abundance of benthos.

Table - 12 i. Showing the species with significant correlation (significant at 5% level - P <0.05) in Station 9.

With species		1	-	2
"	"	2	-	12
"	"	4	-	12
"	"	5	-	19, 20.
"	"	6	-	18.
"	"	8	-	13.
"	"	9	-	11.
"	"	10	-	22.
"	"	11	-	17.
"	"	14	-	18.
"	"	15	-	18.
"	"	16	-	14.
"	"	17	-	21.

Number denotes name of species as in the list.

Table - 13 i. Showing the species with significant correlation with parameters at 5% level - $P < 0.05$ at Station 9.

With temperature	-	8 (-ve), 13 (-ve).
" salinity	-	16.
" BOD_5	-	5, 12, 2 (-ve).
" 'K' Factor	-	6, 8, 11, 13, 15, 18.
" suspended solids	-	6, 8, 13, 14, 15.
" particulate organic matter	-	7, 8.
" phosphate	-	9.
" ammonia	-	16.
" silt	-	1.
" organic carbon	-	1.

Number denotes name of species as in the list.

<u>List of species for Station 9</u>.

Sl.No.	Name of species.
1	*Lycastis indica*.
2	*Dendronereis aestuarina*.
3	*Lumbriconereis pseudobifilaris*.
4	Caprillidae.
5	*Paraheteromastus tenuis*.
6	*Nais* sp.
7	Olygochaeta.
8	Insect larvae.
9	Crustacean larvae.
10	Chironomid larvae.
11	Diamesa.
12	Anatopynia.
13	Plectrocnenia.
14	*Baetis* sp.
15	May fly larvae.
16	Tanytarsus.
17	Water beetle.
18	Ephydra.
19	Platambus.
20	*Villorita cyprinoides*.
21	*Batissa* sp.
22	Gastropoda (Unidentified).

Fig.15 a. Dendrogram showing clusters of species (5% significance level) at Station 1.

Cluster	Sl.No.	Species.
1	1	Sthenelais boa
	25	Sabellidae
	4	Odontosyllis gravelyi
	50	Nematodes
	15	Glycera alba
	36	Balanus sp.
	10	Eunice tubifex
	12	Lumbriconereis simplex
	13	L. notocirrata
	5	Lycastis indica
2	22	Pista indica
	44	Pandora flexosa
3	2	Notopygos sp.
	32	Caprillidae
	8	Nephthys polybranchia
	51	Sipunculids
	32	Echinoderm larvae
	42	Modiolus striatulus
	49	Sea anemone
4	48	Littorina littorina
	53	Fish larvae
	16	Glycera convoluta
	45	Arca sp.
5	7	Perinereis cavifrons
	40	Crab megalopa
	37	Acetes sp.
	39	Decapods
	30	Melita zeylanica
6	38	Alpheids
	46	Meritrix casta
	31	Eriopisa chilkensis
	33	Tanaidaceans
	34	Cirrolinia fluvialis
7	8	Nephthys oligobranchia
	26	Corophium triaenonyx
	27	Quadrivisio bengalensis
8	6	Dendronereis bengalensis
	20	Heteromastides bifidus
	29	Grandidierella bonnieri
9	28	G. gilesi
	35	Anthuridae
	47	Gastropod (unidentified)
	21	Paraheteromastus tenuis

Fig. 15. b. Dendrogram showing clusters of species (5% significance level) at Stn. 2.

Cluster	Sl. No.	Species
	11	*Goniada emerita*
	25	Hesprillidae
	24	*Melita zeylanica*
1	28	Anthuridae
	5	*Perinereis cavifrons*
	23	*Grandidierella bonnieri*
	22	*G. gilesi*
2	30	Cumacea
	41	Nematodes
	20	*Corophium triaenonyx*
	34	Insect larvae
	33	Plectrocnemia
3	27	*Cirrolinia fluviatilis*
	15	*Heteromastus similis*
	21	*Quadrivisio bengalensis*
	26	Tanaidaceans
	1	Aphroditidae
	2	*Ancistrosyllis constricta*
	7	*Nephthys oligobranchia*
4	12	*Glycera alba*
	6	*Nephthys polybranchia*
	3	*Lycastis indica*
	8	*Eunice tubifex*
	29	Decapods
	13	*Glycera convoluta*
5	37	*Paphia papilliona*
	17	*Paraheteromastus tenuis*
6	36	*Villorita cyprinoides*
	43	Sipunculids
	10	*Lumbriconereis notocirrata*
	40	*Littorina littorina*
7	38	*Arca* sp.
	18	*Pista indica*
	42	Flat worms
	39	Gastropods (unidentified)
8	35	*Pandora flexosa*
	45	Fish larvae
9	9	*Diopatra neapolitana*
	31	Chironomid larvae

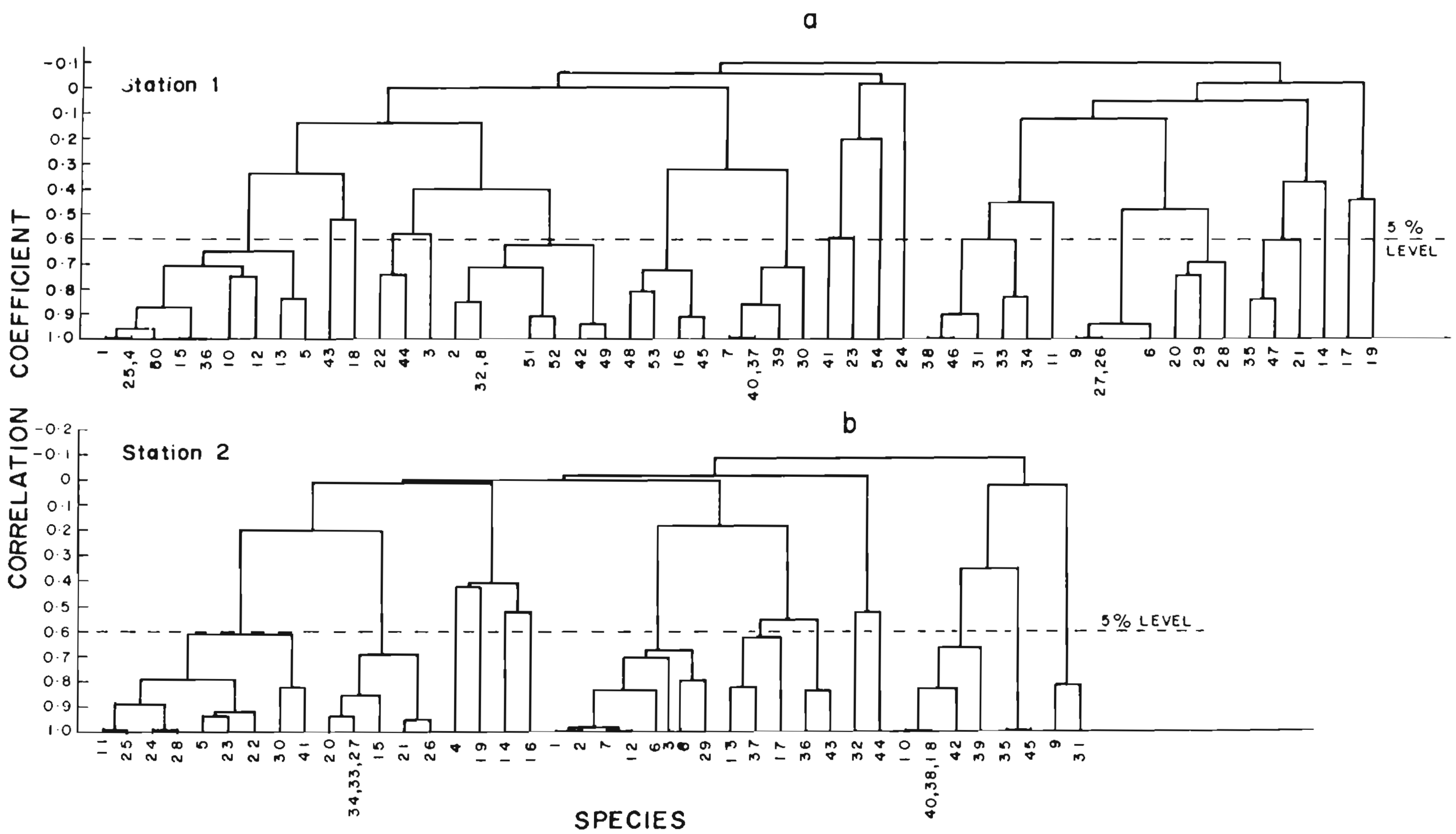

a
b
Station 1
Station 2
CORRELATION COEFFICIENT
5 % LEVEL
5% LEVEL
SPECIES

Fig.15

Fig. 15 e. Dendrogram showing clusters of species (5% significance level) at Stn. 3.

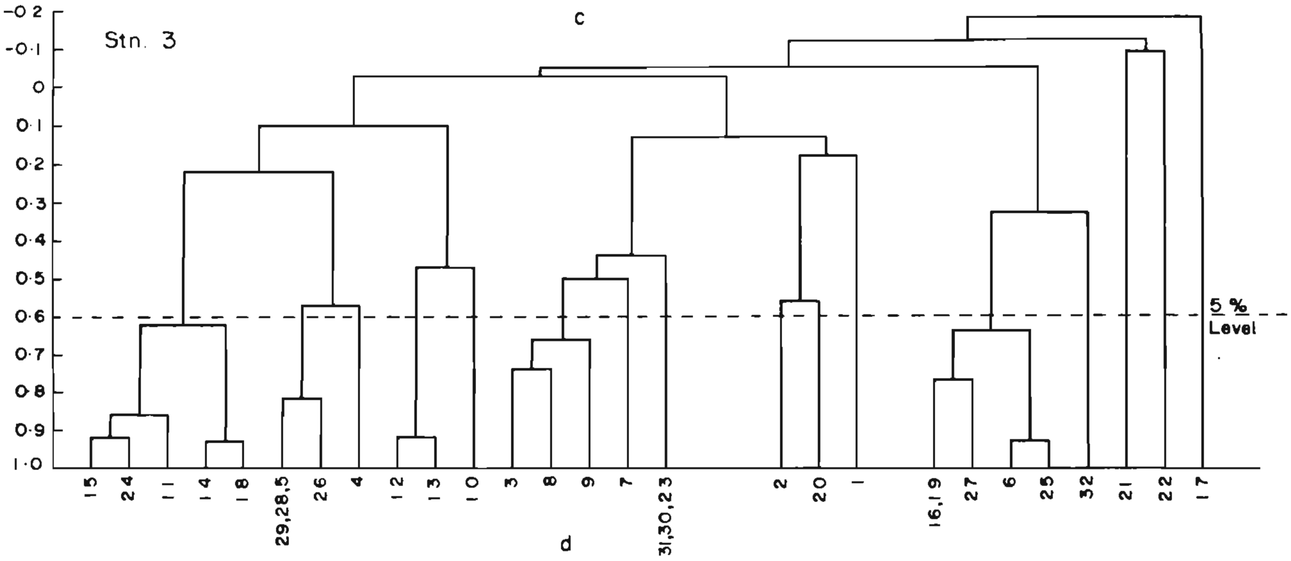
Cluster	Sl.No.	Species
	15	Melita zeylanica
	24	Ephydra sp.
1	11	Owenia sp.
	14	Grandidierella gilesi
	18	Cirrolinia fluviatilis
	29	Sipunculids
2	28	Littorina littorina
	5	Eunice bublex
	26	Villorita cyprinoides
3	12	Corophium triaenonyx
	13	Quadrivisio bengalensis
	3	Dendronereis aestuarina
4	8	Heteromastides bifidus
	9	Paraheteromastus tenuis
	16	Caprillidae
	19	Anthuridae
5	27	Modiolus striatulus
	6	Glycera convoluta
	25	Pandora flexosa

Fig. 15 d. Dendrogram showing clusters of species (5% sig. level) at Stn. 4.

Cluster	Sl.No.	Species
1	10	*Corophium triaenonyx*
	14	*Melita zeylanica*
	12	*Grandidierella gilesi*
2	20	Cumacea
	22	*Pandora flexosa*
	13	*Ericopisa chilkensis*
	19	Megalopa larva
	6	*Heteromastus similis*
3	4	*Eunice tubifex*
	18	Decapoda
	15	Caprillidae
	11	*Quadrivisio bengalensis*
	16	Tanaidaceans
	8	*Parheteromastus tenuis*
4	23	*Villorita cyprinoides*
	2	*Lycastis indica*
	1	*Talehsapia annandalei*
5	7	*Heteromastides bifidus*
	17	Anthuridae.

Fig. 15 e. At Stn. 5.

Cluster	Sl.No.	Species
	8	*Corophium triaenonyx*
	12	*Ericopisa chilkensis*
	6	*Heteromastides bifidus*
1	9	*Quadrivisio bengalensis*
	5	*Prionospio polybranchiata*
	13	Caprillidae
	10	*Grandidierella gilesi*
	11	*Melita zeylanica*
	20	*Pandora flexosa*
2	22	*Littorina littorina*
	21	*Villorita cyprinoides*
	3	*Dendronereis aestuarina*
3	2	*Lycastis indica*
	14	Decapoda
4	1	*Talehsapia annandalei*
	7	*Parheteromastus tenuis*


c
Stn. 3
-0·2
-0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
5 %
Level
15
24
11
14
18
29,28,5
26
4
12
13
10
3
8
9
7
31,30,23
2
20
1
16,19
27
6
25
32
21
22
17

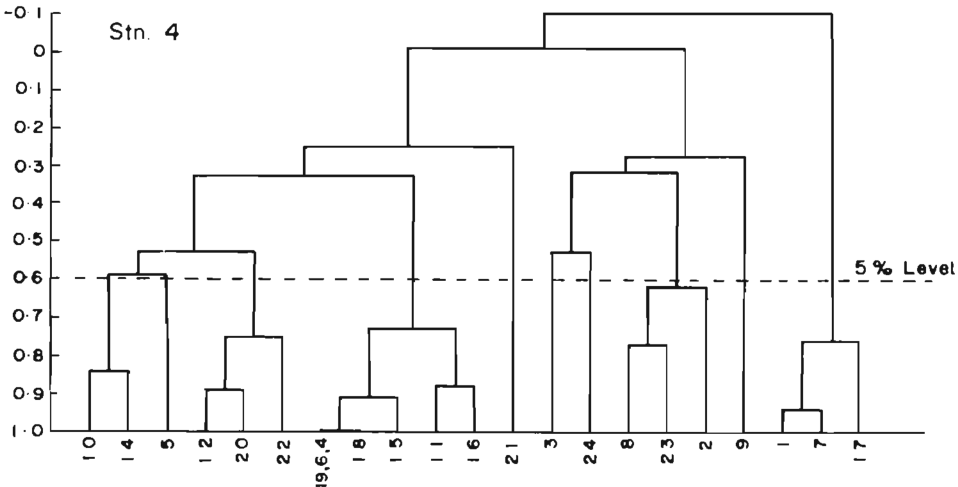

d
Stn. 4
-0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
5 % Level
10
14
5
12
20
22
13,19,6,4
18
15
11
16
21
3
24
8
23
2
9
1
7
17

Fig. 15

Fig. 15 f. Dendrogram showing clusters of species (5% sig. level) at Station 6.

Cluster	Sl.No.	Species
1	9	Tanaidaceans
	7	*Grandidierella gilesi*
	16	*Villorita cyprinoides*
2	5	*Capitella capitata*
	10	Anthuridae.
	8	Caprillidae.

Fig. 15 g. At Station 7.

Cluster	Sl.No.	Species
1	3	*Nais* sp.
	11	Caprillidae
	4	*Prionospio polybranchiata*
2	5	*Heteromastides bifidus*
	10	*Eriopisa chilkensis*
3	9	*Quadrivisio bengalensis*
	13	Insect larvae
	2	*Dendronereis aestuarina*
	15	*Anatopynia* sp.
4	7	*Capitella capitata*
	8	*Corophium triaenonyx*

Fig. 15 h. At Station 8.

Cluster	Sl.No.	Species
1	2	*Lycastis indica*
	4	*Paraheteromastus tenuis*

Fig. 15 i. Dendrogram showing clusters of species (5% sig. level) at Station 9.

Cluster	Sl.No.	Species
	15	Mayfly larvae
1	14	*Baetis* sp.
	6	*Nais* sp.
	18	*Enhydra* sp.
2	4	*Capitella capitata*
	12	Anatopynia
3	8	Insect larvae
	13	*Plectrocnemia*
	11	*Diamesa* sp.
4	17	Water beetle
	21	*Batissa* sp.
5	5	*Paraheteromastus tenuis*
	19	Platambus
6	10	Chironomid larva
	22	Gastropod (unidentified)
7	1	*Lycastis indica*
	2	*Dendronereis aestuarina*

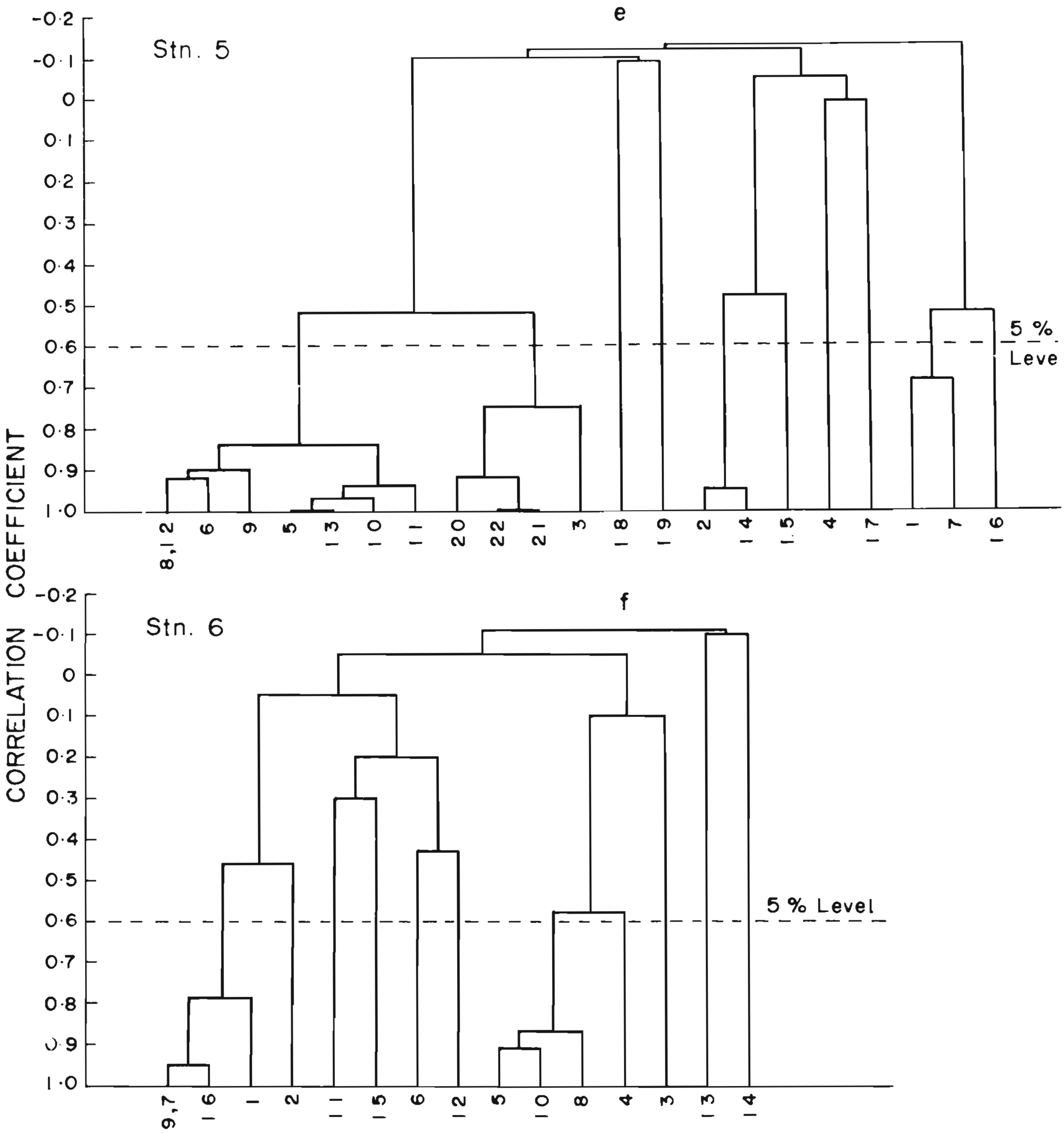


Fig. 15

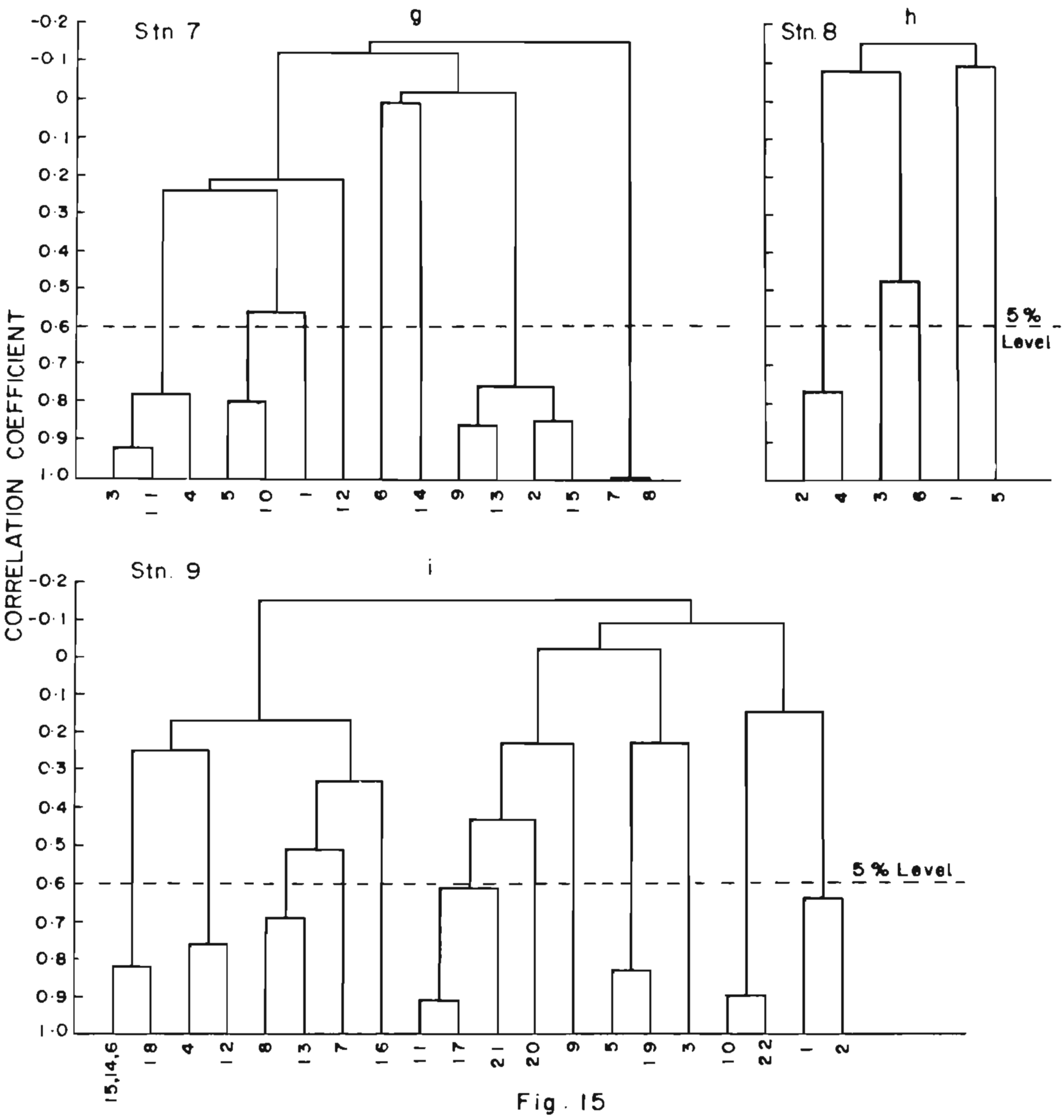


Fig. 15

Fig. 16 a. Dendrogram showing clusters od environmental parameters (5% sig. level) at Station 1.

