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RECORDS OF THE ZOOLOGICAL SURVEY OF INDIA

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SOBHANA PAUL
N. C. NANDI

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PREFACE

The study of river ecology has gained immense importance because of the multiple use of river waters. Almost all major rivers of India have become highly polluted. Even the Ganga, with high self-purification capacity, is among India's most polluted rivers. River Hugli which originates from Ganga experiences considerable human activities of various kinds along its course including domestic, commercial, agricultural and industrial activities. As a result, different types of waste materials enter the river continuously altering its water quality and are bound to affect the living resources, i.e., animals and plants occurring in the river water. The water quality of this river in particular and the habitat in general have become somewhat inhospitable to shelter the organic diversity. The rich variety of flora and fauna, which has so long sustained, have now become threatened. In view of the above facts, a comprehensive plan had been in mid 1980's undertaken by the Central Ganga Authority to restore the purity of the river water which will obviously help in the preservation of its natural living resources. A nationwide effort to restore and maintain the water quality got underway with the passing of Water Prevention and Control of Pollution Act in 1974.

In an effort to understand and evaluate the hydrobiological status of Hugli estuary in and around Calcutta metropolis, a comprehensive biomonitoring study of physico-chemical characteristics of water and sediment and benthic fauna was undertaken (1995 1997) in the present research programme. Herein, the physico-chemical status of the riverine ecosystem is described covering a wide spectrum of parameters like dissolved oxygen, biological oxygen demand, chemical oxygen demand, etc., while the study of the benthic fauna is emphasized in relation to their importance as an effective tool for supplementing the physico-chemical information on the river system. Various biological indices were calcutated to reflect the overall condition of the aquatic system of Hugli river. On the other hand, statistical analyses were done to elaborate the inter-relationship between the selected abiotic factors and benthic components of the river. It is assumed that, the baseline information gained from this research work would clearly and convincingly demonstrate the state of 'health' of the stretch of Hugli riverine ecosystem concerned. Herein, a detailed desctription of the physico-chemical and biological parameters is given highlighting the recognition, description and understanding the effect of pollution especially from Tolly's nullah using indicator organisms.

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CONTENTS

INTRODUCTION

Rivers are precariously balanced aquatic ecosystem existing in close proximity to man. They have been particularly vulnerable to uses and abuses over the years. The growing influx of population has exerted tremendous pressure and stress on the rivers. Urbanisation and industrialisation has bred enormous pollution into the riverine systems. Life of fish and other aquatic organisms as well as cattle and human being forming intermeshing fabric of river are threatened now-a-days. Recognizing the magnitude of the problem aspects and prospects of this natural resource, the need for greater attention to major Indian rivers is prescribed in the Water Act, 1974. The importance of water quality is a cardinal element of river management for optimum exploitation to benefit dwellers along the river bank. To day most of the rivers of India receive millions of liters of sewage, domestic wastes, and industrial wastes containing substances varying in characteristics from simple nutrients to highly toxic substances. The intensity of pollution arising out of the improper disposal of sewage, industrial wastes and other human activities affects the organisms living in the river by lowering the available oxygen in the water and increasing the biological oxygen demand (BOD) and can also cause water borne diseases. As river Hugli runs through the heart of one of the largest urbanized city-the Calcutta, it has been continuously affected by anthropogenic environmental distortion and the rich variety of fauna have now become threatened. The increased silt deposition and reduced discharge from feeder rivers, discharge of large amount of industrial effluents and domestic sewage from innumerable industries and urban centres and drawal of huge amount of water both for human consumption and industrial requirements have considerably altered the condition of the river in terms of its diversity. The changes in river water quality brought about by modern civilization can be assessed by chemical and biological analyses. Chemical analysis provide quantitative data of changes in the water as measured by parameters such as dissolved oxygen, biochemical oxygen demand etc., whereas biological analysis may be useful in monitoring and assessment of pollution. Benthos have been employed to assess the water quality in the present study as they are known to reflect past and present environmental conditions of an ecosystem more efficiently than physical and chemical indices of water and soil (Hynes, 1960; Hofmann, 1978) and are regarded as the best indicators of pollution as they are sedentary, sessile, long lived and easily collectable. Benthos include animals which migrate to bottom for : a) feeding and breeding, b) spending their lives on bottom and c) burrowing (Petersen, 1913). They are categorized depending upon size of the organisms as macro, meio and microbenthos (Mare, 1942). Macroinvertebrates both larval forms and adults whose size varies from 3-5 mm for full grown individuals

(Cummins, 1975) and / or retained by 500 μm seives are referred in this treatise as macrobenthos or more precisely macrozoobenthos.

So, in the present investigation it was proposed to undertake studies on intertidal macrozoobenthos of Hugli river in and around Calcutta with special reference to Tolly's nullah outfall region to understand the impact of sewage discharge from it, causes of deterioration of water quality and related pollution problems. The main objectives of this study include measurements to monitor the relevant physico-chemical and biological indicators of pollution in the aquatic system chosen, assessment of the contaminated states of the system and estimating the efficiency of the system to assimilate the existing pollution load.

Brief Review of Earlier Works

Studies on the benthic ecology as well as intertidal communities in India and abroad have been well documented in the literature. Outside Indian limit, the distribution of benthic macroinvertebrates in the Patuxent river Maryland was analyzed by Ruggiero and Merchant (1979) which was more closely correlated to substrate than to water quality. Scullion *et al.* (1982) found that species composition, diversity and abundance of macrozoobenthic fauna of river Elan and river Wye mid Wales, are greatly related to oxygen concentration and oxygen status of water. The spatial distribution of the fresh water macroinvertebrate fauna of the river Ely, south Wales was investigated in relation to pollutional discharge by Murphy and Edwards (1982). It has been reported that major pollutants affecting species distribution in the Ely catchment were associated with poorly treated sewage and the ammonia and suspended coal solids discharged from two coking plants. Clare and Edwards (1983) found a great relation between diversity abundance of macrozoonbenthic fauna with the O_2 status of water in the drainage channels in south Wales. Attempts were made to establish predictive relationships between the macroinvertebrate fauna and physico-chemistry of running waters by Wright *et al.* (1984) in waters of Great Britain, Ormerod and Edwards (1987) in river Wye. Diaz (1989) found that the distribution of benthic communities in the estuarine portions of the James river was controlled mainly by salinity.

The benthic biology of Tees bay and Tees estuary was studied by Shillabeer and Tapp in 1990. Macrobenthic faunal relationship with physico-chemical conditions of marine and estuarine river systems outside India was investigated by Harrel and Hall III (1991), Degani *et al.* (1992), Harris *et al.* (1992), Dauer *et al.* (1992), Ismail (1993), Quijon and Jaramillo (1993), Pagnotta *et al.* (1993), Lestochova (1994), Kaska and Krzyzanek (1995) on Neches river estuary (Texas), River Dan in Northern Israel, La Trobe river in Victoria (Australia), Chesapeake Bay, Arabian Gulf, Quele river estuary in south-central Chile, Tiber river estuarine system in Italy, Yerik and Nezhegolyok rivers in Russia and Vistula river in southern Poland respectively.

Limnological studies on Indian rivers and estuaries have been made by several workers (Motwani *et al.*, 1956; Chakraborty *et al.*, 1959; Bhaskaran *et al.*, 1963; Ray *et al.*, 1966; Singbal, 1976; Zingde *et al.*, 1980; Ajmal *et al.*, 1982; Mitra, 1982; Bhargava, 1985; Somasekhar, 1985 (a and b); Manikay Reddy and Venkateswarlu, 1987; Rao *et al.*, 1990; Tripathy and Adhikary, 1990; Mittal and Sengar, 1990; Athappan *et al.*, 1992; Barodawala *et al.*, 1992; Asthana and Singh, 1993; Patel and Patel, 1993; Ruparelia *et al.*, 1993; Trivedi and Dodia, 1993; Rajagopal *et al.*, 1993; Reddy *et al.*, 1993; Srivastava *et al.*, 1993; Satyanarayana and Padmavathi, 1993; Krishnamurthy and Bharati, 1994; Singh, 1995; Sharma and Pande, 1998). However, studies on sediment characteristics are limited (Ramachandra *et al.*, 1984; Tiwari and Kumar, 1984; Bilgrami and Dutta Munshi, 1985; Saha and Pandit, 1986; Fernando, 1987; Rayan *et al.*, 1989; Choudhury, 1991; Israili and Khurshid, 1991; Rao *et al.*, 1998).

The study on benthos was initiated in India by Nelson Annandale as early as 1907 During 1970's the works of Parulekar and Dwivedi (1974) and Dwivedi *et al.* (1975) on Goa estuaries; Bhabanarayana (1975) on Kakinada Bay and Ansari *et al.* (1977) from Bay of Bengal are worth mentioning. Later on, Dutta and Malhotra (1986), Sharma (1986), Sunder and Subla (1986), Fernando (1987), Varshney *et al.* (1988), Parabha Devi and Ayyakkannu (1989), sarala Devi and Venugopal (1989) and Chopra *et al.* (1993) studied the relationship between abiotic variables and benthic fauna of various rivers and estuaries in India. Ramakrishna (1993) and Mary Bai (1993) reported the physico-chemical and biological parameters of river Musi in Hyderabad and river Cooum in Madras in detail repectively.

Vattakeril and Diwan (1991) worked on benthic macroinvertebrates and brought out the significance of these organisms as indicators of pollution to river Kshipra in India. Khan and Kulshreshtha (1993) studied the benthic fauna in relation to pollution at river Chambal in central India. The pollutional aspects of benthic organisms and their values as indicator organisms of water quality has been highlighted in several reports (Srivastava, 1962; Rajan, 1965; Sarkar and Krishnamoorthi, 1977; Sampath *et al.*, 1981; Mahadevan and Krishnaswamy, 1984; Kulshrestha *et al.*, 1989b; Chatterjee, 1994).

In Hugli river water, researches were initiated in late forties by Roy (1949) who reported some potamological aspects of the river in relation to Calcutta water supply. This was followed by Seth and Bhaskaran (1950), Dutta *et al.* (1954) and Bose (1956). Rajagopalan *et al.* (1965), Basu (1966), Dhaneshwar *et al.* (1969), Basu *et al.* (1973), Ghosh *et al.* (1977, 1980b), Ray *et al.* (1979) and Ray and Mitra (1980) studied in detail the quantity, nature and characteristics of the pulp and paper effluents and their impact on plankton. Ray (1981) also reported the results of cage culture experiments conducted around the outfall of a tissue paper mill. The viscose rayon factory effluents and their impact on plankton density around outfall (Ghosh *et al.*, 1976), the effluents from a chemical factory at Rishra (Ghosh and Basu, 1968), a distillery (Ray *et al.*, 1977), a tannery (Ghosh *et al.*, 1980a), a rubber factory (Ghosh *et al.*, 1979) in the upper industrial zone and an oil refinery complex in the lower zone (Ghosh and Bagchi, 1979) have also been studied. Gopalakrishnan *et al.* (1973) studied the pollution problem in Hugli with special reference to the adverse effects on the fishery resources.

In the lower marine zone of Hugli estuary, Bhunia and Choudhury (1982) studied the nutrients of the estuarine waters around Sagar Island. Ghosh *et al.* (1989) made a detailed investigation on the physico-chemical characteristics of water in the lower stretch of Hugli estuary and found a negative relationship between the concentration of nutrients and salinity, and negligible variation of nutrient concentrations in surface and bottom waters. Mitra *et al.* (1992) worked on the seasonal variations in metal content in a gastropod *Cerithidea*. Chaudhuri *et al.* (1994) reported conspicuous seasonal variations of physico-chemical variables like salinity, pH at the Sagar Island. Again, Mitra and Choudhury (1994) reported increased metal concentrations during monsoon in the lower stretch of Hugli estuary. Other studies worth mentioning include those of Bhunia (1979) on ecology, Bhunia and Choudhury (1981) on hydrology and benthos, Nandi and Choudhury (1983) on benthic macrofauna, Subba Rao *et al.* (1987) on molluscs and Chaudhuri *et al.* (1994) on the community organisation of macrobenthic molluscs at Sagar Island.

An analysis of the work done on Hugli estuary reveals that in Hugli river, though observations on hydrology, plankton ecology, and fisheries had been carried out by a number of workers, studies using intertidal macrozoobenthos in and around urban Calcutta is still lacking. However, Subba Rao *et al.* (1995), Misra (1995), Ghosh (1995), Ghatak (1995), Khan (1995) and Mukherjee (1995) recently reported on some macrobenthic groups of Hugli estuary as a whole (vide: Hugli-Matla Estuary. West Bengal. In: Estuarine Ecosystem Series, Part-2, Z.S.I., Calcutta) but detailed quantitative and biological information in relation to water and sediment characteristics of the river system especially under Calcutta metropolis are not yet documented.

MATERIALS AND METHODS

The Hugli estuary, about 290 km in length, is the first offshoot of Ganga and is one of the fourteen major rivers of India. It is situated between $21^0 31'$-$23^0 20'$ N and $87° 45'$-$88^0 45'$E. The river is known as Bhagirathi upto Nabadwip and thereafter as Hugli upto Sagar Island where it opens out into the Bay of Bengal. As the river flows through the heart of Calcutta metropolis (Fig. la) as well as various parts of West Bengal, it is a major water source of this state and is also a very important river because of its port facilities and fisheries of commercial importance. Almost all urban activities have an impact on this water resource.

According to Dutta *et al.* (1973), the estuary can be divided into three zones viz., Zone I extending from Nabadwip to Baranagar (Calcutta), Zone II from Baranagar

(Calcutta) to Diamond Harbour and Zone III stretching entire Sundarbans and a tract below Diamond Harbour on the main channel. According to Ray (1981), between Kakdwip and Falta lies the brackish water zone and upstream of Calcutta is fresh water zone while the area between these two zones possesses transitional characteristics. The tidal limit of the river stretches upto Nabadwip in the upstream. The estuarine region, defined by the intrusion of salt water to a minimum of about 1ppt is however restricted upto Diamond Harbour, a distance of approximately 100km.

In this study, the stretch of the river within the densely populated Calcutta city and around is selected for intensive investigation as this stretch is highly affected due to abstraction of large amount of water for industrial uses, sewer outlets and drainages which open into the river directly causing resource deterioration.

Regular monthly sampling of water, sediment and benthic fauna was carried out for a period of two years (May 1995-April 1997) at six sites of the river, namely, Dakshineswar (station 1), Bagabzar (station 2), Kidderpore Taktaghat (station 3), Kidderpore Doighat (station 4), Kidderpore Jettyghat (station 5), and Shivpur (station 6). Besides these six stations, three additional sites viz., Bally, Achipur and Uluberia were visited seasonally for qualitative sampling to ascertain the general macrobenthic fauna harbouring the river system within this study stretch.

Study Area and Sampling Stations

The six stations (Fig. 1b) under monthly sampling are briefly described as follows:

Station 1. *Dakshineswar:* Located at the left bank 12 km upstream of Kidderpore, Calcutta (i.e. Tolly's nullah outfall region) and subjected to high pilgrim bathing.

Station 2. *Bagbazar:* Beside Kashi Mitra burning ghat, located at about 9 km upstream of Tolly's nullah and characterized by high amount of ritual refuses from the burning place and receives high load of bathing.

Station 3. *Kidderpore Taktaghat:* Located about 500m upstream of Tolly's nullah with limited bathing activities.

Station 4. *Kidderpore Doighat:* About 100m downstream of the Tolly's nullah and constantly subjected to sewage outfall and hence having limited bathing activity.

Station 5. *Kidderpore Jettyghat:* Located about 100m downstream of station 4 with very limited ferry and bathing activity.

Station 6. *Shivpur:* Located on the right bank of the river beside the Indian Botanical Garden, a relatively undisturbed intertidal stretch although with medium bathing activity at specific locations.

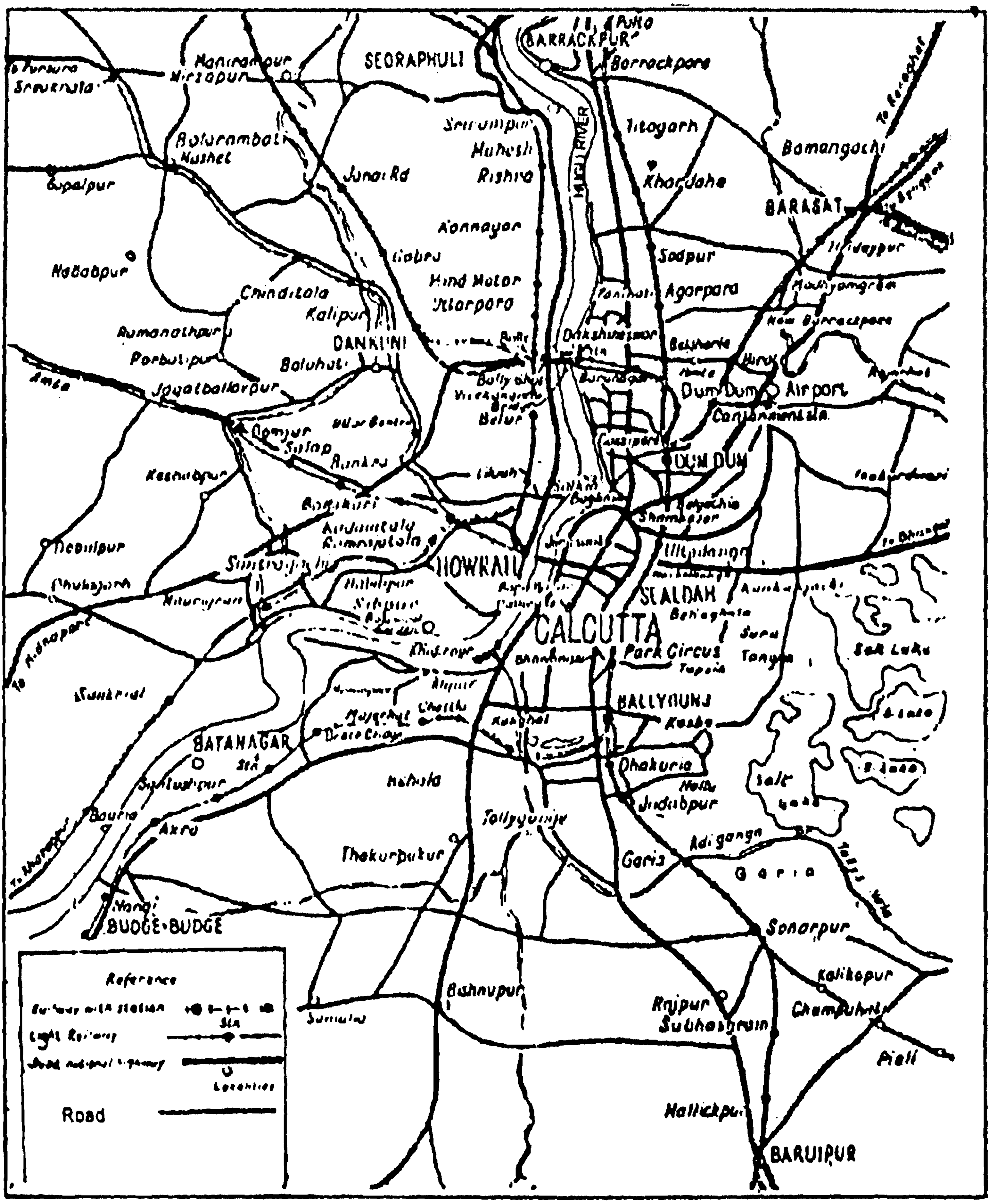


Fig. 1a. Map showing Hugli river with Calcutta and Howrah and suburbs.

All the stations are located on the left bank of the river except Shivpur. The following chart represents the different sources of pollution met with the stations explored during this study.

Sources of pollution	Stations					
	1	2	3	4	5	6
i) Bathing	VH	VH	M	L	L	M
ii) Washing clothes/ utensils	H	VH	M	L	L	M
iii) Defaecation on the banks	M	H	L	VH	L	L
iv) Waste dumping	M	M	L	VH	VL	-
v) Sewage outfall	-	-	-	VH	-	
vi) Open drainage opening	M	M	-	VH	-	VL
vii) Ferry service	-	M	-	-	VL	VL
Viii) Proximity of industries	L	L	L	L	L	L

Abbreviations: VL = Very low, H = High,
L = Low, VH = Very high,
M = Medium, '-' = Nil.

Among the three stations selected for seasonal sampling, Achipur is located on the left bank, 27 km downstream of Kidderpore while Bally and Uluberia are on the right bank, 13.5 km up and 27 km downstream respectively of Kidderpore, Calcutta of the river (Fig. 1b). These are suburban stations and experience limited bathing actives and ferry services.

Collection and preservation of samples

The relevant data regarding rainfall and humidity have been collected from various sources such as newspaper, meteorological office, etc. The samples of physico-chemical characteristics and biological parameters were taken adopting standard methodology as follows.

Collection of water and sediment samples

Water samples in triplicate were collected at a depth of 0.4 m in clean glass bottles for physico-chemical analysis. For BOD estimation, water was collected separately in dark bottles. Sediment samples were collected from each site using a box type sampler which enclosed an area of 15 x 15 cm. The sediment samples were kept in clean polythene bags for future analysis.

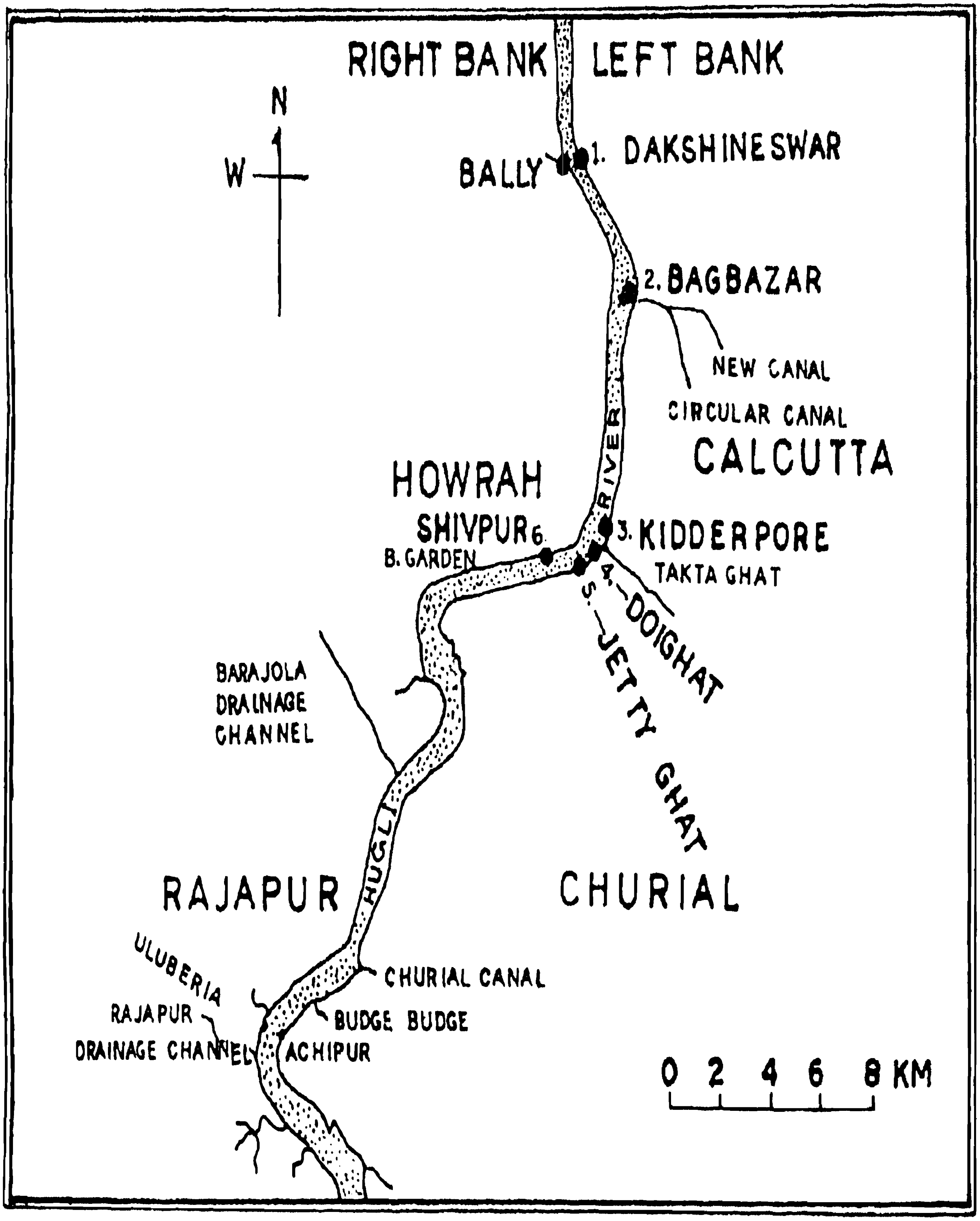


Fig. 1b. Map showing Hugli river with regular monthly sampling stations (1-6) and seasonal sampling sites (.).

Collection of macrozoobenthos

Collection of benthic fauna was done by a box type sampler which was designed to sample an area of 15 x 15 cm and to penetrate a maximum depth of 15cm. All of the samples were seived with 0.5 mm mesh size to obtain the benthic fauna (Jonasson, 1955; Hovgaard, 1973). Qualitative sampling was done by hand picking, drag netting and also with the box type sampler.

Preservation of collected samples

The physico-chemical parameters such as temperature of air, water and soil, pH, dissolved oxygen and alkalinity of water were determined in the field. The other water quality parameters were usually estimated within 24 hours. The samples for physico-chemical analysis, whenever necessary were stored at 4°C. The faunal samples were preserved in the field with 5% formalin solution or 70% alcohol.

Analysis of the collected samples

Water and Sediment

In case of water, 17 physico-chemical parameters, viz., temperature, pH, conductivity, turbidity, total alkalinity, hardness, dissolved oxygen, biological oxygen demand (BOD), chemical oxygen demand (COD), chloride, phosphate, ammonium, nitrite, nitrate, chromium, lead and zinc were estimated monthly for each site for a period of two years. In case of sediment, temperature, pH, phosphate, nitrite, nitrate, percentage of organic carbon and sediment texture were determined. The salinity (less than 0.1 mg/1) and arsenic content of the river water are not included in this study being mostly undetectable.

All the parameters were analysed following standard methods (APHA,1989; Jackson,1973; and Piper,1966) and / or using a photometer SQ118 (Merck, Germany).

Temperature of water and sediment was measured by a digital centigrade thermometer. pH was measured by a pH meter (model - 320, Merck, Germany). Sediment pH was measured in a 1:5 dispersion of mud in 0.01 N Calcium Chloride Solution (Piper, 1966). Conductivity of water was determined with a conductivity meter (model LF 320, Merck, Germany). Turbidity values were determined by photometer SQ118.

Total Alkalinity was determined by titrating the sample with 0.02N sulphuric acid with methyl orange as an indicator (APHA, 1989).

Total hardness was measured by EDTA titrimetric method (APHA, 1989) by titrating with 0.01M EDTA titrant using Eriochrome black T dye and sodium chloride as a dry power indicator.

Dissolved oxygen was determined using azide modification of Winkler's iodometric method (APHA, 1989). As usual 5- day BOD was estimated by measuring the amount of oxygen consumed by the sample in five days at 20^0 C in dark condition. The initial oxygen estimation was done in one of the samples and the others were incubated at 20^0 C in dark for 5 days for further estimation of oxygen. The estimation of COD was done by reflexing the sample with potassium dichromate and sulphuric acid and then titrating the residual potassium dichromate against ammonium ferrous sulphate using ferroin as an indicator (APHA, 1989).

Chloride content was estimated by Argentometric method (APHA), 1989) by titrating with 0.0141N silver nitrate with potassium chromate as indicator.

Phosphates (ortho) was measured by Ascorbic Acid Method (APHA), 1989). Phosphate reacts with the ammonium molybdate to form molybdophosphoric acid. This is transformed by reductants to form a blue complex, which was measured spectrophotometrically.

Ammonium estimation was done by Nesslerization method where zinc sulphate and sodium hydroxide was added to the sample and one drop of EDTA was added along with the Nessler's reagent to develop the colour to be measured (APHA, 1989). Nitrite was estimated colorimetrically by developing a colour with EDTA, sulphanilic acid and napthylamine hydrochloride, sodium acetate. Nitrate was estimated by Phenol Disulphonic acid Method (APHA, 1989).

Among the heavy metals, hexavalent chromium was estimated following acid digestion and then by reaction with diphenylcarbazide in acid solution (APHA, 1989). Lead was also determined after acid digestion, by reaction with dithizone in carbon tetrachloride solution to produce a pink complex, lead dithiozonate which was diluted to given volume to produce the colour intensity to be determined (APHA, 1989). For estimation of zinc, it was separated from other metals by extraction with dithizone and then the colour of the zinc - dithizone complex in carbon tetrachloride was measured (APHA, 1989).

The phosphate, nitrite and nitrate of sediment were determined following the method described for water after preliminary extraction following Jackson (1973) and Trivedy and Goel (1984). Organic carbon in the sediment was estimated following Walkley and Black's rapid titration method (Piper, 1966). Texture of sediment was determined seasonally following Pipette method (Piper, 1966) and expressed as mean values of sand, silt and clay percentage of each station.

Analysis of benthic fauna

Benthic organisms were identified, counted and analysed as follows

Identification

Identifications were made consulting taxonomic references (Weber and de Beaufort, 1951; Tiwari, 1955a, 1955b, Fauvel, 1953; Naidu, 1965; Alcock, 1968; Subba Rao, 1993; Kurian and Sebastian, 1993) and from expert taxonomists of Zoological Survey of India.

Calculation of density and percentage frequency of benthos

Density represents the number of individuals per unit area. In this study the fauna obtained in the sampler (15 x 15 cm) was expressed as number of organisms per meter square using the following formula as outlined by Welch (1948).

$$n = \frac{o}{a \times s} \times 10,000$$

Where,

n = number of organisms / m^2

o = number of organisms counted

a = Area of the sampler and

s = number of replicates taken.

Precentage frequency is the percentage of quadrats in which a given species is found and was determined as follows :

$$\text{Percentage frequency} = \frac{\text{No. of quadrats in which the species occurred}}{\text{Total number of quadrats}} \times 100$$

Calculation of biological indices

Following identification and counting five biological indices viz., index of dominance (Simpson, 1949), Margalef's index (Margalef, 1958), Shannon-Weiner index (Shannon and Weiner, 1949), Evenness index (Pielou, 1966) and Sorensen's index of similarity (Sorensen, 1948) were calculated, details of which are given in the respective sections.

Estination of biomass

For determination of biomass (dry weight) the samples were dried in an oven at 105^{0}C (Winberg, 1971) for a time until the weight became constant. Weight was taken with an electronic balance and was expressed in terms of dry weight (gm / m^2).

Statistical calculations

Pearson's correlation coefficients were calculated to evaluate the parametric relationships between the abiotic and biotic factors supposedly in interaction. The tests were all two tailed and the correlations were tested at 5% and 1% level of significance. For each station statistical analysis was done separately.

In any aquatic system, the occurrence of an organism depends on the various physico-chemical factors of water and sediment operating together. To find out the subset of physico-chemical parameters, **stepwise multiple regression method** was followed. Thus we had to choose a 'p' - x variable (physico-chemical parameters) that best predict the response Y (faunal density). Thus the ultimate linear model used is:

$$Y_{ij} = ß_{0} + \sum_{j=I}^{p} ßj\, X_{ij} + E_{ij}$$

Where, $ß_{0}$ = intercept of the model

$ßij$ = Partial regression coefficients of the j th parameter of faunal density after eliminating the effect of the parameters other than the j th one (j = 1,...p,).

Xij = independent physico-chemical parameters (i=1,...24, j=1, 2.. p).

E_{ij} = random error component (i = 1, 2.......24, j = 1,2... p)

Least square method involves the minimisation of the residual sum of squares with $\sum_{i=I}^{24} \sum_{j=I}^{P} E^{2}ij$ respect to each of the parameters. Such method is used to estimate the unknown's at each step of selection. This is a univariate selection statistical procedure in that the only random variable is Y and the X's are treated as non-random. The significance of ßij's has been tested with the help of t - statistic. The coefficient of determination - R^2, for each model indicates the variation in density explained by the p - variable. The significance of R^2 is tested with the help of F statistic.

A two-way analysis of variance (ANOVA) after transforming the value of each data to log (x + 1) was calculated to find out the significance of the differences in density of the species and groups among the stations and seasons.

The whole analysis was carried out with the help of a relevant software programme under SPSS version 6.0.

RESULTS AND DISCUSSION

Physico-chemical characteristics

The present investigation includes the study of both water and sediment of river Hugli to know the status of this aquatic ecosystem. The physico-chemical characteristics of water and sediment are represented in appendix 1 to 23 and their mean values along with the range are represented in Table 1 and Figs.3-5.

In India, most of the limnological works are based on different aspects of physico-chemical factors operating in water [Roy, 1949; Seth and Bhaskaran, 1950; Dutta *et al.*, 1954; Bose, 1956 in Hugli river; Pahwa and Mehrotra (1966) in river Ganga, Venkateswarlu (1969) in river Moosi, Singbal (1976) in Mandovi estuary of Goa, Bhargava (1985) in Yamuna river, Trivedi and Dodia (1993) in river Mahi, Gujarat, Sharma and Pande (1998) in Ramganga river at Moradabad, etc.]. Although some documents are available on the analysis of bottom sediment of lentic waters (Saha *et al.*, 1971; Mandal and Moitra, 1975; Pillai and Sreenivasan, 1975; Nasar, 1978; Satpathy *et al.*, 1982 Ahmad *et al.*, 1996), rivers have not received proper attention in this regard as only few workers have attempted the study of sediment characteristics of the river (Tiwari and Kumar, 1984; Bilgrami and Dutta Munshi, 1985; Saha and Pandit, 1986; Choudhury, 1991).

Physical factors

Air Temperature

West Bengal exhibits tropical climate with mean maximum day temperature rising to 37.24 degree celsius during summer and 30.7 degree celsius during winter, whereas mean minimum temperature ranges from 21.73 to 27 57^{0}C in summer and in winter from 13.64 to 20.18^{0}C. (Fig.2).

Sunshine and Rainfall

In Calcutta district, West Bengal, winter (November-February) is characterised by low air temperature, shorter day length and rare rain. Summer months (March June) have higher air temperature, occasional rain and longer day length and in rainy season (July - October) there is relatively short hours of sunshine with appreciable rainfall. Monsoon retreats by October with the advent of autumn and latter is characterised by moderately hot day and cooler night (Bose, 1968).

The lowest rainfall was encountered during January in both the years (6.0mm in the first year and 1.9mm in the second year) while highest total rainfall was during September in the first year (589.2mm) and in August (626.6mm) in the second year (Fig.2).

Humidity

Maximum percentage of relative humidity was noticed during period of highest rainfall (97.10% in September in first year and 97.86% in August in second year) and minimum humidity was during February (38.52%) in the first year and in March (36.97%) in the second year (Fig.2).

Physico-chemical characteristics of water

Temperature

Water temperature followed a characteristic seasonal cycle at all the selected stations, the maximum generally in the month of May (30-37.5°C in the first year and 31.5-34.6°C in the second year) and minimum in the months of December- January (21.2-25.8°C in the first year and 20.4-27.0°C in the second year). The monthly fluctuation in water temperature of the six stations is represented in Appendix 1.

pH

The pH of the water varies widely between different rivers and streams and is influenced by carbonate - bicarbonate alkalinity and the concentration of carbon dioxide (Talling, 1976). In the present case the pH of water was found to be in alkaline range in all the stations varying from 7.2 to 8.9 (Appendix 2).

Ellis (1937) and Klein (1972) have pointed out that the pH values between 6.7 and 8.4 are suitable, while pH values below 5.0 and above 8.8 are detrimental. In the study stretch, pH value was well within this permissible limit in almost all the cases except few sampling occasions.

Most of the Indian rivers are reported to contain slightly to moderate alkaline waters (Mitra, 1982; Bhargava, 1985; Venkateswarlu, 1986; etc.). Ray and Ghosh (1976) stated that the Hugli estuary seems to have high buffering capacity as it maintains the pH fluctuating to its minimum in the entire stretch. Welch (1952) stated that the currents in lotic environment tend to keep the pH uniform over considerable distances and it would seem, in general, that streams develop more intense oxidities unless they are contaminated or receive heavy seepages from certain mineral deposit. In this study, the decompositions of organic matter received by the river either as human waste or as sewage input from Tolly's nullah at station 4 have not suppressed the pH level.

Conductivity

Conductivity which measures the total ionic composition of water and its overall chemical richness is vital as it indicates the biogenic potential of water. It varied from 191-594 μmhos / cm at station 1, 140.0-460 μmhos / cm at station 2, 110-742 μmhos / cm at station 3, 271.8 - 1400 μmhos / cm at station 4, 169.8 - 800 μmhos / cm at

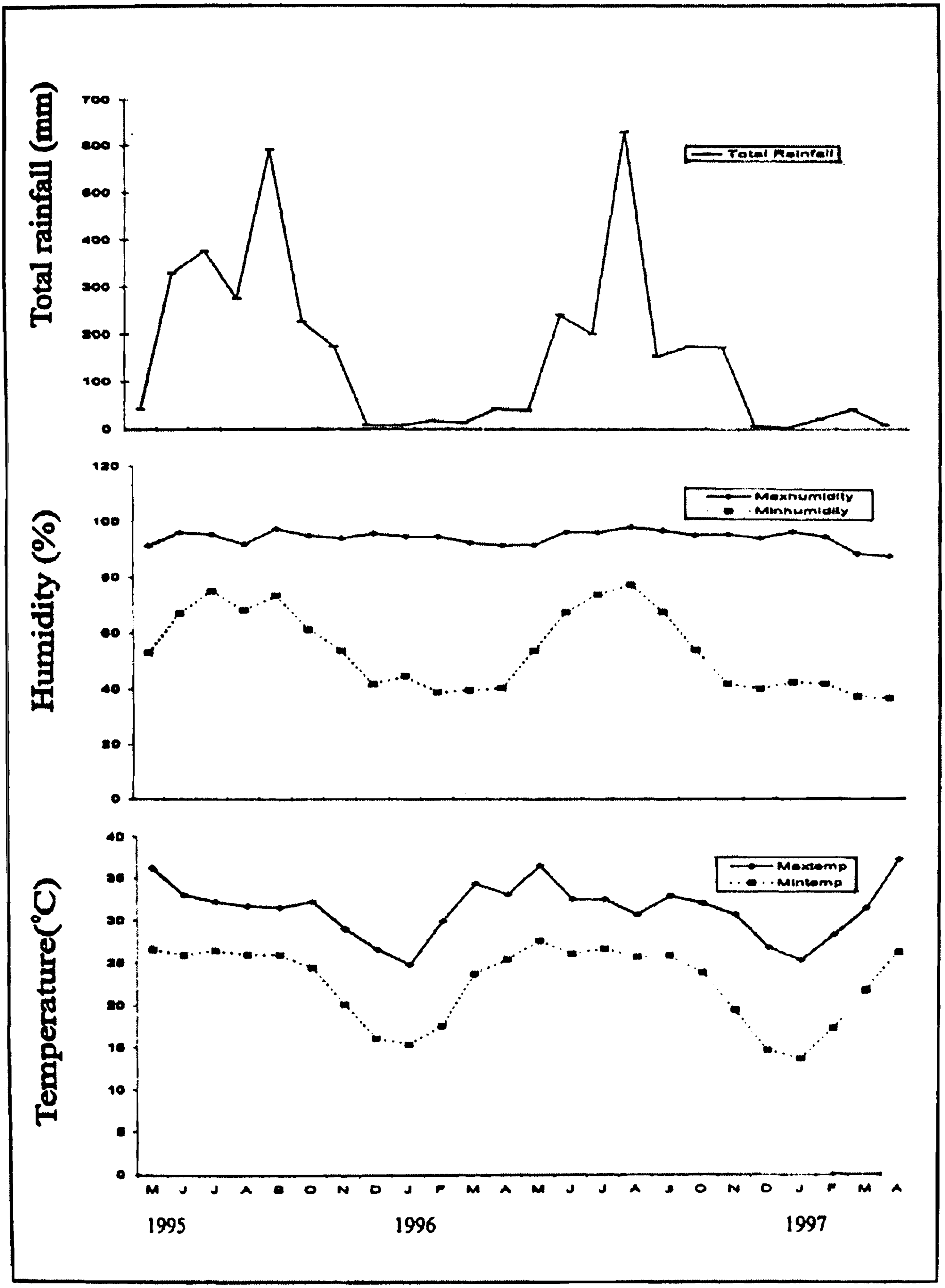


Fig. 2. Variation in meteorological factors in study region of river Hugli

station 5 and 178.0 508 μmhos / cm at station 6 (Appendix 3). The conductivity value was found to be maximum at station 4 (Table 1, Fig. 3b) which was probably due to the anthropogenic influences by way of effluents and sewage released into the river through Tolly's nullah which corroborates the study of Ramakrishna (1993) and Das and Sinha (1994). However, conductivity is less conservative since it is affected by ions other than chloride, that are biologically active.

Table 1. Mean values of physico-chemical properties at six study sites. Range of each parameter is shown in parentheses [All values are expressed in mg/l except temperature (^{0}C), conductivity (μmhos/cm), turbidity (N.T.U. and organic carbon (%)].

Physico-chemical Parameters	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	STATION 6
WATER						
Temperature	**28.43**	**28.93**	**29.11**	**28.13**	**28.62**	**29.37**
	(24.7-33.1)	(21.7-34.7)	(20.4-37.5)	(20.6-35.0)	(22.3-34.4)	(20.7-35.5)
pH	**8.17**	**8.12**	**8.28**	**7.89**	**8.08**	**8.28**
	(7.2-8.9)	(7.2-8.5)	(8.0-8.61)	(7.58-8.4)	(7.68-8.7)	(7.78-8.8)
Conductivity	**328.62**	**299.35**	**402.70**	**625.19**	**420.49**	**346.75**
	(191-594)	(140-460)	(110-742)	(271.8-1400)	(169.8-800)	(178-508)
Turbidity	**129.83**	**119.79**	**164.58**	**153.33**	**184.29**	**239.70**
	(55.0-349)	(43.0-361)	(34.0-400)	(41.0-293)	(50.0-400)	(80.0-400)
Total	**255.45**	**252.95**	**253.33**	**349.62**	**323.37**	**281.66**
Alkalinity	(140-380)	(150-350)	(150-380)	(200-650)	(200-440)	(190-410)
Hardness	**134.90**	**122.85**	**127.74**	**171.89**	**141.37**	**126.61**
	(65.0-231.4)	(77.0-195.8)	(73.0-213.6)	(90.0-302.6)	(81.9-231.4)	(66.0-195.8)
Dissolved	**5.28**	**5.19**	**5.63**	**2.45**	**4.54**	**5.17**
Oxygen	(4.0-6.5)	(4.0-7.0)	(4.0-7.5)	(0.4-4.5)	(2.4-6.9)	(4.0-8.0)
BOD	**10.83**	**9.0**	**5.91**	**27.75**	**8.58**	**10.2**
	(2.6-21.7)	(2.9-19.0)	(2.5-12.1)	(8.6-51.3)	(1.9-15.1)	(1.0-20.3)
COD	**33.23**	**33.61**	**30.46**	**54.71**	**30.79**	**34.30**
	(9.62-70.4)	(13.0-99.4)	(10.28-62.94)	(11.62-179.68)	(14.54-73.04)	(10.0-95.88)

Table 1-cont.

Physico-chemical Parameters	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	STATION 6
WATER						
Chloride	**17.61**	**8.53**	**11.74**	**44.91**	**25.45**	**24.77**
	(12.0-25.0)	(4.0-15.0)	(6.3-24.3)	(12.0-135)	(9.1-59.1)	(10.0-37.0)
Phosphate	**0.29**	**0.18**	**0.23**	**0.70**	**0.38**	**0.48**
	(0.01-0.9)	(0.02-0.5)	(0.09-0.8)	(0.1-1.6)	(0.08-1.6)	(0.01-1.4)
Ammonium	**0.11**	**0.26**	**0.21**	**1.71**	**0.41**	**0.57**
	(0.01-0.28)	(0.01-0.62)	(0.07-0.43)	(0.13-3.7)	(0.07-2.1)	(0.11-1.21)
Nitrite	**0.26**	**0.29**	**0.27**	**0.41**	**0.36**	**0.37**
	(0.01-0.9)	(0.06-0.54)	(0.07-1.16)	(0.13-2.63)	(0.12-0.67)	(0.04-0.79)
Nitrate	**2.6**	**2.89**	**4.3**	**3.31**	**3.74**	**5.33**
	(1.0-5.5)	(1.0-6.5)	(1.0-12.3)	(1.0-8.4)	(1.0-9.3)	(1.4-14.6)
Chromium	**0.08**	**0.09**	**0.12**	**0.13**	**0.19**	**0.24**
	(0.01-0.22)	(0.01-0.42)	(0.01-0.35)	(0.01-0.32)	(0.01-0.49)	(0.01-0.49)
Lead	**0.61**	**0.63**	**0.77**	**1.00**	**0.99**	**1.19**
	(0.08-1.8)	(0.23-2.1)	(0.09-1.9)	(0.4-2.91)	(0.32-2.7)	(0.15-2.91)
Zinc	**0.0008**	**0.008**	**0.02**	**0.15**	**0.05**	**0.03**
	(0.0-0.01)	(0.0-0.12)	(0.0-0.22)	(0.0-2.6)	(0.0-0.51)	(0.0-0.19)
SEDIMENT						
Temperature	**28.18**	**28.26**	**29.99**	**28.40**	**29.97**	**29.41**
	(22.7-33.0)	(21.8-34.2)	(21.8-40.0)	(22.8-35.3)	(23.5-37.8)	(20.2-35.8)
pH	**7.58**	**7.54**	**7.55**	**7.44**	**7.46**	**7.61**
	(6.44-8.4)	(7.17-8.1)	(7.1-8.4)	(6.3-8.3)	(6.8-8.0)	(7.1-8.6)
Phosphate	**4.04**	**3.92**	**3.44**	**3.75**	**4.22**	**4.55**
	(1.5-12.0)	(1.0-10.0)	(1.1-9.2)	(1.1-9.1)	(1.7-9.2)	(1.8-9.1)
Nitrite	**0.71**	**0.83**	**0.76**	**0.84**	**0.63**	**0.82**
	(0.02-2.13)	(0.09-2.56)	(0.09-2.3)	(0.26-1.98)	(0.04-1.37)	(0.08-1.49)
Nitrate	**6.25**	**3.78**	**4.54**	**5.59**	**4.74**	**4.80**
	(2.5-12.1)	(1.2-12.2)	(1.2-9.5)	(1.0-10.5)	(1.4-9.1)	(1.1-10.5)
Organic	**0.73**	**0.47**	**0.28**	**0.33**	**0.22**	**0.32**
Carbon	(0.37-1.5)	(0.11-1.47)	(0.02-0.76)	(0.04-0.57)	(0.02-0.51)	(0.05-0.99)

Turbidity

Turbidity ranged from 55.0 to 349 Nephalo Turbidity unit (N.T.U.) at station 1, 43-361, 34-400, 41-293, 50-400 and 80-400 N.T.U. at stations 2, 3, 4, 5 and 6 respectively (Appendix 4). It showed a wide fluctuation from station to station.

Patralekh (1994) reported greater turbidity in Ganga due to fast water current, greater wind velocity and greater inflow of muddy rainwater. Basu *et al.* (1970) reported that besides the tidal and wind effect the higher turbidity in the Hugli was caused by high turbulence in the water as a result of frequent movement of big vessels and the presence of sand, silt, clay and suspended organic and inorganic matter. This might explain the reason of higher turbidity at different stations in the present study.

Total Alkalinity

The values of alkalinity varied from 140-380, 150-350, 150-380, 200--650, 200-440, and 190-410 mg/l at stations 1-6 respectively (Appendix 5). In general, station 4 reflected a higher trend of alkalinity compared to the other stations. According to Kulshrestha *et al.* (1989a), Sashikant and Raina (1989) and Patil *et al.* (1984), high alkalinity is indicative of pollution. Higher alkalinity at station 4 may also be attributed to the high concentration of sewage (Robert, 1977; Das and Sinha, 1994).

Philipose (1960) has classified the waters of India in three categories, viz., 4-50 ppm alkalinity as 'low', 50-100 ppm as 'moderate' and 100-600 ppm as 'high' Accordingly, the present river with its alkalinity ranging from 140-650 mg/l could be placed in high category of alkalinity types.

Hardness

Temporary hardness in water seems to be caused by the presence of bicarbonates of Ca^{++} and Mg^{++} In Hugli river water hardness varied from 65 mg/l (station 1) to as high as 302.6 mg/l (station 4). The mean hardness value (Table 1, Fig. 3b) is found to be maximum-171.89 (90-302.6) mg/l at station 4 followed by 141.37 (81.9-231.4), 134.9 (65-231.4), 127.74 (73-213.6), 126.61 (66-195.8), 122.85 (77-195.8) mg/l at stations 5, 1, 3, 6 and 2 respectively (Appendix 6).

Generally hardness of water ranging from 50-150 ppm considered moderately hard, 150-300 ppm as hard and over 300 ppm as very hard. Based on the mean values of hardness (Table 1), all the stations except station 4 fall under moderatly hard water while station 4 can be considered as having hard water. The maximum amount of hardness of station 4 indicated the high pollution load by sewage (Sharma *et al.*, 1981; Ho and Furtado, 1982). However, the values of hardness recorded at all stations were within the maximum permissible level of 500 mg/l (WHO, 1971).

Dissolved Oxygen

Dissolved oxygen is a valuable tracer for water and sensitive indicator for biological and chemical processes occurring in it. In the present study, the value of oxygen varied from 4.0-6.5 mg/l at station 1, 4.0-7.0 mg/l at station 2, 4.4-7.5 mg/l at station 3, 0.4-4.5 mg/l at station 4, 2.4-6.9 mg/l at station 5 and 4.0-8.0 mg/l at station 6 (Appendix 7). The mean values of dissolved oxygen at six stations are represented in Table 1 and Fig 3a. The DO value of station 4 reflected a poor concentration of oxygen, wherein for most part of the year, it never exceeded 3mg/l. This may be due to receiving of sewage through Tolly's nullah. Running water contains typically high concentration of dissolved oxygen tending towards saturation, however, larger organic discharges perhaps adding to upstream pollution already present, cause great ecological changes (Dix, 1981), resulting in a large oxygen deficit in the downstream. According to Hawkes (1981), the presence of surface active material in the sewage effluent suppresses the rate of reaeration of the receiving stream and therefore delays self purification, and this effect is greater in sluggish rivers. However, according to Butcher (1940) and Blum (1957), the low value of dissolved oxygen is generally associated with high organic matter and due to the active aerobic bacteria, dissolved oxygen is known to fall down below the sewage outfalls.