Cluster	Sl.No.	Parameters
1	1	Temperature
	16	Organic carbon
2	4	pH
	10	Nitrite
3	7	Suspended solids
	8	Particulate organic matter

Fig. 16 b. At Station 2.

Cluster	Sl.No.	Parameters
1	5	BOD_5
	7	Sus. solids.
2	1	Temperature
	2	Salinity
3	6	'K' values
	12	Ammonia
4	9	Phosphate
	11	Nitrate

Fig. 16 c. At Station 3.

Cluster	Sl.No.	Parameters
1	1	Temperature
	2	Salinity
	11	Nitrate
	13	Sand
2	4	pH
	7	Susp. solids.
3	6	'K' values
	8	Particulate organic matter
4	5	BOD_5
	12	Ammonia
5	3	Oxygen
	14	Silt
	15	Clay
	16	Organic carbon

Fig. 16 d. Dendrogram showing clusters of environmental parameters (5% sig. level) at Station 4.

Cluster	Sl.No.	Parameters
1	6	'K' values
	7	Susp. solids.
	8	Particulate organic matter.
2	5	BOD_5
	14	Silt
3	1	Temperature
	2	Salinity
4	3	Oxygen
	11	Nitrate

Fig. 16 e. At Station 5.

Cluster	Sl.No.	Parameters
1	6	'K' values
	7	Susp. solids
	8	Paryiculate organic matter
2	1	Temperature
	10	Nitrite
3	9	Phosphate
	11	Nitrate
4	14	Silt
	15	Clay

Fig. 16 f. At Station 6.

Cluster	Sl.No.	Parameters
1	6	'K' values
	7	Susp. solids
	8	Particulate organic matter
2	14	Silt
	15	Clay
3	10	Nitrite
	11	Nitrate
4	2	Salinity
	9	Phosphate

Fig. 16 g. Dendrogram showing clusters of environmental parameters (5% sig. level) at Station 7.

Clusters	Sl.No	Parameters
1	1	Temperature
	9	Phosphate
2	6	'K' values
	7	Suspended solids
	8	Particulate organic matter

Fig. 16 h. At Station 8.

Clusters	Sl.No.	Parameters
1	6	'K' values
	7	Suspended
2	9	Phosphate
	16	Organic carbon
3	1	Temperature
	2	Salinity
	11	Nitrate
4	5	BOD_5
	14	Silt

Fig. 16 i. At Station 9.

Clusters	Sl.No.	Parameters
1	2	Salinity
	10	Nitrite
	12	Ammonia
2	6	'K' Values
	7	Suspended solids.
	8	Particulate organic matter
3	14	Silt
	15	Clay

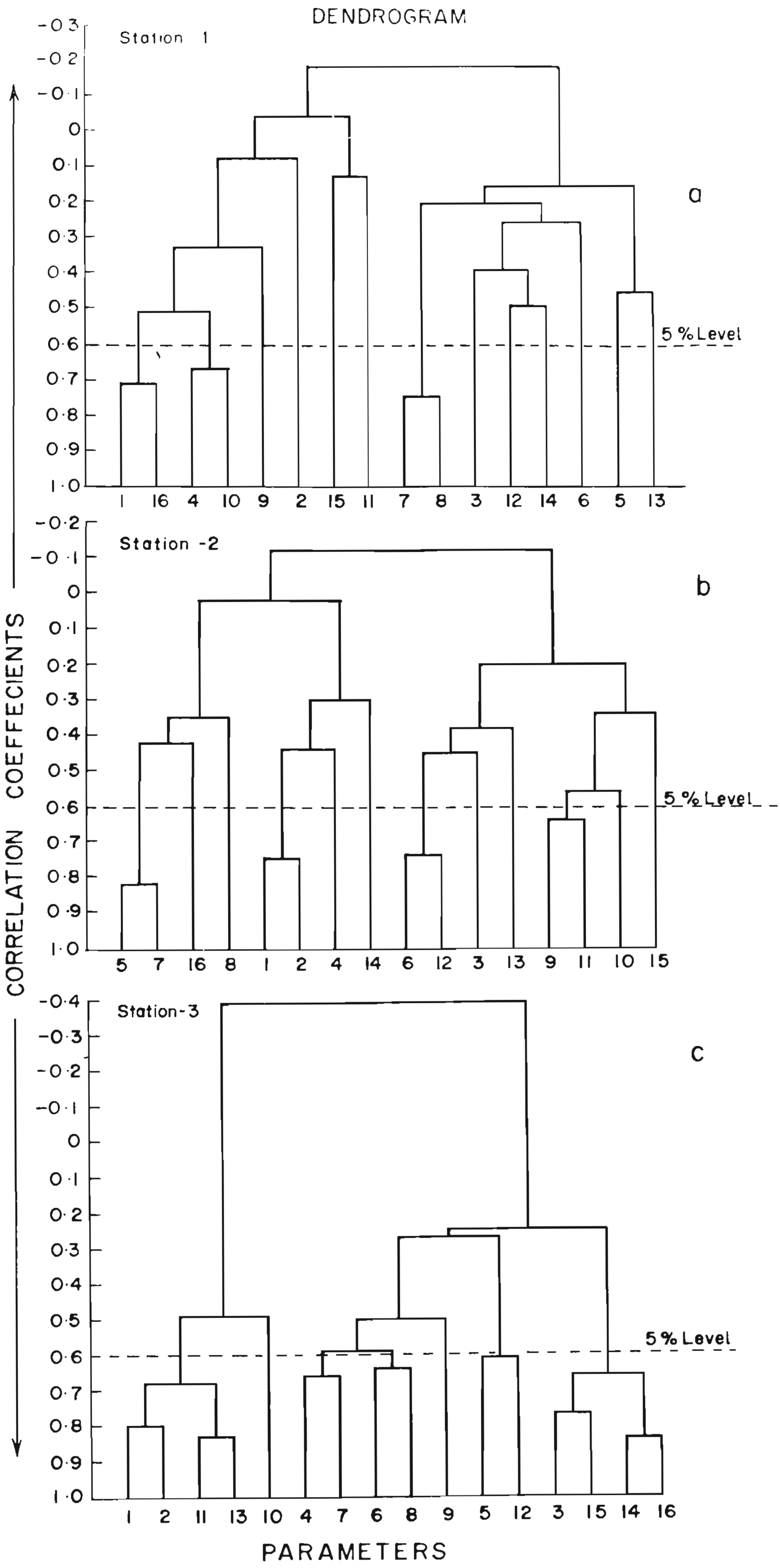

DENDROGRAM
Station 1
a
5 % Level
1 16 4 10 9 2 15 11 7 8 3 12 14 6 5 13
Station -2
b
5 % Level
5 7 16 8 1 2 4 14 6 12 3 13 9 11 10 15
Station-3
c
5 % Level
1 2 11 13 10 4 7 6 8 9 5 12 3 15 14 16
CORRELATION COEFFECIENTS
PARAMETERS

Fig. 16.

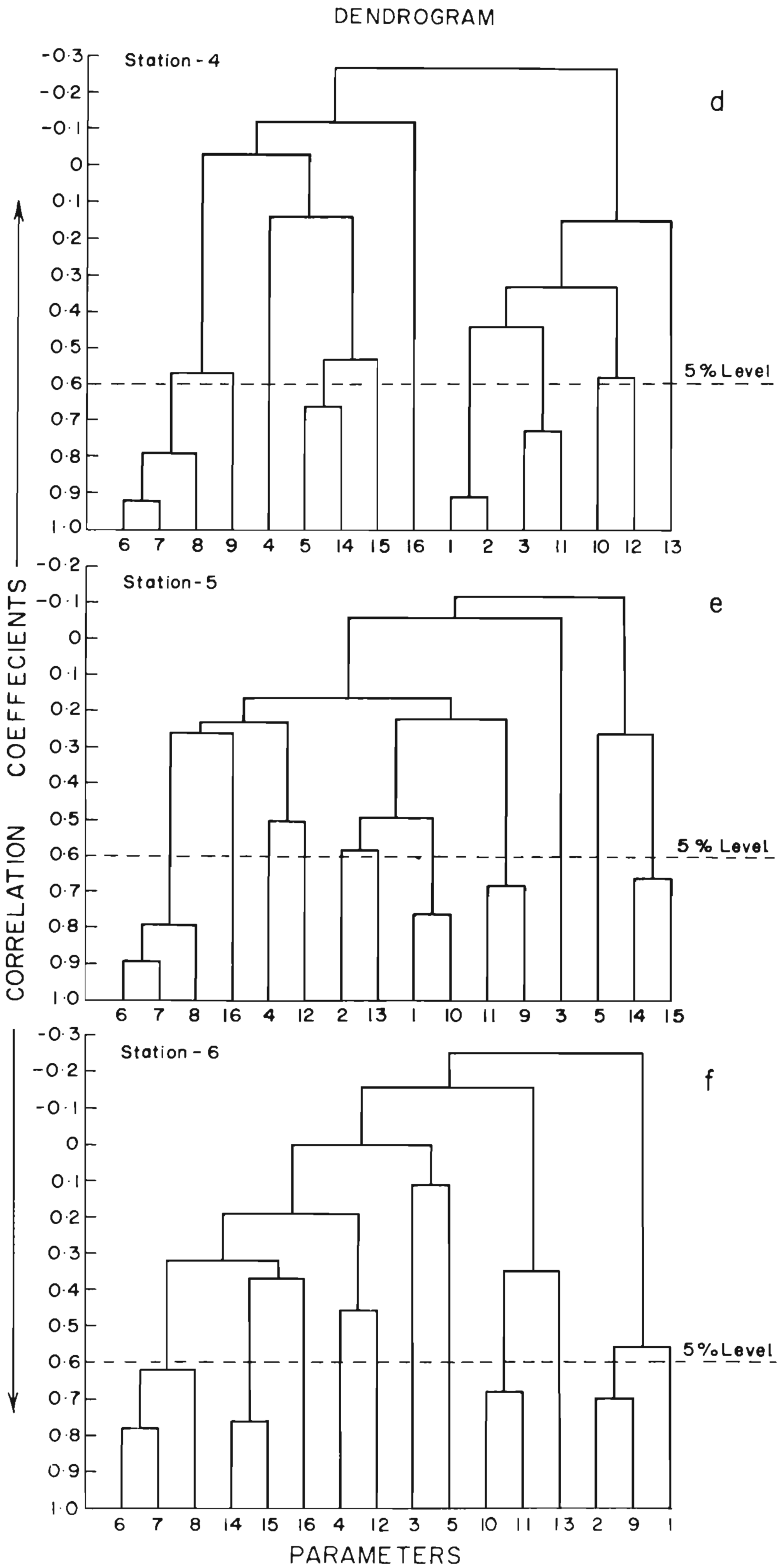

DENDROGRAM
Station - 4
d
5% Level
6 7 8 9 4 5 14 15 16 1 2 3 11 10 12 13
Station - 5
e
5 % Level
6 7 8 16 4 12 2 13 1 10 11 9 3 5 14 15
Station - 6
f
5% Level
6 7 8 14 15 16 4 12 3 5 10 11 13 2 9 1
CORRELATION COEFFECIENTS
PARAMETERS

Fig. 16

DENDROGRAM

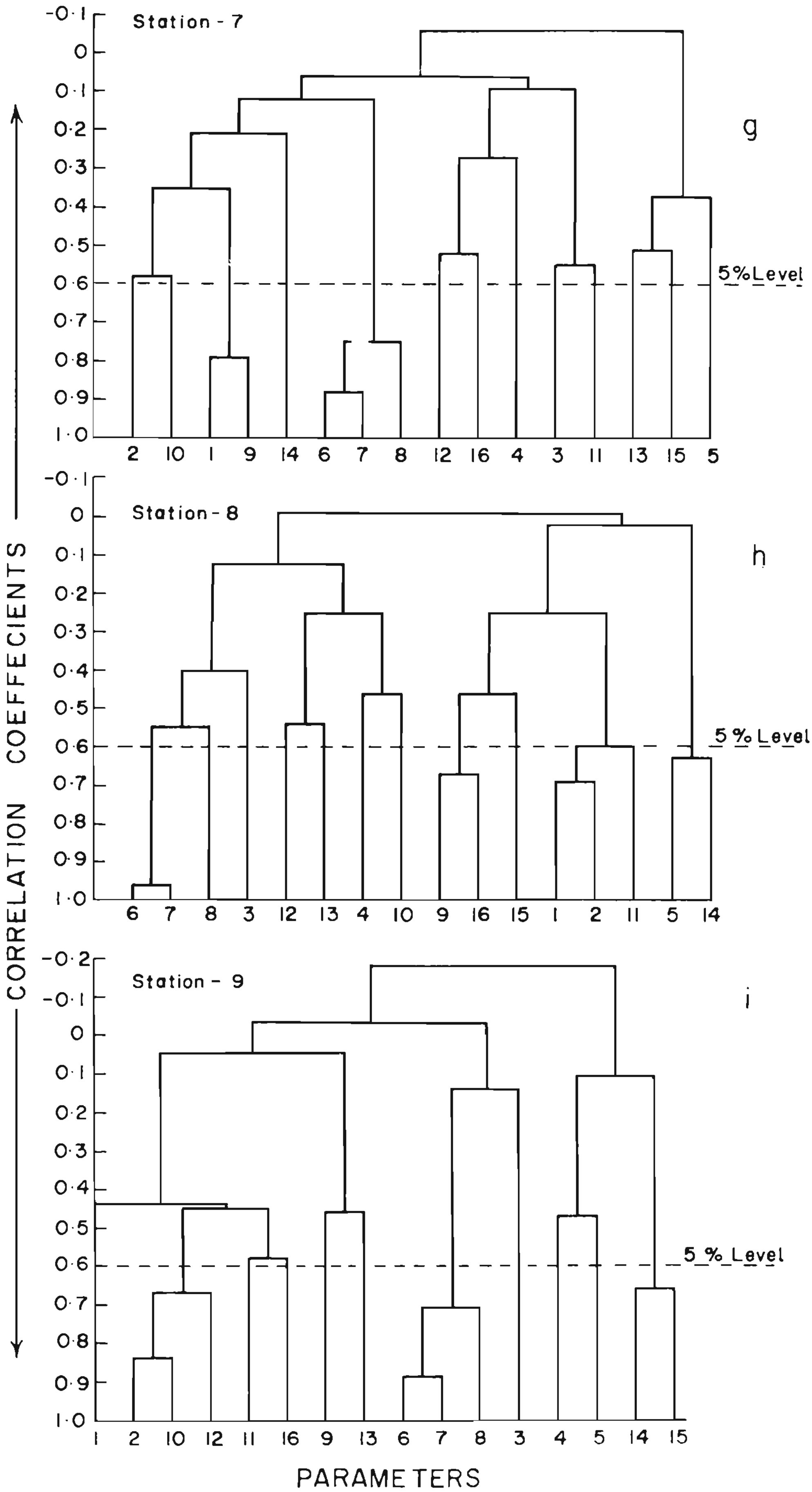


Fig. 16

4. DISCUSSION.

4. DISCUSSION.

4.1. Effect of pollutants on the physico-chemical properties of the water.

Investigations on the water quality carried out revealed, the water in the study area in floods during the monsoon, characterised by a low temperature, high oxygen, high carbon-dioxide and low chloride content. But during summer as the salinity intrudes upstream due to reduced flow of river water the water characteristics changed to a high temperature, lower dissolved oxygen and high chloride content.

The concentration of pollutants were found diminished gradually with distance from the discharge point, mainly due to the dilution of the effluents by the receiving water and by the natural purification processes.

Thus the pattern of variation, of temperature, salinity and oxygen, controlled by the impact of rainfall and river discharge has been similar to other estuaries and backwaters along the south west coast of India (Anto, 1971; Qasim, 1979; NIO, 1982; Abdul Aziz and Nair, 1978; 1980 and Nair et al., 1983). Owing to the shallowness of the Vellar estuary, surface - bottom differences in all parameters was found insignificant (Chandran and Ramamoorthy, 1984). However, the present area, though shallow, showed significant differences in parameters like pH, alkalinity, nutrients, BOD_5 etc.

The major physical and chemical factors, characteristic of the area are discussed in detail as a basis for correlation of these factors with the distribution of individual species, population and communities and to separate biological interactions from the influence of the physico-chemical factors and sediments although it is obvious from the data that all are independent.

The results of studies on the water characteristics of the study area has indicated continuous change as a result of large scale movements of the estuarine waters under the influence of tidal forces, monsoon and land runoff, developing a current speed 4 - 55 cm/sec. Also this water has been found heterogenous in nature due to discharge of effluent waters, containing different pollutants from the industrial areas. As a result, the relatively stationary macrobenthos, the epi and infauna which live upon the surface of the bottom or within the bottom of the soft sediment respectively have to endure a wide range of environmental changes when the circulation also carries different types of pollutants over their site or burrows.

Salinity (‰):

Hydrographical conditions of the Cochin backwaters have been studied by Balakrishnan (1957), Ramamirtham and Jayaraman (1963), George and Kartha (1963), Cheriyan (1967), Qasim and Gopinathan (1969), Sankaranarayanan and Qasim (1969), Josanto (1971), Shynamma and Balakrishnan (1973) and Balakrishnan and Shynamma (1976). Above studies indicated environmental conditions of the study area of this estuary, particularly salinity, being affected by the fresh water discharge depending on the amount of precipitation during active southwest monsoon period and the intrusion of sea water during premonsoon months of March and April.

Similarly a distinct seasonal pattern was observed for salinity values as follows: Along with stratification noted during July to September in Station 1 and January in Stations 2 and 3, during the present study saline content was reduced towards station 9 and temporal studies revealed with the exception of March and April almost prevalence of fresh water from Station 5 onwards during November to January and in May and from Station 2 onwards during June to October.

Nair *et al*. (1986) observed very large spatial variations of salinity in the three areas of study in Cochin backwaters, ranging from 0.24 ‰ to 31‰, controlled by tidal and monsoonal flow and shallowness of the area. Ganapati *et al*. (1958-64) during the hydrobiological and faunistic survey of Godavary estuarine system noted striking salinity changes depending on the SW monsoon. They noted vertical stratification extending up to the river as the neritic penetration becomes more manifested. Such a stratification was noted only at Station 1 during monsoon months and Stations 2 and 3 during January. Nair et al. (1984) also observed a distinct seasonal pattern for the distribution of salinity in which the premonsoon recorded the highest average values with the monsoon registering a steep decline and postmonsoon presenting a trend of recovery. Salinity declined from the estuarine mouth to the lowest value in the riverine zone. Earlier Indian researchers (Jacob and Rangarajan, 1959; Rajendran, 1974; Varma, Rao and Cherian, 1975; Balakrishnan and Shynamma, 1976; and Chandran and Krishnamoorthy, 1984) reported wide fluctuations in the salinity of tropical estuaries affecting the estuarine environment controlled by extreme conditions of draught and monsoon. Jacob and Rangarajan (1959) and Chandran and Krishnamoorthy (1984) in Vellar estuary and Ganapati and Ramasarma (1965) in Gautami-Godavari estuary observed minimal tidal effect and complete absence of vertical salinity gradient during NE monsoon. On the other hand, in Cochin backwaters and Mandovi and Zuari estuaries, inspite of reported heavy monsoonal floods complete scouring was not noticed. Instead Qasim and Gopinathan (1969), Shynamma and Balakrishnan (1973) and Cheriyan, Rao and Varma (1975) recorded a well marked vertical salinity gradient. Such a vertical gradient in salinity was noticed during the present study only in Station 1 during July to September and in Stations 2 and 3 during January only. The reason for the occurrence and absence of salinity gradients in different estuaries as noted above are to be sought in the differences in the nature and bottom topography of the estuaries, depth etc.

Chloride values in the effluents discharged by the factories varied from 125 to 3,470 ppm in February, 75 to 6,990 ppm in April, 100 to 2,060 ppm in June and 50 to 920 ppm in August. Chlorides present in water may undergo decomposition and free chlorine or hydrochloric acid may be produced which is extremely toxic to fish. Doudoroff and Katz (1950) in their critical review have discussed the work of various authors and have given different lethal doses for different species of fish. Allen et al. (1953) observed that chlorination of certain relativity nontoxic sewage effluents, below their chloride demand point, make them highly toxic to fish. Schant (1939) had also previously observed the same phenomenon by treating KCNS solution with chlorine.

Thus as is the case with most estuaries the major variable in the study area too was salinity, which established a continuous gradient of 0.2 to 30.4‰, between the sea and fresh river water. This gradient was found moving up and down the estuary influenced by the monsoonal river runoff and tides. Thus

Station 9 ~~with~~ where almost fresh water prevailed throughout the year except during March and April. As a result the spatial distribution of macrobenthos identified were found controlled by its ability to withstand wide fluctuations in salinity.

Temperature (°C):

According to Klein (1962) the direct effect of temperature as an environmental factor is difficult to assess because in stream's environment it is often linked with the speed of the current and type of bedcooler waters usually being associated with the shallow depths more common in the upper reaches of rivers.

By the term thermal pollution it is meant a change either positive or negative, in the heat content of the water caused by the effluents, which is an undesirable change that may or will harmfully affect the living condition of that aquatic environment.

Temperature effects on water quality can be of three types - physical, chemical and biological.

Temperature affects nearly every physical property of water as density, viscosity, vapour pressure, surface tension, gas solubility and gas diffusion. The amount of dissolved oxygen in water being important in sustaining aquatic life, the lower solubility induced by high temperature, combined with increased organic load and bacterial respiration rate could lead to such low levels of oxygen that organisms could not survive. Increased temperature may lead to increased sedimentation affecting flocculation. The effect of temperature on the regression coefficient can be very important in determinging the waste assimilative capacity of streams. Temperature rise can cause stratification in the ambient water, causing the overflow or underflow of the incoming water of different density.

Biological effects of thermal pollution is limited to purification process in the receiving water only, where, in general, the higher the temperature the more metabolically active a microorganism becomes. Also a possible considerable reduction in the waste assimilation capacity of the receiving water results.

Chemically, temperature affects not only the rate at which a reaction occurs but also the extent to which the reaction takes place.

Further, water temperature - the easiest physical measurement - showed more significant variation seasonally than spatially. It was well correlated with salinity and density (T/S relationship).

The results indicated changes in temperature of the study area influenced by the seasonal as well as diurnal changes in the temperature of the air and of the river, sea and effluent waters. The study area being shallow (2.5 to 4 m) resulting in mixing of water column, the changes were relatively fast and the amplitudes of the extremes were found smaller especially in the areas of effluent discharge.