The estuarine system in the present investigation was not under stress with respect to the dissolved oxygen level as it has been recommended that a minimum of 4mg DO per litre should be maintained in estuarine and coastal waters for healthy growth of fish population (FWQA, 1968). However, sometimes a concentration as low as 0.4 mg/ l at station 4 does recall attention. Depletion of oxygen to such an extent suggests that there was an influx of heavy organic load at this station as depletion of DO due to sewage discharge has been reported by many workers (Mary Bai, 1993; Singh *et al.*, 1994).

Biological oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biological oxygen demand (BOD) and chemical oxygen demand (COD) represent the biologically and chemically oxidized loads existing in water. The BOD values varied from 2.6 to 21.7, 2.9 to 19.0, 2.5 to 12.1, 8.6 to 51.3, 1.9 to 15.1 and 1.0 to 20.3 mg/l at stations 1, 2, 3, 4, 5 and 6 respectively (Appendix 8). The COD values also varied from 9.62 to 70.4 mg/l at station 1 and 13.0 to 99.4, 10.28 to 62.94, 11.62 to 179.68, 14.54 to 73.04, 10.0 to 95.88 at stations 2, 3, 4, 5 and 6 respectively (Appendix 9). Highest BOD and COD values were recorded at station 4 which may be due to receiving of large amount of sewage through Tolly's nullah. Similar conditions have been reported by various workers (Somasekhar, 1985a, 1985b; Sashikant and Raina, 1989; Kulshrestha *et al.*, 1989a; Josheph *et al.*, 1989; Sashikant and Rampal, 1989). However, in monsoon months the average values of BOD were low which may be related to the dilution effect (Shaw *et al.*, 1991; Singh *et al.*, 1994). The BOD values of the selected stations except station 4 were below the tolerance value of 30 mgl^{-1} fixed by Indian standard. The standard for COD is 250 mgl^{-1}. With respect to COD values, all the stations were well below the tolerance limit. Martin (1970) considered water body with BOD level exceeding 8 mgl^{-1} to be moderately polluted. According to this, all the stations fall under moderately polluted zone throughout the year. Sarala Devi *et al.* (1979) reported COD value as high as 3797 mgl^{-1} for a polluted estuarine water. Prati *et al.* (1971) classified water bodies into five classes depending upon the BOD, COD and other values. He put water body with BOD and COD respectively of above 12 and 80 mgl^{-1} into class v, of 12 and 80 mgl^{-1} into class iv, of 6 and 40 mgl^{-1} into class iii, of 3 and 20 mgl^{-1} into class ii and of 1to 5 and 10 mgl^{-1} into class i. Referring to this classification and based on the mean values of BOD and COD (Table 1, Fig. 3a), station 1 (BOD - 10.83, COD - 33.23), station 2 (BOD-9.0, COD-33.61), station -3 (BOD-5.91, COD - 30.46), station 5 (BOD-8.58, COD - 30.79) and station 6 (BOD-10.2, COD - 34.3) fall under class(iv) category. In case of station 4, though it can come under class(iv) due to the mean COD value of 54.71 but it can also be put under class(v) for its mean BOD value of 27.75. However, these stations fall under class(iv) and leaving one under (v) indicating deteriorated water quality.

Chloride

The chloride content of the river varied from 12.0 -25.0 mg/l at station 1, 4.0- 15.0 mg/l at station 2, 6.3-24.3 mg/l at station 3, 12.0-135.0 mg/l at stattion 4, 9.1-59.1 mg/l at station 5 and 10.0-37.0 mg/l at station 6 (Appendix 10). Station 4, in general, showed a higher content of chloride (Table 1, Fig. 3a).

Klein (1957) found a direct correlation between chloride content and pollution level and therefore, higher value of chloride in the river showed high degree of pollution. Several investigators, Blum(1957), Hawkes(1957), Venkateswarlu(1986), Somashekar (1988), Mary Bai(1993), Das and Sinha(1994), Sharma and Pande (1998) have reported sharp increase in chloride content at sewage polluted stretches of various rivers as also found at station 4 in this study. According to Munawar(1970) higher value of chloride is an index of pollution of animal origin. In the study area of Hugli river, however, the values of chloride were well below the limit set by the Indian Standards Institution (1974). At the sampling sites the concentration of chloride was not so high to pose any serious problem even if the river water would have been used for crops, for potable or industrial purposes.

Nutrients (Phosphate, Ammonium, Nitrite, Nitrate)

The concentrations of nutrients viz., nitrogen and phosphorus are important in running water as they are directly related to the biological productivity. Of all the nutrients of primary concern to the aquatic ecology phosphate is one of the most important limiting nutrients. The phosphate content of the river fluctuated between 0.01-0.9 mg/l at station 1, 0.02-0.5 mg/l at stations 2, 0.09-0.8 mg/l at station 3, 0.1-1.6 mg/l at station 4, 0.08-1.6 mg/l at station 5 and 0.01-1.4 mg/l at station 6 (Appendix 11). Highest mean value of phosphate (Table 1, Fig.3b) was at station 4 (0.7 mg/l) followed by station 6 (0.48 mg/l), station 5 (0.38 mg/l), station1 (0.29 mg/l), station 3 (0.23 mg/l) and station 2 (0.18mg/l). Pitcairn and Hawkes (1973) recommended that 0.01

mg inorganic phosphate per liter is the maximum possible concentration if the hazards of supporting undesirable growth of aquatic organisms are to be avoided. From the results it appears that phosphate value has crossed the desired level at the selected stations. Nagarajaiah and Gupta (1983) reported values varying from traces to 9.15μg at l^{-1}.

All types of nitrogenous pollutants including ammoniacal, organic, nitrate and nitrite nitrogen present in a stream are indicators of the pollutional load of the stream. However, nitrogen is one of the important nutrients for plants but excess of this element in water results in eutrophication. Ammoniacal nitrogen is an important indicator of pollution. It arises from the aerobic or anaerobic decompostition of organic nitrogenous matter present in the stream which is oxidized to nitrites and ultimately to nitrates (Sawyer and Mc Carty,1967). Maximum mean amount of ammonium nitrogen (Table 1, Fig. 3b) was found at station 4 as 1.71 (0.13-3.7 mg/l) followed by station 6 as 0.57 (0.11-1.21 mg/l) and as 0.41 (0.07-2.1 mg/l), 0.26 (0.01-0.62 mg/l), 0.21 (0.07-0.43 mg/l) and 0.11 (0.01-0.28 mg/l) at stations 5, 2, 3 and 1 respectively (Appendix 12). Increase in ammonia concentration results in the biochemical, physiological, histological, immunological changes in the vital organs of fish (Colt and Techobanoglous, 1978; Hillaby and Randal, 1979).

The mean concentration of nitrite (Table 1, Fig.3b) was also highest 0.41 (0.13-2.63 mg/l) at station 4 followed by 0.37(0.04-0.79 mg/l), 0.36 (0.12-0.67 mg/l), 0.29(0.06-0.54mg/l), 0.27 (0.07-1.16 mg/l) and 0.26 (0.01-0.9 mg/l) at stations 6, 5, 2, 3and 1 respectively (Appendix 13).

The nitrite level at different stations followed the same trend as that of ammonium in these stations. The concentration of nitrite nitrogen in this estuarine system was found to be much higher than the values of 0.4 to 2.6 μg at l^{-1} reported by Manikoth and Salih (1974) for estuarine waters. Thus it appears that the water in this stretch of Hugli estuary was under stress with respect to the nitrite level.

Nitrate represents the end product of oxidation of nitrogenous matter and its concentration is a product of nitrification and denitrification activities undergoing in water. Results obtained from the variations in nitrate-nitrogen levels (Appendix 14) are interesting as in this case, station 6 reflected the highest mean amount of nitrate (Table 1, Fig.3b) being 5.33 followed by 3.74, 3.31, 4.3, 2.89 and 2.6 at stations 5, 4, 3, 2 and 1 respectively.

River and estuarine waters generally contain more dissolved nitrate than sea water (Stephens and Richard, 1963). Higher values of nitrate obtained in the different stations under study might be due to decomposition of organic matter, which got transferred by aerobic and anaerobic bacteria at high temperature into nitrogenous organic matter. This is in accord with the findings of Rao and Govind (1966) and Ray *et al.* (1966). Reid (1961) also found that the world average of nitrates in unpolluted freshwaters was 0.30 mg/l. In Hugli estuarine waters, at every sampling site the concentration of nitrate was relatively higher than this limit. It is found that in case of nitrate concentration, station 4 did not show the highest value as observed for ammonium and nitrite concentration.

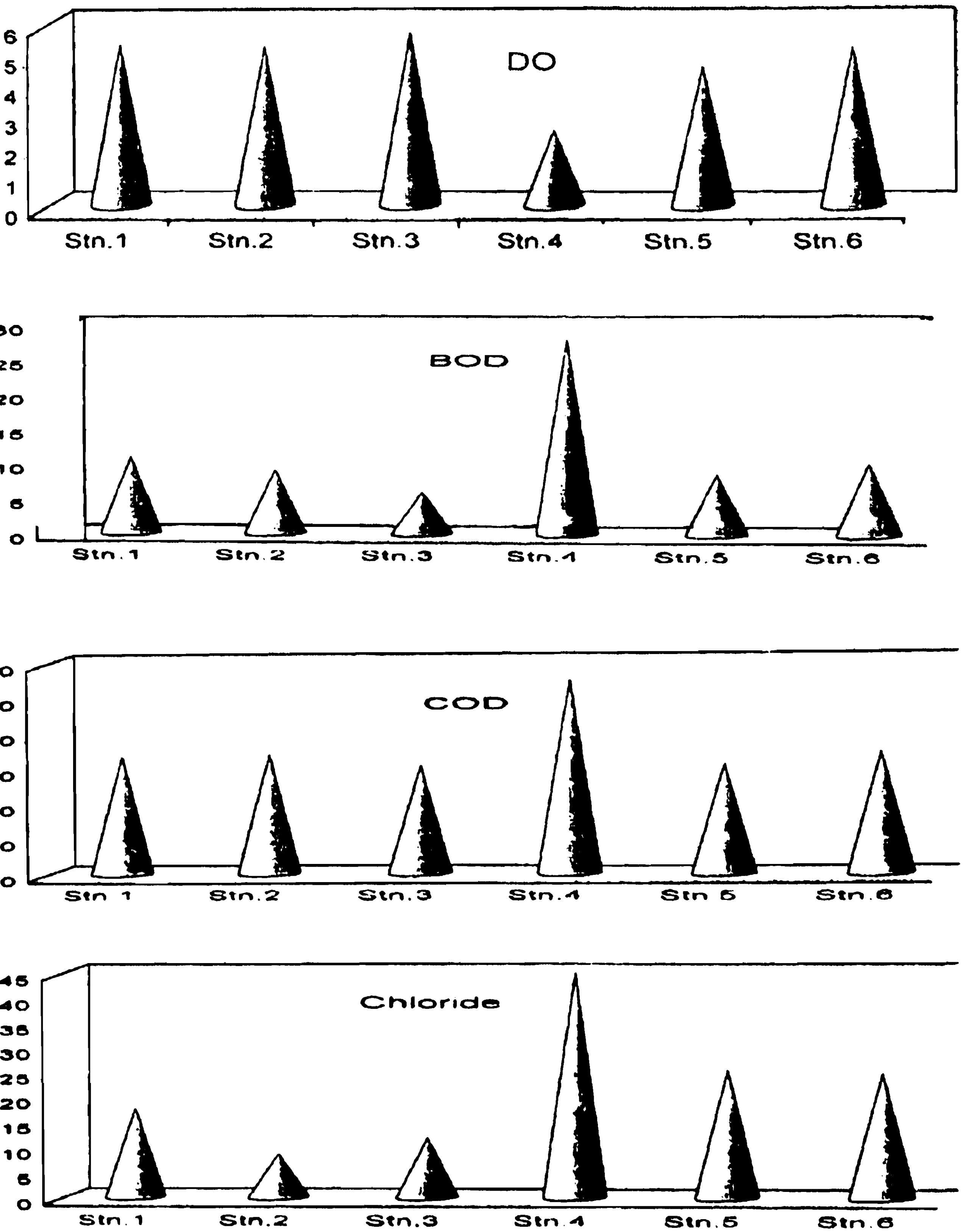


Fig. 3a. Water quality in terms of DO, BOD, COD, and Chloride (Mean values) at different stations

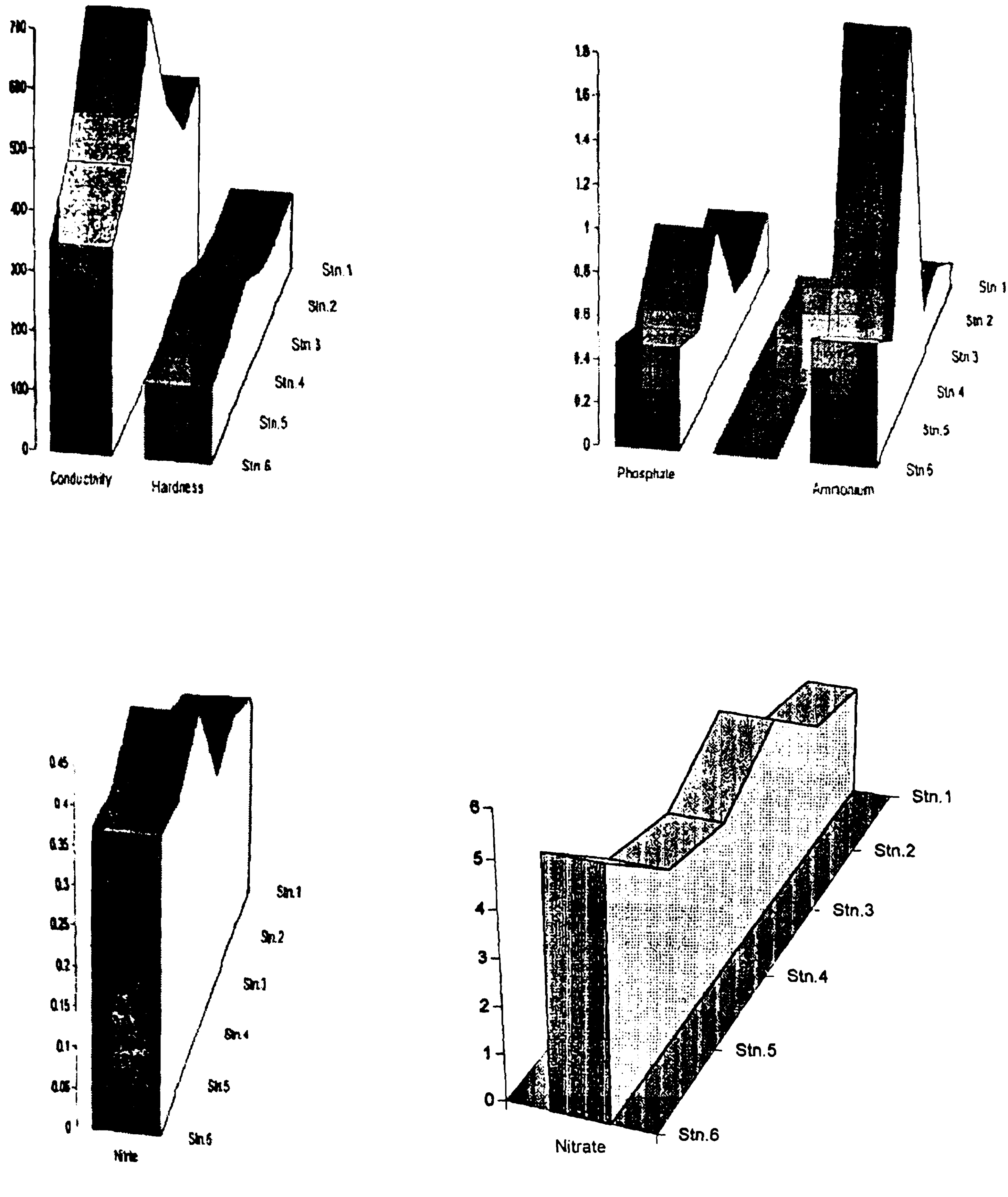


Fig. 3b. Water quality in terms of Conductvity, Hardness, Phosphate, Ammonium, Nitrite and Nitrate (mean values) at different stations.

According to Ganapati (1943) and Zafar (1964) deficiency of oxygen or the absence of proper organisms are being the prime factors responsible for the incomplete oxidation of free ammonia accounting for the low nitrate values.

The high concentration of nutrients particularly nitrogen and phosphorus are expected in polluted waters (Vollenweider, 1968; Munawar, 1970). The concentration of the nutrients like phosphate, ammonium, nitrite were all highest at station 4 indicating that it was under the influence of sewage discharge from Tolly's nullah. In the present study, the phosphate concentration was low when compared to the nitrate content, which is in accord with the observations of Chakraborty *et al.* (1959), Ray *et al.* (1966), Pahwa and Mehrotra (1966) and Ghosh *et al.* (1989) for some Indian rivers.

Heavy metals (chromium, lead, zinc)

Among some heavy metals (chromium, lead, zinc, arsenic), the concentration of zinc was very low compared to chromium and lead, while arsenic was never recorded in Hugli river water. The concentration of chromium in the water ranged between 0.01-0.22 mg/l at station 1, 0.01-0.42 mg/l at station 2, 0.01-0.35 mg/l at station 3, 0.01-0.32 mg/l at station 4, 0.01-0.49 mg/l at station 5 and 0.01-0.49 mg/l at station 6 (Appendix 15). On the basis of mean values of chromium (Table 1) station 6 reflected the highest amount (0.24 mg/l) followed by station 5 (0.19 mg/l), station 4 (0.13 mg/l), station 3 (0.12 mg/l), station 2 (0.09 mg/l) and station 1 (0.08 mg/l).

The value of lead varied between 0.08-1.8 mg/l at station 1, 0.23-2.1, 0.09-1.9, 0.4-2.91, 0.32-2.7, and 0.15-2.91 mg/l at station 2, 3, 4, 5 and 6 respectively (Appendix 16). The mean value of lead (Table 1) was also found to be highest at station 6 (1.19 mg/l), almost equal at stations 5 (0.99 mg/l) and 4 (1.0 mg/l) followed by station 3 (0.77 mg/l), station 2 (0.63 mg/l) and station 1 (0.61 mg/l).

The concentration of zinc was below the detectable limit in most of the time. However, maximum amount was recorded at station 4 having a mean value of 0.15 mg/l (0.0-2.6 mg/l) followed by 0.05 (0.00-0.51) mg/l at station 5, 0.03 (0.00-0.19) mg/l at station 6, 0.02 (0.00-0.22) mg/l at station 3, 0,008 (0.00-0.12) mg/l at station 2, 0.0008 (0.00-0.01) mg/l at station 1 (Appendix 17, Table 1).

The presence of heavy metals in the aquatic environment is dependent on a wide range of chemical, biological and environmental factors. A very important factor which influences the availability of heavy metals in the aquatic system is the hydrogen ion concentration and the precipitation of heavy metals was reported to be enhanced at pH above 7(Polprasert, 1982). In this study, the concentration of chromium and lead was higher than the prescribed limits of WHO (1984, 0.05 mg/l) for drinking water. The value of zinc, however, was found within the prescribed limits for drinking water quality (5.0 mg/l) as proposed by WHO (1984).

Physico-chemical characteristics of sediment

Temperature

The temperature of sediment followed the same trend as that of water being higher in May (32.3-40°C in the first year and 32.9 to 37.8°C in the second year) and minimum in December-January (21.8 to 26.5°C in the first year and 20.2°C to 26°C in the second year) (Appendix 18).

pH

The hydrogen ion concentration of sediment was slightly acidic to moderately alkaline ranging between 6.44 to 8.4 at station 1, 7.17 to 8.1, 7.1 to 8.4, 6.3 to 8.3, 6.8 to 8.0 and 7.1 to 8.6 at stations 2, 3, 4, 5 and 6 respectively (Appendix 19).

The acidity of soil may be due to several reasons such as leaching due to heavy rainfall, origin of soil from acid parent material, use of acid forming fertilizers and also due to microbiological action (Mandal and Moitra, 1975). Microorganisms are responsible for processes such as decomposition of organic residues and nitrification and as a result acids are formed. These on liberation, seek a base either from free calcium carbonate or from the exchange complex. If the exchange complex is low in base saturation, these acids are not neutralized and cause the soil solution to be acidic (Mortimer and Hickling, 1964). Soil may also be slightly acidic due to the presence of humus which possesses different amino acids. Break down of humus results in increased concentration of CO_2, hydrolysis of acid, salts and production of organic acids which add to the total acidity of the sediment (Seatz and Peterson, 1964). In the present study both microorganisms and humus may be responsible for the slightly acidic nature of the sediment.

Phosphates

Both organic and inorganic phosphates are present in the soil. The organic forms present in the plant and animal residues are added to the soil. The availability of these again depend upon pH and the concentration of organic matter. The phosphate content of the sediment (Appendix 20) varied from 1.5 to 12.0 mg/l (station 1), 1.0 to 10.0 mg/l (station 2), 1.1 to 9.2 mg/l (station 3), 1.1 to 9.1 mg/l (station 4), 1.7 to 9.2 mg/l (station 5) and 1.8 to 9.1 mg/l (station 6).

Mortimer (1941; 1942; 1971) and Hutchinson (1975) have emphasized the importance of oxygen at the mud water interface and the redox potential in the sediments for the release and uptake of dissolved phosphorus. The higher content of phosphates (Table1, Fig.4) recorded in the present study at some stations may be due to the availability of oxygen content at the mud water interface, the lack of which causes decreased amount of phosphates in the sediment. Choudhury (1991) reported high phosphate content at the sites of immersion of dead bodies while Saha (1985) reported high phosphate concentration due to its release from the dead cells of algae, particularly the diatoms.

Nitrites and Nitrates

These are not generally present as such but are formed from organic nitrogenous compound by decomposition, ammonification and nitrification brought about by the activities of two groups of bacteria. The nitrite content of the bottom sediment fluctuated from 0.02-2.13 mg/l at station 1 and 0.09-2.56, 0.12-2.3, 0.26-1.98, 0.04-1.37 and 0.08-1.49 mg/l at stations 2, 3, 4, 5 and 6 respectively (Appendix 21). The nitrate content varied from 2.5-12.1 mg/l at station 1 and 1.2-12.2 mg/l, 1.2-9.5 mg/l, 1.0-10.5 mg/l, 1.4-9.1 mg/l, 1.1-10.5 mg/l at stations 2, 3, 4, 5 and 6 respectively (Appendix 22, Table 1, Fig.4).

The addtion of these nitrogenous compounds may occur due to leaching from the catchment areas (Choudhury, 1991). However, at stations 4, the nitrogenous compounds are mainly sewage derived.

Organic Carbon

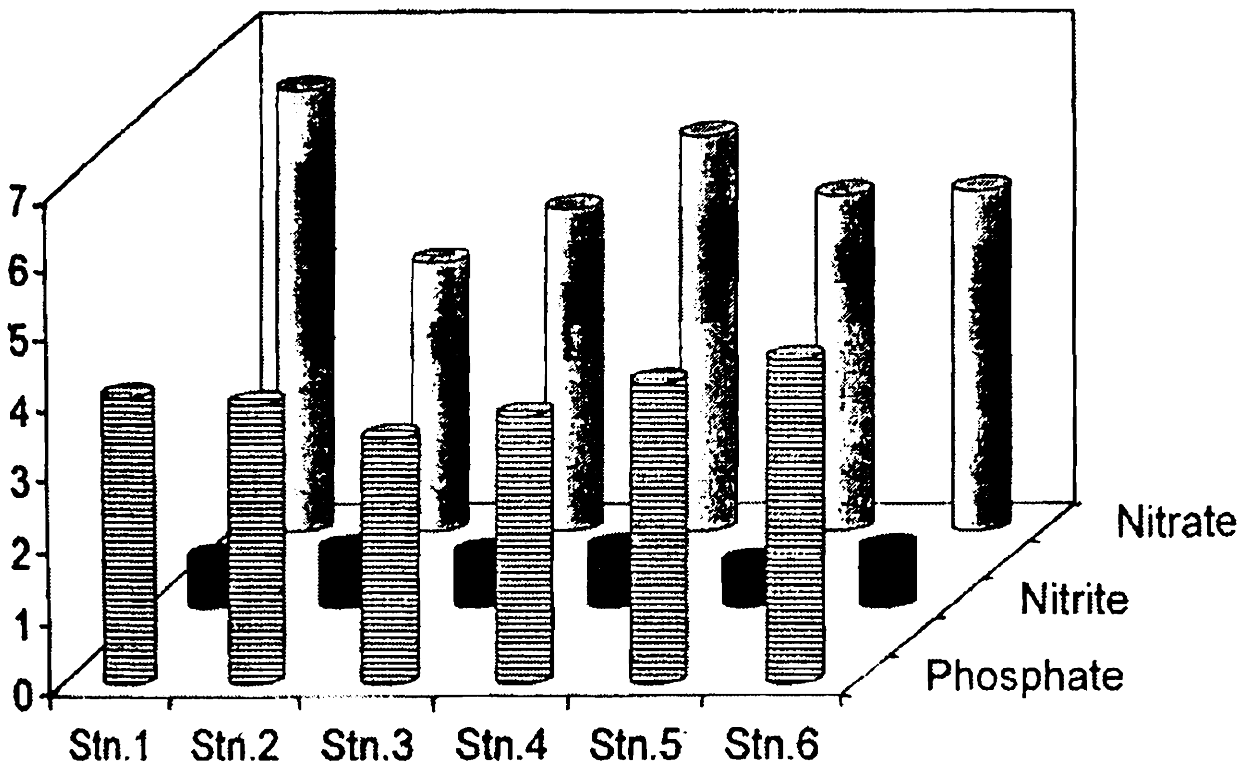
The organic carbon present in the organic matter plays an important role in soil fertility. The availability of organic carbon depends upon several factors. Although the main source of organic matter in soil is from plants yet the contribution of the aquatic animals is considerable. As carbon forms the most important constituent of the total organic matter, the increased percentage of the organic carbon in a soil obviously leads to a greater organic matter content. In the present study the percentage of organic carbon varied from 0.37-1.5, 0.11-1.47, 0.02-0.76, 0.04-0.57, 0.02-0.51, and 0.05 to 0.99 at stations 1, 2, 3, 4, 5 and 6 respectively (Appendix 23, Fig.4).

As urban waste waters are released into the river, a large quantity of organic matter or organic carbon is sewage-derived. The concentrations of organic matter was also indirectly influenced by climatic conditions and the variations were probably due to difference in temperature, pH, rate of accumulation of dead organisms, topography and soil texture (Choudhury, 1991; Jayaraj and Reddy, 1992).

Texture

The sediment of the six stations under study was of silt loam type except station 3 and 6 which have silt type sediment. The percentage contribution of sand, silt and clay to the sediment of different stations is represented in Fig.5. It is evident from the results that clay fractions contributed (3.9% at station 5 to 15.9% at station 1) little to the sediment texture as compared to sand (6.28% at station 1 to 24.94% at station 5) and silt (71.16% at station 5 to 81.68% at station 3) fractions.

Raman *et al.* (1975) obtained fairly equal proportions of fine sand and mud near the bar mouth of Pulicat lake. Bhat (1979) found higher percentages of sand admixed with excess of decaying organic matter in Nethravati-Gurupur estuary. Parulekar *et al.* (1980) noted dominance of sand fractions throughout post and premonsoon seasons in Goan estuaries. Choudhury (1991) found higher concentration of sand followed by silt and



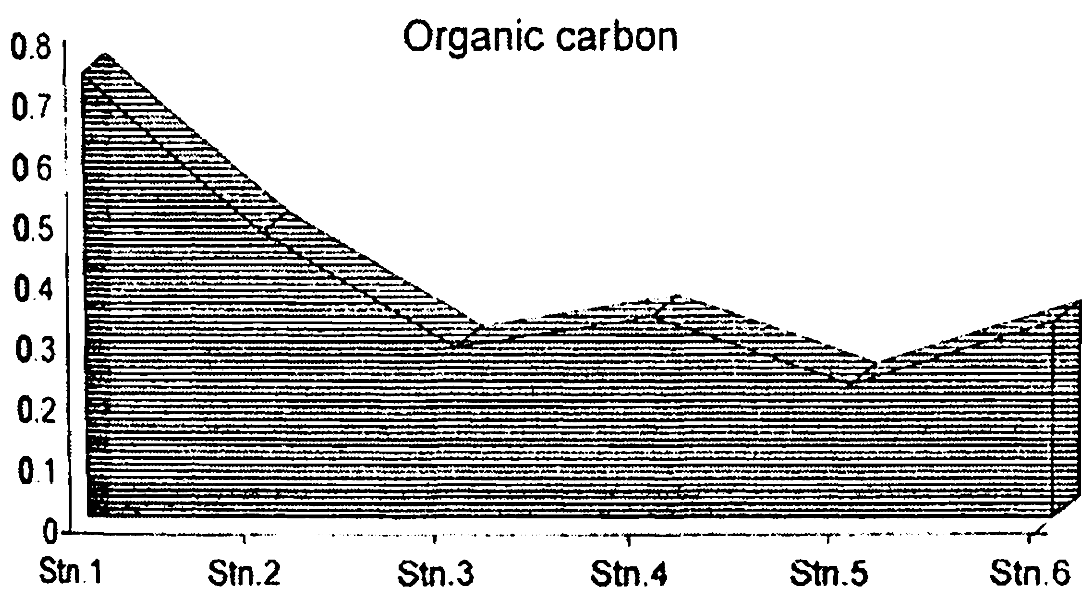


Fig. 4. Sediment quality in terms of Phosophate, Nitrite, Nitrate and Organic carbon (Mean values) at different study sites.

clay in river Ganga in Bihar. The sediment had, however, greater percentage of silt in the present study stretch.

That the nature of substrate greatly influences benthic communities is well accepted (Bhat, 1979; Rama Chandra *et al.*, 1984; Sarala Devi and Venugopal, 1989). Desai and Krishnan Kutty (1967) reported poor fauna in clayey-silty substratum of Cochin backwaters. Rama Chandra *et al.* (1984) noted dominance of bivalves in sediments with medium, fine and very fine sand fractions, while dominance of polychaetes were in regions of sandy substrata in Mulki estuary. In Hugli river, polychaetes were also found more in substrata having higher percentage of sand as evident from the dominance of polychaetes at station 5 and their paucity of occurrence at station 1.

Biological Characteristics

The biotic components, herein, representing macrozoobenthos which occur in the intertidal mudflats of Hugli river in and around Calcutta can be classified into two major groups, namely, epifauna and infauna. Of these, in the intertidal environment of the study area, these macroinvertebrates are comprised of polychaetes, oligochaetes, crustaceans, insect larvae, gastropods and bivalves, while vertebrate members are represented by pisces like gobiids and eels. Amongst these seven groups, mainly gastropods represent the epifauna and other groups such as oligochaetes, polychaetes, bivalves and fishes comprised the infauna, while crustaceans include both epifaunal and infaunal organisms. Their distribution pattern and abundance has been chosen as a fundamental theme in this study of ecological communities as envisaged by May (1975). It is mentioned that the distribution and abundance of benthic macroinvertebrates are related to trophic level, physico-chemical characteristics, life cycles and growth patterns of the major taxa (Cowell and Vodopich, 1981). Gradual changes in environmental factors (eg. Flow, water temperature, food resources) along the longitudinal profile of river systems usually exert a direct influence on the population dynamics of aquatic organisms resulting in characteristic biological communities (Illies and Botosaneanu, 1963; Hawkes, 1975). But anthropogenic activities are virtually interfering the natural environmental conditions of the river system and thereby altering the structure of aquatic communities. The compositions, abundance and distribution of benthic organisms over a period of time provide an index of the ecosystem. Thus, in this treatise, information is provided on such aspects like spatio-temporal distribution, species composition, biomass, population density, seasonal abundance, etc. of commonly encountered benthic macrofauna in the river with relevance to their importance as indicator species and their role in evaluation of pollution level of the water body.

Qualitative Composition

During the course of survey work, a total of 44 species of macrozoobenthic fauna belonging to seven major groups have been encountered in the intertidal region of the

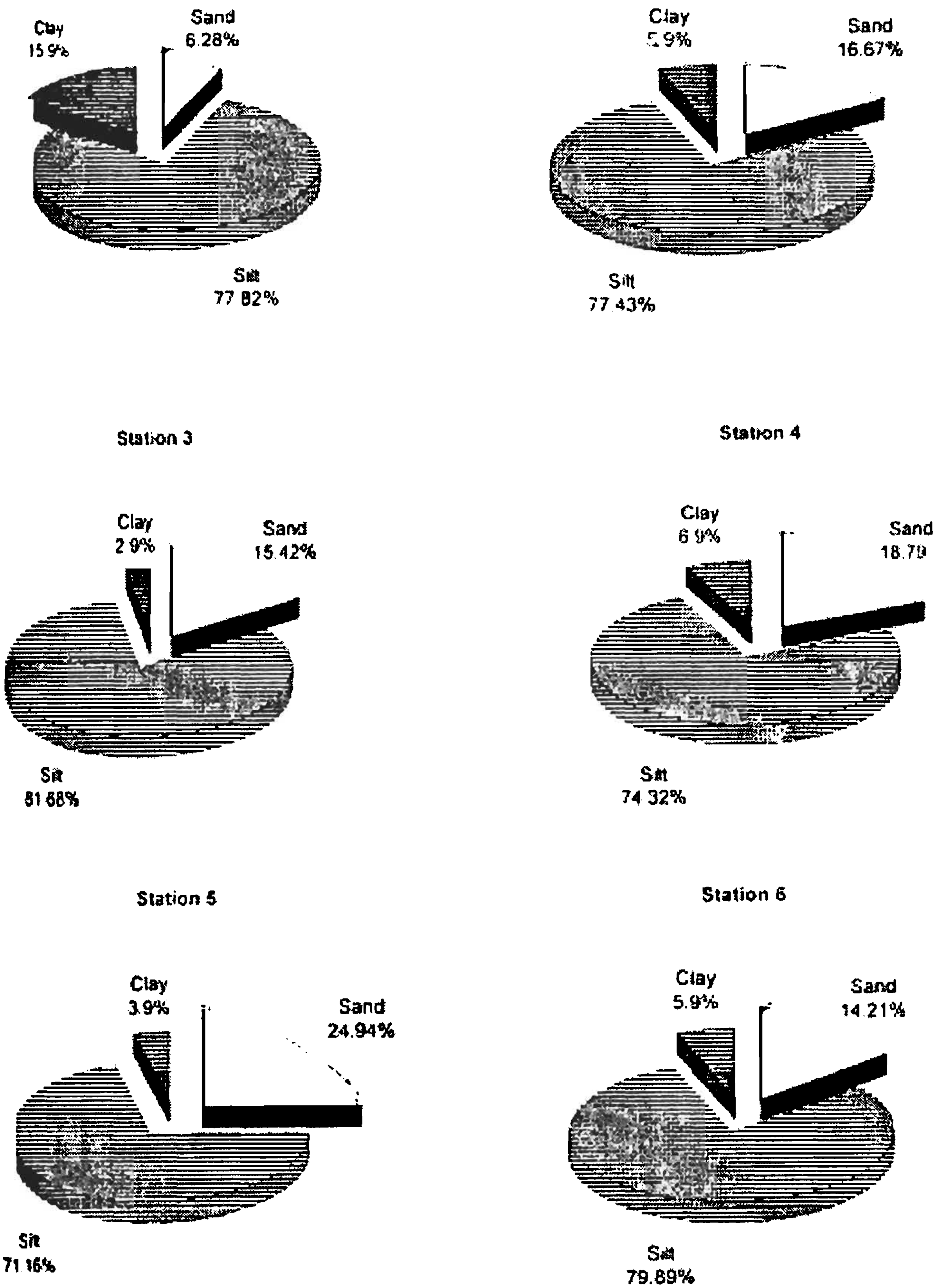


Fig. 5. Sediment texture (percentage) of the selected stations.

study stretch. A composite picture of this faunal community in tne monthly as well as seasonally sampled stations is given in Table 2. The macrobenthos inhabiting the environment was represented by Polychaeta, Oligochaeta, Crustacea, insect larvae, Gastropoda, Bivalvia and Pisces, comprising of 8 species belonging to 3 families, 3 species comprising of one family, 7 species of 5 families, 2 species of 2 families, 18 species of 8 families, 2 species of 2 families, and 4 species of 3 families, respectively. Of these seven groups, four groups viz., Polychaeta, Oligochaeta, Crustacea and Gastropoda occurred more or less throughout the year. However, oligochaetes appeared at station 4 only and rarely at station 5. The predominance of oligochaetes was mainly due to *Limnodrilus hoffmeisteri*. Bivalves and Pisces were occasionally recorded, while the insect larvae were seasonal in occurrence. All the three dominant groups viz., Gastropoda, Polychaeta and Crustacea exhibited a wider distribution.

Accumulated data (Table 2) revealed that Shivpur had the highest number of species (33) followed by Kidderpore Jetty ghat and Bally (both having 25 species), Kidderpore Taktaghat (24), Uluberia (22), Bagbazar (21), Dakshineswar and Achipur (both having 20 species) while the lowest number of species occurred in Kidderpore Doighat (only 12). The lowest diversity of species was recorded from a station (station 4) which is under the continuous influence of sewage from Tolly's nullah corroborating the studies in Chambal and Khan rivers (Rao and Srivastava, 1989) and river Ganga (Sinha and Das, 1993).

In the literatures dealing with macrobenthos of Indian rivers, Rao and Jain (1985) reported 11 species from Chambal river, Vattakeril and Diwan (1991) found 32 species in Kshipra river and Chatterjee (1994) recorded 35 species in river Brahmani. In the lower high saline stretch (marine zone) of river Hugli 142 species, while in the upper freshwater zone 38 species were recorded (Paul *et al.*, 2000).

The present study stretch representing 44 species is nearer to the freshwater zone, thus acquiring an intermediate status with regards to species diversity.

The important factors which influence the distribution of benthic animals in the intertidal region are salinity, temperature, nature of substratum, effect of tide, grazing and predation (Damodaran, 1973; Perkins, 1974; Ansari *et al.*, 1986). In this study, all the groups and species are either freshwater or euryhaline form as they occurred in salinity less than 0.1 mg/l in the present study stretch.

A survey of benthic community from countries outside India revealed the occurrence of 106 taxa from river Tigris in Iraq (Salih *et al.*, 1986) and 115 taxa in James river estuary in Virginia (Diaz, 1989). Harrel and Hall III (1991) noticed 104 taxa during their collection in 1984 - 1985 in Neches river estuary (Texas), while Degani *et al.*, (1992) reported 76 taxa from river Dan in northern Israel.

Table 2. List of Intertidal Macrozoobenthos of Hugli river in and around Calcutta ('+'= present, '--'= not found).

GROUPS AND SPECIES	Bally	Dakshin-eswar	Bag-bazar	Takta-ghat	Doi-ghat	Jetty-ghat	Shiv-pur	Achi-pur	Ulu-beria
POLYCHAETA									
Family NEREIDIDAE									
1. *Namalycastis fauveli* Rao	+	+	+	+	+	+	+	+	+
2. *Namalycastis indica* (Southern)	+						+		+
3. *Dendronereides heteropoda* Southern	+								
4. *Dendronereis aestuarina* Southern			+	+	+	+	+	+	+
5. *Neanthes meggitti* (Monro)	+				+	+	+		
Family NEPHTYIDAE									
6. *Nephtys oligobranchia* Southern	+	+	+	+	+	+	+	+	+
7. *Nephtys polybranchia* Southern	+		+	+		+	+		
Family CAPITELLIDAE									
8. *Parheteromastus tenuis* Monro					+				
OLIGOCHAETA									
Family TUBIFICIDE									
9. *Branchiura sowerbyi* Beddard					+				
10. *Limnodrilus hoffmeisteri* Claparede					+	+			
11. *Bothrioneurum iris* Beddard					+				
CRUSTACEA									
Family ?									
12. Isopods (1 sp.)	+	+	+	+			+		
Family GRAPSIDAE									
13. *Sesarma edwardsi* deMan	+	+	+	+	+	+	+	+	+
14. *Ptychognathus onyx* Alcock	+		+				+		
Family PALAEMONIDAE									
15. *Macrobrachium rosenbergii* (de Man)							+		
16. *Macrobrachium malcolmsonii* (Milne Edwards)	+	+	+	+		+	+	+	+
Family PENAEIDAE									
17. *Metapenaeus* sp.							+		
Family ATYIDAE									
18. *Caridina* sp.				+					
INSECTA									
Family ?									
19. Coleopteran larva (1sp.)				+		+	+		
Family CHIRONOMIDAE									
20. Dipteran larva (1sp.)	+	+	+	+		+	+	+	+
GASTROPODA									
Famuly THIARIDAE									
21. *Thiara (Thiara) scabra* (Mueller)	+	+	+	+	+	+	+	+	+
22. *Thiara (Tarebia) lineata* (Gray)	+	+	+	+	+	+	+	+	+
23. *Thiara (Tarebia) granifera* (Lamarck)	+	+	+	+		+		+	+

Table 2-cont.

GROUPS AND SPECIES	Bally	Dakshin-eswar	Bag-bazar	Takta-ghat	Doi-ghat	Jetty-ghat	Shiv-pur	Achi-pur	Ulu-beria
24. *Thiara (Melanoides) tuberculata* (Mueller)	+	+	+	+	+	+			+
Family ASSIMINEIDAE									
25. *Assiminea francesiae* (Wood)	+	+	+	+		+	+	+	+
Family PLANORBIDAE									
26. *Indoplanorbis exustus* (Deshayes)	+	+	+	+		+	+	+	+
27. *Gyraulus convexiusculus* (Hutton)	+	+				+	+	+	+
28. *Gyraulus labiatus* (Benson)			+	+			+	+	+
29. *Brotia (Antimelania) costula* (Rafinesque)	+	+	+				+	+	+
Family LYMNAEIDAE									
30. *Lymnaea acuminata* Lamarck	+	+		+		+	+	+	
31. *Lymnaea luteola* Lamarck	+	+					+	+	
Family VIVIPARIDAE									
32. *Bellamya bengalensis* (Lamarck)	+	+				+	+	+	+
Family NERITIDAE									
33. *Neritina (Vitina) smithi* Wood									+
34. *Neritina (Dostisa) violacea* (Gmelin)	+		+	+		+	+	+	+
35. *Septaria lineata* (Lamarck)	+	+	+	+		+	+	+	+
36. *Pseudonerita obtusa* (Benson)						+			
Family STENOTHYRIDAE									
37. *Stenothyra deltae* (Benson)				+			+		
Family BITHYNIIDAE									
38. *Digoniostoma cerameopoma* (Benson)	+	+	+	+		+	+	+	+
BIVALVIA									
Family CORBICULIDAE									
39. *Corbicula striatella* Deshayes		+					+		+
Family SOLECURTIDAE									
40. *Novaculinga gangetica* Benson			+					-	
PISCES									
Family GOBIIDAE									
41. *Parapocryptes macrolepis* (Bleeker)							+		-
42. *Apocryptodon madurensis* (Bleeker)							+		-
Family TAENIOIDIDAE									
43. *Odontamblyopus rubicundus* (Hamilton-Buchanan)				+		+	+	-	-
Family ANGUILLIDAE									
44. Eel (1sp.)				+		+	+		-
Total species	**25**	**20**	**21**	**24**	**12**	**25**	**33**	**20**	**22**

The overall qualitative assessment of the benthic organisms under the present communication suggests that the river Hugli supports considerable diversity compared to the other Indian rivers but compared to rivers outside India, this river system has less diversity which may be due to the difference in water flow, climatic regions in which the river is situated, current of river water and also the varying substratum of rivers.

Quantitative Evaluation

Population density

The population of benthos in the intertidal area experience peculiar and varying seasonal conditions from biotic and abiotic standpoints. Monthly density of total benthic organisms at the six selected stations for two consecutive years is represented in Fig. 6(a and b). In general lowest population density was recorded in the monsoon months except station 4 which showed lowest density in March (Table 3.) The population density of total macrobenthos varied from 13 no./m^2 at station 5 in October 1995 to 24,686 no./m^2 at station 4 in December 1996 (Fig. 6b).

Factors determining the distribution of invertebrate population in streams include food supply, substrate, current, competiton for space and predation (Cummins, 1975). Wide fluctuations in the spatio-temporal distribution and abuncance of aquatic organisms observed from year to year and within the same year was attributed to differences in general ecology as well as the disturbance of their habitat as reported by Holme (1961) corroborating the earlier observations of Ruggles (1959) and Oliver (1960).

The seasonal change in the quantum of benthos has been attributed to a number of environmental factors such as oxygen (Hynes, 1970), temperature (Hynes, 1970), substrate (Ruggiero and Merchant, 1979; Jonasson and Lindegaard, 1979; Arunachalam *et al.*, 1991), salinity (Desai and Krishnankutty, 1967; Ansari, 1974; Mclusky *et al.,* 1975; Gopalakrishana Pillai, 1977), life cycle pattern (Whitlatch, 1977), changes in particle size (Sanders, 1958), etc. In the present study, highest population density was always found at station 4 which was under stress due to very poor oxygen concentration. This finding is in agreement with the study of Varshney *et al.*, (1988) who reported high density of benthos in stressed inshore stations with low DO concentrations in Versova coast of Bombay and finds further support from Ghosh *et al.* (1990) who had reported a dense population of benthos (12, 297 - 42, 856 no./m^2) in stressed stations of Mathabhanga - Churni river of West Bengal.

The total macrobenthic population in the study area showed one or two maxima in a year. Sunder and Subla (1986) found two maxima, one in winter (653 no./m^2) and the secondary peak in late spring / summer months in river Jhelum. Sharma (1986) reported a single peak of abundance in February (1006 no./m^2) and lowest in July and August (33 no./m^2) in river Bhagirathi. Fernando (1987) found maximum abundance in postmonsoon and summer in Vellar estuary. Prabha Devi and Ayyakkannu (1989) found

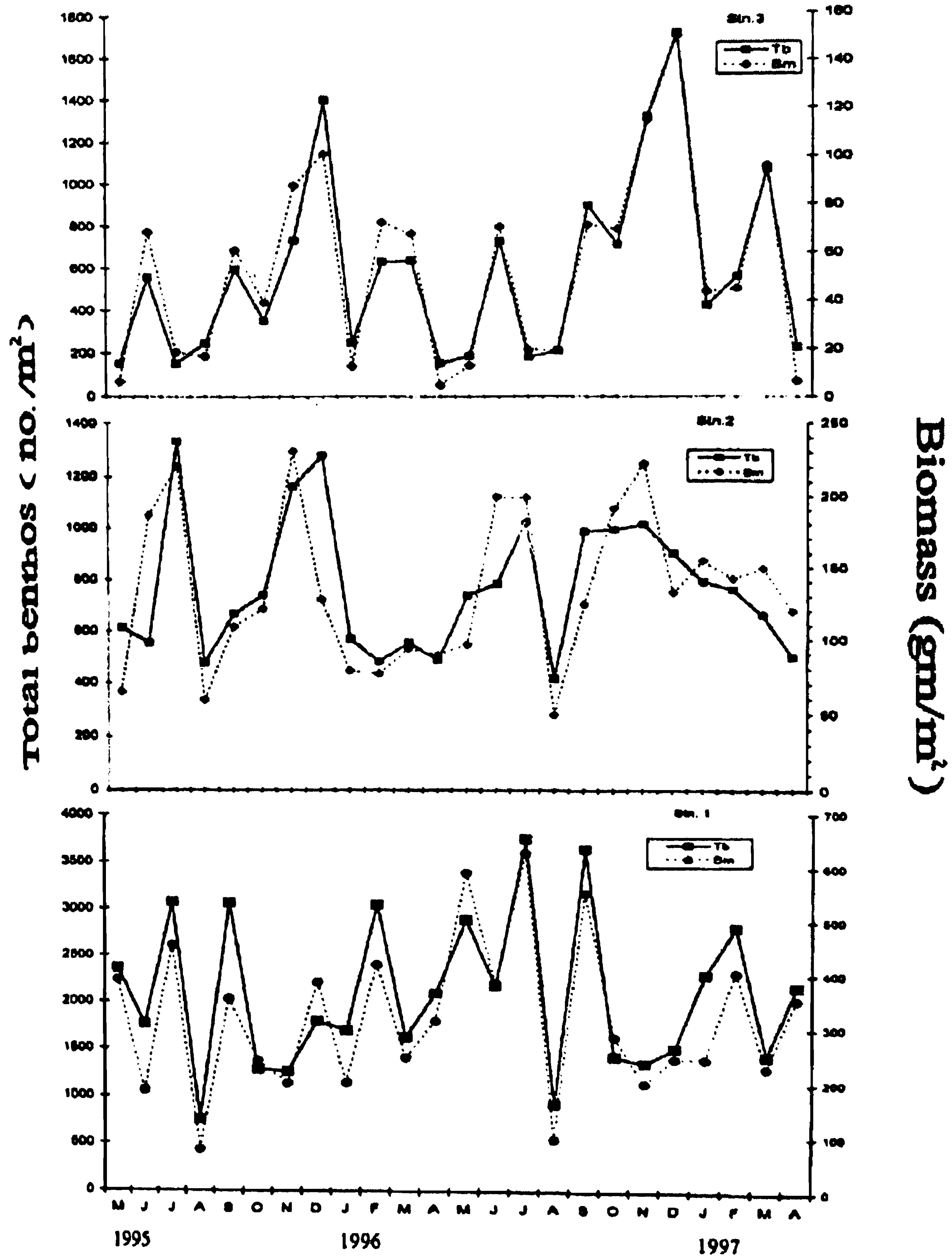


Fig. 6a. Monthly variations (1995-1997) in density of total benthos (Tb, no./m^2) and biomass (Bm, gm/m^2) at stations 1, 2 and 3.