Hydrographical and faunistic survey of Godavari estuarine systems conducted by Ganapati *et al.* (1958 to 1964) indicated similar trends of seasonal changes in temperatures. Nair *et al.* (1984) also found relatively higher temperature during the premonsoon compared to low monsoon values, in the Ashtamudi estuary.

Jayapalan *et al.* (1976) recorded similar monsoonal changes in temperature in the study area (Periyar waters). Also they observed a temperature variation from 22.5°C to 56.0°C for the effluent discharged, the maximum recorded being for the effluent discharged from the Ammonium Chloride Plant. During the present study the temperature of the effluents discharged was found to vary from 25.3°C to 45.0°C only as shown in Table (5). Also considerable variations existed as noted in the table, even some effluents from FACT showing a fall in temperature from 45°C in February to 29.8°C in August for the black and 42.0°C in July to 27.0°C in Aug. for the white effluent. Similar variations in temperature were noted for other effluents also. Temperature measurements made at distances 10 m away from the discharge points showed considerable fall in values as noted for effluents from Catalysts Factory. Dissolved oxygen also were consistently higher at these places.

Compared to temperate estuaries, tropical estuaries are found to have relatively less (8° to 10°C) annual variation in temperature. The study area in Cochin backwaters exhibited an annual variations of 24.5°C (June) to 34.4°C (March).

Nair *et al.* (1986) noted in three different areas of Cochin backwaters low temperature during the months of December to February showing an increasing trend afterwards, followed by a decrease during monsoon months and again an increase afterwards. The temperature varied from 25°C to 30.5°C with an annual variation of $\sim$ 5°C. Studies on temporal variation in Vellar estuary by Chandran and Ramamoorthy (1984) revealed variations in water temperature from 24° to 33.5°C mostly influenced by the fluctuating atmospheric temperature of 23.5° to 36.5°C than tidal influence. Similar findings have also been reported by Qasim and Gopinathan (1969) in Cochin backwaters and Dehadrai (1970a) in Mormugao Bay. Also, observations of Chandran and Ramamoorthy (1984) and Varma, Rao and Cherian (1975) found that the influence of tide was prominent in the downstream region of the Mandovi (near the mouth) while isolation was predominant in the upper reaches. A lack of vertical stratification in temperature, the maximum differences between surface and bottom temperatures being 1.6°C (at Stn. 8) during March, noted in the present study has been reported, for Cochin backwaters by Qasim and Gopinathan (1969) and Vellar estuary by Chandran and Ramamoorth (1984). This could be attributed to the shallow nature of these estuaries. However, Shynamma and Balakrishnan (1973) noted preminent vertical stratification in temperature in Cochin backwaters between surface and 8 m depth the temperature values at 4 m depth showing parity with surface values.

Based on the above observations, it can be concluded that thermal pollution has not been a pervasive threat in the past but could become so in the future unless present flow pattern is maintained.

Dissolved Oxygen:

Dissolved oxygen in the estuarine environment is chiefly controlled by tidal ingress and fresh water runoff. The intensity of pollution is determined usually by estimating the dissolved oxygen present in water i.e. the lower the dissolved oxygen the higher the intensity of pollution and vice-versa. The high organic load of the waste water affected the dissolved oxygen level of the receiving waters (Anon, 1980). The aquatic life in the estuarine environment is mainly dependent upon the availability of dissolved oxygen in water and hence it is an inevitable factor for survival and growth of aquatic fauna.

Nirmala *et al*. (1976) from their studies in Chaliyar river observed great decrease in dissolved oxygen values during summer months and increase during monsoon seasons. This decrease lead to mortality of fishes in Chaliyar due to asphyxiation for want of oxygen. Similar observations were made by Jacob and Menon (1948) while studying the incidence of fish mortality along the west coast. Jayapalan *et al*. (1976) found in agreement with Chacko and Sreenivasan (1955) well oxygenated water during monsoon and low oxygen content during March-May in Periyar when the water inflow was very low. They also noted often nil values for oxygen in the effluents from sulphuric acid, phosphoric acid and ammonium phosphate plants while that of sulphate, ammonium chloride and ammonia and oil gassification plants fairly oxygenated.

Oxygen content of effluents collected during the present study however showed comparable changes from nil values to 5.96. Very often oxygen content of water 10 m away from discharge points, also recorded high and nil values.

Although the vertical differences in oxygen was not conspicuous, surface waters showed slightly higher values than bottom waters.

Spatial and temporal variations in oxygen contents except from November to January, were significant in the estuarine waters. Instead of reduced values, oxygen recorded nearly fully saturated conditions at times. Surprisingly, inspite of discharge of large amounts of effluents anoxic condition never prevailed. Even bottom water layers did not record low oxygen values. Similar well oxygenated condition in the study area was noted by Sarala Devi <u>et al</u>. (1979). Dissolved oxygen content in the three widely separated areas of Cochin backwaters showed wide fluctuations with the tide and with the varying rate of flow (Nair, <u>et al</u>., 1986). They noted annual variations in oxygen content from 1.5 to 7 ml/l with low values in high saline waters.

Occasionally high phytoplankton biomass were noticed during the study period. The high concentration may also be contributing to the increase of oxygen content as noted by Subramanyan (1959) and Damodaran (1973). The occasional decrease in dissolved oxygen may be due to utilisation of oxygen by bacterial flora (Nash, 1947) and respiration of zooplankton and consumption of oxygen by detritus in the upper layers (Sewell, 1939). Also low salinity and temperature might favour an increase in oxygen content. But during the studies in the retting yard, Remani (1979) noticed hydrogen sulphide content of 4.97 mg/l, where the oxygen content was $<$ 0.05 ml/l during premonsoon. Unnithan <u>et al</u>. (1979) while estimating organic pollution in Cochin backwaters found low and fluctuating oxygen values ($<$ 0.05 to 3.8 ml/l) in the bottom water.

Vijayan *et al.* (1976) during their studies on the effect of organic pollution on some hydrographic features of Cochin backwaters observed significant seasonal and tidal flustuations in oxygen values. They also noted oxygen content varying proportionately with sewage discharge. Zingde *et al.* (1985) during the physico-chemical investigation in Auranga River estuary in Gujarat observed nil oxygen values at locations where BOD ranged from 21 to 859. However, in other locations they found oxygen values ranging from 2.8 to 12.4 mg/l. This indicated absence of any effect in areas other than those in the immediate vicinity of the effluent release point, in agreement with the inferences made during the present study.

Nair *et al.* (1984) recorded monthly averages of dissolved oxygen content ranging from 2.55 to 7.29 ml/l in the Ashtamudi estuary of Kerala.

In accordance with the findings of Dehadrai (1970 a & b) in the Mandovi and Zuari estuaries, Rajendran (1974) and Chandran and Ramamoorthy (1984) in Vellar estuary, in general higher dissolved oxygen values were noted in the monsoon and premonsoon seasons. However during the present studies higher values were recorded in the postmonsoon also. Qasim and Gopinathan (1969), Dehadrai (1970 a & b), Vijayalakshmi and Venugopalan (1973) and Chandran and Ramamoorthy (1984) observed dissolved oxygen showing an inverse relationship with salinity, with high values at ebb tides and low values at flood tides. During high tides entry of neritic water into the estuary is known to lower dissolved oxygen.

Chandran and Ramamoorthy (1984) during their studies on the temporal variations in the hydrography of Vellar estuary recorded invariably high values of dissolved oxygen, during low tides of day time. However, the variation between high and low tide was not significant.

<u>BOD_5 (mg/l):</u>

Reish (1959), Mcnulty (1961) and Pauli Bagge (1969) have emphasised the importance of BOD_5 in the assessment of pollution of an environment as it is dependent on the amount of suspended/dissolved organic matter in the water. Dissolved oxygen was seen generally correlated with the BOD_5 i.e. low the dissolved oxygen, high the BOD_5 and vice-versa as noted by Remani (1979). She observed high BOD_5 values (34.36 - 513.75 mg/l) in the retting yard of Cochin backwaters along with very low oxygen content of < 0.05 ml/l and high value of 4.97 mg/l of hydrogen sulphide. While pollution brought about by retting of coconut husks does not affect temperature and salinity significantly, oxygen depletion, sulphide production and high BOD_5 values indicating high organic content and bacterial activity are observed to be the most affected.

According to Bhargava (1977) the low BOD_5 values may be indicative of the removal rate of organic pollution. But during the present studies such a correlation did not exist probably because the effluents discharged from the factory were toxic to bacterial flora present. Remani (1979) also noted heavy consumption of dissolved oxygen due to rapid decomposition of organic matter at high temperature. Vijayan et al. (1976) observed high BOD_5 values in the sewage pollution area fluctuating with area and time, brought about by the quality and quantity of sewage, monsoonal and tidal effects. Whereas highest values of BOD_5 recorded earlier were 280.4 ppm (Unnithan et al., 1976) both near barmouth and 513.75 mg/l in the retting yard (Remani, 1979) away from barmouth, during the present study in the areas of industrial discharge the maximum BOD_5 recorded was 570 mg/l for the grab water, 12.2 for the surface water and 8.9 for the bottom water.

Sarala Devi et al. (1979) during their studies on the water quality of Cochin backwaters in relation to industrial pollution observed quite variable BOD_5 values of the effluents varying from negligible values (TCC and FACT black effluent) to 51.3 mg/l (Periyar Chemicals).

Similar fluctuations in BOD_5 values ranging from negligible values to 18.5 mg/l (IRE) were noted in the effluents from the 8 factories during the present study. Fluctuations were also observed in BOD_5 values in the effluents from each factory on a month to month basis.

In agreement with earlier observations BOD_5 values were found in most cases well above that for natural waters i.e. 1 mg/l.

A water body with a BOD_5 of 8 mg/l is considered to be moderately polluted (Martin, 1970). According to standards recommended by Royal Commission the sewage disposal should have 20 ppm BOD and for suspended load 30 ppm (Klein, 1962). However, the highest value recorded during the present study was only 1/15th to 1/25th of that recommended for domestic sewage (WHO, 1972), compared to 1/6th to 1/10th recorded by Sarala Devi et al. (1979).

When organic matter is added to a stream it is immediately attacked by bacteria which breakdown to simple substances and in doing so they use up oxygen. The rate at which a particular type of effluent is able, in the presence of ample oxygen, to satisfy the oxygen demand, depends on the organic load. On the other hand industrial effluents which contain only chemical reducing agent such as ferrous salts or sulphite, take up oxygen by purely chemical action; they do this very rapidly exerting what is sometimes known as immediate oxygen demand (Hynes, 1966).

In the polluted region of Par river estuary (Bombay) which receives about 25,000 m^3/day of effluent from a large chemical complex, Zingde et al.(1979 c) reported a BOD_5 value varying between 100 and 323 mg/l. In the polluted region of Mahim Creek, Zingde and Desai (1980) noticed a high BOD_5 value of 100 mg/l.

Zingde *et al*. (1985) have reported an average BOD_5 value of 206 mg/l for an industry manufacturing nitrocellulose which releases 0.6 mld of acid waste water. They noticed that the inputs does not seem to have affected the estuary except in the immediate vicinity of the effluent release point. In their study the BOD_5 of the effluent ranged from 21 - 107 mg/l and the receiving water from 2.4 to 12 mg/l. In another location BOD_5 for the effluent ranged between 125 and 859 (average 206 mg/l), and 2.8 and 19.0 for the receiving water.

Thus, the variation noticed in BOD_5 values during the present study can be attributed to the relative toxic effects of the pollutants on the bacterial flora.

In view of the high BOD_5 values registered in the grab waters especially during October to December and very low values in the water column it appeared that BOD_5 in general may not be a factor contributed by the industrial effluents.

COD:

Chemical Oxygen Demand values were nil in 50% of the observations and when recorded these values were very low except in 16 isolated observations where it ranged from 107 to 1,669.

The occurrence of high values at isolated patches may be due to the locally added load of organic matter brought in with the land drainage. Role of first monsoonal showers in bringing this load was not seen as values were very low during monsoon periods.

Sarala Devi *et al.* (1979) observed higher values during premonsoon indicating a build up of organic load. But during the present investigation the premonsoon values were negligible. Whereas they found fairly high values indicating fluctuating COD load at the present Stations 7/8 in the premonsoon and throughout in Station 9, during the present studies also fluctuating COD load was recorded but with low values. Again the oxygen assets of this water did not show any depletion.

While earlier studies (Sarala Devi *et al.*, 1979) showed consistently higher values throughout the period of observations in 1976/77 at the present Station 1, during the present study this station was totally devoid of any COD except in March. Thus the effect of domestic sewage and other particulate wastes discharged into the harbour area, as noted earlier, was not seen during the present study. Previous studies by Unnithan *et al.* (1975) and Vijayan *et al.* (1976) have shown appreciable degree of organic pollution in the harbour area. But surprisingly the present COD values could not reflect this.

While Sarala Devi *et al.* (1979) observed a range of COD load for effluents from 10 - 4,400 mg/l in February, 1977; the values ranged from 1.55 to 887 mg/l in the present study. While the effluent of Periyar Chemicals in 1977 gave a COD value of 4,404 mg/l, during the present study it varied from 133.4 to 887 mg/l only. A single high value of 17,800 mg/l was noted for a sporadic distillery waste discharge.

From the above observations it is clear that the dichromate COD values observed, as such is not capable of indicating the organic load present in an area of the estuarine system. Thus the hazardous role indicated by COD values required further confirmation.

Alkalinity:

Analysis of alkalinity as mg $CaCo_3$/l in the study area indicated considerable spatial variations compared to low temporal variations. Alkalinity of grab water fluctuated much and was of higher order compared to surface and bottom waters. In general, Station 1 recorded high values on par with Station 7. Very low values occurred in Stations 2/3 to 5/6 and also in Station 9.

The uniform high values noted in Stations 1 and 7 might indicate occurrence of high alkalinities caused by industrial pollution on one side and sewage pollution on the other side.

Sarala Devi et al. (1979) noted an alkalinity ranging from 10.8 to 195.8 mg $CaCo_3$/l in the effluents throughout in February 1977 near Station 8 of the present study. However, during the present observations the alkalinity of the effluents send out from the factories were found to vary from 4.9 (Cominco) to 1,796 (Catalyst). This indicated wide fluctuations in alkalinity of the effluents. It did not show any uniform periodicity. Alkalinity of water samples collected 10 m away from the discharge point displayed values from nil (FACT White) to 166 (TCC I), indicating great dilution of the high alkaline content effluents.

Nampoothiri et al. (1976) studying the pollution of the river Kallada, by the effluents of the Punalur Paper Mills found an alkalinity varying from 46 to 270 ppm in zone of immediate pollution, from 58 to 180 ppm in the septic zone, from 36 to 120 ppm in the recovery zone and from 20 to 180 ppm in the fresh water zone. The lime sludge released from the pulp mill had an alkalinity ranging between 850 and 3,100 ppm. Carbonate alkalinity was found toxic to fishes. But carbonate were present rarely as the pH of the water is on the acidic side and normally carbonates in acid medium will give rise to CO_2. So low alkalinity indicated an acid medium and peak values of alkalinity indicated high alkaline pH.

Alkalinity measurements are made as a means of evaluating the buffering capacity of sewage, industrial wastes and sludges. Carbonate alkalinity as bicarbonate was found in the effluents discharged from the alkaline plants.

Many regulatory agencies prohibited the discharge of wastes containing caustic (hydroxide) alkalinity to receiving waters, because alkalinity as well as pH are important factors in determining the amenability of waste waters to biological treatment. Also calcium carbonate, clay and calcium sulphate (gypsum) are objectionable in a stream as they interfere in the self purification by diminishing photosynthesis. They also created aesthetic nuisance.

The results indicated the industrial effluents exerting a positive toxic influence on the receiving water eventhough their contents fluctuated considerably.

pH:

The range of pH value expected for normal sea water were 8.0 - 8.3 and coastal waters 7.9 - 8.2. pH values were mainly reduced by river outfall and discharge of industrial effluents containing acids. According to Oppenheimer and Kornicker (1958), Oppenheimer (1960) and Lyman (1966), pH of the sediment is a result of CO_2 and H_2S production during microbial decomposition of organic matter.

Hydrogen ion concentration of water is an important indicator of the chemical condition of the depositing environment. It shows whether the water is acidic or alkaline. The The productivity of the water can be determined by knowing the pH of the water.

Hydrobiological studies carried out by Chandran and Ramamoorthy (1984) in the gradient zone of the Vellar estuary indicated no definite seasonal or tidal variation in pH. The tidal and diurnal variations in pH values fluctuated only from 7.7 to 8.35, the low value coinciding with heavy floods as reported earlier in the Vellar estuary by Rajendran (1974). Jayapalan et al. (1976) in the Udyogamandal area found variation in pH in the fresh water zone from 6 to 7.6, in the immediate pollution zone from 4.7 to 8 in the septic zone, 5.3 to 9.5 and in the recovery zone from 6 to 8.4. However, they found no proof to suggest that pH affected the fishery wealth. The pH of the effluents from the sulphuric acid and ammonium phosphate plants varied from 3 to 5 while that of effluent discharged from Ammoniumsulphate, ammonia and ammonium chloride plants were alkaline in nature.

During the present investigation very low acidic pH of up to 3.6 was noticed from Stations 5 to 8 and in general acidic pH prevailed from Station 4 onwards mainly during post and premonsoon. Alkaline pH was noted only in May, August and September, when the monsoon was at its peak. Also alkaline pH occurred up to Station 4. pH of the effluents thrown out from the factories were found to vary from 2.1 (Cominco & TCC) to 12.3 (from Catalyst). Also month to month variations were noted depending on amount and time of discharge. While Periyar Chemicals, Cominco and TCC II maintained low acidic pH, Catalyst, TCC with a certain extent FACT recorded alkaline pH.

Samples collected from 10 m away from discharge points surprisingly showed higher values compared to the effluents of Periyar Chemicals and Cominco Binani, whereas lower values prevailed for Catalysts, TCC II and FACT I while alkaline pH was noted for effluent from TCC I and acid pH prevailed for TCC II.

Comparative studies of pH values from water column (surface and bottom) and grab water indicated always a higher pH for grab water which can be well tolerated by the benthic fauna. It is worth noting that pH never rose to a higher level which in combination with high NH_3 content can be toxic to aquatic benthic life.

This clearly ruled out any toxic effect on benthos of acid and alkalies thrown out from the industrial factories of this study area. Thus the role of pH as one of the factors governing the reduction of macrobenthos may be mostly a local affair, noticeable at the time of reduced water flow.

Tolerable pH range for most of the fishes is 5.0 to 9.0 (Michael et al., 1956). But water with pH below 6 are less productive than alkaline water.

Ellis (1937) pointed out that fish and common aquatic life prefer pH values between 6.7 and 8.4 and pH values below 5 or above 8.6 are definitely detrimental or even lethal to aquatic life. High and low pH will definitely be detrimental to aquatic life and may prevent the self purification process of the river water.

Nirmala *et al*. (1976) found among the effluents low pH liquor to be most fatal effluent affecting fish life due to its highly acidic nature. Even in waters containing 5 to 8 g/l H_2SO_4 fishes could not live. Nair *et al*. (1986) in the three areas of Cochin backwaters recorded low pH values during monsoon months.

Variations in pH over short distance across the river at the area of discharge were noticed which make the environment hazardous to quatic life. The settlement of black suspended particles from the FACT effluent on the intertidal flora, some distances down stream of the point of discharge was also noticed, indicating existence of discrete plumes at and near the points of discharge.

Nutrients:

Data on various nutrients from the effluent discharge site at an area about 15 km southeast from the Cochin harbour area (Nair *et al*., 1986) indicated that they are not limiting the primary production of that area as the nutrient concentrations were high throughout the year, (phosphate 50 to 2,195 µg at/l, ammoniacal nitrogen 22 - 3,980 µg at/l, nitrite 5 - 539 µg at/l and nitrate 5.5 - 325 µg at/l). The high primary and secondary trophic levels and the benthic production (71.4 g/m^2) did not indicate any possible ill effects other than a reduced prawn production eventhough mortality of fishes have been reported from the vicinity of the factory (Venugopalan *et al.*, 1980). The lowered prawn production might be due to low saline waters and the toxic effect on them. The reason for the high benthic production may be due to the dilution of the effluents discharged. Also, the unionized ammonia which is injurious to organisms may not be present inlarge scales. Boyd (1982) during his studies on water quality management in pond fish culture noted that in waters when pH was not high the percentage of unionized ammonia was kept minimised. Nair *et al.* (1986) studying the relevance of environmental characters of Cochin backwaters in terms of maintaining optimum ecological conditions in prawn fields found an area least affected ecologically, a second area near the vicinity of an effluent discharge from a fertilizer factory showing high concentration of nutrients with low prawn production and a third area most favourably situated to resist ecological distortions because of its proximity to the sea. Surprisingly, they recorded a highest biomass of 71.4 g/m^2 in the industrially polluted area, the biomass from prawn field near barmouth amounted to 6.37 g/m^2 only, inspite of its large prawn production. The above fact clearly indicated lack of environmental impact arising from the industrial development.

NH_3:

Ammonia, in the form of free NH_3 and ammoniacal nitrogen, was found to be one of the major pollutants present in the effluents. The NH_3 content of the effluents discharged from ammonia and ammonium phosphate plants was greater than that of in the effluents discharged from other plants. The major source was from the FACT which released on an average 685 tons of free ammonia per year (1.8 tonnes per day) along with ammoniacal nitrogen at the rate of 2,512 tonnes per year (7 tonnes per day) as given in the environmental Status Report of Greater Cochin, Kerala by KSPCB, 1982. Of the 180 million litres of industrial effluents discharged into the river Periyar per day, the contribution from FACT was in the order of 5.7 million litres. This works out to be 120 mg/l of ammoniacal nitrogen on an average. But as the discharges were not uniform the values for ammoniacal nitrogen in the river was likely to fluctuate very much. Estimation of ammoniacal nitrogen in the effluents from FACT during the present study as shown in Table 5 amounted to 32.78 to 8,033.4 µg at/l. Ammoniacal nitrogen values for the water column ranged from 7 µg at/l to 1,138 µg at/l (Stn. 5) in December in the study area. Compared to pre and post-monsoon, monsoonal values were very low. The ammonia in grab water fluctuated between 9.82 and 514.11. In general, the levels of ammonia increased towards upstream stations, with low values in Stations 1 to 4 and 9 and high values in Stations 5 to 8. Temporal variations were highly irregular depending on discharge and flow rate.

Many investigators as Peter and Max (1930) and Ellis (1937) have already proved the toxic effect of NH_3 and NH_4 compounds to fish with varying results. Toxicity of NH_3 as well as its oxidation to harmless compounds by bacteria is pH dependent.

Wuhrman (1952) and Edmond and Gunn (1936) investigating the toxicity of NH_3 and NH_4 compounds to fish found toxicity depending on the concentration of unionized NH_3 or NH_4 base. Ammonia was found much more toxic in alkaline than acid waters (Wuhrman, 1952) because its unionised form (NH_3) is more poisonous than the unionised form NH_4. High levels of the common salt of ammonium, ammonium carbonate is reported to be toxic in alkaline media (Reid, 1969; Klein, 1972). The pH ranging of 7.5 - 8 will minimise the toxic effect of ammonia.

Gopalakrishnan et al. (1969) observed that effluents from the Sindri Fertilizer Factory discharged into the Tillaiya and Panchet reservoirs, caused mortality of fish spawn.