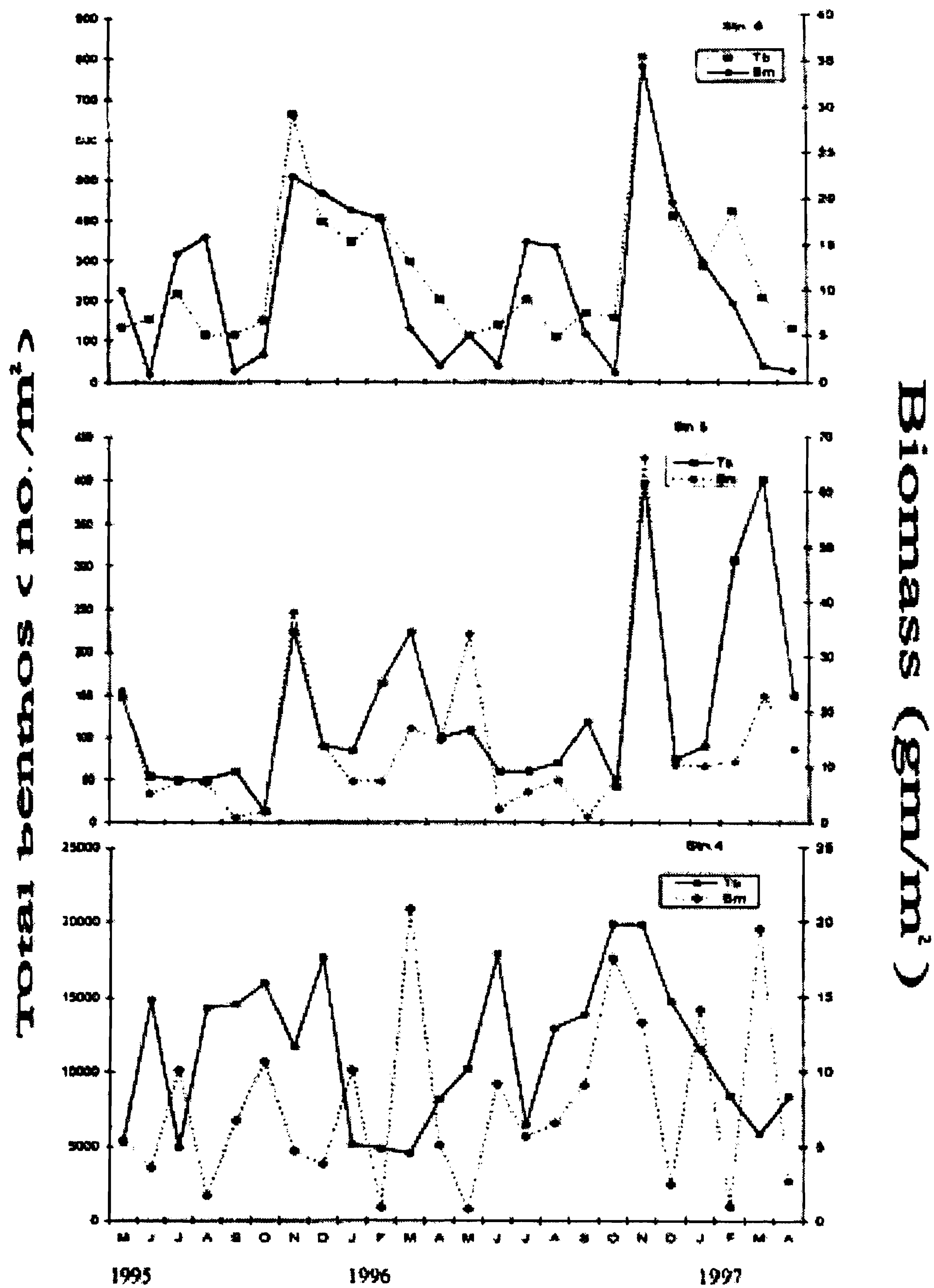


Fig. 6b. Monthly variations (1995-1997) in density of total benthos (Tb, no./m^2) and biomass (Bm, gm/m^2) at statons 4, 5 an 6.

rich population in post monsoon and poor macrobenthic population in monsoon and summer periods in Buckingham Canal backwaters of Coleroon estuary. Kasza and Krzyzanek (1995) recorded greatest density of bottom macrofauna in May and lowest in March in river Vistula in Poland.

Table 3. Mean monthly distributions of total macrobenthos (no./m^2) and biomass (gm/m^2) in parentheses at the six study stations.

MONTHS	STUDY STATIONS					
	1	2	3	4	5	6
May	**2625**	**673**	**170**	**7733**	**128**	**123**
	(492.49)	(81.26)	(9.49)	(3.14)	(29.11)	(7.5)
June	**1971**	**666**	**641**	**16329**	**57**	**146**
	(285.93)	(193.72)	(69.52)	(6.38)	(3.75)	(1.25)
July	**3409**	**1177**	**168**	**5715**	**54**	**210**
	(542.56)	(210.36)	(18.75)	(17.89)	(6.31)	(14.67)
August	**837**	**444**	**229**	**13584**	**59**	**111**
	(86.44)	(54.98)	(17 77)	(4.15)	(7.24)	(15.37)
September	**3352**	**824**	**745**	**14164**	**89**	**141**
	(455.49)	(117.49)	(66.14)	(7.95)	(1.03)	(3.19)
October	**1359**	**863**	**530**	**17883**	**28**	**153**
	(263.06)	(156.87)	(54.17)	(14.11)	(4.93)	(1.94)
November	**1312**	**1085**	**1019**	**15730**	**311**	**730**
	(199.92)	(226.77)	(101.56)	(8.99)	(52.11)	(28.5)
December	**1653**	**1088**	**1549**	**21147**	**81**	**402**
	(316.58)	(130.66)	(125.83)	(3.14)	(12.0)	(20.14)
January	**1998**	**677**	**335**	**9815**	**86**	**316**
	(222.8)	(117.17)	(28.04)	(12.13)	(8.73)	(16.03)
February	**2925**	**617**	**595**	**6633**	**234**	**412**
	(413.37)	(110)	(58.62)	(0.95)	(9.12)	(13.23)
March	**1532**	**604**	**848**	**5212**	**311**	**252**
	(238.3)	(122.05)	(81.77)	(20.18)	(19.94)	(3.72)
April	**2131**	**488**	**192**	**8244**	**123**	**166**
	(334.56)	(105.05)	(5.57)	(3.89)	(14.02)	(1.46)

Data on seasonal abundance of total benthic population in this study illustrates that peak density in most of the stations (3, 4, 5, 6) was in the winter months of November and December which may be due to less predation of benthos by the fish inhabiting the river in winter and availability of copious food for benthic communities in the form of plankton (Sunder, 1983). This view is further supported by Pahwa (1979) who in his studies on river Ganga suggested that quantitative distribution in total macrobenthic organisms is very much related to plankton population. On the other hand, lowest density of benthos in almost all the stations (1, 2, 3, 5 and 6) was observed in one of the monsoon months (between July and October) during heavy rainfall probably due to rising water level, habitat destruction and mass mortality of macrobenthos after heavy rainfall (Goodbody, 1961) and also due to heavy turbulence of bottom sediment thereby reducing the number of benthic animals (Goobdody, 1961; Desai and Krishnankutty, 1967; McLusky *et al.*, 1975).

Biomass Assessment (gm/m^2)

The mean total benthic biomass ranged from 0.95 gm/m^2 at station 4 to 542.56 gm/m^2 at station 1 on dry weight basis (Table 3). The seasonality was characterised by one peak and one trough (Fig.6a and 6b) in every station. In terms of biomass, gastropods were dominant throughout the year owing to their larger body size and weight. Kurian (1971) reported a value of 76 to 400 g/m^2 benthic biomass along the coast of Mangalore. Parulekar *et al.* (1982) from their extensive studies along the Indian coast reported benthic biomass to fluctuate from 0.01 to 601 gm/m^2. Dwivedi *et al.* (1982) reported average biomass from 63.5 to 79.3 gm/m^2 in beaches of Bombay. In the studies of Jayaraj and Reddy (1992) in coastal waters of Mangalore, a biomass ranging from nil to 367.44 gm/m^2 was recorded. Varshney *et al.* (1988) reported the polychaetes to be the main contributor of biomass in the Versova coast of Bombay. Woffl *et al.* (1993) accounted for larger biomass due to a large bivalve. In the present investigation, biomass was higher at stations highly dominated by gastropods. However, the biomass fluctuated (Table 3) highly from station 4 (0.95-20.18) to station 1 (86.44-542.56) due to difference in taxonomic composition in different stations. The poorest value at station 4, which is located below the Tolly's nullah outfall region, corroborates the study of Varshney *et al.* (1988).

Group Abundance

The numerically abundant macrobenthic groups which are considered herein for adundance study were represented by Polychaeta, Oligochaeta, Crustacea and Gastropoda. The other groups mainly consisting of bivalves, gobiid fishes, eels, etc. were occasional and present in some stations only.

Polychaeta

Polychaetes constituted one of the dominant groups at stations 5 and 6 followed by station 3 and was found negligibly at stations 1, 2 and 4 (Table 4). The group showed almost similat pattern of population abundance in the two consecutive years (Fig.7). The populations reflected the peak in March at stations 3 (126 no./m^2) and 5 (192 no./m^2) and in February at station 6 (281 no./m^2). The trough occurred usually in monsoon i.e., during August at station 6 (22 no./m^2), September at station 3 (5 no./m^2) and October at station 5 (10 no./m^2). No pattern in temporal distribution was evident at stations 1, 2 and 4 where the density of polychaetes varied from 0-13 no./m^2, 0-89 no./m^2 and 0-54no./m^2 respectively (Table 4).

Table 4. Mean monthly variations in major groups of organisms expressed per metre square of bottom surface at the study stations.

MAJOR GROUPS / STATION NOS.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
POLYCHAETA												
1	0	10	5	13	13	0	0	0	0	0	0	2
2	5	10	17	0	5	0	0	89	30	0	17	0
3	39	12	15	12	5	10	37	94	74	64	126	123
4	17	2	27	7	54	0	12	0	0	0	5	5
5	15	35	30	30	84	10	69	25	47	158	192	74
6	57	123	84	22	99	118	224	111	126	281	160	78
OLIGOCHAETA												
4	7694	16292	5555	13537	14070	17792	15668	21132	9736	6633	5096	8214
5	0	0	0	0	0	0	12	10	0	20	0	0
CRUSTACEA												
1	0	47	49	0	47	9	0	25	244	5	0	54
2	0	39	229	10	0	0	0	67	7	0	5	89
3	10	2	2	5	0	0	2	2	2	5	25	39
4	0	0	69	5	0	2	0	0	0	0	5	10
5	0	5	5	0	0	0	10	0	2	5	0	0
6	15	5	47	2	5	5	12	7	47	76	47	46
GASTROPODA												
1	2625	1914	3355	825	3243	1350	1312	1628	1354	2639	1532	2074
2	668	617	920	355	819	863	1085	666	640	617	582	400
3	121	627	150	59	740	520	977	1453	257	525	698	30
4	22	35	64	35	39	89	49	15	79	0	106	15
5	113	15	20	30	5	18	217	47	30	35	118	44
6	49	17	76	86	35	30	493	281	141	54	44	27

Note : Oligochaetes were absent at station 1-3 and 6.

Oligochaeta

Oligochaetes were the dominant group at station 4 only, while it was rare at station 5 and absent in the other stations. The population consisting of *L. hoffmeisteri* fluctuated from a minimum of 5096 no./m^2 in March to a maximum of 21,132 no./m^2 in December (Table 4) at station 4. At station 5, its density varied from 0-20 no./m^2 reflecting no temporal pattern.

Crustacea

Though present in all the stations, the crustaceans reflected a definite pattern of temporal variation in stations 3 and 6 with a major peak during April (39 no./m^2) and

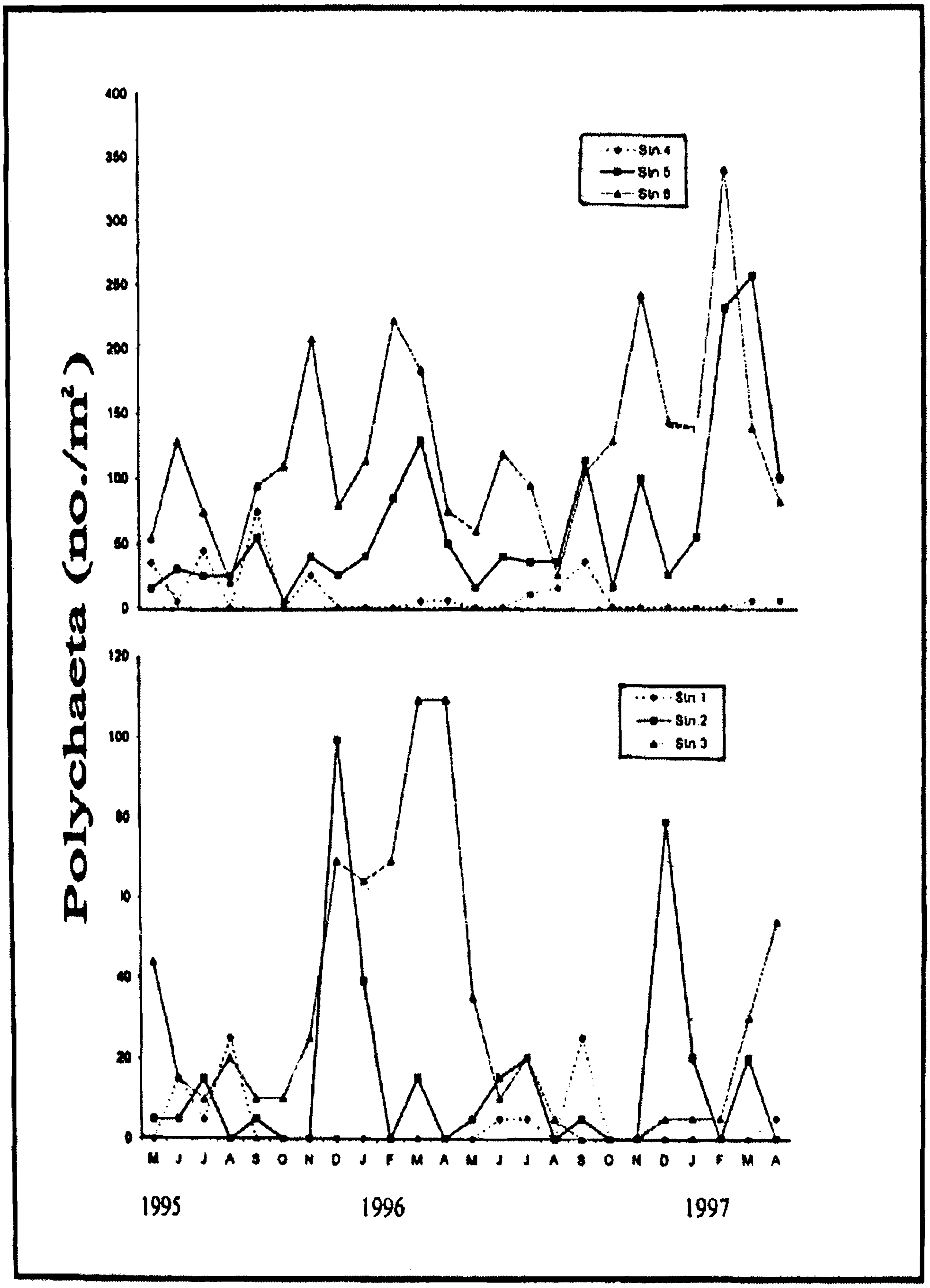


Fig. 7. Monthly variations (1995-197) in density of Polychaeta (no./m^2) at the study stations.

February (76 no./ m^2) respectively while the trough was encountered during monsoon being nil during September-October at station 3 and representing 2 no./m^2 in August at station 6 (Table 4). However, in the remaining regular sampling stations, the population profile exhibited densities varying from 0-244 no./m^2, 0-229 no./m^2, 0-69 no./m^2 and 0-10 no./m^2 at stations 1, 2, 4 and 5 respectively (Table 4, Fig. 8).

Gastropoda

Gastropods were dominant at stations 1, 2, 3, 5 and 6, which showed wide temporal fluctuations in both the years (Fig. 9). They were, however, observed in all the stations with densities varying from 825-3355, 355-1085, 30-1453, 0-106, 5-217 and 17-493 no./m^2 at stations 1, 2, 3, 4, 5 and 6 respectively (Table 4).

From the results, it is clear that these four macrobenthic groups exhibited prominent spatial variations. The temporal changes in abundance, on the other hand, showed either almost similar pattern in the two consecutive years (Fig.7-9) or reflected no definite pattern of temporal variation with respect to groups as discussed above.

Species Abundance

Of the 44 species of macrobenthos encountered in the study area, nine species were regularly occurring abundant species, the others were occasionally/irregularly occurring species. The distribution and abundance of the regularly occurring species are highlighted here under.

Namalycastis fauveli

Though the species was common in all the stations, it reflected a greater contribution to total bottom fauna at station 6 (13.81%) and station 5 (10.74%) followed by feeble contribution at stations 3 (1.72%), 2 (0.13%), 1 (0.07%) and 4 (0.02%). The population attained the maximum value during February at stations 3 (20 no./m^2), 6 (99 no./m^2) and in March at station 5 (49 no./m^2) (Table 5). Thereafter the density declined and the trough was noticed usually in monsoon months (Fig.10). At stations 1, 2 and 4 no temporal distribution pattern was displayed and showed lesser contribution (0.85%, 1.59% and 4.5% respectively) to the total bottom fauna (Table 5).

Nephtys oligobranchia

The species was also common in all the stations. However, their percentage contribution to the total bottom fauna varied highly being 0.09% 1.63%, 5.48%, 0.06%, 22.57% and 21.07% at stations 1-6 respectively. The population attained a single peak during March at stations 5 (81 no./m^2), 6 (109 no./m^2) and in at station 3 (109 no./m^2). The trough occurred usually in monsoon being nil in September at station 3, 5 no./m^2 in September - October at station 5 and 10 no./m^2 in August at station 6 (Table 5). At stations 1, 2 and 4 no temporal distribution pattern was evident (Fig.11).

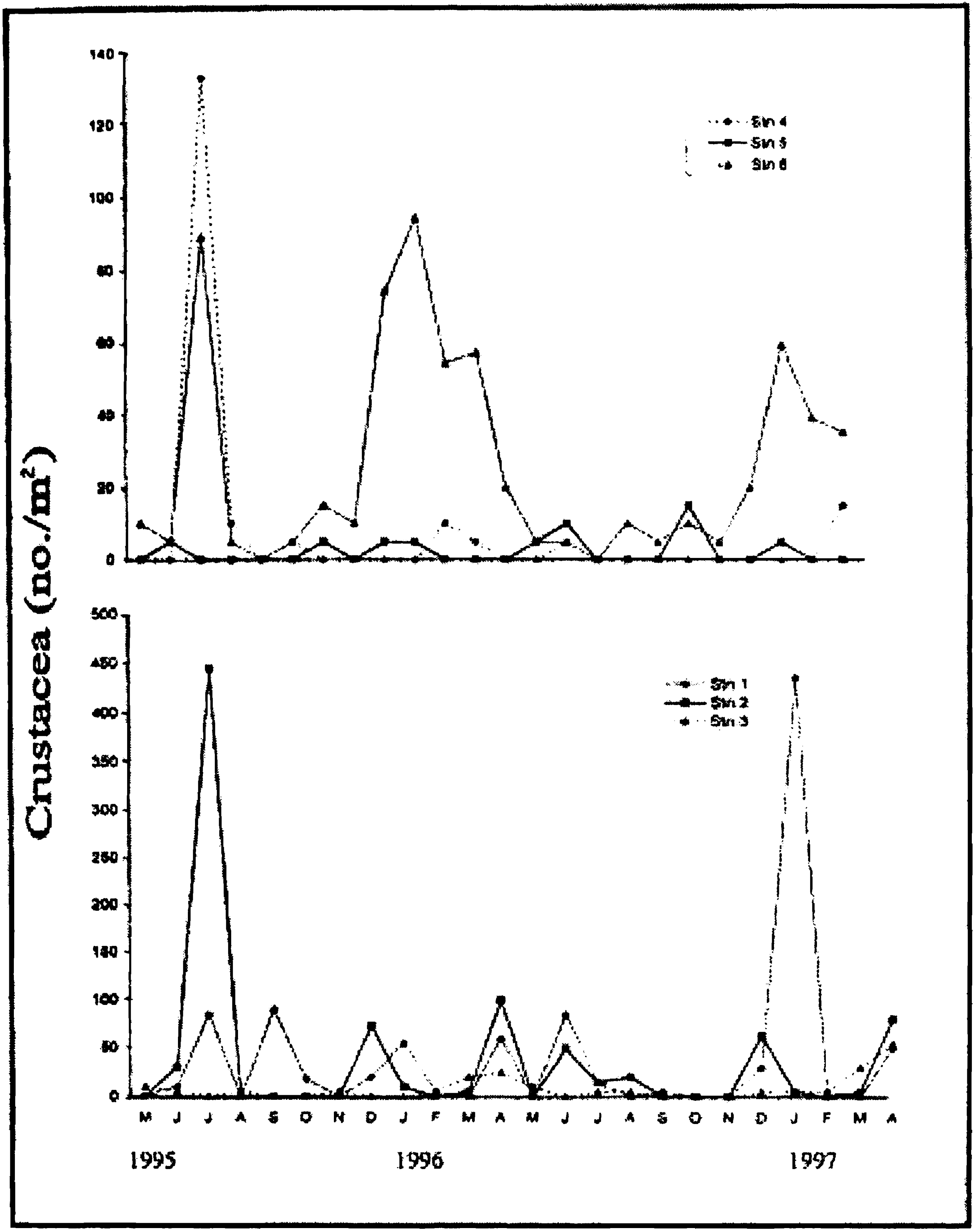


Fig. 8. Monthly varations (1995-1997) in density of Crustacea (no./m^2) at the study stations.

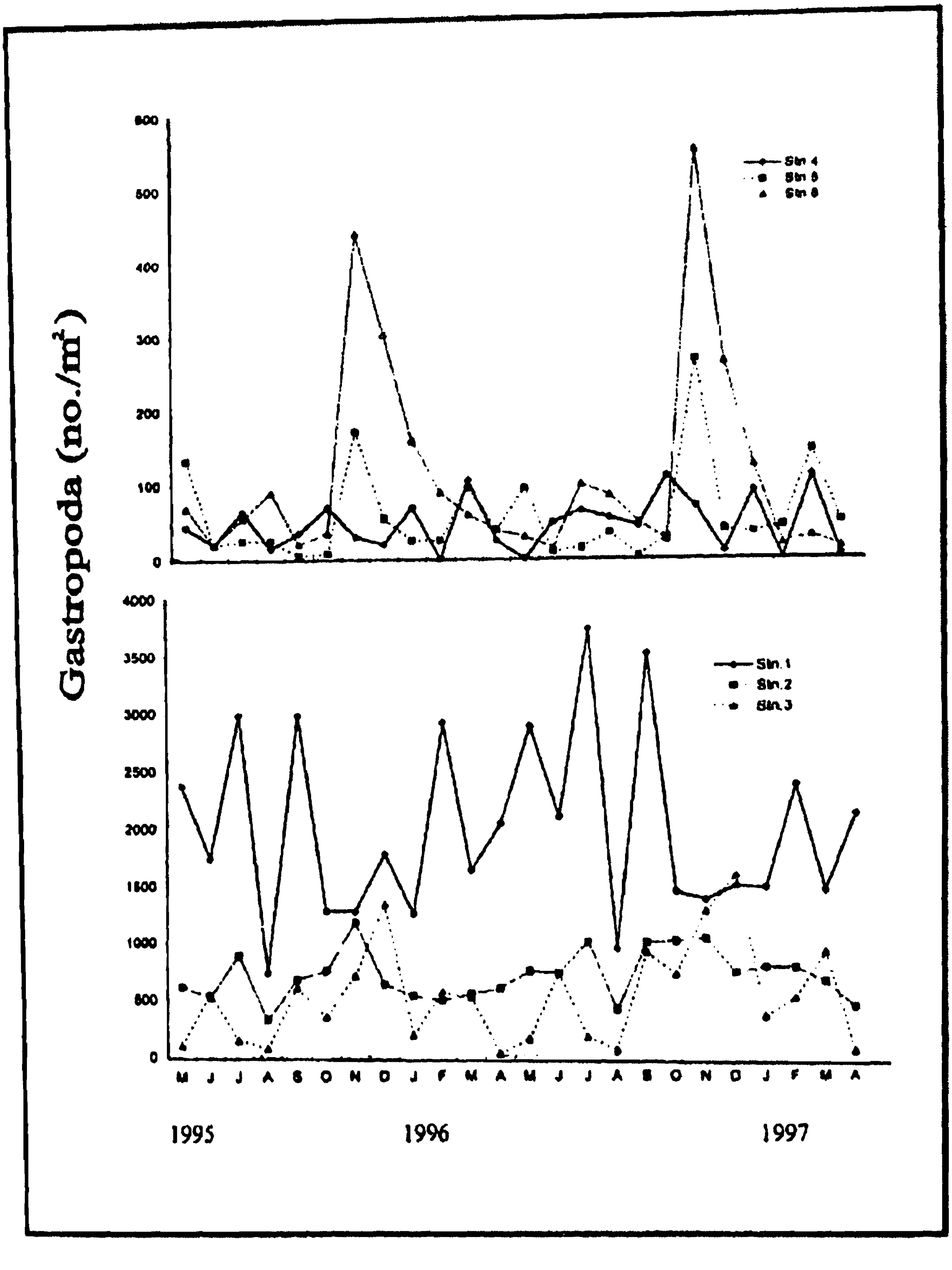


Fig. 9. Monthly variations (1995-1997) in density of Gastropoda (no./m^2) at the study stations.

Table 5. Mean monthly variations in the dominant species expressed as no./m^2 at the study stations.

SPECIES/ STATIONS	MONTHS May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
N. fauveli												
1	0	5	0	6	6	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	7	0	5	0
3	7	5	5	5	0	5	12	17	15	20	17	12
4	0	2	2	7	0	0	12	0	0	0	0	0
5	5	10	5	5	10	5	10	5	15	39	49	10
6	10	15	32	7	30	22	94	35	37	99	30	27
N. oligobranchia												
1	0	5	5	6	6	0	0	0	0	0	0	2
2	5	10	10	0	5	0	0	89	22	0	10	0
3	22	5	5	5	0	5	15	57	42	22	99	109
4	17	0	17	0	39	0	0	0	0	0	5	5
5	5	15	15	20	5	5	54	10	17	67	81	59
6	37	69	12	10	35	76	104	44	54	89	109	27
D. aestuarina												
2	0	0	7	0	0	0	0	0	0	0	2	0
3	10	2	5	2	5	0	10	20	17	22	10	2
4	0	0	2	0	10	0	0	0	0	0	5	0
5	5	10	10	5	5	0	5	10	15	52	59	5
6	10	39	39	5	35	20	27	12	35	74	22	22
L. hoffmeisteri												
4	7694	16292	5555	13537	14070	17792	15668	21132	9736	6633	5096	8214
5	0	0	0	0	0	0	12	10	0	20	0	0
S. edwardsi												
1	0	5	10	0	5	9	0	25	244	5	0	54
2	0	39	0	10	0	0	0	44	7	0	5	44
3	7	2	2	5	0	0	2	2	2	5	25	39
4	0	0	5	5	0	2	0	0	0	0	0	10
5	0	5	5	0	0	0	10	0	2	5	0	0
6	15	5	5	2	5	5	12	5	35	76	47	37

Table 5. contd.....

SPECIES/ STATIONS	MONTHS May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
T. lineata												
1	1751	1090	2536	292	2114	861	444	686	666	1169	821	1182
2	212	183	291	178	244	252	224	222	184	252	232	187
3	22	301	49	15	301	111	49	197	118	143	121	20
4	11	20	57	17	39	49	10	10	44	0	49	10
5	15	5	15	2	0	0	10	15	15	15	12	12
6	0	0	0	5	2	0	0	2	7	0	0	2
T. scabra												
1	804	765	750	395	804	408	824	784	555	804	555	740
2	454	434	614	178	533	587	834	400	401	335	335	212
3	96	321	91	10	439	400	883	1219	138	348	575	10
4	11	15	7	17	0	39	39	5	35	0	35	5
5	69	10	5	2	5	5	190	20	10	15	94	25
6	0	0	0	5	0	2	0	12	22	0	7	5
T. tuberculata												
1	35	42	44	25	59	53	44	138	133	345	155	123
2	0	0	10	0	10	15	12	22	30	30	2	0
3	2	0	0	2	0	0	0	5	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	22	0
5	2	0	0	0	0	0	0	0	0	0	10	2
A. francesiae												
1	5	7	0	6	10	9	0	10	0	155	0	2
2	0	0	0	0	0	0	5	0	0	0	2	0
3	0	0	5	2	0	2	37	17	0	35	2	0
5	0	0	0	10	0	0	7	0	0	0	2	0
6	39	15	52	2	27	20	451	261	104	44	25	20

Note : 1. *D. aestuarina* was absent at station 1.

2. *L. hoffmeisteri* was absent at stations 1-3 and 6.

3. *T. tuberculata* was absent at station 6.

4. *A. francesiae* was absent at station 4.

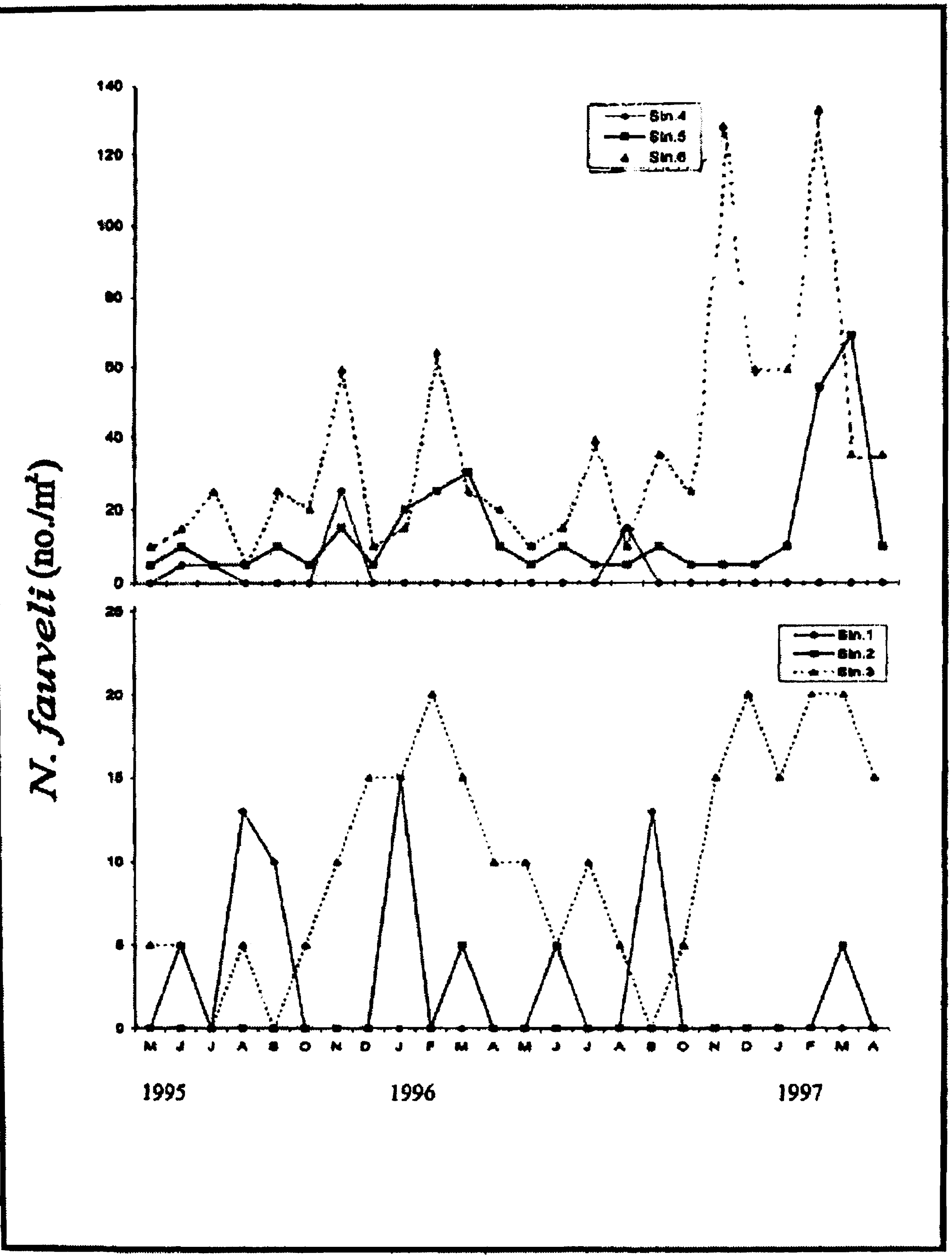


Fig. 10. Monthly variations (1995-1997) in density of *N. fauveli* at the study stations.

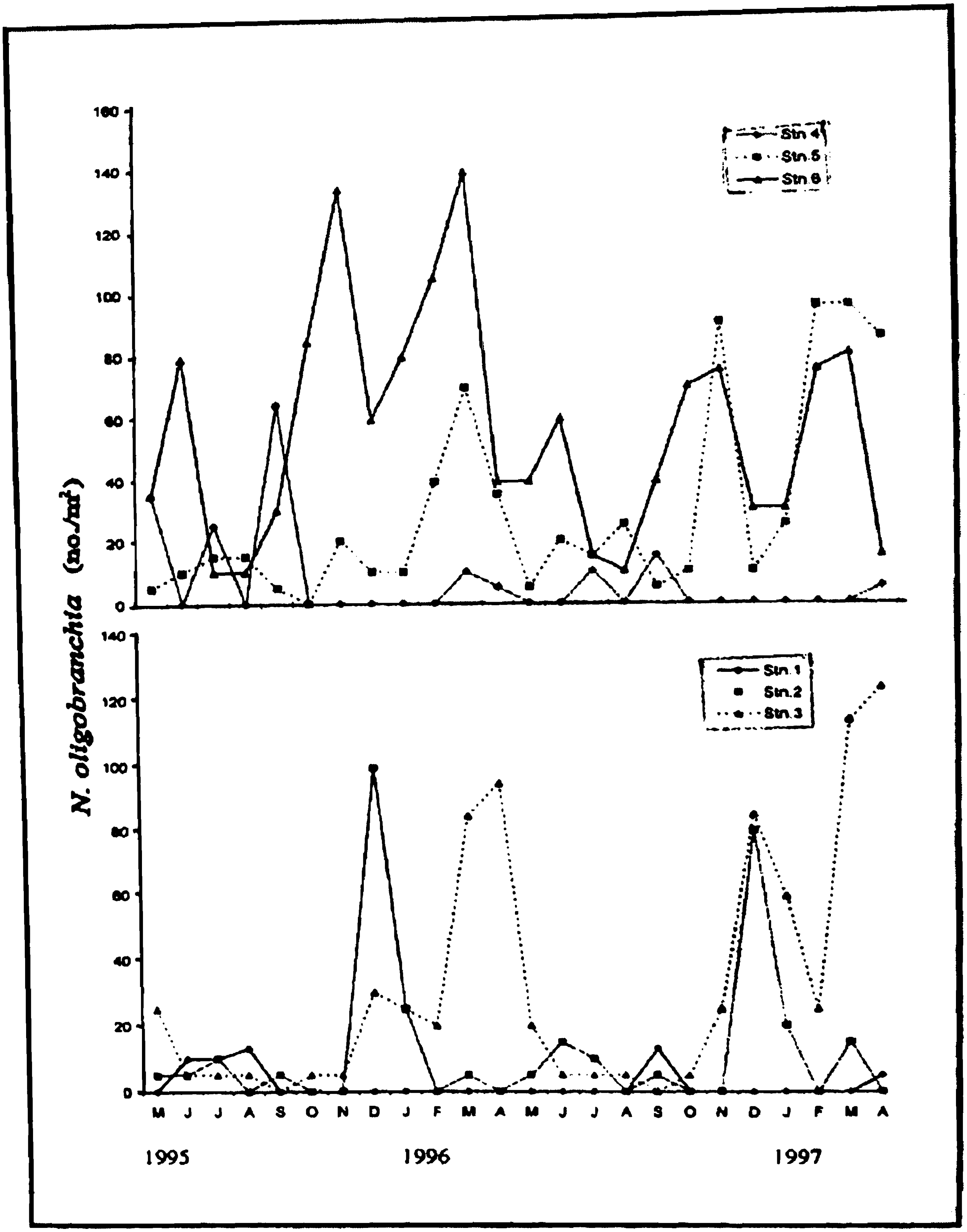


Fig. 11. Monthly variations (1995-1997) in density of *N. oligobranchia* at the study stations.

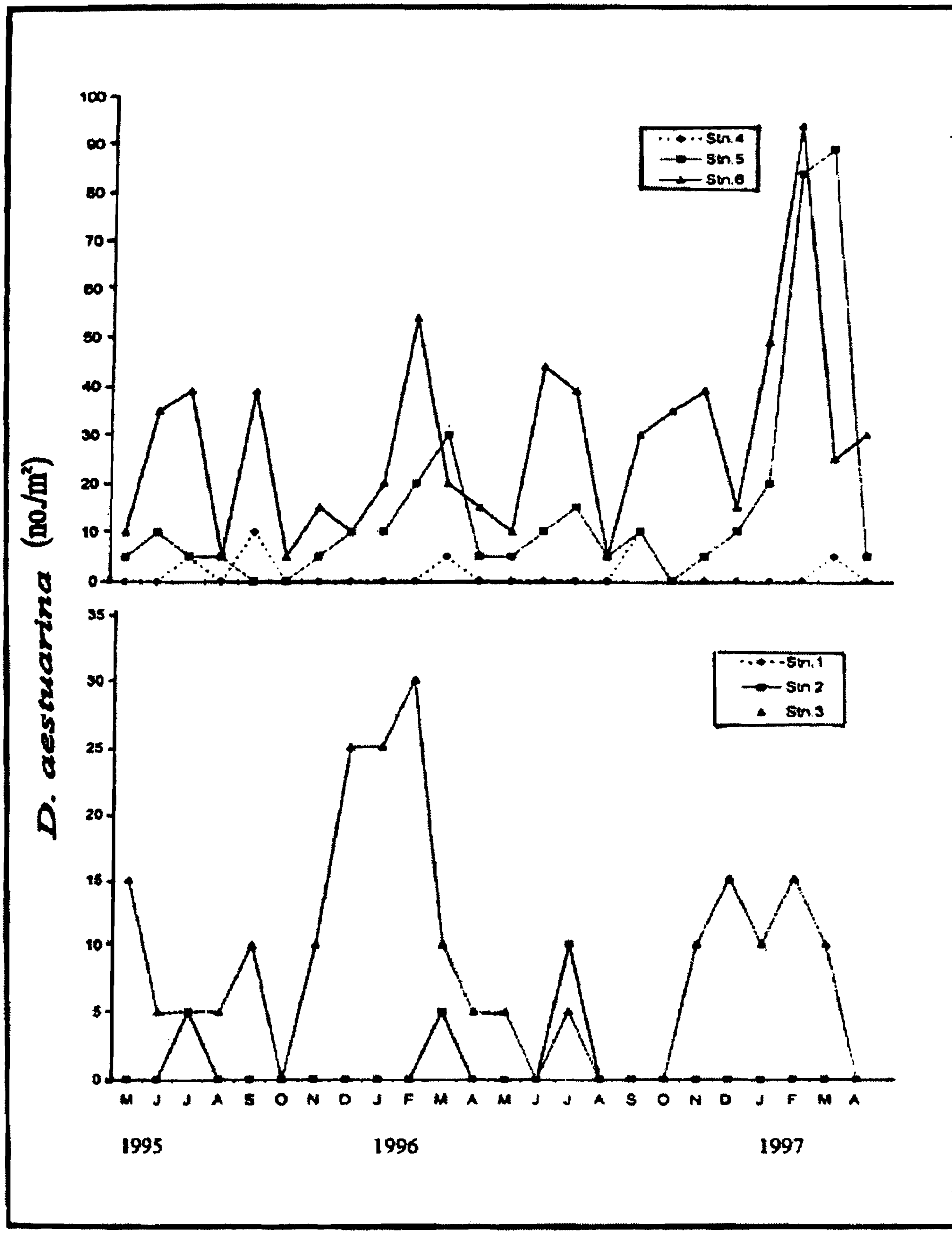


Fig. 12. Monthly variations (1995-1997) in density of *D. aestuarina* at the study stations.

Dendronereis aestuarina

It accounted for 1.5%, 11.53% and 10.77% benthic population at stations 3, 5 and 6 respectively and contrigibuted negligibly at stations 2 (0.1%) and 4 (0.01%) and absent at station 1. The temporal variation was prominently shown by stations 3, 5 and 6 (Fig. 12) being maximum in density during February at station 3 (22 no./m^2), and 6 (74 no./m^2) and in March at station 5 (59 no./m^2) while the lowest population was encountered during August at station 6 (5 no./m^2) and 0 no./m^2 in October at stations 3 and 5 (Table 5).

Limnodrilus hoffmeisteri

It was the most highly dominating species at station 4, contributing 99.45% of the total bottom fauna. The species was rarely present at station 5 accounting for 2.68% of total benthos and absent in the other stations. At station 4, the population showed fluctuations throughout the year (Table 5, Fig. 13) with one major peak during December (21, 132 no./m^2)and one trough in March (5096 no./m^2).

Sesarma edwardsi

The percentage contribution of this species to the average annual population was comparatively high i.e., 7.88% at station 6, followed by 1.74%, 1.63%, 1.42%, 1.33% and 0.02% at stations 5, 2, 1, 3 and 4 respectively. The temporal variation was conspicuous at stations 3 and 6 (Fig. 14), but it was irregular in the other stations. At station 3, the population exhibited little variation in most part of the year. The population attained the maximum density in April (39 no./m^2) with a sharp decline in the following months being nil during September-October. At station 6, the peak occurred in February (76 no./m^2) after which the population declined gradually culminating into a trough in August (2 no./m^2) (Table 5).

Thiara (Tarebia) lineata

It was dominant at stations1, 2 and 3 contributing 54.22%, 28.9% and 20.61% respectively to the total bottom fauna. It exhibited a very irregular fluctuation of population density in both the years (Fig. 15). However, the maximum density was shown during July at station 1 (2536 no./m^2) and station 2 (291 no./m^2) and during June at station 3 (301 no./m^2) whereas the minimum density in these three stations occurred during August being 292 no./m^2, 178 no./m^2 and 15 no./m^2 at stations 1, 2 and 3 respectively, but the species was capable of rapid recovery in the following month (Table 5). At stations 4, 5 and 6 this species contributed negligibly to the total bottom fauna (0.22%, 7.42% and 1.26% respectively) reflecting no such significance in its temporal distribution. (Table 5).

Thiara (Thiara) scabra

It occurred as the dominant species at stations 1, 2, 3 and 5 accounting for 32.62%, 57.75%, 64.49% and 28.74% respectively of the total macrobenthic population in those stations. The species fluctuated throughout the years (Fig. 16) with one major peak at

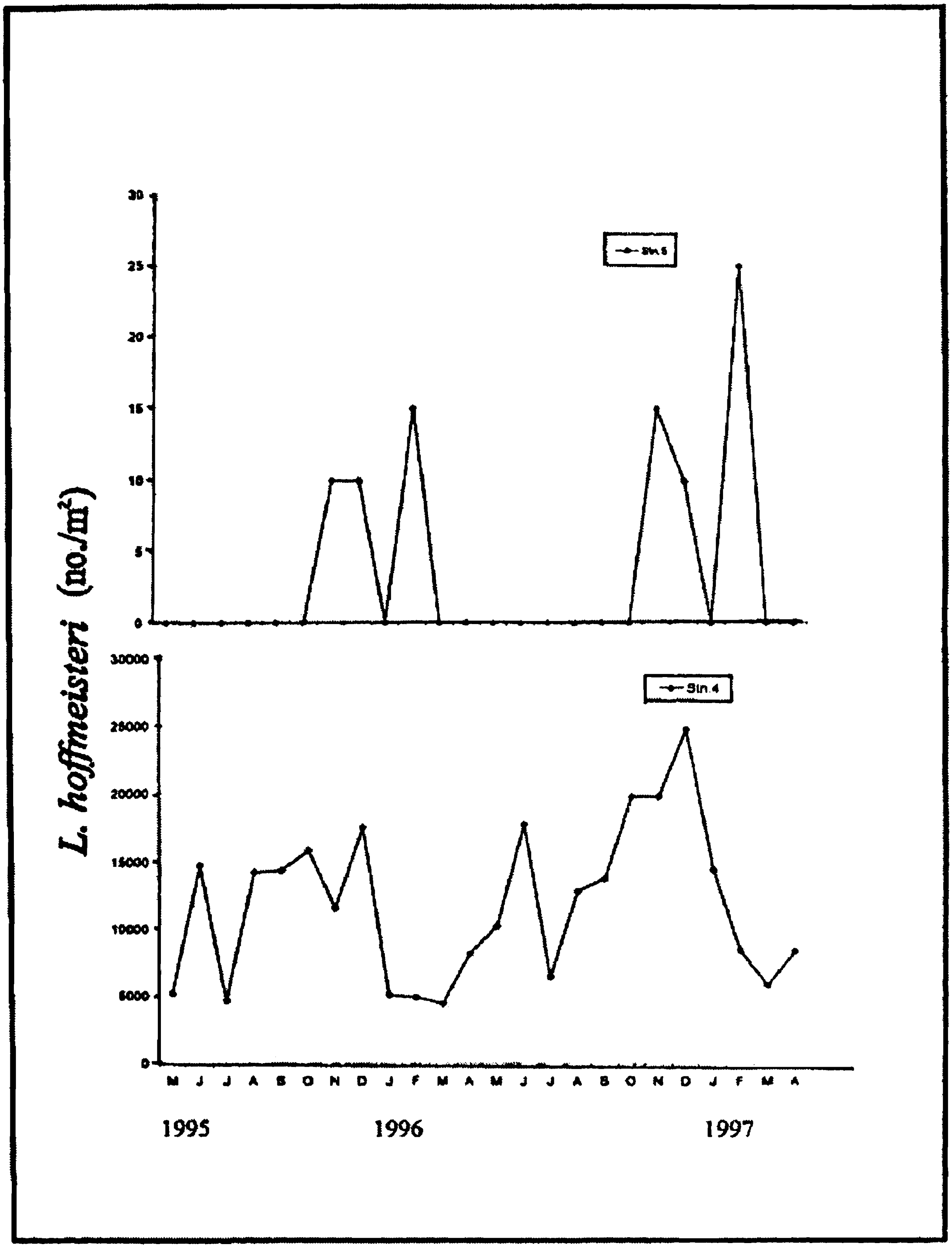


Fig. 13. Monthly variations (1995-1997) in density of *L. hoffmeisteri*.

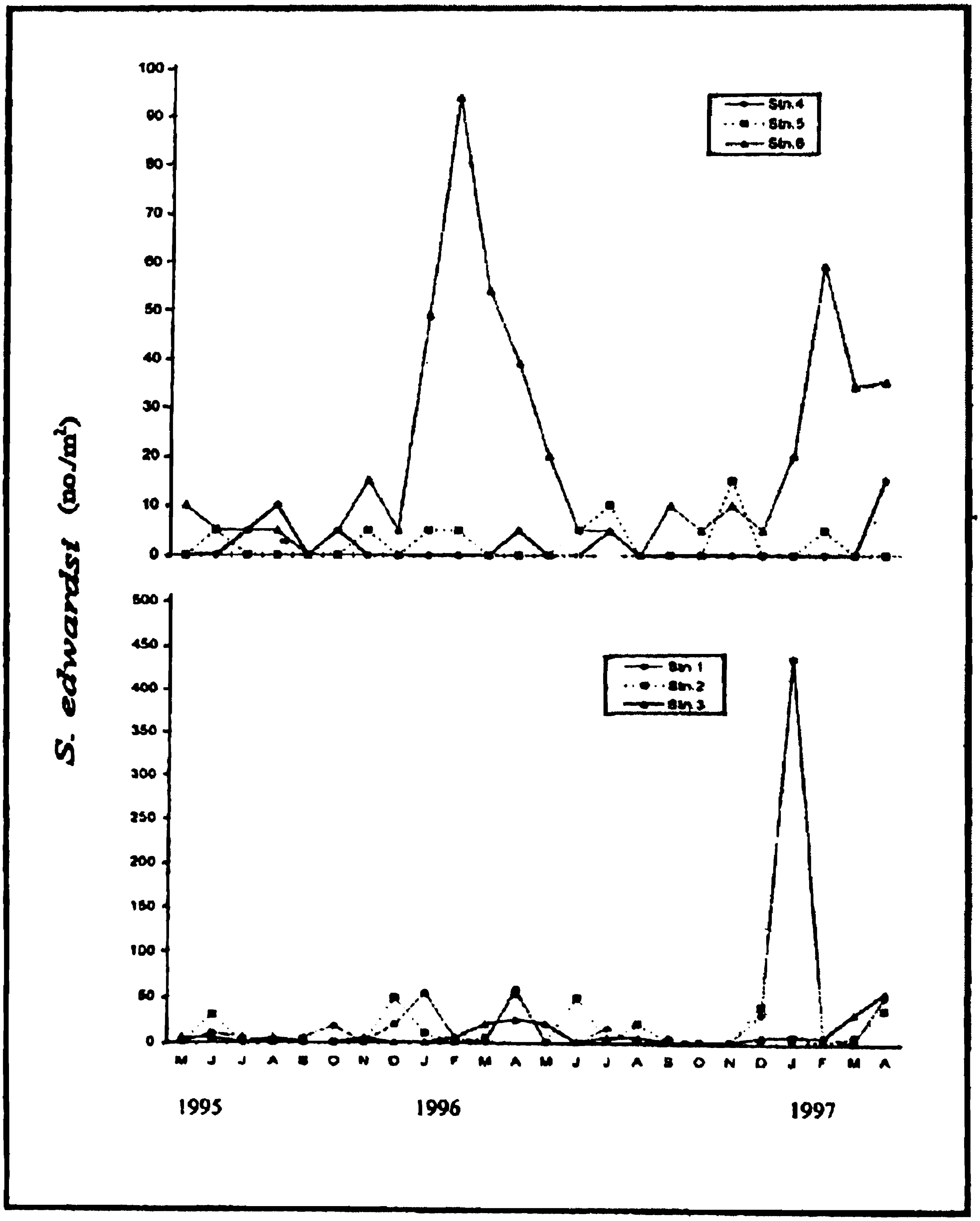


Fig. 14. Monthly variations (1995-1997) in density of *S. edwardsi* at the study stations

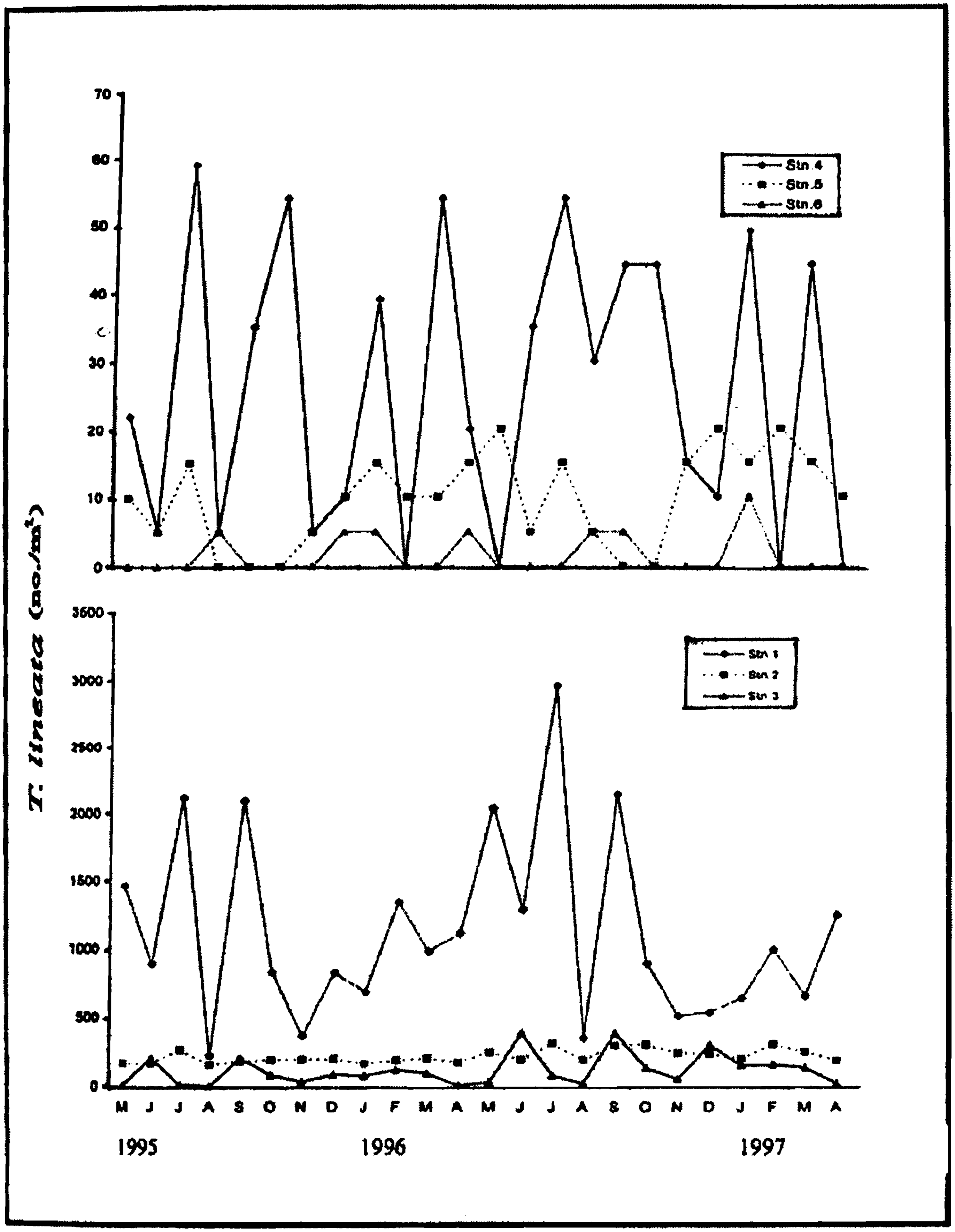


Fig. 15. Monthly variations (1995-1997) in density of *T. lineata* at the study staions.