A stream or lake containing more than 1.2 mg/l of NH_3N_2 is considered unsuitable for pisciculture (ISI, 1978). While nitrate nitrogen, the final oxidized product of NH_4N_2 above a level of 10 mg/l in water may prove to be a potential hazard to live stock and human beings (Sattel and Smith, 1965).

Chandran *et al*. (1981) estimated the ammonia content and the nitrate nitrogen concentration in the composite effluent from IFFCO Complex, Allahabad as 11.40 mg/l, and 63 mg/l respectively which were thought to be responsible for heavy fish mortality.

Ellis (1937) was also of the opinion that ammonia at concentration above 2.5 ppm is harmful in the pH range of 7.4 - 8.5. He also described 3 main ways of pollutants injuring fish. He emphasised the acceleration of the toxicity of the environment by the synergestic action of ammonia and pH. Similar observations were made by Unnithan *et al*. (1977) in the industrial belt at Eloor. The authors have reported high pH up to 12.5 and ammonia 460 - 560 µg at/l. Jayapalan *et al*. (1976) recorded high concentration of ammonia from the area. Fish mortality in Chitrapuzha river due to effluents from FACT, Ambalamedu Division having high pH (8.20) and high ammonia (23.04 ppm N) was reported by Venugopal *et al*. (1980). They noted ammonia content in the zone of mortality around half that specified for trade wastes (ISI, 1976 a) and about 20 times that for receiving waters (ISI, 1976 b). However, during the present investigations ammonia content of the receiving waters varied from about 29.3 µg at/l to 844 µg at/l. Studies on three widely separated areas from Cochin backwaters (Nair *et al*., 1986) showed a definite annual pattern of distribution for ammoniacal nitrogen. Ammoniacal nitrogen varied from 1.2 to 199.1 µg at/l. They attributed high values of ammonia nitrogen during the monsoon months due to the heavy fresh water discharge. However, the high values on the discharge sites were due to the effluents from the factory.

No such detrimental effect on fish was observed during the present study though the ammonia content was high (844 µg at/l at Stn. 8). This could be because of the lower pH in the water column which reduced the toxic effect of ammonia.

It is known that ammonia is toxic to many of the biological systems wherein its high concentration disrupts the integrity of the cells which may result in the leaching of the chlorophyll. Natarajan (1970) studied the toxicity of ammonia to marine diatoms and observed that free ammonia concentrations above 1.2 mg/l were toxic; concentration around 55 mg/l inhibited photosynthetic carbon fixation by 90% and concentration around 275 mg/l stopped photosynthesis completely.

A considerable amount of urea is being discharged as waste into streams by almost all the industries manufacturing urea (Bhattacharya et al., 1973), a nitrogenous fertilizer. This component of the waste goes untreated into the receiving water bodies even after treatment because of its biodegradability under normal condition which later on mineralises to ammonia thereby causing ill effects.

Inorganic phosphate:

Inorganic phosphate values in general were found to be very high being 272.42, 276.85 and 145.18 for surface, bottom and grab water in the effluent discharge areas, its concentration being controlled by the intensity of monsoonal flow. Lowest phosphate content was encountered at Station 9 and low values at Stations 2 and 3 thereafter recording high values from Stations 4 to 8. The fluctuations noted may be the after effect of intermittent discharges of effluents.

Rochford (1951), Rittenberg et al. (1955), Seshappa and Jayaraman (1956), Jayaraman and Seshappa (1957), Zobel (1959) and Hayes (1964) have shown the importance of bacteria in the mineralization of organic matter in the sediments and release of inorganic phosphate and nitrogen compounds into the overlying water. Also Zobel (1959) and Hayes (1964) have recognized the mud water interface as an active zone for mineralization of organic matter. According to Barnes (1959), in shallow systems, major recycling of nutrients is affected through the sediments.

Reddy and Sankaranarayanan (1972) who estimated the phosphate regenerative activity in the muds of a tropical estuary established marked differential reaction of muds in their chemical characteristics and activity. While marine zone sediments appeared to be stable and in near equilibrium state with the overlying water, that of high saline brackish water released PO_4 continuously to the overlying water whereas less saline sediment showed a reverse trend by adsorbing PO_4 from the overlying water. However they could not locate associated regular changes in the release or adsorption of PO_4 from or to the sediment.

A general association of lowered pH with the regeneration of PO_4 from the sediment was evident from a close examination of their results. In one of the three stations adsorption of PO_4 from the overlying water was found to occur at a relatively lower pH. It was found that the pH of the sediments has been in the range of 7.2 - 8 and within this range the influence of pH indicated an intense bacterial decomposition affecting a greater release of PO_4 on the overlying water.

Depending on the differences in the bacterial activity and physico-chemical composition of the muds, as the regenerative capacity of the muds differ from place to place, the nutrient concentration of the overlying water will also differ (Reddy and Sankaranarayanan, 1972).

During the investigation on nutrients of Cochin backwaters, Sankaranarayanan and Qasim (1969) attributed the large scale variation in the nutrient content of the waters to the seasonal hydrographical and meteorological conditions. But Reddy and Sankaranarayanan (1972) attributed this variation to the differences in the regenerative property of the muds of the estuary at different sites.

Carrit and Goodgal (1954 and 1965) suggested that the sediments act as a buffer on the PO_4 concentration of the overlying water. This supported observation of Reddy and Sankaranarayanan (1972) for the marine sediment, but not for estuarine sediments. For marine sediments the process of adsorption and desorption may be taking place more or less simultaneously maintaining an equilibrium condition with overlying water. According to Reddy and Sankaranarayanan in the estuarine sediments it appeared that one process or the other may be dominating perhaps due to the highly variable nature of the estuarine sediments caused by terrestrial pollution and rapid changes in the hydrographical features of the environment.

The variation in the texture of sediments also appeared to play a significant role in the regeneration and adsorption of PO_4. They noted that the adsorptive tendency is high with higher silt clay percentage of the sediment and the low silt clay content with the high percentage of fine sand appear to be conducive for active regeneration.

Very often concentration of organic carbon and total phosphorus in the sediments were found to be inversely related to the PO_4 regenerative capacities. The sediment where in the apparent adsorption of PO_4 was noticeable the iron and phosphorus contents were also relatively high. While Reddy and Sankaranarayanan (1972) could not trace any noticeable depresent effect on the PO_4 adsorption, Jettis (1959) observed considerable depressant effect of organic matter on the PO_4 adsorption sediments with lowest concentrations of iron, phosphorus and organic matter.

On adsorption, regeneration of the sediments was not quite appreciable. The natural pH buffering capacity of the sediments may also be rendering it difficult to realize the true correlation between the change in pH of the sediment and its PO_4 regeneration activity.

During high bacterial decomposition, the lowering of pH affected by the formation of CO_2 and organic acid, results in the release of PO_4. The concentration of PO_4 may sometimes far exceed the capacity of PO_4 regeneration of the muds at that pH levels rendering the relation of pH with PO_4 regeneration activity of the sediments complicated. Therefore it is clear that the observed pH of the sediment alone, especially at lower levels may not give definite indication of the adsorption or desorption of PO_4 by the sediments.

Carrit and Goodgal (1954) reported that the bottom deposits under fresh water frequently become anaerobic and acidic during stagnation and under these conditions the PO_4 release during the decomposition of organic debris favour solid phosphorus complex as maximum uptake was found to occur in the pH range of 4 yo 6. The return of phosphorus to solution from adsorption complex is favoured by an increase in pH.

Very low oxygen content and continuous increase in the PO_4 concentration on the overlying water indicate a possible microbiological activity at the mud water interface.

Depletion of phosphorus content of the overlying water and high oxygen content indicate weak microbial activity.

The adsorption of phosphorus of the overlying water may be due to higher ion exchange capacity or fixation as ferric PO_4 under the sediment to a considerable extent.

A slow and progressive decrease in the dissolved oxygen of the water suggests controlled bacterial activity.

Nair _et al._ (1986) did not record any seasonal trend for inorganic phosphate from three different areas in Cochin backwaters. The values ranged from 0.4 to 37.88 μg at/l. They noted high concentration of phosphate contributed by the factory effluents being followed by an abundance of phyto-plankton, leading to a decrease in the concentration of phosphate due to its utilisation by phytoplankton. Sankaranarayanan et al. (1986) also had recorded high amounts of phosphate due to the discharge of effluents from the fertilizer factory.

Venugopalan et al. (1980) investigating causes of fish kill in Chitrapuzha found high phosphate content of 13.62 ppm, indicating eutrophicated condition of the water. Phosphate content in excess of 200 µg at/l was reported to be prima facie evidence of pollution and a potential cause for eutrophication (Riley et al., 1972). Accordingly, eutrophication leading to polluted condition was noted in the present study area only during December at Stations 6, 7 and 9 and that too only in the water column and not in the sediment water.

An analysis of effluents discharged also did not record phosphate content sufficient to cause pollution by eutrophication, except the effluents from FACT. Also samples collected 10 metres away from the discharge point showed considerable reduction in phosphate content. Thus it was found that the phosphate content of the effluents discharged from the factories in general was of little significance in controlling the benthos.

Nitrite:

Nitrite content in the effluent discharge area was of the low order varying from 0.8 to 2.67 µg at/l indicating nil effect of the effluents discharged. High concentration occurred during December to May owing to extracellular nitrite produced by phytoplankton bloom as reported by Carlucci et al. (1970). Further it could also be presumed that excretion by phytoplankton oxidation of ammonia and reduction of nitrate could also contribute to the concentration of nitrite in the estuarine environment.

Seasonal variations in nitrite content observed may be due to the predominance of any of this process depending upon the biological activity of a particular biological agency as stated by Chandran and Ramamoorthy (1984).

The nitrite concentration (Nair et al., 1986) in the three different areas in Cochin backwaters fluctuated between 0.2 to 22.5 µg at/l. Whereas very poor level of nitrite-nitrogen was found by Nair et al. (1984) in the Ashtamudi estuary, in general estuarine stations had more nitrite content during the present study. Also nitrite content was relatively high in grab (Fig. 9) than the water column.

Nitrite being an intermediate product produced both during nitrification and denitrification processes, its unstable nature would have been a major factor responsible for the low and varying values noticed during the study.

Mackay and Leatherland (1976) noted high rate of bio-chemical oxygen demand prevailing in the vicinity of regions with high organic load. Nair et al., (1984) attributed this as one of the factors responsible for the nearly total depletion of nitrite at polluted stations of the Ashtamudy estuary.

Nitrite contents of the effluents showed values ranging from nil to 7.42 µg at/l, except in April for the effluent from Catalysts, when it registered exhorbitantly high value of 110.69 which also dropped to 3.37 after 10 metres.

<u>Nitrate</u>:

Importance of nitrate is that the fertility of water masses is solely dependent on it in line with other nitrogenous nutrients.

Spatial and temporal distribution of nitrate content in the study area indicated irregular patterns. However, in general an increase was registered from Station 1 to Station 3, thereafter either declining during premonsoon or maintaini the level during monsoon months of August, September, October and postmonsoon month of November. Grab water exhibited very high as well as low values.

Temporal variations from January to December in each station was considerably high without any regular pattern.

In the present studies high concentrations of nitrate and nitrite were also noticed along with high ammonia contents. The nitrate-nitrite reduction activity was completely suppressed by the presence of ammonia.

The annual variations of nitrate content in the seasonal and perennial fields of Cochin backwaters was found to be between 0.1 and 32.6 µg at/l (Nair et al., 1986). In general nitrate availability was very low all along the study area with wide spatial variations in surface waters as noted for Ashtamudi estuary (Nair et al., 1984). They observed a peculiar distribution pattern in the backwaters with very high nitrate content in highly polluted area while other polluted stations had very low content. The low nitrate content of the polluted region may be the result of low rate of replenishment during the degradation of organic matter and also possibly due to nitrate reduction. Higher values recorded at Station 5 in general and in grab water at times can be due to flooding of nitrate rich fresh water/ sediment load. Unlike other nutrient contents, nitrate values in the effluents were of comparatively low order, but for a single stray value of 503.1 for the effluent from Catalyst during August.

Suspended solids:

All rivers after getting polluted by pollutants like organic matter, pathogens, toxicants etc. through several activities of man such as domestic, industrial, agricultural etc. undergo natural purification. Bhargava (1977) after an analysis of the data from the water quality survey of Ganga and Yamuna made significant conclusion about the extremely fast natural purification of rivers.

The colloidial and suspended matter was removed through physical and chemical operations such as coagulation and settling. It was found that the exocellular polymers present in the water interact with the colloidal matter resulting in a considerable reduction of BOD and hence turbidity also, in a very short time. The BOD was met by the dissolved oxygen and reaeration mainly and was stabilized through the agencies of aerobic bacteria. The high or low BOD values may be indicators of their removal rate.

The suspended load of the study area in the waters varied considerably from 3 to 252.5 mg/l for surface and 24.8 to 256.7 for bottom waters both intime and space probably under the influence of tides, currents and monsoonal flow. Thus the estuarine waters were found relatively turbid. But continuous turbidity was not recorded and clear water was present temporarily. However, the turbidity clouds or mud section, which is a common feature of many estuarine rivers found in the transition zone between fresh and brackish water, generally characterized by extremely high suspended load and low transparency, was not recorded probably as the transition zone was not distinct.

Generally POC and Seston were higher in the bottom than in the surface. Suspended material in the Cochin backwater varied considerably with the state of tides and seasons, the water column having maximum load during monsoon. Seston originated from domestic sewage and industrial wastes released into the estuary in addition to the agricultural runoff joining the estuary in the upper reaches.

Chandran et al. (1984) noted that the amount of total solids is very high in the mixed waste, ranging between 1320 to 1340 mg/l and may also reduce the light penetration and clog the delicate breathing mechanism of fish as described by Jones (1962) and Patrick (1972). Suspended matter may cause mechanical injury to fishes especially during high stream flow. It can also choke the gills of fishes and so cause mortality. A questionnaire to River Boards (Water Pollution Research, 1959) suggested that the fishes can exist in river containing up to 75 ppm of suspended matter from various industries. It is however difficult to draw an exact demarcation line between harmful and harmless suspended solids. Suspended solids in concentrations of more than 350 mg/l affected the fish adversely causing mechanical injury to the gills (Panwar et al., 1979; Verma and Daleta, 1976). Suspended solid according to Patrick (1953) while settling down on the substratum may burry eggs, thereby reducing fish population.

Analysis of suspended load of effluents from factories indicated very low values ranging from 8 to 32 (IRE & Cominco) to very high values of 140 to 5,040 (FACT white & TCC I). A peak value of 17,333 mg/l was noted for effluents from distillery. But suspended load of water samples collected from areas 10 m away from effluent discharges recorded very low values only ranging from 3.33 to 76, but for a high load of 352 mg/l for TCC I.

However, suspended load in the water column of the study area recorded comparatively higher values indicating original suspended load from other sources. Thus it appeared that the part played by the suspended load of the effluents does not seem to affect much the fauna of the area.

Particulate Organic Carbon:

A study of the life cycle in the pelagic realm indicates that a good amount of living matter occurs as nanoplankton, which with the more resistant portion of decomposing organisms and detritus contributed what is termed as particulate organic matter. Most research on detritus food webs has focussed on production of particulate organic matter. Estuarine organic matter consists of autochthonous contribution resulting from primary production within the estuary, and allochthonous contribution from adjacent ecosystem. Particulate matter whether derived from the standing biomass of water column or from autochthonous and allochthonous sources are of great value as they form food for filter feeding pelagic animals and for benthos after decomposition. Organic carbon is associated with and is derived from all living systems. In its various forms it may function as a nutrient, an energy source, growth stimulant and growth inhibitor. Thus it may be of general interest simply as a source of nutrients or energy or it may be of special interest as a result of its specific biological activity. It's role ofcourse depends upon its chemical and biological state.

Organic carbon and energy content of the water was found to be closely related to the amount of particulate matter.

An assessment of particulate organic matter and energy perhaps provides a more meaningful estimation of the pool of available energy to the next trophic level particularly in shallow coastal and estuarine system dominated by detrital material.

It is important to stress the central role of particulate matter as particle, carrying pollutants, which may be introduced into aquatic systems by surface runoff as well as by atmospheric fall out. Heavy metals and other pollutants carried by river transported particles may to some extent be mobilised when the river water is mixed with sea water. The suspended particles to an extent may be grazed directly by plankton indicating a direct means for input of toxic persistent residue to the pelagic community. During the present study the POC content in the mouth of the estuary was higher compared to other upstream station with an annual ranges of 0.39 - 8.02 mg/l in the surface and 0.81 - 15.81 mg/l in the bottom waters, in agreement with the high particulate matter from 7.24 mg/l to 152.3 mg/l and 14.22 mg/l to 231.0 in the surface and bottom respectively.

POC content in the three Stations (2, 3 and 4) of lower reaches showed an annual range of 0.47 - 3.5 mg/l in the surface and 0.45 - 8.48 mg/l in the bottom. Peak value was noticed in August. Suspended load (seston) ranged between 2.43 - 60.75 mg/l in the surface and 4.65 - 138.0 in the bottom waters.

In the upper reaches, Stations 5, 6, 7 and 8, the surface and bottom POC did not show much difference except at Stations 5 and 8. In this zone the peak value of POC was 5.67 mg/l at Station 6. At the discharge site (Stn. 8) also a high POC content was noticed (5.33 mg/l). Particulate matter in these areas ranged between 2.3 - 75.72 mg/l in the surface and 2.75 to 88.5 mg/l in the bottom.

At Station 9 high concentration of POC (5.48 mg/l) and particulate matter (85.42 mg/l) were noticed.

Leach (1971) found a correlation between rainfall and POC content by five streams into Ythan estuary in Scotland, the seasonal averages for the POC concentration ranging from 1.02 - 1.93 mg/l in the estuary. Odum and de Lacruz (1967) recorded concentrations of up to 20 mg/l POC for streams draining salt marshes in United States. Bhosle et al. (1985) analysing the particulate matter in Mahi river estuary observed short term variations.

The concentration of total organic carbon typical of British untreated sewage is about 300 mg/l (Painter & Viney, 1959). Abdulla et al. (1973) reported POC concentration of between 0.5 - 5.0 mg/l in British Channel and Severn estuary. Biggs and Flamer (1972) recorded value of up to 3 mg/l in Chespeake Bay. In the Cochin backwater seasonal average ranged between 2.11 - 4.43. In the effluent discharge site (Stn. 8) the mean value was 5.53. These values were also high when compared to the POC content of the 4 estuaries namely, Kallai, Mahe, Korapuzha and Beypore in the north Kerala coast (Venugopal et al., un-published).

"K" Values:

Generally higher light attenuation values were expected in the monsoon months especially during flood conditions, due to the likely increase in turbidity of the water and low intensity of solar radiation. However, during the other seasons variations in "K" values are likely to be rather erratic following no definite seasonal pattern due to the dominance of clear neritic water and the prevalence of higher solar radiation. Thayer (1971) observed that tropical estuaries are generally characterised by a wide range of light attenuation coefficients in contrast to temperate estuaries.

Chandran and Ramamoorthy (1984) analysing the physico-chemical aspects of the gradient zone of the Vellar estuary found that the light attenuation coefficient was low (1.4) during summer when the estuary was dominated by clear neritic water and high (17) during monsoon season owing to the heavy water flow. Although no definite tidal variation in light attenuation coefficient was noticed the values were generally higher during low tides. In Goa estuaries Bhattathiri and Devassy (1977) noticed a range of 4.8 to 7.5 in "K" values. Qasim *et al.* (1968) also recorded in Cochin backwaters commendable reduction in the light penetration during monsoon, the attenuation coefficient varying from 0.6 to 3.

However, during the present study, compared to the above observations very high "K" values were recorded, values ranging from 10 to 15 in July and 5 to 7.5 in October. Rest of the months showed an irregular pattern. Spatial variation in "K" values could not indicate any influence by the effluents discharged.

Sediment characters and organic carbon:

Sediments are indicators of the quality of water overlying them and hence their study is useful in the assessment of environmental pollution. Keith and Degens (1959), Kaplan and Rittenberg (1963) and Bordovsky (1965) have studied in detail about the components and composition of the sediments. The nature and extent of fluctuations in the composition and nature of sediments can indicate the extent of stress in an environment. Recent sediments especially in the estuaries also indicated the balance reached in the system between erosional and depositional forces. The supply and the source of these materials and the sites of deposition depend upon the type of estuarine wave action and tidal regime. Relative dominance of coarse fraction over fine grained material in the sediment of estuaries depends on the shape of the estuary, nature of the river flow, tidal currents and availability of fine grained material (Postma, 1967). Muus (1967) stressed the importance of substratum as an abiotic factor in respect of its physical characters as consistency, water content, grain size etc. and as a biological factor, as regards to its content of the organic matter and its microbial turnover. Due to the shifting of the sediments from coastal region into the estuarine mouth, Shirodkar and Sen Gupta (1985) noted high turbulence at station close to the river mouth followed by muddy sediments with more clay and silt. Nair et al. (1984) analysing the textural characters of the sediment of Ashtamudi estuary found its composition varying markedly over the course of the year in all stations. According to them the water currents, the ebb and flow of the tides and various physiographic features of the estuary are believed to play a key note in the distribution and deposition of sediment particles in the bed of the Ashtamudi estuary.

In estuaries, the sediments are exposed to overlying water of varying salinities. Studies in the estuarine environment by Reid (1930) have indicated that the chemistry of the pore water depends on the salinity of the overlying water. According to Shirodkar and Sen Gupta (1985) interstitial waters of coastal and estuarine sediments of Mandovi river showed high salinity in most of the sediments rich in clay and silt as compared to the sandy sediments, due to semipermeable character of clay and silt. Accordingly, during the present studies salinity values of grab water were found fluctuating between 0.21 and 28.28 ‰, depending on the nature of the sediments. Shirodkar and Sen Gupta (1985) observed, sediments in the coastal and estuarine regions having a reducing environment during October to May (post and premonsoon season) whereas during June to September (monsoon season) oxidising conditions prevailed.

During the present study temporal and spatial variations in colour and texture of sediments noted were similar to the observations made by Remani et al. (1980) in the northern limb of Cochin backwaters where a variety of effluents were discharged. The reddish brown colour of the sediments noted at Station 9 indicated oxidized condition, whereas the light grey sediments indicated presence of terrigenous matter as reported by Hashimi et al. (1978). The sediments of the effluent discharge sites (Stns. 6, 7 & 8) were black in colour and malodorous akin to the green and black mud of the retting yard (Remani et al., 1981) and stagnant basin (Kuenen, 1950 & Hynes, 1966).

Organic carbon content in the sediments of the riverine systems is of interest as a potential food for the benthic fauna. Generally the state of preservation depends partly on its texture. Association of organic matter with fine grained material is well established by works of Hashimi et al. (1978), Jayapalan et al. (1976), Trask (1939), Emery and Rittenberg (1952). Kisma et al. (1966) and Pillai (1978) stated that the main reason for such a close relationship between the organic content and texture of the sediment has been attributed to the similar settling velocity of organic matter and fine mineral particles. While Remani et al. (1980) noticed direct relationship between fine grained sediments and organic matter at barmouth, the present study showed direct relationship between organic carbon and sediment texture in all stations except at Station 9, where no such definite pattern was seen.

Sverdrup et al. (1942) have given three factors which favoured high organic content in the bottom. They are (1) the abundant supply of organic matter from the overlying water, (2) the relatively rapid accumulation of fine grained terrigenous organic matter and (3) the low oxygen content of the bottom water.