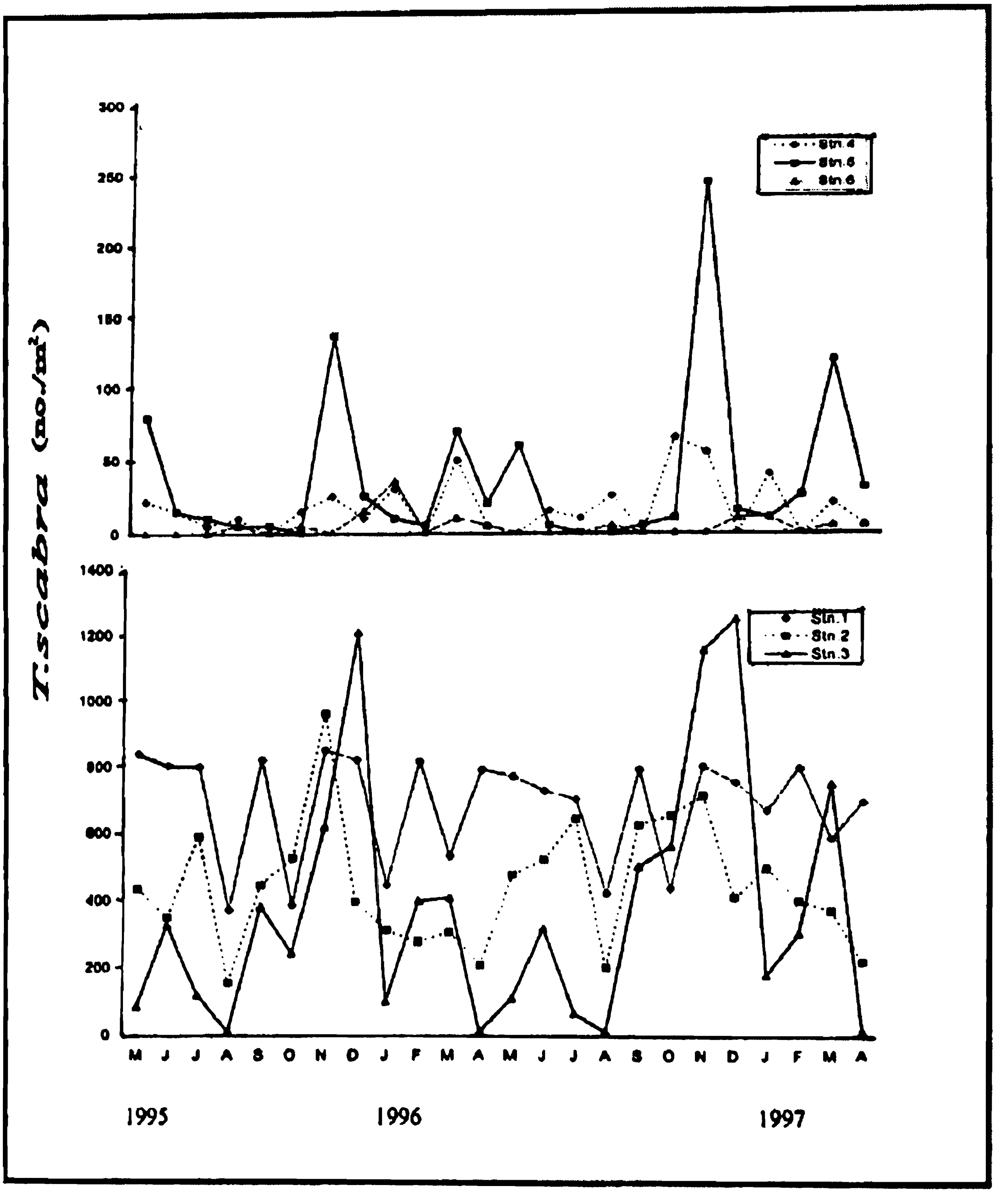


Fig. 16. Monthly variations (1995-1997) in density of *T. scabra* at the study stations.

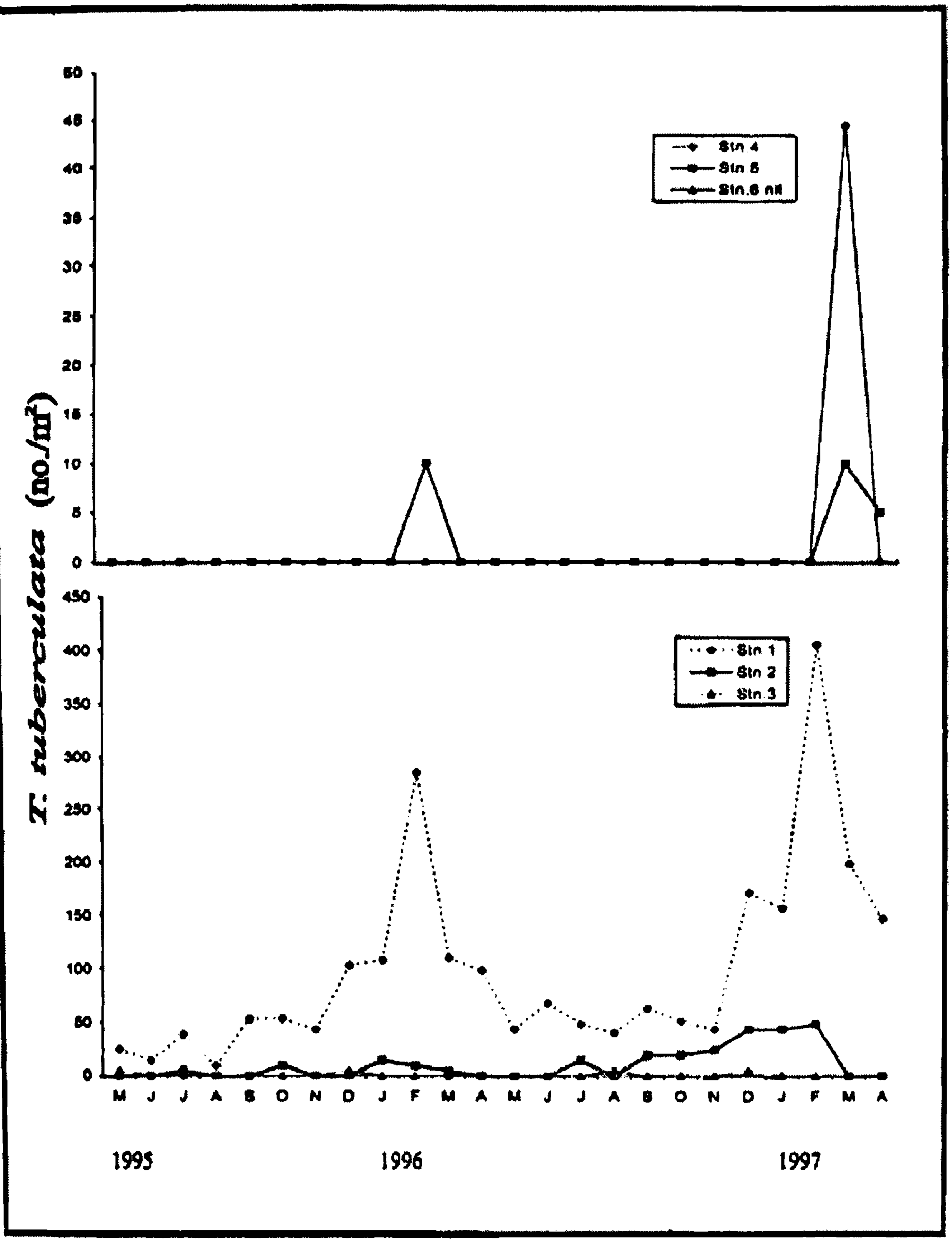


Fig. 17. Monthly variations (1995-1997) in density of *T. tuberculata* at the study stations.

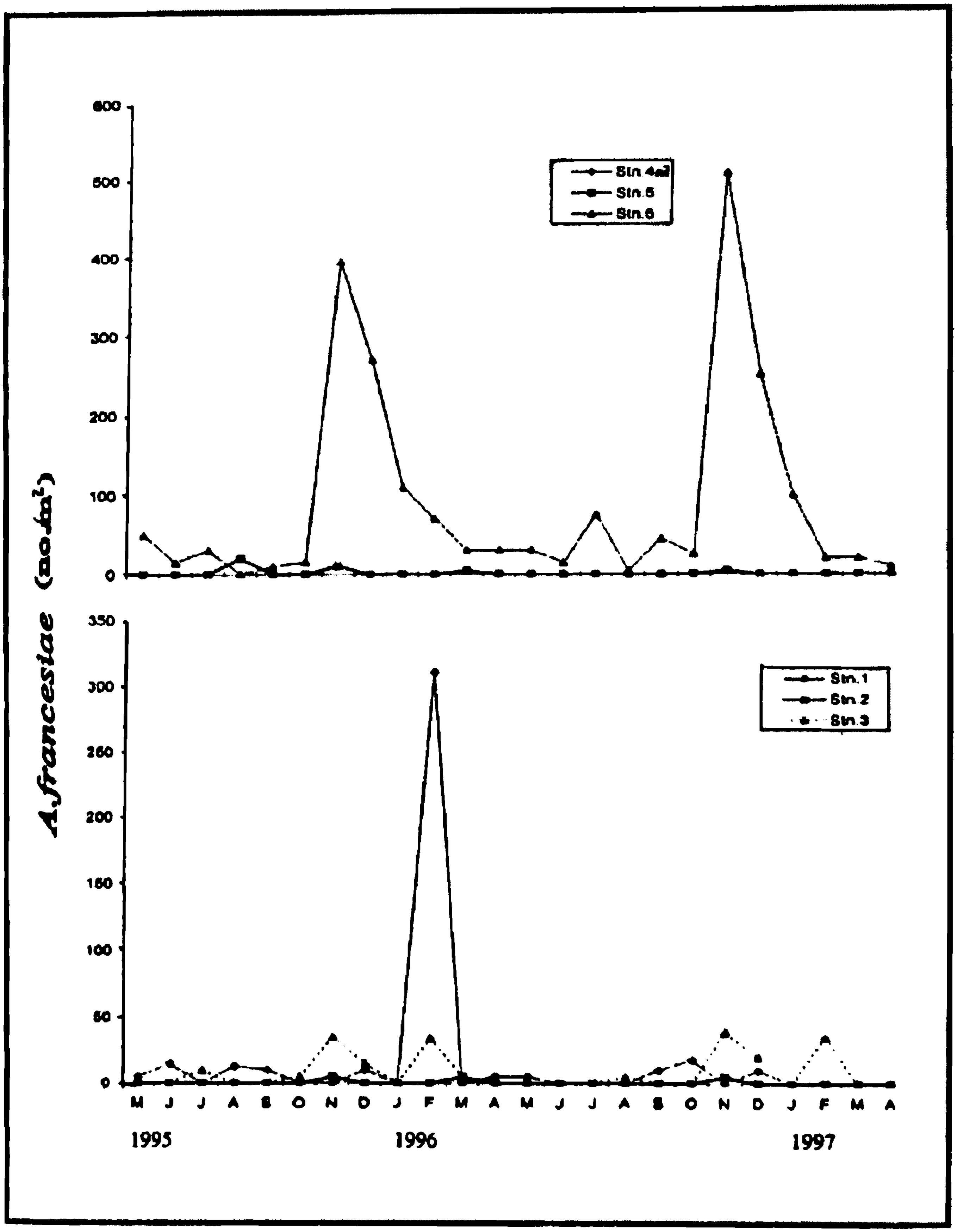


Fig. 18. Monthly variations (1995-1997) in density of *A. francesiae* at the study stations.

stations 1 (824 no./m^2), 2 (834 no./m^2) and 5 (190 no./m^2) in November and at station 3 (1219 no./m^2) in December while a trough occurred in August at stations 1, 2, 3 and 5 being 395 no./m^2, 178 no./m^2, 10 no./m^2 and 2 no./m^2 respectively (Table 5). At stations 4 and 6, the occurrence of the species was irregular contributing only 0.4% and 1.71% respectively to the total bottom fauna exhibiting no temporal pattern (Fig. 16).

Thiara (Melanoides) tuberculata

This species occurred regularly at station 1 only, contributing little (4.77%) to the total benthic fauna. It attained the maximum density in February (345 no./m^2). Thereafter the density declined, culminating into a trough in August (25 no./m^2) (Table 5, Fig. 17). At the rest five stations viz., 2, 3, 4, 5 and 6 the species was irregular, contributing negligibly (1.41%, 0.14%, 0.02%, 0.94% and 0% respectively) to the total bottom fauna showing no variation in temporal distribution (Table 5).

Assiminea francesiae

It contributed one of the dominant species of station 6, accounting for 33.56% of total bottom fauna. The population was marked by a single peak in November (451 no./m^2), while a gradual reduction was observed in the following months, attaining the lowest population in August (2 no./m^2) at the aforesaid station (Table 5). In general, the population was higher during winter months (Fig. 18). The species was of very low and irregular in occurrence at stations 1, 2, 3 and 5 showing negligible contribution to total fauna (0.82%, 1.58%, 1.44%, 0% and 4.93% respectively) reflecting no temporal pattern in these stations (Fig. 18).

Other macrobenthos

The remaining 35 macrobenthic species were scarce and irregular, contributed mainly by *T. granifera, D. cerameopoma, B. costula, G. convexiusculus, G. labiatus, I. exustus, B. bengalensis, L. luteola, L.acuminata, S. lineata, N. violacea, S. deltae and P. obtusa* among gastropods, a crab - *Ptychognathus onyx* among crustaceans and a polychaete *N. meggitti.* The mean densities of the aforesaid species and their average percentage frequency of occurrence are represented in Table 6. The distribution of these minor macrofaunal groups and species was poor and uneven. Their presence was very much important in view of their role in the food chain. Their absence may bring about a break in the food cycle and ecological imbalance.

The temporal and spatial dispersion of a population is a fundamental characteristic and property of a species which reflects environmental pressure and behavioural pattern (Parsons *et al.*, 1977). The presence of benthic organisms depend, in addition to pollution effects, on a number of other factors such as life cycle, availability of food, breeding pattern, substratum, habitat favourability, etc. Taking station-wise qualitative collection, it was noticed that the polychaetes were comparatively numerous at stations 5 and 6 as they were more in weed infested areas and substratum containing greater amount of sand. The polychaetes were scanty at station 1, which although had weed infested portions could not harbour them due to paucity of sand in the substratum compared to the other stations (Fig.5 please vide supra). The occurrence of polychaetes in greater weedy and sandy area in the present study corroborates the studies of Patnaik (1971) and Raj and Raj (1987).

In the present investigation, the polychaetes, represented by *N. oligobranchia, N. fauveli* and *D. aestuarina* occurred more or less throughout the year as reported by Kurian *et al.*, (1975) and Raman *et al.*, (1975). The month-wise variation in their density showed that they were fewer during monsoon due to heavy rain, when weeds were detached and consequently there was disturbance in the habitat causing unstable bottom and lowering of density in *N. oligobranchia, N. fauveli* and *D. aestuarina. N. oligobranchia* reflected its peak in March while *N. fauveli* and *D. aestuarina* showed peak in February. This finding is in agreement with the studies of Desai and Krishnankutty (1967), Damodaran (1973), Bhat (1979), Varshney *et al.* (1988), Prabha Devi and Ayyakkannu (1989), Vizakat *et al.* (1991), etc. Patnaik (1971) indicated March as a period of abundance of Polychaeta in Chilka lake while Ansari and Parulekar (1993) found peak abundance of polychaetes in the months of February and March giving further support to the present study.

Thus, it can be inferred that peak population of the polychaetes occurred during February-March period by addition of new individuals presumably due to increased breeding activity whereas sandy and weedy substrate was required for their proliferation and settlement. Several investigators have demonstrated a substratum preference by polychaetes (Desai and Krishnankutty, 1967; Bhat, 1979; Raj and Raj, 1987).

The Oligochaeta, consisting mainly of *L. hoffmeisteri* in the present investigation contributed more than 98% of the total fauna at station 4. Sang and Erseus (1985) reported over 80% occurrence of *Limnodrilus* with a high density of 700,000 ind/m^2 in lower Pearl river of China. Goodnight and Whitley (1960) suggested that if oligochaetes attain 80% or more with regard to the total densities of benthic macroinvertebrates, the habitat can be considered as highly enriched with organic material or polluted industrially. Rama Rao *et al.* (1978) also reported that the tubificid worms representing 80% of the total number of benthic macroinvertebrates indicated organic enrichment and polluted condition. Ghosh *et al.* (1990) found oligochaetes contributing 96% to the total benthic population in the polluted section of Mathabhanga- Churni river in West Bengal. In the present study too, oligochaetes were dominant and occur in large numbers at station 4, which is polluted due to the inrush of sewage from Tolly's nullah. According to Carr and Hiltunen (1965), Egglishaw and Mackay (1967), Learner *et al.* (1971) and Hawkes (1979) oligochaetes are the common inhabitants of polluted water. Kasza and Krzyzanek (1995) also found oligochaetes to develop in masses in polluted sections of river Vistula.

The monthly occurrence of the oligochaetes reflected that they were present throughout the year showing peak in December. Kennedy (1966) reported that breeding takes place throughout the year with increased activity in winter and spring and in less productive habitats the breeding period appears to be shorter and seasonal. Sunder and Subla (1986), Barbhuyan and Khan (1992) also found greater oligochaetes in winter, supporting the present finding.

Table 6. Average percentage frequency (in parentheses, and mean density (no./m²) of the bottom fauna.

SPECIES	STATIONS					
	1	2	3	4	5	6
T. granifera	6 (13.67)	4 (8.96)	3 (3.03)	-	1 (0.62)	-
D. cerameopoma	3 (3.42)	1 (0.79)	1 (0.51)	-	1 (0.62)	1 (1.39)
B. costula	1 (0.85)	1 (0.79)	-	-	-	1 (0.92)
G. convexiusculus	1 (0.85)	-	-	-	1 (1.23)	2 (1.38)
G. labiatus	-	1 (0.79)	1 0.51)	-	-	1 (0.46)
I. exustus	3 (1.95)	2 (0.79)	1 (2.02)	-	2 (2.47)	6 (6.01)
B. bengalensis	2 (1.09)	-	-	-	1 (3.08)	2 (5.55)
L. luteola	2 (0.85)	-	-	-	-	1 (1.85)
L. acuminata	2 (0.85)	-	1 (0.51)	-	1 (1.23)	1 (0.46)
S. lineata	1 (0.85)	1 (5.55)	1 (1.52)	-	2 (3.70)	2 (0.46)
N. violacea	-	1 (0.79)	1 (0.51)	-	1 (0.62)	1 (0.92)
S. deltae	-	-	1 (1.51)	-	-	1 (3.24)
P. obtusa			-	-	1 (0.62)	-
P. onyx	-	1 (0.79)	-	-	-	2 (0.46)
N. meggitti	-	-	-	1 (0.46)	6 (0.62)	3 (0.92)

Many workers have related the abundance of oligochaetes to the amount of organic material present (Oommachan and Belsare, 1986; Dutta and Malhotra, 1986; Bais *et al.*, 1992). In this study, the reduction in oligochaete population in March cannot be related to lesser organic carbon or organic matter in the sediment as it varied very little in different months. Hence, the reason for decrease in oligochaete population might be due to consumption as food by bottom dwelling predators corroborating the study of Barbhyan and Khan(1992). However, from the present study it can be concluded that these worms seemed to find a suitable living condition in areas with sewage inlet and low oxygen in so far as the general spatial distribution pattern is concerned though the quality of organic matter might have an influence on the oligochaeta population (Hawkes and Davies, 1971; Ghosh and Banerjee, 1996).

The crustaceans in this study are mainly represented by a crab, *S. edwardsi.* Like most of the species, they were also scanty in monsoon due to habitat disturbance. Their population peaks during February and April may be related to the higher amount of detritus, which in turn supports a rich population of benthos. Detritus in turn are related to plant production. When the monsoon retreats after October, the weeds again appear on the mudflat favouring population surge during February to April as this sesarmine species predominantly feed on plants (food) grown in the intertidal region (Paul and Nandi, 1998). Datta and Sarangi (1980) also reported that the crustaceans occupy the zones overgrown with some grasses. Death and decay of aquatic plants by micro-organisms results in the production of detritus which in turn supports a rich population of benthos (Dutta and Malhotra, 1986).

The fluctuation in gastropod population was mainly controlled by the dominating species of this group at various stations. At stations 1, 2, 3 and 5 the population consisted mainly of *T. lineata* and *T. scabra.* These species as well as *T. tuberculata* were found to be continuous breeders (Muley, 1977; Subba Rao and Mitra, 1982) and hence, release of young ones took place several times in a year thereby increasing the population density. However, the peak population of *T. tuberculata* in the present study corroborated the study of Subba Rao and Mitra (1982). Berry and Kadri (1974) concluded that *T. tuberculata* reproduces throughout the year in Malaysia while Dudgeon (1986) reported a single period of reproductive activity each year in summer in Hong Kong. Ismail and Arif (1993), on the other hand, reported two main periods of young release in May and October, though some hatchlings started to appear during April, August and September in their study. In the present investigation, *T. lineata* exhibited its peak in July and trough in August which deviated little from the study of Subba Rao and Mitra (1982) who reported the highest occurrence of this snail in May and lowest in June perhaps due to environmental factors. *A. francesiae,* the chief contributor of Gastropoda population at station 6, was abundant in winter months, reflecting the peak in November due to recruitment of young individuals which corroborates the study of Subba Rao *et al.* (1987) who reported maximum number of assiminids in November-December period in Sagar Island, West Bengal.

The variation in density of gastropod polpulation was also influenced by the monsoonal rain. Drastic fall in gastropods in monsoon occurred due to heavy rain. Heavy rainfall and high water discharge displace or destroy the habitats causing a drastic reduction in their number (Goodbody, 1961; Singh and Roy, 1991).

Various othe factors are also known to limit gastropod distribution. Exclusion of gastropods and other taxa from small streams low in pH and dissolved ions have been reported by Sutchiffe and Carrick (1973) and Townsend, Hildrew and Francis (1983). In the present investigation, gastropods were numerically dominant at stations 1 and 2 whereas all other groups are very few in number. This may be due to higher amount of organic matter of sediment (Table 1 please vide supra) recorded there (Aho, 1966; Pip 1987).