During the present study the organic carbon content was found to vary between 1.19 and 46.9 mg/g affecting considerably the pH of the sediments, indicating the release of acidic compounds by breakdown of organic matter. This is in confirmation with the observation of Shirodkar and Sen Gupta (1985).

High organic carbon content noted during premonsoon at Station 1 may be the result of dredging activities. Land runoff and terrigenous sources contributed to monsoonal increase of organic carbon content. Nair *et al.* (1983) and Damodaran and Sajan (1984) recorded high values of organic matter in the sediments of Ashtamudi estuary, as a result of discharges from the Punalur Paper Mills. The organic carbon/organic matter content of the different estuarine systems, estimated by several authors are given in Table 14.

Sarala Devi *et al.* (1979) have attributed the termination of the blooms along with an increase in organic load of the effluents, as a factor for the very high values. High oxygen content, high temperature and shallow depth of stations seems to encourage oxidisation of organic matter in the sediments as observed by Murthy and Veerayya (1972).

In general, organic matter in the estuarine sediment is high, as high percentages of clay is capable of holding a high proportion of organic matter. Hence organic matter is predominantly trapped by clay and to a lesser extent by fine silt, coarse silt and sand (Russel, 1950). Qasim *et al.* (1969) have reported the planktonic production of the backwater to be about 195 g/m^2/year and the zooplankton grazers leave a considerable surplus of unconsumed basic food which sinks to the bottom and become part of the sediment.

Table - 14. Showing reported values of organic carbon/organic matter in sediment in different estuaries of India.

Sl.No.	Author	Region	Reported values of organic matter/organic carbon
1.	Murthy, Reddy and Varadachari, 1969.	Chilka Lake	Average organic matter - 1.38%.
2.	Murthy and Veerayya, 1972.	Vembanad Lake	Average organic matter - 2.55% Range - 0.1 - 6.0%.
3.	Ganapati and Raman, 1973	Visakhapatnam Harbour	Organic carbon Average - 6.0%.
4.	Patel, Mulay and Ganguly, 1975.	Tidal estuary - Bombay harbour.	Organic carbon. Range - 3.0 - 3.2%.
5.	Ganapati and Raman, 1976.	Visakhapatnam harbour	Organic carbon Average - 2.5%.
6.	Gopalakrishna Pillai, 1978.	Cochin backwaters.	Organic matter. Average 3.78%. Range - 2.86 - 5.02%.
7.	Serlathan and Seetharama Swamy, 1979.	Cauvery river.	Organic matter. Average 3.5%. Range - 0.14 - 3.68%.
8.	Sankaranarayanan and Saramma Panampunnayil, 1979.	Cochin backwaters.	Organic carbon. Average - 1.62%. Range - 0.74 - 3.84%.
9.	Ramani, Venugopal, Sarala Devi, Lalitha & Unnithan, 1980.	Cochin backwaters. Barmouth Eloor	Organic matter Average - 3.5%. Average - 3.33%

Contd..

Table - 14. (Contd.)

Sl.No.	Author	Region	Reported values of organic matter/organic carbon.
10.	Ramani, Venugopal, Sarala Devi and Unnithan, 1981.	Retting yard in the Cochin backwaters.	Organic matter - Average - 8.43%. Range - (4.3 - 24.2%).
		Reference Station.	Organic matter - Average - 4.89%. Range - 0.6 - 9.2%.
11.	Varshney, Govindan and Desai, 1981.	Narmada estuary.	Organic matter. Range - 0.03 - 4.666% in the upper reaches. 0.06 - 0.49% in the lower reaches.
12.	Balakrishnan Nair, N., M. Arunachalam, P.K. Abdul Aziz, K. Krishnakumar & K. Dharmaraj, 1983.	Ashtamudi estuary.	Organic carbon. Range - 0.06 - 4.95%.
		Riverine zone.	Range - 0.9 - 3.24%.
13.	Nagarajaiah and Gupta, 1983.	Nethravathy estuary.	Organic carbon. Average - 0.65 - 4.25%.
14.	Damodaran and Sajan, 1984.	River mouth of Ashtamudi estuary.	Organic matter. Average - 8.48%.

4.2. Effect of pollutants on the distribution of macrobenthos:

4.2.1. Temporal and spatial variations in the macrofaunal biomass and population density:

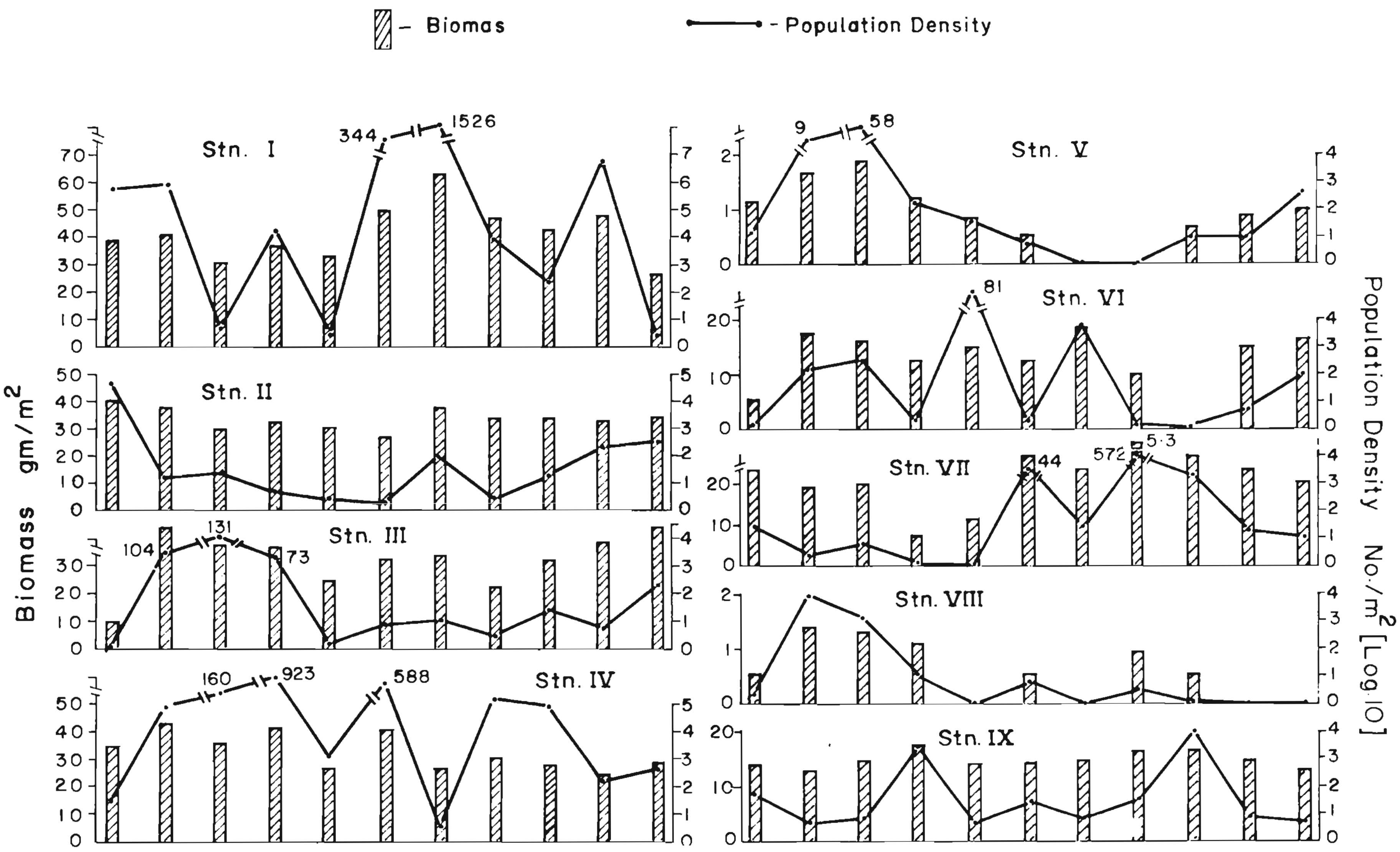
Variations in biomass (g/m^2) and population density ($number/m^2$) of benthic organisms at the nine stations during different months studied are given in Fig. 15. 17.

Temporal variations in biomass and population density:

At Station 1 maximum biomass value of 1,526.9 g/m^2 was noted in August and low value of 3.06, 4.7 and 6.8 g/m^2 in December, June and April respectively. Rest of the months recorded moderate values ranging from 23.5 to 344.75 g/m^2. The population density also varied in general corresponding to the biomass values, the highest density of 18,62,428/m^2 occurring in August. The low values of 405, 1,147 and 2,309/m^2 were noted in December, April and June respectively. In other months the population density varied from 6,076 to 89,323/m^2.

At Station 2 highest biomass 46.9 g/m^2 and density of 12,241/m^2 were observed in January, compared to lowest biomass of 2.84 g/m^2 and density of 556/m^2 in July. Similar low biomass values occurred in the months of May, June and September respectively. Rest of the stations showed biomass values varying from 12.1 to 25.1 g/m^2.

Fig. 17. Distribution of biomass and population density at 9 stations during 1981.


Biomas
Population Density
Biomass gm/m2
Population Density No./m2 [Log 10]
Stn. I
344
1526
Stn. II
Stn. III
104
131
73
Stn. IV
160
923
588
Stn. V
9
58
Stn. VI
81
Stn. VII
44
572
5·3
Stn. VIII
Stn. IX

Biomass at Stations 3, 5 and 8 and population density at Stations 2, 3, 4 and 9 showed more or less the same trend of distribution.

The biomass values exhibited wide variations at Station 3 ranging between 0.21 g/m^2 in January and 131.2 g/m^2 in April. The total number of organisms also varied from $14/m^2$ in January corresponding to the lowest biomass value of 0.21 g/m^2 and 25,062 $/m^2$ in December in spite of a low biomass of 22.9 g/m^2. However, April with highest biomass, recorded a density of only 5,777 $/m^2$.

The biomass value at Station 4 ranged from the highest value of 923.5 g/m^2 in May to the lowest 5.1 g/m^2 in August. The population density ranged from $20,003/m^2$ during March to $292/m^2$ in November. Station 5 recorded low biomass values throughout declining from a maximum of 58.3 g/m^2 in April to their total absence in August and September. Station 6 recorded highest biomass of 81.66 g/m^2 in June with a population density $1,043/m^2$ whereas the highest density was in August $5,436/m^2$ when the biomass was only 18.85 g/m^2. The lowest biomass recorded from this Station was in September (0.69 g/m^2) with 97 specimens$/m^2$. Benthos were totally absent in October.

Both, biomass values, 572.2 g/m^2 and population density values, $1,90,973/m^2$ were highest in September at Station 7. The lowest biomass values of 0.21 and 0.17 with a population density of $14/m^2$ and $56/m^2$ were recorded in May and June respectively.

Of all the stations the lowest values for biomass were noticed at Station 8, maximum recorded being 1.96 g/m^2 in March with a population density of $653/m^2$. During the rest of the months population density and biomass were sparse being totally absent in June, August, November and December. Except for the high values of 17.48 and 19.7 g/m^2 in May and October respectively at the upstream Station 9, the biomass values were more or less consistent ranging from 3.32 to 8.16 g/m^2. However, population density ranged from $418/m^2$ in December to $3,275/m^2$ in May.

Spatial variation in biomass:

During January peak biomass of above 46.9 g/m^2 occurred at Stations 1 and 2 which showed an abrupt fall to very low value of less than 1 g/m^2 at Stations 3, 5, 6 and 8. The higher values of 9.8 and 8.66 recorded at Stations 7 and 9 were noteworthy.

Biomass values during March however showed very high values of 104 g/m^2 to 49.0 g/m^2 at Stations 3 and 4 respectively due to the presence of Villorita cyprinoides. But for that, Station 1 had high biomass value of 59 g/m^2 as in January. Of the rest of the Stations 2, 5 and 6 showed a value around 10, whereas Stations 7, 8 and 9 had very low values of less than 3.32 g/m^2.

April too had very high biomass of 58 to 160 in Stations 3, 4 and 5 owing to the presence of Villorita cyprinoides. However, Station 1 had comparatively low values similar to Stations 2, 6, 7 and 9 lowest of 1.55 being recorded at Station 8.

May also recorded a high peak value of 923.5 g/m^2 at Station 4 followed by high values of 72.89 at Station 3 and 41.8 at Station 1. The very high value at Station 4 was due to the size increase noticed among Villorita cyprinoides. However rest of the stations recorded very low values ranging from 0.21 to 17.5 g/m^2.

Except for Station 6 with a high value of 81.66 and Station 4 with 31.3, rest of the stations including Station 1 during June showed comparatively low values. Station 8 was totally devoid of fauna.

July recorded peak values of biomass ranging from 344 to 588 g/m^2 at Stations 1 and 4 due to patchy occurrence of amphipods and Isopods. But for that except Station 7 with 43.9 g/m^2 rest of the stations indicated low values of biomas

An abundance of amphipods and isopods found in Station 1 during August contributed to a high biomass value of 1,526.9 g/m^2. While fauna was totally absent at Stations 5 and 8, low biomass values were noted at other stations.

In September due to the presence of Capitella capitata a very high biomass value of 572.3 g/m^2 was recorded at Stat 7 whereas Stations 1 and 4 also had high biomass because of amphipods and Villorita cyprinoides. Rest of the stations showed lower values, but for their total absence at Station 5. October with moderate values at Stations 1, 4, 7 and 9 recorded reduced strength especially at Station 8 and total absence at Station 6. November had comparatively high biomass values at Stations 1, 2 and 4 while other stations recorded low values. During December except for Stations 2, 3 and 4, rest of the stations recorded low biomass values.

To sum up, at Station 1 located near barmouth the monthly mean biomass of 197.76 g/m^2 was higher than the rest of the stations. The lowest mean biomass value of 0.42 and low mean population density of $128/m^2$ was noted at Station 8 located near the effluent discharge site. High mean biomass value was noticed at Station 4 with 176.47 g/m^2. Rest of the stations exhibited comparatively low values ranging from 7.64 at Station 9 to 62.43 g/m^2 at Station 7. The order of abundance was as follows: Stations 8, 9, 5, 6, 2, 3, 7, 4 and 1. The above results indicated 4 types of distribution of biomass - Stations 1 and 4 with peak biomass value of above 176.5 g/m^2, Stations 3 and 7 with moderate biomass value of 34.43 to 62.4 g/m^2, Stations 2, 5, 6 and 9 with low biomass values of 8.98 to 15.69 g/m^2 and Station 8 with lowest biomass value of 0.42 g/m^2.

Spatial variation of population density:

An analysis of spatial variation in numerical abundance at the 9 stations during each month gave following inferences.

In January numerical density was maximum with 12,241/m^2 at Station 2 followed by Stations 1, 7 and 4. Rest of the stations had low numbers only. March indicated very high numerical abundance at Stations 1 to 4 which was gradually reduced to 421 at Station 9.

In April, Stations 3, 4 and 5 had high population densities followed by medium values at Stations 1, 2, 6 and 7 and comparatively low values at Stations 8 and 9. While peak values of 14,498/m^2 was noted at Station 4 in May; Stations 1 and 3 recorded more than 5,367/m^2, Stations 2 and 9 more than 2,159/m^2 and rest of the stations low values. June in general had low numerical density ranging from nil (Station 8) to 2,309 /m^2. Owing to the occurrence of isopods, amphipods, Villorita cyprinoides and a dense polychaete population during July Stations 1, 4 and 7 recorded very high numerical abundance. Rest of the stations recorded low densities only.

A rare abundance of amphipods and isopods numbering 18,62,428/m^2 occurred at Station 1 in August while no organisms was present at Stations 5 and 8. Rest of the stations had a density ranging from 488 to 6,546/m^2.

Presence of the polychaete species (<u>Capitella capitata</u>) at Station 7 during September gave a peak density of 1,90,973 $/m^2$. This was followed by another peak of 49,092/m^2 amphipods at Station 1. Lower densities of 1,211 to 2,517/m^2 were noted at Stations 2, 4 and 9. Low numbers were present at Stations 3, 6 and 8 while no specimens were noticed at Station 5.

October recorded a high density of 21,436/m^2 at Station 1, followed by low values of 1,501 to 3,074/m^2 at Stations 2, 3, 7 and 9. Except for total absence at Station 6 rest of the stations had very low densities of 28 to 668/m^2.

November too had a similar pattern as in October, with a peak value of 60,940/m^2 at Station 1, low values of 1,083 to 8,063/m^2 at Stations 2, 3, 6 and 7. However 70 individuals were present at Station 5 and only 180 at Station 9 while none was recorded at Station 8.

While an amphipod swarm of 25,062/m^2 at Station 3 formed the peak density during December, Stations 2, 6 and 7 had low values of 1,154 to 3,060/m^2. While none was present at Station 8, rest of the stations had very low densities of 98 to 766/m^2.

Thus, the population density also showed wide fluctuations between 128/m^2 at Stations 8 and 1,92,124/m^2 at Station 1. At Stations 2 to 4 located at the lower reaches population density ranged between 3,773 at Station 2 and 6,765 at Station 3. In the upper reaches of the estuary the population density ranged between 128/m^2 at Station 8 and 20,643/m^2 at Station 7. The source water (Stn. 9) off the effluent discharge site showed monthly average population density of 1,178/m^2. In all, 3 ranges of abundance could be noted. Station 1 with very high density of 192 per thousand, Stations 2, 3, 4 and 7 with lower densities of 4 to 20 per thousand and Stations 5, 6, 8 and 9 with the lowest density of around one per thousand. In the order of abundance the population density increased from Stations 8, 5, 6, 9, 2, 4, 3, 7 to 1.

4.2.2. Seasonal variations in macrofaunal biomass and population density: (Table 15 and Fig. 17).

At Station 1 seasonal variations in biomass indicated an average of 388 g/m^2 during monsoon compared to 36.1 and 47.78 g/m^2 during the pre- and post-monsoon periods. Similarly, mean population density was maximum with 4,04,917/m^2 during the monsoon, and the lowest density of 6,351/m^2 was recorded during the premonsoon, compared to 23,241/m^2 in the postmonsoon.

Biomass values of Station 2 had high values of 31.76 g/m^2 and 11.01 g/m^2 during pre- and post-monsoon periods and low values of 8.86 g/m^2 during the monsoon. Mean population density was high during the postmonsoon (5,754/m^2), whereas the monsoon and premonsoon values were 2,794 and 3,422/m^2 respectively.

Station 3 was characterised by high mean biomass value of 102.82 g/m^2 during the premonsoon compared to a gradual fall in mean values to 7.9 and 10.26 g/m^2 during monsoon and postmonsoon (June to January). However, mean population densities were high with 11,398 and 11,040/m^2 during the premonsoon and postmonsoon respectively, whereas the monsoon period recorded only 1,416/m^2.

The mean biomass value at Station 4 was high with 377.78 g/m^2 during premonsoon followed by 148.9 g/m^2 during the monsoon, reaching a low value of 21.5 g/m^2 during the postmonsoon. Mean population density with the same trend as above, had the maximum population density of 12,997/m^2 during the premonsoon and the lowest density of 1,389/m^2 during the postmonsoon. Monsoon exhibited an intermediate density of 3,088/m^2.

Station 5 recorded the highest (23.1 g/m^2) mean biomass during premonsoon leading to a sudden decline in mean values to 0.8 and 0.36 g/m^2 during the postmonsoon and monsoon respectively. Similar decline in the mean population densities were observed from 2,642/m^2 during the premonsoon to 126 and 20/m^2 during the postmonsoon and monsoon periods.

The mean biomass value at Station 6 was high (20.5 g/m^2) during the monsoon compared to 8.36 and 4.69 g/m^2 during the pre- and post-monsoon respectively. However, the mean population densities exhibited a decrease in values from premonsoon to postmonsoon having 1,863, 1,415 and 1,121/m^2 during premonsoon, monsoon and postmonsoon respectively.

The high seasonal mean biomass (130.6 g/m^2) observed at Station 7 during the monsoon was reduced to 8.42 and 2.78 g/m^2 during the post and premonsoon respectively. The mean population densities also exhibited a similar pattern with 43,547/m^2 during the monsoon decreasing to 2,449 and 665/m^2 during the post and premonsoon respectively.

Station 8, where the effluents were discharged was noteworthy in the sense the low mean seasonal biomass value of 1.34 g/m^2 during the premonsoon was reduced to 0.07 g/m^2 during the monsoon and postmonsoon. As noted above the low mean population density of 423/m^3 during premonsoon declined to 22/m^2 during the monsoon and a low value of 9/m^2 during the postmonsoon.

The upstream Station 9, but for the low mean biomass value of 5.46 g/m^2 during postmonsoon recorded a high mean value of 8.3 and 8.5 g/m^2 during the premonsoon and monsoon seasons respectively. In association with the above changes the mean population density varied from 1,547/m^2 and 1,281/m^2 during the premonsoon and monsoon seasons respectively to a low mean value of 631/m^2 during the postmonsoon. Thus considerable seasonal variation could be noted in the biomass values and population densities from Station to Station. Seasonal averages showed high biomass during premonsoon period at Stations 3 and 4, whereas high values prevailed at Stations 1, 4 and 7 during monsoon. During postmonsoon only Stations 1 and 2 with

Table - 15. Seasonal and annual averages of population density (No./m^2) and biomass (g/m^2) at Stations 1 to 9 during 1981.

Stations / Seasons	1		2		3		4		5	
	Pop. density	Biomass	Pop. density	Biomass	Pop. density	Biomass	Pop. density	Biomass	Pop. density	Biomass
Premonsoon	6,351	36.10	3,422	11.01	11,398	102.82	12,997	377.78	2,642	23.10
Monsoon	4,04,917	388.00	2,794	8.86	1,416	7.90	3,088	148.90	20	0.36
Postmonsoon	23,241	47.78	5,734	31.76	11,046	10.26	1,389	21.15	126	0.82
Annual	1,92,124	197.76	3,773	15.69	6,765	34.43	5,327	176.50	764	8.98

Table - 15. (Contd.)

Stations / Seasons	6		7		8		9	
	Pop. density	Biomass	Pop. density	Biomass	Pop. density	Biomass	Pop. density	Biomass
Premonsoon	1,863	8.36	665	2.78	423	1.34	1,547	8.30
Monsoon	1,415	20,50	43,547	130.60	22	0.07	1,281	8.50
Postmonsoon	1,121	4.69	2,449	8.42	9	0.07	631	5.46
Annual	1,171	12.87	20,643	62.43	128	0.42	1,178	7.64

values above 31.76 g/m^2 had the high biomass. The lowest biomass values prevailed at Station 8 throughout the year while Station 9 recorded low values in all the seasons.

4.2.3. Faunal occurrence, density, succession and diversity:

Faunal occurrence: (Tables 10 a to 10 i):

Benthic fauna of the 9 stations in the study area consisted of amphipods, polychaetes, isopods, tanaidaceans, molluscs, other crustaceans (Decapods, *Acetes* sp., alpheids, *Balanus* sp., insect larvae, chironomid larvae, *Tanytarsus* sp., *Plectrocnemia* sp., Ephdra larva, *Simulium* sp., *Cricotopus sylvestris*, *Bezzia* sp., Water beetle, *Anatopynia* sp., *Diamesa* sp., *Baetes* sp., May fly larvae, *Platambus* sp., unidentified larvae, *Cumacea* sp.) and miscellaneous groups (Sea anemone, flat worm, nematods, sipunculoides, echinoderms, and fish larvae). Of these 31 groups, the first five were preminent because of their numerical abundance as a result of swarming and patchiness. Rest of the 26 minor groups were found less significant due to their rare occurrence and low numerical densities. Polychaetes and molluscs were the only major faunal groups present in all the nine stations. Amphipoda ranked third in occurrence being present at Stations 1 to 7. Next in occurrence was isopods and tanaidaceans present in the same Stations of 1 to 4 and 6.

Among the 26 minor groups including 13 riverine forms, Chironomid larvae were present at 7 stations except Stations 1 and 6. Next in occurrence was insect larvae being present at 6 stations except 3, 4 and 8. Decapods and _Tanytarsus_ sp. were present in 4 stations each, former at Stations 1, 2, 4 and 5 and latter in Stations 2, 3, 5 and 9. The seven groups namely nematodes, sipunculoides, fish larvae, cumaceans, _Plectrocnemia_ sp., _Ephydra_ sp., _Anatopynia_ sp. were identified from three stations each. Echinoderm larvae and _Diamesa_ sp. were collected from two stations each.

Faunal density - Spatial variation:

Major Groups:- Polychaetes were the most common fauna present at all the stations constituting the largest assemblage of the benthic organisms in the study area. Station-wise variations showed their maximum density of 2,26,083/m^2 (Comprised solely of _Capitella capitata_) at Station 7 followed by high values of 24,651/m^2 at Station 2 and 20,759/m^2 at Station 1. But for very low values of 947/m^2 at Station 8 and 3,616/m^2 in Station 5, values at the rest of the stations ranged between 11,229/m^2 and 13,526/m^2. The numerical abundance of polychaetes, did not show any definite pattern with variations in environmental parameters.

Mollusca, the second most common group, present at all the stations showed a peak density of 26,898/m^2 composed of Villorita cyprinoides at Station 4. Moderate values ranging from 1,949/m^2 to 4,817/m^2 were noted at Stations 1, 3, 4, 5 and 6. Low densities were observed at Station 2 with 669/m^2, Station 7 with 140/m^2, Station 8 with 430/m^2 and Station 9 with 196/m^2.

Amphipods, eventhough highest in numerical abundance among the 31 groups, were third in rank in occurrence as they were missing at Stations 8 and 9. The peak abundance of amphipods (20,36,402/m^2) occurred at Station 1. Subsequently they exhibited a substantial reduction towards Stations 6 and 7 with counts of 182/m^2 and 627/m^2 respectively, thereafter being totally absent at Stations 8 and 9.

Isopods ranking 4th in occurrence were recorded at 5 stations, only. Their peak abundance of 41,466/m^2 occurred at Station 1. However, the other 4 stations recorded considerably lower densities ranging from 241/m^2 to 501/m^2. But for a very low density of 14/m^2 at Station 6, they were totally absent at Stations 5, 7, 8 and 9.

Tanaidaceans, like isopods, were seen at the same five stations with a peak value of 4,073/m^2 at Station 1. As is the case with isopods, low densities ranging from 42/m^2 to 140/m^2 were recorded at Stations 2, 3 and 4. But for a very low density of 14/m^2 at Station 6, tanaidaceans were not present at Stations 5, 7, 8 and 9.

<u>Minor Groups</u>:- Chironomid larvae, a pollution indicator formed the most common faunal group being present at 7 stations except at Stations 1 and 2. Of the 501 specimens collected 375 belonged to Station 3, followed by 28 each at Stations 2, 8 and 9 and 14 each at Stations 4, 5 and 7 respectively.

Of the 168 insect larvae collected from 6 stations, 42 were present at Station 7, followed by 28 each at Stations 1, 5, 6, and 9, and 14 at Station 2. Decapod larvae including crab megalopa numbering 488 were recorded from 4 stations. A maximum of 181 were present at Station 5 followed by 167 at Station 1 and 70 each at Stations 2 and 4. *Tanytarsus* sp., a riverine form was found at 4 stations. Of the total of 168 specimens, 112 belonged to Station 9, whereas Stations 2 and 3 had 14 each and Station 5 had 28 specimens. Nematodes numbering 821 occurred ~~in~~ only in 3 stations with an abrupt decline from 751 at Station 1 to 56 at Station 2 and 14 at Station 3. Sipunculoides, as above, recorded from 3 stations numbered 280 with a peak of 196 at Station 1, reduced to 17 at Station 2 and 14 at Station 3. Fish larvae numbering 98 were collected from Stations 1, 2 and 3 with a peak presence of 70 at Station 1, and 14 each at Stations 2 and 3. Cumacea also, present at 3 stations, had a maximum count of 84 at Station 1 and 14 each at Stations 2 and 3.

Plectrocnemia sp., a riverine form numbering 871 was found at 3 stations, a maximum of 663 being present at Station 9. They were recorded in reduced numbers of 194 from Station 2 and 14 from Station 3.

70 *Ephdira* sp. also, another riverine form, was obtained from 3 stations - 42 from Station 9 and 14 each from Stations 3 and 6.

Another riverine form, *Anatopynia* sp. numbering 293 was also recorded from 3 stations. Its maximum density of 168 at Station 9 followed by 111 at Station 6 declined to 14 in Station 7.

Echinoderm larvae were present only at 2 stations, Station 1 with $166/m^2$ and Station 2 with $42/m^2$.

A riverine form *Diamesa* sp. also was recorded at 2 stations, Station 7 with 14 and Station 9 with 362 specimens.

Fifty six flat worms were identified from Stations 2 and 3 with 42 and 14 specimens respectively.

Rest of the 12 minor groups were located only at one station each.

Acetes sp. numbering 14, Alpheids 28, Balanus 56, and sea anemones 3,684 were encountered at Station 1 only.

Riverine forms,as *Simulium* sp. and *Cricotopus sylvestris* numbering 28 and 14 respectively were recorded at Station 5.

Fourteen *Bezzia* sp. were present, only at Station 6. Station 9 had 5 riverine forms endemic to it. They were *Baetis* sp. (28), May fly larvae (28), water beetle (84), *Platambus* sp. (28) and an unidentified crustacean larvae (14).

Faunal density:-

Temporal variations: Amphipods predominated the benthic fauna comprising ~~of~~ over 92% during August to November at Station 1, over 74% during January and March at Station 2, over 91% during November to January at Station 3, over 82% during March at Station 4 and 100% during June at Station 7. Rest of the months recorded lower densities at all the stations.

Polychaetes were over 65% during March and April at Station 1, over 88% from April to December at Station 2, over 91% from June to August at Station 3, Over 62% during August at Station 4, over 94% during May at Station 5, over 85% during March, May and July to December at Station 6, over 77% in all months at Station 7 and 100% during March, July, September and October at Station 8, and over 78% during March to December at Station 9.

Molluscs constituted 100% during January at Station 3, over 78% of benthic population during May and September to December at Station 4 over 97% during June at Station 6, 100% during May at Station 7 and over 78% during April at Station 8.

Surprisingly only polychaetes were present during April at Station 2, only molluscs during January at Station 3, only insect larva during July at Station 5, only _Ephydra_ sp. during January at Station 6 and only chironomid larvae during January at Station 8.

Benthic fauna were totally absent during August and September at Station 5, during October at Station 6 and during June, August, November and December at Station 8.

Above results clearly indicated faunal succession at all stations during the period of study.

Even indicator species were not present in polluted stations during all months. The above facts clearly indicated that the presence or absence of benthic organisms depended, in addition to pollution effects, on a number of other environmental parameters.

Faunal diversity:

Of the 31 faunal groups identified consisting of five major and 26 minor ones, 16 groups each were present at Stations 1 and 2 followed by 14 groups each at Stations 3 and 9, nine groups each at Stations 4, 5, and 6, 7 groups at Station 7 and only three groups at Station 8. This clearly indicated a reduction in faunal diversity from 16 to 3.

Taking into consideration of the five major groups, all of them were present at Stations 1 to 4 and 6, whereas Stations

5 and 7 had three groups each and Stations 8 and 9 only two groups each.

Regarding the 26 minor groups a maximum of 12 of them were present at Station 9; followed by 11 each at Stations 1 and 2; 9 at Station 3; 6 groups at Stations 4 and 5; 4 groups each at Stations 6 and 7 and only one minor group at Station 8. Reduction in species diversity at Station 8 might be indicating the polluted environmental of that area.

4.2.4. Species occurrence, dominance and diversity:

Amphipods:

Seven species of amphipods were identified from 9 stations (Table 11 a - 11 i). All the 7 species were recorded only from Station 1, near the barmouth, whereas not even a single species was present at Stations 8 and 9. While Stations 2, 4 and 5 had six species each, Stations 3, 6 and 7 had 5, 3 and 4 species respectively. No amphipods were present in Stations 8 and 9, whereas, *Quadrivisio bengalensis* and Caprillidae were present in Seven stations, *Corophium triaenonyx* and *Grandidierella gilesi* in 6 stations and *Melita zeylanica*, *Ericopisa chilkensis* , and *G. bonnieri* at Stations 5, 4 and 2. *G. bonnieri* was not tolerant and was found more sensitive to low salinity. They were absent upstream in

Stations 3 to 9 but continued to thrive in Stations 1 and 2. The few exceptions to the above are stray occurrences. E. chilkensis occurred in few numbers during July and August in Station 1 and it continued to be less in Stations 4, 5 and 7 during January and March. G. gilesi was found in the salinity range of 3.4 to 3.7 %. at Stations 2 to 5. Corophium triaenonyx was found uniformly abundant at Stations 2, 3, 4 and 7, with very high values at Station 1 and very low values at Station 5, and total absence at Station 6. But for a high value at Station 6 and low values at Stations 4 and 1, Q. bengalensis was uniformly present at Stations 2, 3, 5 and 7. Whereas G. gilesi showed high values at Stations 2 to 5, Caprillidae showed high values at Stations 5, 6 and 7. Except for the above, rest of the species, G. bonnieri, M. zeylanica and E. chilkensis when present were only in few numbers.

An analysis of 7 amphipod species as percentage of total benthic fauna (Table 16) collected from Stations 1 to 9 revealed the following: Q. bengalensis showed an increase from Stations 1 to 3 and a decrease from Stations 4 - 7. Caprillidae, though present in very low percentage increased from Stations 1 to 5 and decreased from Stations 6/7. C. triaenonyx with very high percentage of 85.21 at Station 1 got reduced to low values of 12.57 to 34.33 % in Stations 2-4 and very low percentage from Stations 5 to 7. G. gilesi increased from Stations 1 to 3, decreased from Stations 4 to 6 reaching a very low at Station 6 and then was absent in Stations 7, 8 and 9. *M. zeylanica* with very low percentage increased from Stations 1 to 5. *E. chilkensis* noted in very very low percentage was absent in Stations 2, 3,6, 8 and 9. *G. bonnieri* with low percentage at Stations 1 and 2 was absent from Station 3 onwards.

Polychaetes:

Thirty polychaete species have been identified from the study area (Table 11 a to 11 i). Of these a maximum of 25 species were recorded from Station 1 (near barmouth). Other stations indicated substantial reduction in the number of species towards the upper reaches of the estuary, having comprised of 19, 10, 8, 7, 5, 6, 4 and 6 species at Stations 2 to 9 respectively.

Species-wise occurrence (Table 11 a to 11 i) showed presence of 2 species i.e. *Lycastis indica* and *Dendronereis aestuarina* in all the stations whereas 3 species i.e. *Heteromastides bifidus*, *Prionospio polybranchiata* and *Paraheteromastus tenuis* were noted at 7 stations each. *Capitella capitata* was present only in 6 stations. Those species present in 4 stations each were *Eunice tubifex* and *Owenia* sp. Three species namely *Glycera convoluta*, *Heteromastus similis* and *Perenereis cavifrons* were noticed in three stations each.

However, 2 stations recorded 9 species each i.e. Diopatra neapolitana, Pista indica, Ancistrosyllis constricta, Lumbriconereis notocirrata, Gonida emerita, Glycera alba, Nephthys oligobranchia, Talesmia annandalei and Nais sp. The rest 10 species were recorded from one station each. They are Notopygos sp., Lumbriconeriea simplex, Sthenelais boa, Sabellidae, Nephthys oligobranchia, Odontosyllis gravelyi, Serpula vermicularis, Aphroditidae, Lumbriconereis pseudobifilaris and Prionospio pinnata.

Of the 30 species of polychaetes identified the following 8 species namely P. polybranchiata, Notopygos sp., L. simplex, S. boa, Sabellidae, N. polybranchia, Odontosyllis gravelyi and S. vermicularis were recorded only from Station 1 near barmouth. Probably their absence at Stations 2 to 9 was caused by a fall in salinity from 21 to 0.2 ‰. Absence of Aphroditidae at Station 1 and its presence especially at Station 2 may be incidental. However absence of L. pseudobifilaris at Stations 1 to 8 and its presence in Station 9 is significant.

Regarding 9 species recorded from 2 stations each 7 of them namely D. neapolitana, P. indica, A. constricta, L. notocirrata, G. emerita, G. alba and N. oligobranchia were encountered from Stations 1 and 2. Their absence at Stations 3 to 9 may be attributed to environmental conditions prevailing at those stations. E. tubifex and Owenia sp. were seen at Stations 1 to 4 again controlled by environmental factors prevailing there. Capitella capitata not recorded at Station 1 were found in increasing abundance from Station 2 towards Station 7 (0.17 to 99.1%) indicating its tolerance to stress conditions. However its absence at Stations 5 and 8 can be due to lack of suitable substratum. Its presence at Station 9 might be a chance occurrence. H. bifidus and P. polybranchiata present in 7 stations each were found gradually reduced in abundance towards Station 7 indicating stress from industrial pollution. But their abundance at Station 4 shows its tolerance to pollution caused by retting. P. tenuis which showed increased occurrence from Stations 1 to 4 was reduced in abundance at Station 5 from leading to their absence at Stations 6 and 7, but gradually increased from 1 to 3.11% of the total benthos at Stations 8 and 9 respectively. Of the 2 species present in all stations L. indica with low densities at Stations 1 to 7 showed a sudden increase to 7.98 % in Station 8 and 50.99% at Station 9. D. aestuarina increased from 0.006% at Station 1 to 57.44% at Station 8, followed by a fall to 18.07 % at Station 9. However Station 7 with 0.69% recorded a very low occurrence.

<u>Dominance as percentage of total benthos</u>: (Table 16).

<u>Polychaeta</u>:

At Station 1, of the 25 species present 4 species namely *H. bifidus*, *L. simplex*, *D. neapolitana* and *P. polybranchiata* were the dominant ones forming only a maximum of 0.71%. However at Station 2, of the 19 species present *H. bifidus* formed 38.25% followed byy *P. polybranchiata* with 8.32%, *D. neapolitana* with 0.64% and *L. indica* with 2.28%. Of the 10 species noted at Station 3, *H. bifidus*, *D. aestuarina*, *L. indica* and *P. polybranchiata* formed 6.03, 5.77, 2.35 and 1.4% respectively. Station 4 had 4 dominant species out of 8 species present namely *P. tenuis*, *P. polybranchiata*, *H. bifidus*, and *D. aestuarina* forming 9.69, 5.42, 2.06 and 2.02 % respectively. Of the 7 species at Station 5, *D. aestuarina* (36.78%) dominated followed by *P. polybranchiata* with 3.13%. While 5 species were collected from Station 6, *Capitella capitata* with 52.8%, *D. aestuarina* with 29.7% and *P. polybranchiata* with 1.67% dominated. Station 7 with 6 species marked an abundance of *Capitella capitata* comprising 98.8%. *D. aestuarina* constituting 57.44% and *L. indica* with 8% were the dominant ones out of the 4 species present at Station 8. The almost fresh water dominated Station (9) had 6 species with *L. indica* with 51%, *D. aestuarina* with 18% and *Capitellidae* with 6.6% and *P. tenuis* with 3.1% in order of abundance. Of the above mentioned 6 most dominant species only 4 were prominent. C. capitata dominant at Stations 6 and 7, D. aestuarina dominant in Stations 5, 6, 8, and 9, L. indica at Station 9 and H. bifidus at Station 2.

Mollusca:

Of the 9 molluscan species identified, not a single species was recorded from all stations. However, one species Pandora flexosa was collected from 8 stations, another species Villorita cyprinoides was recorded at 6 stations, Litterina litterina at 5 stations, and the unidentified gastropod from 3 stations, 3 species namely Paphia papillions, Modiolus striatulus and Arca sp. from 2 stations each and one species each of Meretrix casta and Batissa sp. was collected from one station each.

While 7 species were noticed at Station 1, 6 species at Station 2, 4 at Station 3, 3 each at Stations 4, 5 and 9, 2 species at Station 6 and 1 species each was recorded in Stations 7 and 8. An analysis of their dominance (Table 16) indicated an increasing abundance of P. flexosa from 0.01 at Station 1 to 30.61% at Station 8. However it was not present at Station 9. The second species in abundance was V. cyprinoides which comprised 35.4% at Station 4 with reduced density on either side. Equally dominant was Litterina litterina which at Station 5 exhibited a sudden spurt from 0.02% to 34.3%, thereafter showing total absence.

Minor Groups:

Isopods - Of the 2 isopod species identified *Anthuridae* was present at Stations 1 to 4 and 6 whereas *Cirrolinia fluviatilis* was recorded at Stations 1 to 3,. While both species were recorded at Stations 1 to 3, Stations 4 and 6 had only *Anthuridae* sp., *Cirrolinia* sp. (Table 16) forming 1.9% of total benthos at Station 1 could tolerate the lower salinity in some months near barmouth.

Tanaidaceans also were represented by 2 species *Apseudes gymnophobium* and *Apseudes chilkensis*. While both were present at Stations 1 and 2, Station 3 had only *A. chilkensis*, whereas Stations 4 and 6 recorded *A. gymnophobium* only. Of the total population in those stations, their representation was meagre.

Among other 26 minor groups recorded, 13 of them are fresh water forms listed in Table 16. Of this special mention may be made on the occurrence of chironomid larvae in view of their role as indicators of pollution. They were present at 7 stations except the one near barmouth and Station 6. A maximum of 2 percent was noted at Station 8 in the area of effluent discharge with comparatively low percentage in other stations.

Table - 16. Percentage frequency of different benthic species/groups at different stations.

Sl. No.	Species	STATIONS 1	2	3	4	5	6	7	8	9
	POLYCHAETES									
1.	*Diopatra neapolitana*	0.14	0.64							
2.	*Heteromastides bifidus*.	0.25	38.25	6.03	2.06	1.00	0.88	0.04	-	-
3.	*Prionospio polybranchiata*	0.11	8.32	1.40	5.42	3.13	1.67	0.02	-	-
4.	*Pista indica*	0.08	0.07	-	-	-	-	-	-	-
5.	*Ancistrosyllis constricta*.	0.02	0.97	-	-	-	-	-	-	-
6.	*Lumbriconereis notocirrata*.	0.03	0.13	-	-	-	-	-	-	-
7.	*Eunice tubifex*.	0.008	0.03	0.02	0.02	-	-	-	-	-
8.	*Goniada emerita*.	0.01	0.07	-	-	-	-	-	-	-
9.	*Paraheteromastus tenuis*.	0.03	0.94	0.63	9.69	1.00	-	-	1.0	3.11
10.	*Prionospio pinnata*	0.02	-	-	-	-	-	-	-	-
11.	*Glycera convoluta*.	0.02	0.27	0.04	-	-	-	-	-	-
12.	*Lumbriconereis simplex*.	0.21	-	-	-	-	-	-	-	-
13.	*Lycastis indica*.	0.02	2.28	2.35	0.64	0.33	0.27	0.01	7.97	50.99
14.	*Glycera alba*.	0.006	0.24	-	-	-	-	-	-	-
15.	*Dendronereis aestuarina*.	0.006	3.44	5.77	2.02	36.78	29.73	0.69	57.44	18.07
16.	*Heteromastus similis*.	0.005	0.57	-	0.02	-	-	-	-	-
17.	*Perinereis cavifrons*.	0.03	0.37	0.13	-	-	-	-	-	-
18.	*Sthenelais boa*.	0.04	-	-	-	-	-	-	-	-

Contd...

Table - 16. (Contd.)

Sl. No.	Species	STATIONS 1	2	3	4	5	6	7	8	9
	POLYCHAETES									
19.	Sabellidae.	0.01	-	-	-	-	-	-	-	-
20.	Nephthys oligobranchia.	0.005	0.5	-	-	-	-	-	-	-
21.	Nephthys polybranchia.	0.0007	-	-	-	-	-	-	-	-
22.	Notopygos sp.	0.0007	-	-	-	-	-	-	-	-
23.	Odontosyllis gravelyi.	0.0007	-	-	-	-	-	-	-	-
24.	Owenia sp.	0.0007	0.34	0.02	0.02	-	-	-	-	-
25.	Serpula vermicularis.	0.0007	-	-	-	-	-	-	-	-
26.	Aphroditidae.	-	1.67	-	-	-	-	-	-	-
27.	Capitella capitata.	-	0.17	0.08	-	0.5	52.8	98.77	-	6.63
28.	Talehsapia annandalei.	-	-	-	-	0.17	-	-	1.0	-
29.	Nais sp.	-	-	-	-	-	-	0.15	-	0.11
30.	Lumbriconereis pseudobifilaris	-	-	-	-	-	-	-	-	0.64
	AMPHIPODS									
1.	Corophium triaenonyx.	85.21	12.57	34.33	18.57	0.33	-	0.14	-	-
2.	Quadrivisio bengalensis.	8.78	10.06	14.11	2.09	3.63	0.71	0.09	-	-
3.	Grandidierella gilesi.	2.99	13.33	26.70	11.80	5.10	0.09	-	-	-
4.	Grandidirella bonnieri.	0.34	0.30	-	-	-	-	-	-	-
5.	Melita zeylanica.	0.05	0.47	0.43	0.02	1.32	-	-	-	-
6.	Ericopisa chilkensis.	0.03	-	-	0.02	0.33	-	0.006	-	-
7.	Caprillidae.	0.005	0.1	1.36	0.55	2.85	0.35	0.05	-	--

Table - 16. (Contd.)

Sl. No.	Species	STATIONS								
		1	2	3	4	5	6	7	8	9
	MOLLUSCS									
1.	*Pandora flexosa*.	0.01	0.10	2.33	4.83	5.09	10.01	0.06	30.61	-
2.	*Modiolus striatulus*.	0.17	-	0.06	-	-	-	-	-	-
3.	*Paphia papillions*.	0.003	0.20	-	-	-	-	-	-	-
4.	*Arca* sp.	0.02	0.30	-	-	-	-	-	-	-
5.	*Meritrix casta*	0.007	-	-	-	-	-	-	-	-
6.	*Litterina litterina*.	0.02	0.03	0.58	5.88	34.31	-	-	-	-
7.	Gastropod (unidentified).	0.003	0.17	-	-	-	-	-	-	0.54
8.	*Villorita cyprinoides*.	-	0.80	2.39	35.41	0.66	2.29	-	-	0.65
9.	*Batissa* sp.	-	-	-	-	-	-	-	-	0.32
	ISOPOD									
1.	Anthuridae.	0.007	0.40	0.51	0.85	-	0.09	-	-	-
2.	*Cirrolinia fluviatilis*.	1.95	0.10	0.02	-	-	-	-	-	-
	TANAIDACEANS									
1.	*Apseudes gymnophobium*.	0.01	0.07	-	0.07	-	0.09	-	-	-
2.	*Apseudes chilkensis*.	0.18	0.27	0.15	-	-	—	—	—	-

Contd...

Table - 16. (Contd.)

Sl. No.	Species	STATIONS 1	2	3	4	5	6	7	8	9
	OTHER MINOR GROUPS									
1.	Sea anemone	0.17	-	-	-	-	-	-	-	-
2.	Decapoda	0.008	0.17	-	0.12	2.15	-	-	-	-
3.	*Balanus* sp.	0.003	-	-	-	-	-	-	-	-
4.	*Alphids* sp.	0.001	-	-	-	-	-	-	-	-
5.	*Acetes* sp.	0.0007	-	-	-	-	-	-	-	-
6.	Insect larvae	0.001	0.03	-	-	0.33	-	0.02	-	0.54
7.	Echinoderm larvae	0.008	0.10	-	-	-	-	-	-	-
8.	Fish larvae	0.003	0.03	0.02	-	-	-	-	-	-
9.	Nematoda	0.04	0.13	0.02	-	-	-	-	-	-
10.	Sipunculoidea.	0.009	0.17	0.02	-	-	-	-	-	-
11.	Flat worm.	-	0.10	0.02	-	-	-	-	-	-
12.	Cumacea.	-	0.03	0.02	0.14	-	-	-	-	-
13.	*Plectronemia*. sp.	-	0.47	0.02	-	-	-	-	-	5.10
14.	Chironomid larvae.	-	0.07	0.50	0.02	0.17	-	0.006	2.0	0.11
15.	Tanytarsus.	-	0.03	0.02	-	0.33	-	-	-	0.86

Contd..

Table - 16. (Contd.)

Sl.No.	Species.	STATIONS 1	2	3	4	5	6	7	8	9
	<u>OTHER MINOR GROUPS (Contd.)</u>									
16.	*Ephydra* sp.	-	-	0.02	-	-	0.09	-	-	0.32
17.	Simulium.	-	-	-	-	0.33	-	-	-	-
18.	*Cricotopus sylvestris.*	-	-	-	-	0.17	-	-	-	-
19.	*Anatopynia* sp.	-	-	-	-	-	0.70	0.006	-	1.29
20.	*Bezzia* sp.	-	-	-	-	-	0.09	-	-	-
21.	*Diamesa* sp.	-	-	-	-	-	-	0.006	-	2.78
22.	*Baetis* sp.	-	-	-	-	-	-	-	-	0.11
23.	*Platambus* sp.	-	-	-	-	-	-	-	-	0.22
24.	May Fly Larvae.	-	-	-	-	-	-	-	-	0.11
25.	Water beetle.	-	-	-	-	-	-	-	-	0.65
26.	Unidetified Crustacean larva.	-	-	-	-	-	0.18	-	-	0.11

Species diversity:

The diversity of a benthic community may be expressed using data of number of individuals on the number of species present. From a heuristic approach an index of diversity may be used in the same way as other environmental parameters as salinity/temperature erc. to explain the distribution of the species. Hence an attempt was made to determine the diversity index at the 9 stations of the study area.

The Fisher's diversity index α and its variance $V(\alpha)$ and Shanon Wiener diversity function H (S) at Station 1 (Table 17 a) indicated that more and more species occur during post and premonsoon periods and that diversity did not alter very frequently. It changed gradually. Mac Arthur's coefficient of equitability being more than 50% during post and premonsoon butless than 25% during the monsoon period, showed that due to the inequitability in the distribution of the individuals among the species, the sample community had a species diversity appropriate to a community of only 50% as many species as actually occurred during pre and post-monsoon period, except December, while only 25% during the monsoon period.

Table - 17 a. Showing values of number of specimens (N), number of species (S), diversity index (α) its variance ($V(\alpha)$), Shannon-Wiener function ($H(S)$), $\bar{S}$ and Mac Arthur's equitability coefficient (ε), at Stn. 1.

Months	N	S	α	$V(\alpha)$	H(S)	$\bar{S}$	ε (%)
January	7,601	24	3.07	0.09	3.13	12	50.00
March	12,511	29	3.55	0.09	3.69	18	62.06
April	1,148	13	2.05	0.10	1.89	5	38.46
May	6,119	24	3.09	0.09	2.91	10	41.67
June	2,309	9	1.19	0.04	2.37	7	77.77
July	61,164	14	1.30	0.02	1.29	3	21.43
August	78,109	15	1.37	0.02	1.34	4	26.66
September	29,000	13	1.29	0.01	0.73	2	15.38
October	21,394	15	1.58	0.03	0,88	2	13.33
November	60,884	21	2.04	0.03	2.14	6	28.57
December	406	16	3.32	0.22	3.61	18	112.50

α, V (α) and H (S) at Station 2 (Table 17 b) showed maximum values during pre and postmonsoon and very low value during monsoon as is the case with Station 1 resulting in the presence of largest number of species during pre and post-monsoon and their absence during monsoon period, this period being unfavourable to those species. Equitability coefficient with maximum at July and minimum in October was found changing in a zig zag manner throughout the year probably due to increased external disturbance, as accordingly sample community throughout the period at this station was found to be only nearly 50% of the species actually occurred in order to have the same diversity.

Table - 17 b. Showing values of number of specimens (N), number of species (S), diversity index(α), its variance (V (α)), Shannon-Wiener function (H (S)), $\bar{S}$ and Mac Arthur's equitability coefficient (ε) at Stn. 2.

Months	N	S	α	V(α)	H(S)	$\bar{S}$	ε(%)
January	12,243	19	2.20	0.05	2.32	7	36.84
March	7,079	20	2.52	0.07	1.82	5	25.00
April	1,030	2	0.24	0.01	0.36	1	50.00
May	2,160	19	2.87	0.13	3.15	13	68.42
June	1,280	7	0.97	0.04	1.44	3	42.85
July	557	5	0.74	0.03	1.51	4	80.00
August	6,546	6	0.65	0.01	0.53	2	33.33
September	2,518	7	0.88	0.03	0.82	2	28.57
October	3,075	8	0.96	0.03	1.10	2	25.00
November	1,963	15	2.21	0.09	2.95	11	73.33
December	3,061	18	2.53	0.99	2.01	5	27.78

α and V (α) values at Station 3 (Table 17 c) were comparatively high during the end of the premonsoon and up to the middle of the monsoon and very low during the rest of monsoon period. More species occurred from the end of pre-monsoon to the middle of monsoon period, this being the most favourable period. However compared to Stations 1 and 2 this station had less diversity. Increase in the number of species was a slow process to be ended with the onset of postmonsoon. H (S) values however were higher than α . Equitability values were also high being 125% for September indicating that the diversity will remain the same till the number of species goes up by 25%.

α values at Station 4 (Table 17 (d) were maximum in January, very low during other postmonsoon months and almost constant during premonsoon and monsoon periods. V (α) was relatively high in January, pre and monsoon periods. Species which occurred from January to monsoon period slowly got perished with the onset of postmonsoon indicating that the most favourable period for benthic organisms was the premonsoon and monsoon periods. H (S) values were comparatively high eventhough they all were of the same pattern. Equitability coefficient was very high (100%) during October indicating most even distribution of individuals. Nearly 68% of the time points (months) had a species diversity appropriate to a community of more than 50% of species as much as actually occurred during these months.

Table - 17 c. Showing values of number of specimens (N), number of species (S), diversity index (α), its variance (V (α)), Shannon-Wiener function (H (S)), $\bar{S}$ and Mac Arthur's equitability coefficient (ε) at Stn. 3.

Months	N	S	α	V(α)	H(S)	$\bar{S}$	ε(%)
January	15	1	0.24	0.03	0.00	1	100.00
March	23,097	10	0.99	0.03	0.92	2	20.00
April	5,772	19	2.45	0.02	2.74	9	47.36
May	5,368	15	1.89	0.07	2.89	10	66.67
June	335	7	1.22	0.05	2.30	7	100.00
July	2,378	11	1.49	0.07	2.16	6	54.54
August	2,415	9	1.18	0.05	2.00	5	55.56
September	155	4	0.75	0.05	1.82	5	125.00
October	1,502	4	0.50	0.01	1.58	4	100.00
November	8,065	9	1.00	0.02	1.49	4	44.44
December	28,061	8	7.77	0.01	1.59	4	50.00

Table - 17 d. At Station 4.

January	3,057	19	2.63	0.09	2.95	11	57.89
March	20.007	8	0.79	0.01	1.75	4	50.00
April	4,506	15	1.93	0.05	2.40	7	46.67
May	14,990	12	1.28	0.03	1.73	4	33.33
June	530	7	1.14	0.06	1.56	4	57.14
July	12,906	11	1.18	0.02	1.67	4	36.36
August	419	7	1.19	0.07	1.80	5	71.43
September	1,198	7	0.99	0.04	1.39	3	42.85
October	669	2	0.25	0.01	4.15	2	100.00
November	293	2	0.29	0.01	0.28	1	50.00
December	767	6	0.81	0.04	1.96	5	83.33

α values at Station 5 (Table 17 e) being comparatively high during postmonsoon and in the begining of monsoon periods, the middle of monsoon period (August and Sept.) was the most unfavourable, as evidenced by the nonoccurrence of species. V (α) and H (S) were high during postmonsoon and beginning of pre-monsoon indicating occurrence and disappearance of species. All the months (time points) having high equitability coefficient especially from June to December, in this station, in this period, all being the most unfavourable, evenness is attained in distribution by the absence of species unlike other stations. Whereas, the distribution tended to be uneven during January to May due to occurrence of more species.

At Station 6 α and H (S) values (Table 17 f) got reduced from the beginning of premonsoon through monsoon to postmonsoon. With the high value in July, variance of α was same throughout the year, July with maximum. Mc Arthur's coefficient of equitability (100%) showed that during postmonsoon with a few species distribution had become more and more even than in other periods with more species.

Table - 17 e. Showing values of number of specimens (N), number of species (S), diversity index (∝), its variance (V (∝)), Shannon-Wiener function (H (S)), S̄ and Mac Arthur's equitability coefficient (ε) at Stn. 5.

Months	N	S	∝	V(∝)	H(S)	S̄	ε(%)
January	210	3	0.50	0.03	0.91	2	66.67
March	206	12	2.78	0.34	2.77	9	75.00
April	5,601	9	1.05	0.03	1.71	4	44.44
May	265	2	0.29	0.01	0.30	1	50.00
June	57	3	0.67	0.11	1.50	4	133.33
July	15	1	0.24	0.03	0	1	100.00
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
October	29	2	0.49	0.07	1.00	2	100.00
November	71	3	0.63	0.06	1.57	3	100.00
December	99	5	1.11	0.12	2.24	6	120.00

Table 17 f. At Station 6.

Months	N	S	∝	V(∝)	H(S)	S̄	ε(%)
January	15	1	0.24	0.03	0	1	100.00
March	3,462	2	0.21	0.004	0.04	1	50.00
April	1,783	8	1.08	0.04	1.84	5	62.50
May	335	5	0.83	0.03	1.14	3	60.00
June	1,044	3	0.38	0.01	0.21	1	33.33
July	321	5	0.84	0.05	1.18	3	60.00
August	5,437	6	0.67	0.01	0.50	2	33.33
September	279	3	0.38	0.01	1.14	3	100.00
October	1	0	0	0	0	0	0
November	43	1	0.18	0.01	0	1	100.00
December	140	2	0.33	0.02	0.72	2	100.00

At Station 7 (Table 17 g), low values of α except for March indicated low species diversity irrespective of very large number of individuals. Few species appeared during the change over period from postmonsoon to premonsoon but disappeared with the advance of monsoon and postmonsoon period which proved to be most unfavourable with only 2 species for benthos. H (S) values were different from that of α values due to less number of individuals. Equitability coefficient during the period with high values of α were found to be nearly 60% on an average i.e. diversity present is appropriate to a community of only 60% of the species as much as present now.

Station 8 (Table 17 h) had generally very small α values due to occurrence of a few number of species but with large number of individuals, that too only in premonsoon. Particularly during monsoon and postmonsoon no species was found, but for a few numbers in July and September. Appearance of a few species in September and which perished with the onset of post-monsoon season was indicated by high values of N (α) in September. H (S) values, eventhough agreed with the above results, were high. At all months, but for May equitability coefficient was 100% i.e. the diversity obtained was the actual diversity which indicated that the number of individuals was evenly distributed among the species. This evenness was strictly due to the lesser number of species.

Table - 17 g. Showing values of number of specimens (N), number of species (S), diversity index (α), its variance (V (α)), Shannon-Wiener function (H (S)), $\bar{S}$ and Mac Arthur's equitability coefficient (ε) at Stn. 7.

Months	N	S	α	V(α)	H(S)	$\bar{S}$	ε(%)
January	3,345	4	0.45	0.01	0.72	2	50.00
March	742	9	1.44	0.05	1.72	4	44.44
April	1,240	4	0.51	0.02	1.09	3	75.00
May	15	1	0.24	0.03	0	1	100.00
June	57	2	0.40	0.04	1.00	2	100.00
July	14,514	4	0.38	0.002	0.04	1	25.00
August	3,046	5	0.58	0.01	0.24	1	20.00
September	974	3	0.38	0.001	0.02	1	33.33
October	9,147	1	0.09	0	0	1	100.00
November	2,851	1	0.01	0	0	1	100.00
December	1,141	2	0.24	0.01	0.46	2	100.00

Table - 17 h. At Station 8.

January	29	1	0.20	0.02	0	1	100.00
March	654	1	0.12	0.02	0	1	100.00
April	459	2	0.27	0.01	0.75	2	100.00
May	125	3	0.32	0.01	1.49	4	133.33
June	0	0	0	0	0	0	0
July	15	1	0.24	0.03	0	1	100.00
August	0	0	0	0	0	0	0
September	85	2	0.37	0.07	0.65	2	100.00
October	15	1	0.24	0.03	0	1	100.00
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0

In Station 9 (Table 17 i) α values, V (α) and H (S) values were high during December and January in postmonsoon and in July during monsoon. The results revealed that the species at Station 9 were present only for short periods in an year, displaying a clearly multimodel distribution. Equitability coefficient was more than 50% except for September and October indicating a diversity of community having 50% less species than this community.

Table - 17 i. Showing values of number of specimens (N), number of species (S), diversity index (α), its variance (V(α)), Shannon-Wiener function (H (S)), $\bar{S}$ and Mac Arthur's equitability coefficient (ε) at Stn. 9.

Months	N	S	α	V(α)	H(S)	$\bar{S}$	ε(%)
January	683	8	1.27	0.06	1.94	5	62.59
March	422	3	0.44	0.02	0.85	2	66.67
April	962	5	0.69	0.03	1.48	4	80.00
May	3,276	6	0.71	0.08	1.48	4	66.67
June	696	6	0.90	0.04	1.25	3	50.00
July	474	11	2.01	0.14	2.95	11	100.00
August	947	5	0.69	0.02	1.50	4	80.00
September	2,032	6	0.76	0.02	0.99	2	33.33
October	2,059	6	0.76	0.02	1.90	2	33.33
November	781	6	0.88	0.04	1.42	3	50.00
December	4,190	9	1.09	1.03	2.00	5	55.55

4.2.5. Impact of environmental parameters on the distribution of macrobenthos:

The pattern of distribution of benthic fauna exhibited considerable variation both qualitatively and quantitatively at the different stations of the study area round the year. The estuary, being a transition area between the more stable marine and fresh water environments; the animals inhabiting this biotope have to be highly accommodative to cope with the stress brought about by the wide variations in physical and chemical features of the water column and the sediment. On ranking the 9 relatively important parameters at each station based on the multiple regression analysis, it was found that, considerable variations in the relative importance of parameters occurred from station to station. Eventhough the estuarine benthic fauna could tolerate wide range of salinity, it turned out to be deciding factor at Stations 2 to 9 except Station 5. Role of temperature was insignificant, whereas, importance of oxygen BOD_5 values when noted were inversely propertional. While nitrate was of great importance at Stations 1 to 3, rest of the stations indicated only an average nature. But for Station 5, rest of the stations had light attenuation coefficient at the middle level of importance. Role of remaining parameters were of low magnitude.

The study of benthic fauna during the investigation revealed a progressive reduction in the number of taxa from the mouth of the estuary (near barmouth) to the upstream stations up to the discharge site (Stn. 8). Of the 76 species recorded 53 species belonging to different taxa were encountered at Station 1. This was reduced to 45, 31, 24, 22, 16, 16, and 6 at Stations 2 to 8. Station 9 (upstream of the discharge site) recorded a high diversity (22) which included mainly fresh water forms.

In general, fauna of a tropical estuary comprises of marine, brackish and fresh water species. The brackish water fauna must be able to put up with the wide fluctuations in physical conditions especially salinity caused by the seasonal and tidal changes. The population of marine species inhabiting the estuary are by and large restricted to the barmouth area.

Sanders et al. (1965) demonstrated that infauna species survived in interstitial water but died in the ebb water flowing over the sediments in the locality where they were collected. That is why marine infaunal species occur further up in the estuary than do marine epifaunal species (Sanders et al., 1965; Cariker, 1967).

A major behavioural adaptation of estuarine benthic animals is their widespread burrying behaviour. Reid (1930, 1932), Sanders et al. (1965) and Wolff (1973) recorded more stable salinities within sediments and on an average higher than that in the water flowing over them.

Density of benthic fauna was high during summer months except at the barmouth (Stn. 1) and Stations 6 and 7. Maximum density recorded at Station 1 was 18,62,428/m^2 in August. 98.7% of this was constituted by the amphipod species, Corophium triaenonyx which can tolerate low salinity. Abundance of fauna near barmouth region may be attributed to favourable condition for the marine and estuarine life as observed by Desai and Krishnan Kutty (1967). They recorded a maximum benthic density of 8,137/m^2. Polychaetes and bivalves formed the dominant groups in their study. Kurian (1972) recorded a benthic population of 35,000/m^2 in the Cochin backwater. Ansari (1977) reported a much lower density constituted by polychaete, bivalves, amphipods and decapods. Desai and Krishnan Kutty (1967) also noticed a progressive decrease in the annual population from the lower part of backwaters towards the upper reaches. Variations in salinity has been attributed as a major factor in limiting the distribution of benthic fauna in coastal waters (Seshappa, 1953 and Kurian, 1972). The low density during monsoon may be due to the fall in salinity. Devassy and Gopinathan (1970) have noted an increase in benthic biomass from marine to fresh water region during monsoon in Cochin backwaters. Large portion of phytoplankton and zooplankton production in estuaries contribute to the productivity of coastal waters and form a major source of organic matter in the bottom deposits. This helps to sustain a rich benthic life.

The turbidity of Vembanad lake remain high especially during monsoon and hence the euphotic zone becomes narrow (Qasim & Reddy, 1967). Owing to the shallowness of the lake the phytoplankton sinks to the euphotic zone quickly and may be availabl as main food source for the benthic fauna which are either filter feeders or detritus feeders. Pillai (1978) observed the maximum production of benthos in pre and postmonsoon periods where the primary production is also very high. He also noticed a direct correlation between the benthic production and organic production in the Cochin backwater. Rao (1967) and Kuttiyamma (1971) observed that most of the commercially important species of prawns (*Penaeus monodon* & *P. indicus*) consume amphipods, decapoda, polychaetes, small bivalves and isopods, in addition to organic detritus. They also noticed that macrobenthos play an important role in the food chain of Cochin estuary. The macrobenthos constituted predominantly by polychaetes, crustacea and bivalves appear to form an important component of food of fishes and prawns in the estuary. The reduction inthe number of species towards the upstream station is a noticeable feature here. This is due to the fluctuation in salinity in this region. The effect of salinity and the saline water intrusion were noticed up to Station 5 which is considered to be the margin of fresh water zone. In the case of amphipod population six species were identified. Most of these are euryhaline species and hence their presence in the upstream. The benthic fauna at Stations 6 and 7 showed higher abundance in monsoon, constituted mainly by the polychaete Capitella capitata, maximum density of the species (1,90,533/m^2) being recorded in September.

Low diversity and higher population levels of a few organism denote some major stress condition which eliminate many species but promotes survival of a few. Contrary to this, high diversity and a little dominance of species characterises areas of relative environmental stability. Low diversity and lower number of benthic fauna at Eloor (Stn. 8) indicate the prevalence of stress condition. This effect was reduced slowly towards the downstream because of dilution and hence an increased species diversity. Ganapati and Raman (1973) and Zingde et al. (1980a) are of the opinion that though the effect of the industrial effluents are not apparent in the beginning, the cumulative effect of continued discharge will endanger the safety of aquatic life and can reach the human body through the food chain.

In the present study benthic fauna was found to be very low both in abundance and diversity at Station 8 where industrial effluents are discharged. But it increased at stations away from this point since the concentration of the effluents are gradually diluted and finally nullified. While this is so at the industrial discharge point, the faunal composition exhibited a different picture from the sewage discharge point and the retting yard in the Cochin backwaters where Remani (1979) recorded 45 and 15 species respectively belonging to different groups. The higher abundance of benthic organisms in these polluted environments could be due to the organic enrichment while the various chemical contents of the industrial effluents affect adversely the survival of many benthic species. Jayapalan et al. (1976) have also reported the deleterious effect of the effluents on the plankton productivity in the area. Fish mortality due to high ammonia content was noted by Unnithan et al. (1977). Sarala Devi et al. (1979) had already noticed the absence of benthic fauna in this effluent discharge point. To, sum up, it can be stated that the low density and diversity of benthic fauna at the effluent discharge point may be due to the cumulative toxic effects.

Benthos and substratum:

The composition of the sediment is of vital importance to the biota of an estuary. The supply and source of these materials and sites of deposition depend upon the estuarine type, wave action and tidal regime. The nature and rate of sediments deposited affects the density and nature of biota in the area. Increase in sediments resulting from coastal structure and various industrial effluents may drastically alter the number and type of species dwelling in the region.

It has been well documented that qualitative and quantitative distribution of benthic fauna has a direct relationship with the type of the bottom and the physical nature of the substratum act as a limiting factor to a great extent Sanders, 1958). Bloom et al. (1972) and Brodovsky (1964, 1965) stated that sediments are not only the substrate in which benthic organisms exist but also the main source of food for many of them. The presence of high concentration of phosphate in fine grained substratum has been reported by several workers (Jitts, 1959, Balasubramanian, 1961, Anzari and Rajagopal, 1974; Mortimer, 1941 and Rochford, 1951). The importance of mud nutrients especially phosphate content which has a strong bearing on the organic production of water above has been shown by Mortimer (1941) and Rochford (1951). Murthy and Veerayya (1972) and Bhosle et al. (1985) pointed out that apart from hydrographic changes, materials brought in, drained by river discharge plays an important role in the cycle of organic matter, in the sediments of Cochin backwaters. Nair et al. (1984) stated that various physiographic features of the estuary are believed to play a role in the distribution and deposition of the sediment particles in the bed of Ashtamudi estuary.

Newell (1965) found that population densities, sediment grain size and organic carbon concentration were strongly inter-related. The highest density of deposit feeders occurred in areas with fine grained sediments and high levels of organic carbon. Similar observation was reported by Longbottom (1970). Soft Bottom marine communities are dominated in terms of numbers and biomass by polychaetes, bivalves and amphipods (Sanders, 1956, Sanders & Hessler, 1969).

In the present study, Stations 1 and 2 where the bottom was silty clay with higher organic content also supported a large abundance of bottom fauna. However regression analysis showed different species being present at the 2 stations with reference to the most abundant, least consistent and comparatively homogeneous species. Similarly the group of co-existing species tolerant to the common physical environment at each station, were different. Though the bottom texture at Stations 7 and 8 was clayey silt, the population at Station 8, where the effluent is discharged, had a low benthic life while Station 7 showed a very high biomass which was mainly constituted by polychaetes which were tolerant of such an environment. While Dendronereis aestuarina formed the least consistent and the most abundant species at Station 8, Capitella capitata and Dendronereis aestuarina formed the most abundant and least consistent species respectively at Station 7. The sandy bottom at Stations 4, 5 and 6 supported a high bivalve population, mainly of Villorita cyprinoides, while formed the abundant species at Station 4. But Dendronereis aestuarina formed the most abundant and the least consistent species at Stations 5 and 6 respectively. Also the homogeneous species at these 3 stations were different.

The benthic fauna of polluted habitats:

Seventy six different species of benthos have been identified from the study area. The number of individuals of each species ranged from 14 to 18,00,777 per station. The average number of individuals per station for the abundant species was about 4,63,000 per station, while the monthly average number of individuals per station varied between 128 and 1,92,124. Thus over 2.47 million individuals were used to prove or disprove variability and even existence of real estuarine benthic communities.

The results are first discussed in a more or less classical sense and then they were evaluated statistically. The distribution of the organisms within an estuary in time and space is the product of the physical, chemical and biological gradients on the genotype, physiological tolerance and behaviour of the total number of species available from all sources (Carriker, 1967). One of the most important factors modifying the estuarine environment leading to secondary succession in the estuarine communities is pollution.

Wide distribution of some euryhaline species as the amphipod species *Corophium triaenonyx*, *Quadrivisio bengalensis*, *Grandidierella gilesi*, and the mollusc species *Pandora flexosa* etc. lead to a remarkable correspondence between the fauna of different habitats in the same salinity zone as noted by Pauli Bagge (1969). Also faunal composition varied station to station, the dominant species in polluted stations being different from other stations.

Pauli Bagge (1969) analysing the effects of pollution on estuarine ecosystem found a major role for oxygen and salinity in deciding the composition of benthic fauna. In areas of low oxygen content inthe bottom while he noted dominance of oligochates and chironomids in the oligo and mesohaline zones, these were replaced by the capitellids and spionids in the more saline environments. Wherever the oxygen content near the bottom is low there is a tendency for limiverous (Non-selective deposit feeder) species or some selective deposit feeders to dominate the type species groups.

Nair *et al*.(1984) analysing the ecology and distribution of benthic macrofauna in the Ashtamudi estuary observed their maximum occurrence in station close to the sea and minimum at stations polluted by effluents from Punalur Paper Mills in the lower reaches of the river.

Industrial waste accumulation decreased macrofaunal abundance during premonsoon and postmonsoon associated with low dissolved oxygen and high nutrient values. Increase in biomass and population count associated with better water quality during monsoon support the above. Very low benthic production were noted in polluted waters.

Nirmala et al. (1976) observing on the pollution of Chaliyar river by the effluent of Gwaliyor Rayon Factory found the pollution caused by the effluents adversely affected not only the fish but also the whole fauna of the river. They found the high percentage of acidity or alkalinity, the high concentration of reducing sugars in the effluent and presence of carbonates, bicarbonates and chlorides in water highly fatal to fish.

Nair et al. (1984) made quantitative studies on the distribution of the different groups of benthic fauna in the Ashtamudi estuary of Kerala. They found the benthic fauna comprised of eleven taxa namely Nemertenia, Grastrotricha, Oligochaeta, Polychaeta, Amphipoda, Isopoda, Tanaidacea, Insect larva, Sipunculoida, Gastropoda and Bivalve compared to 31 groups in the present area (Table 16). However Gastrotricha, nemertines and oligochaets were not recorded in the study area. As noted by Nair et al. (1984) and Remani (1979) the fauna of the polluted Station 8 and adjacent Station 7 was found quantitatively extremely poor (excepting Capitella capitata).

As was the case with Ashtamudi estuary polychaetes were present in all stations and the highest numerical abundance of benthos was observed at Station 1, near barmouth and the lowest at Station 8 located in the effluent discharge area. The highly favourable hydrographic conditions and the high rates of primary production may be the main factor for the higher abundance at Station 1 (Nair *et al.*, 1983).

Many of the polychaete species reported from the present study area have been reported earlier by Divakaran *et al.* (1981) from Neendakara; Murugan *et al.* (1980) from Veli lake and Nair *et al.* (1984 from Ashtamudi estuary. As in the present study, polychaete formed the largest group, of benthic organism at Shertallai beach (Trevallion *et al.*, 1970), in the mud banks of Kerala (Damodaran, 1973) and in the Vellar estuary (Ajmal Khan *et al.*, 1975).

The richest amphipod population in terms of incidence, number and species was found at Station 1 and the poorest in Stations 6 and 7 with total absence in Stations 8 and 9.

The absence of isopods and tanaidaceans, in estuarine areas are attributed to the highly unstable characteristics of the bottom sediments prevailed in the area.

Molluscan population in the study area was mostly contributed by the pollution tolerant species *Pandora flexosa* and the extensively exploited species *Villorita cyprinoides* occurring in salinities ranging widely.

Migration of estuarine benthic animals seems to be fairly common mainly relying more or less passive transport by tidal currents as noted for snails (Newell, 1968) and for *Arenicola* species (Wolff and Dewolf, 1977). Migration into and out of the estuary also occur among benthic animals as crabs, and larvae of oysters and barnicles migrate for reproductive or nursery functions. Since exploitation of benthic animals is done only during favourable periods, these animals are often characterised with ecological adaptations achieved by migration as seen among crustaceans.

Another opportunistic method of exploitation is found among polychaetes and molluscs, which rapidly colonise an area rapidly with their pelagic larvae, during favourable periods, reproduce quickly and thus are able to build up large populations. When the circumstances become less favourable these species disappear rapidly by owing to mortality. Species showing this kind of behaviour are the polychaetes, *Capitella capitata*, *Polydora ligni*, *Streblospio benedicti* and molluscs *Mytilus edulis* etc. (Wolff *et al*., 1977, Grassle and Grassle, 1974).

There are no consistant relationship noticed in the seasonal variation of crustaceans at different stations.

Patchy distribution:

Patchy occurrence of 6 species were recorded in the study area. Of these *Capitella capitata* were found in Stations 6, 7 and 9. The sediment texture at Stations 6 and 7 was compos of black clayey silt and at Station 9 it was reddish brown and sandy nature. This indicated their preference to black clayey silt sediment. But at Station 8 with similar sediment did not have even a single individual of Capitella capitata, probably an attempt to avoid the higher concentration of toxic effluents. However, majority of the polychaetes collected from Station 8 belonged to a spevies Dendronereis which was able to tolerate the toxic conditions compared to Capitella capitata.

Organic matter at Stations 6 and 7 varied from 11.6 to 32.2 mg/l. However at Station 8 where C. capitata was absent low organic low organic matter of 2.8 to 23.6 mg/l was recorded.

The one advantage of this estuary to the benthos is the shallow depth by which suspended food particles are readily available for them through sinking as well as the rough downward transport by turbulent water movements as noted by Wolff et al. (1976).

Eventhough the estuarine environment means the environment of the tidal mouth of a river, many benthic animals considered to be estuarine in a geomorphological sense as the same species may occur in many other coastal areas, characterised by environmental instability and an ample supply of food as shown by Remane (1958, 1971) and Muus (1967).

As the environmental factors indicated entirely different chemical and physical conditions, existing from Station to Station and month to month, consequently it might be expected that the fauna also would change across similar distances and times.

For most of the major taxa represented in the study area, the patchiness of species population and complete change over in the community composition over similar distances and time hold true.

4.3. Indicator species:

Wilhelmi (1916) was the first to suggest the use of marine invertebrate animals or populations as indicators of pollution. Subsequently usefulness of benthic organisms as indicators of pollution has been well recognised in both fresh and marine environment (Blegvad, 1932; Gauffin and Tarzwell, 1952; Reish, 1957; Hynes, 1966; Pauli Baggae, 1969; Henrickson, 1969; Butler *et al.*, 1972; Arlet, 1975 and Anger, 1975).

By contrast to monitoring organisms, indicator organisms are used primarily to identify rather than to measure environmental changes, whose cause may be unknown, or which may be t result of a varying mixture of pollutants, for example, industrial effluents. Also indicator organisms may be useful in identifying persistant physical changes as well as chemical changes in the environment (Butler *et al.*, 1972). Tolerant species of unusually high population densities may direct attention to pollution. On the other hand, sensitive indicator species indicate pollution by their absence. In a pol ted environment, the pollutants eliminate the more sensitive organisms from the more tolerant successful species which may dominate the community. However, Reish (1959) noted fatal effect of accumulated pollutants on the tolerant species, leaving a highly polluted zone totally devoid of macrofauna. Thus the density of tolerant species may help in evaluating the effect and the extent of pollution.

Further, success of presence of an estuarine benthic organism depends on its physiological adaptations in regulating the osmotic and ionic composition of the body fluids and in the maintenance of life under reduced oxygen content (Brafield, 1972 and Beaden, 1975 & 1977). Whereas in areas of industrial pollution, toxic effect of pollutants was a major factor.

Based on changes brought about by pollution, benthic organisms can be grouped under three categories, namely, those which tolerate pollution, those which are indifferent to pollution and those which avoid pollution.

During the present investigation, <u>*Paraheteromastus tenuis*</u> a limivorous polychaete species (Capitellidae) was recorded from all Stations except one (Stn. 6). However, except at Stations 4 and 9 which had 9.7 and 3.1 percent of total benthos respectively, rest of the stations had low densities. Substratum at Stations 4 and 9 was sandy. But Remani (1979) observed in the retting grounds of Cochin backwaters, where soft sulphide clay prevailed, occurrence of <u>*P. tenuis*</u> in very high densities as they favoured feeding on the considerable quantity of decaying detritus and bacteria resulting from the retting of coconut husks. Pauli Bagge (1969) too had observed high number of limiverous species in the bottom sediments indicating pollution.

Similarly a spionid worm, Prionospio polybranchiata a selective deposit feeder, was recorded only in low densities 0.02 to 8.3% of benthic fauna) in Stations 2 to 7, indicating their ability to occur in areas of industrial pollution. But Remani (1979) proposed this species as an indicator organism, owing to its abundance among the benthos in the retting grounds (uo to 80%).

As noted above, occurrence of different indicator organis in different localities with similar pollution effects, indicate influence of various abiotic factors in determining the indicators and the characteristic assemblages in each area. The type of food and nature of sediment may also govern the selection of species to a particular pollution stress.

During the present study in the areas of industrial pollution, the benthic fauna were dominated by two polychaete species namely (1) Capitella capitata representing 5.2 and 98.8 percent of the population at Stations 6 and 7 respectiv and (2) Dendronereis aestuarina comprising 36, 29.7 and 57.5 percent of the population at Stations 5, 6 and 8 respectively. Of the above 2 species, Capitella capitata is found to be an indicator species of industrial pollution as proposed by earlier workers like Gaufin & Tarzwell (1952), Reish (1959), Wass (1967), Ganapati & Raman (1973), Ganapati (1976). It was totally absent in Station 8 and in Station 9 it constituted only 6.6 % of the fauna. Its total absence and the very low population density at Station 8 can be attributed to the toxic effect of the pollutants in the effluents.

Wass (1967) indicated that among higher metazoans, certain aspects of polychaetes belonging to the family Capitellidae and Spionidae appear to replace the fresh water Tubificidae in the polluted marine waters. Ganapati (1976) has reported large abundance of Capitella capitata in the industrially and domestically polluted waters of Visakhapatnam harbour. This species was recorded for the first time in the tropical waters of the Indian Ocean. This has been suggested as an indicator species of pollution by several workers from cold and temperate waters. Gaufn and Tazzwell (1952) considered higher numerical density, exclusion of other species in the environment, scavenger feeding habit and tolerance to low dissolved oxygen and some other adaptations to circumvent this as factors indicating pollution. In Los Angles harbour Reish (1959) found large number of capitellid polychaete in polluted waters of high organic content. He stated that C. capitata occurs in the vicinity of domestic outfalls in most parts of the world. Capitellids have been reported to be the dominant benthic fauna in the polluted waters of Japanese estuaries. The other polychaete species, D. aestuarina which was present at all stations can be considered as a pollution resistant species because of their high densities at Stations 5, 6 and 8.

Similarly the other 5 species recorded from Station 8 can be considered tolerant ones, eventhough they were seen in very low numbers. They are Lycastis indica, Paraheteromastus tenuis, Talchapia annandalei, chironomid larvae, and a molluscan species Pendora flexosa. The suspension feeder P. flexosa common in waters of rich suspended load, was found to occur in Stations 1 to 8. Their fluctuations can be attributed to the saline conditions. This species has planktonic larvae susceptible to normal changes in the hydrographic features. Chironomid larvae commonly occur in polluted waters rich in organic matter and ammonia (Hynes, 1966).

5. SUMMARY.

5. SUMMARY.

1. This thesis embodies the results of the studies on the effect of industrial pollution on the benthic communities of a tropical estuary, carried out during 1981, at 9 stations along a stretch of 21 km in the Cochin backwaters extending from the barmouth to Kalamassery (upstream of the industrial complex).

2. The introductory chapter covers a brief account on the studies on estuaries in India with special reference to the Cochin backwaters with an account on the scope and purpose of the study.

3. The second chapter deals with the materials used and the methodology employed.

4. Chapter 3 presenting the results of the analysis consists of 3 sections namely (a) physico-chemical investigations, (b) biological investigations and (c) statistical inferences.

5. Physico-chemical aspects deal with the spatial and temporal variations of the 16 environmental parameters studied viz. salinity, temperature, dissolved oxygen,

BOD_5, COD, alkalinity, pH, ammonia, phosphate, nitrite, nitrate, suspended solids, particulate organic carbon, attenuation coefficient ("K" factor), sediment nature and organic carbon. Estimations were made for the surface water, bottom water and grab water.

6. Biological investigations are centered around 2.47 million specimens belonging to 8 faunal groups consisting of 76 species of benthos. The number of species were maximum at Station 1, gradually reducing to the minimum at Station 8 and with an increase at Station 9. Species-wise temporal and spatial distribution is also given in detail. Patchy occurrence of species was recorded in the study area.

7. Cluster analysis showed highest number of species clusters with maximum affinity at 5% level in Stations 1 and 2, gradually reducing to Station 8 and with an increase in Station 9.

8. The 9 relatively important parameters, based on multiple regression analysis, were ranked in the order of their significance at all the 9 stations. As these parameters alone could not predict the abundance of benthos, the interaction effects of parameter clusters, which might be able to predict the abundance of benthos at each station,

were located. In general the order of importance reduced from salinity, temperature, dissolved oxygen, BOD_5, nitrate and 'K' factor. Remaining parameters were of low significance.

9. Chapter 4 deals with the discussion under 3 sections namely the effect of pollutants on the physico-chemical properties of water, the distribution of benthos including the impact of environmental parameters and a narration on indicator species.

10. Measurements of 12 parameters made at distances 10 m away downstream from the discharge points showed considerable fall in values for all effluent characteristics.

11. The results of studies on the water characteristics of the study area indicated continuous change as a result of large scale movements of the estuarine water under the influence of tidal forces, monsoon and land runoff coupled with its heterogeneous nature owing to the effluent discharges from the industries.

12. Investigations on the water quality in the study area revealed water in floods characterised by low temperature, high oxygen and low salinity during the monsoon and intrusion of saline water upstream due to reduced flow of river water

characterised by high temperature, low oxygen and high salinity during the summer. Chloride values in the effluents discharged by the factories, which may decompose and produce free chlorine or hydrochloric acid which is extremely toxic to fish, ranged between 125 to 3,470 ppm in February, 75 to 6,990 ppm in April, 100 to 2,060 ppm in June and 50 to 920 ppm in August. Salinity values indicated a distinct spatial and temporal pattern as follows: As in the case with most of the estuaries, salinity in the study area was the major variable establishing a continuous gradient of 0.2 - 30.4‰ between the sea and fresh river water which moved up and down the estuary influenced by monsoons. Along with stratification(caused by differences in the nature, bottom topography and depth of the estuary) noticed during July to September in Station 1 and January in Stations 2 and 3, salinity values reduced towards Station 9. Seasonal variations revealed, with the exception of March and April, prevalance of almost fresh water from Station 5 onwards during November to January and in May and from Station 2 onwards during June to October.

13. Changes in temperature in the study area were brought about by the seasonal as well as diurnal changes in the temperature of the air, river, sea and effluent waters. The area being shallow (2.5 to 4 m), resulting in the well

mixing of the water column, the changes were relatively fast and the amplitudes of the extremes were found smaller especially in the areas of effluent discharges eventhough the temperature of the effluents discharged from different factories varied between 25.3°C to 45.0°C.

14. The dissolved oxygen content chiefly controlled by tidal ingress and fresh water run-off and being an inevitable factor for survival of aquatic benthic fauna varied from nil values to 5.96 ml/l. Oxygen content of water 10 m away downstream from the discharge points also recorded nil to high values. In spite of discharge of large amounts of effluents anoxic conditions never prevailed. Even the bottom water layers recording high oxygen contents, the water mass of the study area was not affected much by the effluents discharged by the factories.

15. BOD dependent on the amount of suspended/dissolved organic matter is very important in the assessment of pollution in an environment as it is inversely proportional to the oxygen content of the water. In the present study, in the areas of industrial discharge the maximum BOD_5 recorded was 570 mg/l for grab water, 12.2 for the surface water and 8.9 for the bottom water, while the values for the effluents from the 8 factories ranged from

negligible to 18.5 mg/l. In view of the high BOD_5 recorded in the grab water and very low values in the water column it appeared that BOD_5 in general may not be a factor contributed by industrial effluents. It can be due to the relative toxic effects of the pollutants on the bacterial flora.

16. COD values were negligible in 50% of the observations and when recorded the values were very low except in 16 isolated observations where it ranged from 107 to 1,669. The hazardous role indicated by COD values required further confirmation.

17. Carbonate alkalinity measurements indicated the industrial effluents exerting a positive toxic influence on the receiving water eventhough alkalinity indicated considerable spatial variations compared to low temporal variations.

18. Comparative studies on pH values from the water column (surface and bottom) and grab water indicated always a high pH for grab water which can be well tolerated by the benthi fauna. pH never rose to a higher level which in combination with high NH_3 content can be toxic to aquatic benthic life. This clearly ruled out any toxic effect, o benthos, of acids and alkalies thrown out from the factories of this area. Thus the role of pH as one of th

factors governing the reduction of macrobenthos may be mostly a local affair, noticeable at the time of reduced water flow.

19. The levels of ammonia increased towards upstream stations with low values in Stations 1 to 4 and 9 and high values (844 µg at/l) in Stations 5 to 8. Temporal variations were highly irregular depending on discharge and flow rate. The toxic effect of ammonia was reduced by the low pH values in the water column.

20. The concentration of inorganic phosphate in general at the effluent discharge sites were not that high so as to indicate pollution by eutrophication. The fluctuations noted may be the after effect of intermittent discharges of effluents, also regulated by the intensity of monsoonal flow. The low values in the sediments reduced the chances of phosphate contents controlling the benthic fauna.

21. Nitrite content in the effluent discharge area was of the low order varying from 0.8 to 2.67 µg at/l indicating insignificant influence of nitrite on benthos.

22. Nitrate, an important factor in controlling the fertility of water masses, indicated irregular pattern of spatial and temporal variations.

23. The suspended load, subjected to natural purification processes varied considerably from 3 to 256.7 mg/l both in time and space, leading to relatively turbid water. Eventhough, values for effluents discharged from factories went up from 8 to 17,333 mg/l at times, it does not appear to affect the benthic fauna adversely.

24. Particulate organic matter forming the food of organisms varied in contents from 0.39 to 15.81 mg/l.

25. Attenmuation coefficient, known as "K" values, correlated with turbidity and intensity of solar radiation, recorded values ranging from 5 to 15.

26. Temporal and spatial variations in sediment, colour (reddish brown, light grey, black etc.) and texture (combinations of sand silt and clay) were analysed as they indicated quality of water overlying it. Also, organic carbon content which varied between 1.19 and 46.9 mg/g affected considerably the pH of the sediment depending on its texture, high organic content being associated with high percentage of clay.

27. Temporal and spatial variations in macrofaunal biomass at the 9 stations were wide and considerable, indicating 4 types of distribution of biomass - Stations 1 and 4 with peak biomass values of above 176.5 g/m^2

and Stations 3 and 7 with moderate biomass values of 34.43 to 62.4 g/m^2, Stations 2, 5, 6 and 9 with low biomass values of 8.98 to 15.69 g/m^2 and Station 8 with the lowest biomass value of 0.42 g/m^2.

28. The population density fluctuating between 128/m^2 at Station 8 and 1,92,124/m^2 at Station 1 showed 3 ranges - Station 1 with high density of around 1,92,000/m^2, Stations 2, 3, 4 and 7 with lower densities of around 4,000 to 20,000/m^2 and Stations 5, 6, 8 and 9 with the lowest densities of around 1,000/m^2.

29. Seasonal averages in the biomass values and population densities showed considerable variations from station to station - high biomass values being recorded during pre-monsoon at Stations 3 and 4, during monsoon at Stations 1, 4 and 7 and during postmonsoon at Stations 1 and 2. While lowest values prevailed at Station 8 throughout the year, Station 9 recorded low values in all the seasons.

30. Polychaetes and molluscs were found to be the major groups among the benthos and were present in all the stations Spatial variations in faunal density did not show any definite pattern with variations in environmental parameters. But temporal variations clearly indicated faunal succession at all stations.

31. The fact that even indicator species were not present in polluted stations during all the months clearly indicated that the presence or absence benthic organisms depended, in addition to pollution effect, on a number of other environmental aspects.

32. Faunal diversity indicated a reduction from 16 groups at Stations 1 and 2 to 3 groups at Station 8.

33. Species occurrence and their dominance as percentage of total benthos exhibited considerable spatial and temporal variations irrespective of fluctuations in environmental parameters.

34. Distribution of species was explained using index of diversity (Fisher's Diversity index α and its variance V (α) and Shannon-Wiener diversity function H (S) and Mac Arthur's coefficient of equitability as is the case with other environmental parameters.

35. Studies on the impact of environmental parameters on the distribution of macrobenthos revealed the quantum of endurance warranted by the infauna living within the sediment to tide over the wide range of environmental stress.

36. Low diversity and lower number of benthic fauna at Station 8 may be due to the stress caused by the cumulative toxic effects of effluents.

37. The qualitative and quantitative distribution of benthic fauna was found to have a direct relationship with the type of the bottom and its physical nature.

38. An attempt was made to identify indicator species in the study area. Paraheteromastus tenuis a limivorous polychaete species (Capitellidae), very common retting yards, was recorded from all stations except Station 6.

The spironid worm Prionospio polybranchiata a selective deposit feeder, recognized as an indicator of retting and pollution was recorded only in low densities at Stations 2 to 7 indicating their ability to occur in areas of industrial pollution also. Capitella capitata an indicator species of pollution constituting 98.8% of the benthic population at Station 7 was proposed as an indicator of industrial pollution too. Dendronereis aestuarina present in all stations and at high densities at Stations 5, 6 and 8 can be ranked as a pollution resistant species.

Other 5 species namely Lycastis indica, Paraheteromastus tenuis, Talehsapia annandalei, chironomid larvae and Pendora flexosa present at Station 8, eventhough in very low numbers cam be considered as pollution tolerant species.

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