While it is true that the physico-chemical condition in the environment controls the overall nature and distrubution of the organisms in the interridal zone, it is equally true that biological factors may profoundly influence conditions in the habitat (Newell, 1979). Eggleton (1931) emphasized the need for great caution in pointing out any single criterion as the sole determining factor in influencing abundance and distribution of bottom fauna. Perkins (1974) stressed on the combination of factors like temperature, salinity, nature of substratum, effect of tide, grazing and predation for the macrozoobenthos distribution of which he found salinity playing a limiting role. Parulekar *et al.* (1980) attributed the prolonged breeding season, high fecundity and fast growth rate of tropical euryhaline species to be the major influencing parameters for population density. In case of the present study, it appears that, the compostition of sediment, its organic carbon content, favourable substratum, dissolved oxygen, food supply from detritus etc. as well as reproductive periodicity of the major invading species lead to the variation in the abundance of bottom fauna. However, it can be ascertained that the animal communities become more abundant where the interaction of all these physico-chemical and biological factors results into a stable favourable environment.

Community Analysis

Community structure delimits and defines the magnitude of production and energy pathways, and is essential in evaluating environmental and man made changes on biota as well as in the conservation and management of the environment. It is extensively used in water quality studies especially with reference to estuarine macrobenthos by various workers (Reish and Winter, 1954; Boesch, 1972; Tenore, 1972; Holland *et al.*, 1973; Harrel *et al.*, 1976; Junot *et al.*, 1983; Jordan and Sutton, 1984; Dolah *et al.*, 1984). The different community indices provide a better understanding of the environment and has been widely used by several workers (Vattakeril and Diwan, 1991; Ragupathi *et al.*, 1994; Harkantra and Parulekar, 1994; Ghosh and Banerjee, 1996). Five indices, namely, index of dominance, species richness, Shannon-Weiner species diversity index, evenness index and Sorensen's index of similarity were employed and estimated in the present investigation as follows.

Index of dominance

Within a major community there are species or groups which largely control the energy flow and strongly affect the environment of all other species. They are known as ecological dominants (Odum, 1971). The degree to which dominance is concentrated in one or many species can be expressed by an appropriate index of dominance that sums each species importance in relation to the community as a whole. The index of dominance (Simpson, 1949) is the sumtotal of squares of the proportion of the species in the community and is expressed as-

$$C = \Sigma \left(\frac{n_i}{N} \right)^2$$

Where n_i = importance value for each species (number of individuals, biomass, production etc.).

N = Total of importance values.

The value of 'C' varies between 0 to 1.

Margalef's diversity index

Species diversity has a number of components which may respond differently to geographical, developmental or physical factors (Odum, 1971). One major component might be called the species richness or Margalef's diversity index (d) and is expressed by simple ratios between total species (s) and total numbers (or importance values N).

$$d = \frac{s-1}{\log N}$$

as proposed by Margalef (1985).

Larger the index value, a more healthy body of water. When it tends towards 1, pollution is thought to increase and a damage should be suspected.

Shannon-Weiner index

The most widely used index for estimating the species diversity is the Shannon- Weiner index (Shannon and Weiner, 1949) given by the formula -

$$H\ C = \Sigma \left(\frac{n_i}{N} \right) \log \left(\frac{n_i}{N} \right)$$

Where n_i = importance value of each species

N = total of importance values.

The value of this index can theoretically range from 0 to infinity. However, values normally range from 0.0 to 4.0.

Evenness index

Another major component of diversity is evenness or equitability in the apportionment of individuals among the species.

It is expressed as $e = \frac{\bar{H}}{\log S}$ (Pielou, 1966)

Where $\bar{H}$ = Shannon index

S = Number of species

It can be noted that both e and $\bar{H}$ behave inversely to the index of dominance since high values indicate a low concentration of dominance.

Sorensen's index of Similarity

The index of similarity (S) between two samples as proposed by Sorensen (1948) is given by the formula -

$$S = \frac{2C}{A+B}$$

Where A = number of species in sample A

B = number of species in sample B

C = number of species common to both the samples.

It measures the similarity in the species composition in the sample and the value of S range between 0 to 1.

A widely used approach to describe the responses of biotic communities to environmental change has been the calculation of dominance diversity indices (Modde and Drewes, 1990); these emphasize the use of maximum information. However, Winget and Mangum (1979) and Hawkes (1979) argued that dominance diversity indices are ineffective in evaluating several forms of environmental influence. But Pianka (1976a and 1976b) stressed on index of dominance (c) which is sample size dependent and relfects the proportional abundance of species richness and individual richness. Mac Arthur (1965, 1972) explained the diversity variation on the basis of resource, resource utilisation and niche overlap. The index of dominance is always higher where the community is dominated by a fewer number of species and lower where the dominance is shared by a large number of species (Whittaker, 1965), or the total population of the community is uniformly distributed among different species that mainly occur in clean and pollution free waters (Osborne *et al.*, 1976). In the present study, the highest value of 0.99 (0.84 to 0.99) was shown by station 4. In the other stations, the values varied as 0.28 to 0.87 at station 1, 0.32 to 0.74 at station 2, 0.3 to 0.62 at station 3, 0.90 to 0.45 at station 5 and 0.17 to 0.61 at station 6 (Table 7). The high value of index of dominance observed at station 4 itself indicates that the station has fewer number of species.

Species diversity has been termed as 'non-concept' by Hurlbert (1971) and meaningless because to him the diversity indices, which are necessarily linear in nature, do not represent the actual situation. But Hill (1973) suggested that it is an extremely useful notation that can be defined as the effective number of species present, either in a broader geographic area, a community or a portion. The number of species present in a community is variously referred to as 'species richness' and/or species density. Various indices of diversity weight these two components rather differently (Hill, 1973) and some indices all but ignore one component or the other (Pianka and Huey, 1971). Mason (1981) quoted from a number of studies that the species richness is better and more realistic indicator of diversity than information statistics.

The Margalef's diversity index varied considerably from 1.09 to 2.83 at station 1, 1.01 to 4.73, 0.92 to 4.26, 0.45 to 1.49, 2.39 to 5.76 and 1.97 to 6.26 at stations 2, 3, 4, 5 and 6 respectively (Table 7). The higher diversity values reflect the suitability of habitat for the organism in one hand while on the other the high species diversity has been reported to be correlated with longer food chain and complex food web of the ecosystem and also relatively more stable community (Margalef, 1956). Larger the index value, a more healthy body of water. Based on the maximum value of the index at each station, station 6 can be considered a comparartively healthy one while station 4 is the poorest one.

Table 7. Mean monthly fluctuation in index of doinance (e), Margalef's index (d), Shannon - Weiner's index (H) and evenness (e) at the different study stations.

INDEX/ STATIONS	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
c 1	0.48	0.41	0.50	0.44	0.87	0.49	0.47	0.45	0.28	0.47	0.43	0.43
2	0.74	0.63	0.46	0.46	0.50	0.47	0.63	0.32	0.5	0.36	0.71	0.45
3	0.35	0.47	0.34	0.35	0.51	0.59	0.62	0.48	0.3	0.37	0.51	0.38
4	0.99	0.98	0.94	0.94	0.98	0.99	0.99	0.99	0.99	0.84	0.93	0.99
5	0.30	0.19	0.09	0.19	0.36	0.38	0.45	0.34	0.16	0.19	0.19	0.29
6	0.34	0.61	0.31	0.17	0.31	0.30	0.39	0.58	0.22	0.31	0.22	0.3
d 1	1.83	2.39	2.47	2.83	1.13	2.26	1.24	1.60	2.05	1.44	1.09	2.27
2	1.01	1.88	2.33	1.43	1.56	1.33	1.72	4.73	2.42	2.0	2.64	2.88
3	3.48	1.42	4.26	3.92	0.92	2.31	2.81	3.52	3.90	3.40	2.01	2.51
4	0.48	0.91	1.49	1.17	1.24	0.70	0.99	0.54	0.45	1.05	0.92	0.62
5	3.53	4.80	5.76	5.56	2.39	3.32	4.53	3.45	5.26	4.95	3.43	4.05
6	3.12	1.97	4.52	6.26	3.37	4.12	4.09	3.7	4.72	3.42	4.68	4.39
H 1	1.18	1.56	1.19	1.48	1.03	1.22	1.19	1.33	1.95	1.21	1.35	1.47
2	1.05	1.13	1.59	1.26	1.76	1.18	1.11	2.25	1.38	1.52	1.11	1.49
3	1.86	2.02	1.94	1.93	1.03	1.09	1.19	2.18	2.10	1.81	1.94	1.89
4	0.02	0.07	0.23	0.21	0.10	0.05	0.03	0.007	0.05	0.44	0.24	0.03
5	2.06	2.48	2.44	2.56	1.63	1.5	1.61	1.89	2.76	2.59	2.52	2.14
6	1.86	2.0	2.52	2.82	1.96	2.08	1.96	1.55	2.99	2.1	2.74	2.06
e 1	0.46	0.57	0.39	0.53	0.21	0.45	0.46	0.58	0.97	0.52	0.85	0.53
2	0.52	0.49	0.59	0.63	0.62	0.59	0.41	0.71	0.61	0.96	0.35	0.74
3	0.77	0.99	0.71	0.67	0.65	0.45	0.45	0.78	0.77	0.71	0.59	0.81
4	0.02	0.03	0.03	0.09	0.04	0.03	0.02	0.004	0.03	0.27	0.13	0.015
5	0.79	0.96	0.85	0.92	0.81	0.95	0.53	0.82	0.95	0.87	0.84	0.79
6	0.8	0.51	0.85	0.88	0.77	0.77	0.59	0.52	0.93	0.72	0.87	0.79

Although several species diversity indices have been proposed particularly on species richness and individual richness (Preston, 1948; Good, 1953; Brillouin, 1960) and the study of species diversity has produced an extensive literature, some important and useful reviews include those of Mac Arthur (1965), McIntosh (1967), Whittaker (1972), Peet (1974), one of the most promising indices of diversity measure is derived from the information theory (Margalef, 1956; Patten, 1962; Wilhm and Dorris 1966; Mathis, 1968).

In estimating the species diversity probably the most widely used index is the Shannon-Weiner index, which actually is not a real assessment of species diversity in community but the relative importance value of species, taken into account (Whittaker, 1977). This is why the index obtained by the formula is good indication of water quality of the habitat and forms a base of bio-monitoring. The mean observed value of Shannon-Weiner diversity index was found to be highest at station 6 being 2.22 followed by station 5 (2.18), station 3 (1.74), station 2 (1.4), station 1 (1.34) and station 4(0.12). At station 4, the maximum value of Shannon-Weiner index recorded was 0.44 (Table 7) indicating a site of very low diversity. Evidently, a single species dominance *(Limnodrilus hoffmeisteri)* was observed at this station. Wilhm and Dorris (1966) proposed a relationship between species diversity and pollution status of the sampling zone as follows : Species diversity value greater than 3 is clean water, values in the range of 1-3 indicate moderate pollution and values less than 1, indicate heavy pollution. According to them all the selected stations fall under moderate pollution except station 4 which goes under the heavily polluted one.

Staub *et al.* (1970) proposed another scale of pollution status in terms of species diversity as follows: Species diversity value 3.0-4.5= slight pollution, 2.0-3.0= light pollution, 1.0-2.0= moderate pollution, 0.0-1.0= heavy pollution.

According to this scale, the stations under study should be recognized as follows based on the mean values of index: Station 6 and 5 fall under the category of light pollution, stations 1, 2 and 3 under moderate pollution zone, while station 4 represents heavy pollution. Both the scales, however, suggest that the stations under study are polluted throughout the year but station 4 exhibits the site of heavy pollution apparently due to heavy influence of pollution from Tolly's nullah. Several authors have questioned the use of Shannon's diversity index stating that it depends upon a hypothetical number of species and must be considered an empirical value (Peet, 1974). Washington (1984) cited a lack exploration of its biological relevance. Nichols (1973) criticized the past use of diversity indices in the San Francisco Bay estuary stating that they were employed without regard for standardizing methodology and species identification, or an understanding of the natural biological processes that affect them. Most of the criticisms have been very subjective while in applied studies diversity values give additional information to competent ecologist which enables them to ask questions and formulate hypothesis about the environment. Harrel *et al.* (1976) stated that diversity values should always be used to compliment tabular analysis of taxa distribution and abundance with physico-chemical data and a knowledge of the organisms and the system. According to Hughes (1978) factor other than pollution could also affect diversity values and concluded that they were useful indices of community structure but cannot stand-alone.

The evenness is thought to denote a batanced relation between the species and individual richness of a sample. The evenness index values were found ranging between 0.21 to 0.97 in station 1, 0.35 to 0.96, 0.45 to 0.99 0.53 to 0.96, 0.51 to 0.93 in stations 2, 3, 5 and 6 respectively (Table 7) while station 4 showed the apportionment of individuals among the species present in this station.

In the present study it has been revealed that though the diversity indices and concentration of dominance did not vary considerably in temporal series, they did furnish some interesting information in spatial series. The low concentration of dominance and the high diversity indices values at station 6 signify that a larger number of species contributed to the community organization there. On the other hand, the high dominance and low diversity values at station 4 imply dominance of very few species, in this case only by *Limnodrilus hoffmeisteri*. The values fell between the two extremes at the other stations.

A coefficient of similarity (Sorensen's index of similarty) was computed to compare the animal populations occurring at each station. This method considers the frequency of distribution of the genera at the stations and the mean density of the genera at each station. Two areas having exactly the same animal population would have a similarity value of 1, conversely, two stations having no genera in common would have a value of 0.

In this study, station 4 which lies below the outfall region of Tolly's nullah, had an unbalanced community and similarity with any other station was no greater than 0.44. In contrast, similarity between station 3 and 5 was 0.61 (Table 8) which indicated a "recovery" at station 5 from the pollution from Tolly's nullah.

Use of Sorensen's coefficient for comparing animal population between different stations of an aquatic system has been used by various workers (Harrel and Hall III, 1991; Harkantra and Parulekar, 1994; Venkataraman and Nandi, 1997).

Table 8. Sorensen's similarity index values between pairs of study stations.

Stations	1	2	3	4	5	6
1	-					
2	0.58	-				
3	0.49	0.55	-			
4	0.44	0.43	0.44	-		
5	0.45	0.45	0.61	0.36	-	
6	0.36	0.34	0.53	0.26	0.51	-

Pollution status of the selected stations

Animal communities respond to intermittent pollution, which may be missed in chemical sampling programme. Waters which are slightly or periodically polluted yield variable water quality data. The presence of mild or periodic pollution can be detected by the use of quantitative biologocal methods. In the present study an attempt is made to show that quantitative analysis of macrozoobenthos can be used in conjunction with water quality data to evaluate the condition of a body of water.

At the point of discharge of pollutant, the clean water fauna is eliminated being unable to tolerate low oxygen tension and the tolerant fauna such as tubificids, may be present below the discharge. As the water body gradually reoxygenates, the clean water fauna increases in number and diversity. In fact, chemical data measure the concentration of pollutants but the degree of imbalance of ecosystem is measured by biological information. However, biological and chemical data cannot replace each other and both are essential in estimating the pollution status of a water body.

Inference from physico-chemical characteristics

Salient physico-chemical characteristics of river water have already been discussed. Unlike lake system, river water quality cannot be characterized by the concentrations of nutrients (Wong *et al.,* 1979). However, dissolved oxygen content, which plays a vital role in supporting aquatic life in running waters, is susceptible to silght environmental changes. Oxygen depletion often results during times of high community respiration. For this reason, dissolved oxygen has been extensively used as parameter delineating water quality (Wong *et al.,* 1979). In this study, the dissolved oxygen value at station 4 which is located at the sewage outfall region of Tolly's nullah was seen to fall as low as 0.4 mg/l also. In most part of the year the dissolved oxygen value remained below 3 mg/l (Appendix 7). Marked variation from the other stations in BOD, COD and conductivity values were also noticed (Table 1, please vide supra). The higher values of conductivity (up to 1400 μmhos/cm) and lower values of dissolved oxygen coupled with high load of BOD (up to 51.3 mg/l) and COD (up to 179.68 mg/l) at station 4 indicated a stressed condition and higher pollution compared to the other stations.

Inference from benthic community

The damage to an aquatic ecosystem is caused by different kinds of pollutants, the estimation of all of them is extremely difficult at one time. The organisms through their presence, number and behaviour can integrate the whole effect and tend to preserve the past effect of a waste discharge or any ecological perturbation, even if the source of pollution is removed. When an environment become stressed, species sensitive to that particular stress will be eliminated, thus reducing the richness of the community and certain species may be favoured so that they become abundant compared to the other members of the community.

As for the biological characteristics, the occurrence of faunal components in the present case were restricted to organisms capable of living in anaerobic condition mainly represented by pollution indicator tubificid worm, *Limnodrilus hoffmeisteri*, at station 4 finding support from earlier studies (Aston, 1973; Brinkhurst, 1974). The other stations had diverse macrobenthic population when compared to station 4 which consisted predominantly of only one genus of tubificid worm viz., *Limnodrilus* and sporadically and sparsely of other genera (Table 1).

This tubificid worm, *L. hoffmeisteri* contributed over 99% to the total benthic fauna at station 4. The anaerobic condition as noted in this station could be favourable for rapid multiplication of these worms as also reported by many workers (Cowell and Vodopich, 1981; Mason, 1981; Reddy and Rao, 1987).

According to Szczesny (1991) if a river is more polluted with organic compounds, there is greater number of oligochaetes. Carr and Hiltumen (1965) classified polluted water bodies into different categories according to the density of oligochaetes as follows: 100-999 individuals/m^2 indicates polluted water, 1000-5000 individuals/m^2 indicates moderate pollution and 5000 individuals/m^2 and above indicates heavily polluted condition. According to this classification, station 4 (5096- 21,132 oligochaetes/m^2, Table 4) falls under the heavily polluted ones. Gaufin and Tarzwell (1952) were of the view that a single species merely connot be used as an indicator of pollution. But Brinkhurst (1966) opined that occurrence of *L. hoffmeisteri* alone indicates pollution. This polluted condition prevailing at station 4 can be attributed to the heavy discharge of sewage through Tolly's nullah which provides favourable condition for the development of oligochaetes. In general, polluted areas contain fewer species but certain organisms become exceedingly abundant (Gaufin,1985; Ingram and Towne, 1959). Goodnight and Whitly (1960) suggested that a bottom invertebrate community containing 80% or more of the tubificid worms indicate a high degree of organic enrichment as in the case of station 4.

The values of biological sampling for assessment of environment quality has long been recognized (Hynes, 1960). The species diversity indices has also been used in pollution studies. The widely used Shannon-Weiner species diversity index value for the different stations revealed that all the stations are moderately polluted throughout the year as values (Table 7, please vide supra) never exceeded 3 which is indicative of clean water according to Wilhm and Dorris but station 4 reflected heavy pollution as their values were always very low (0.007 - 0.44) indicating a site of very low diversity. Thus the scale proposed by Wilhm and Dorris also points out that station 4 is under the heavy influence of pollution from Tolly's nullah.

Recovery Potential of the River

An indication of recovery tendency of pollution at station 4 was observed at about 100m downstream at station 5 as evident from the rise in dissolved oxygen (up to 6.9 mg/l) associated with lowering of BOD (1.9 - 15.1 mg/l), COD (14.54 - 73.04 mg/l) and conductivity values (169.8 - 800 μmhos/cm). Various macrobenthic species such as *I. exustus, N. violacea, S. lineata* and many other species, which were present even at the upstream station of Tolly's nullah, (i.e., at station 3) disappeared completely at station 4 may be due to their sensitivity to the polluted condition of that station. Thus diverse macrobenthic fauna which were absent at station 4 again made their appearance at station 5 (Table 2, please vide supra). The pollution indicator worm *L. hoffmeisteri* was recorded rarely from station 5 and that too at very low density (Table 5) where *Limondrilus* is a member of a complex community rather than a monoculture of an 'indicator' species. Mason (1981) pointed out that tubificids gradually decrease when the water becomes more oxygenated. Similar situation seem to have occurred at station 5. Recovery is further supported by the comparatively higher Shannon-Weiner species diversity value (1.5 to 2.76) and lowering of index of dominance value (0.09 - 0.45) at station 5. The capacity of the river to cope up with the pollution load, depends on oxygen balance, resulting from competition between the demands imposed by oxidizable materials and the existing oxygen resources and the capacity of re-aeration.

A high degree of self-purification capacity appears to be a feature of tropical ecosystem. Ghosh *et al.* (1976) recorded that the recovery distance was 50-100m in case of outfall of a rayon factory. Ray *et al.* (1979) reported that the condiions improved within 100m below the outfall in case of soda process of pulp and paper mill. In the present study, the recovery distance is about 100m from the sewage outfall area of station 4 which indicates autopurification potential of Hugli river. Self-purification capacity of different rivers has been reported by many workers (Rao and Srivastava, 1989; Diaz, 1989; Ghosh *et al.* 1990; Vattakeril and Diwan, 1991). But high self purification capacity is applicable as long as there is sufficient flow of water. So, if it is possible to maintain a proper flow of water in the river Hugli, a balanced equilibrium between the pollution load and self-purification capacity of the river can be reasonably sustained.

Statistical Analysis

The different water and sediment parameters of the river are very unpredicatable and variable which are bound to have significant effect on the biotic components. Further, these parameters as well as faunal abundance vary from place to place and from time to time. At a particular place, relationship may or may not exist between every pair of the paramenters. There are various studies on this aspect in India (Sharma, 1986; Prahba Devi and Ayyakkannu, 1989; Harkantra and Parulekar, 1991; Sarala Devi *et al.*, 1991).

It may be mentioned that statistical analysis helps to simplify the massive data for clear interpretation. This is an exploratory approach as the results do not divulge the mechanism of ecobiological interaction. The biotic and abiotic data obtained from each station under study were subjected to different statistical analysis, namely, A) Pearson's correlation co-efficient B), Stepwise multiple regression analysis and C) Analysis of variance (ANOVA - 2 way). An approach is made herein to understand the effect of different abiotic factors in the distribution and abundance of benthic fauna separately for each of the six selected stations of the river.

Correlation Analysis

For understanding the interdependence of benthic fauna on physico-chemical parameters, Pearson's correlation coefficient was calculated between abiotic factors (water and sentiment paremeters) and biotic components viz., Total benthos (no./m^2), major groups (Polychaeta, Oligochaeta, Crustacea and Gastropoda in no./m^2) and only those species of each station which occurred most frequently at that station. Only significant correlations are presented in Tables 9-14 for stations 1-6 respectively in ascending order, which reveal the effect of individual paramenter on the benthic fauna at different levels of probability.

Correlation between water quality parameters and total benthos (Tables 9-14) :

A strong positive correlation was found between the density of total benthos and pH ($r = 0.4629$ $p<0.05$ at station 1) as well as turbidity ($r = 0.4123$, $p<0.05$, at station 1 and $r = 0.4971$, $p<0.05$ at station 2), dissolved oxygen ($r = 0.4665$, $p<0.05$ at station 3 and $r = 0.4163$, $p<0.05$ at station 6), phosphate ($r = 0.5475$, $p<0.01$ at station 4) and COD ($r = 0.5023$, $p<0.05$ at station 6), while a strong negative correlation was observed between total benthos and temperature ($r = -0.4555$, $p<0.05$ at station 3 and $r = -0.5204$, $p<0.01$ at station 6) and also chloride ($r = -0.4646$, $p<0.05$ at station 2 and $r = -0.5050$, $p<0.05$ at station 6), ammonium ($r = -0.5329$, $p<0.01$ at station 6), nitrite ($r = -0.4434$, $p<0.05$ at station 3), lead ($r = -0.4395$, $p<0.05$ at station 6) and conductivity ($r = -0.5213$, $p<0.01$ at station 3) of the river water. At station 5 the total number of benthos, however, failed to establish any relationship with the water quality parameters.

Correlation between sediment parameters and benthos (Tables 9-14):

The temperature of sediment showed a negative correlation ($r = -0.5072$, $p<0.05$ at station 3 and $r = -0.4688$, $p<0.05$ at station 6) with total benthos density. The same trend was followed by pH ($r = -0.5480$, $p<0.01$ at station 3; $r = -0.4386$, $p<0.05$ at station 5 and $r = -0.4771$, $p<0.05$ at station 6) and nitrite ($r = -0.4869$, $p<0.05$ at station 5 and $r = -0.4865$ $p<0.05$ at station 6) while nitrate exhibited a highly positive correlation ($r = 0.5613$, $p<0.01$ at station 3) with total benthos.

Correlation between major groups of organisms (no./m^2) and water parameters (Tables 9-14):

The number of polychaetes were positively correlated with dissolved oxygen ($r = 0.5838$, $p<0.01$ at station 3 and $r = 0.4625$, $p<0.05$ at station 6), pH ($r = 0.6032$, $p<0.01$ at station 4), BOD ($r = 0.4075$, $p<0.05$ at station 5) and negatively correlated with temperature ($r = -0.4415$, $p<0.05$ at station 2), turbidity ($r = -0.5996$, $p<0.01$ at station 3), alkalinity (r = -0.5264, p<0.01 at station 1), nitrate (r = -0.4942, p<0.05 at station 1), hardness (r = -0.4138 p<0.05 at station 4) and lead (r = -0.5857, p<0.01 at station 3) of the waterbody.

The oligochaete density was positively effected by phosphate (r = 0.5490, p<0.01 at station 4) and negatively by temperature (r = -0.6321, p<0.01 at station 5) and turbidity (r = -0.4174, p<0.05 at station 4).

The crustaceans had significant positive correlation with alkalinity (r = 0.5804, p<0.01 at station 3 and r = 0.5228, p<0.05 at station 6), hardness (r = 0.4328, p<0.05 at station 3 and r = 0.4090, p<0.05 at station 6) and turbidity (r = 0.5853, p<0.01 at station 2 and r = 0.4926, p<0.05 at station 4), while significant negative relations existed with BOD (r = -0.4060, p<0.05 at station 6), conductivity (r = -0.4085, p<0.05 at station 5) and nitrite (r = -0.5369, p<0.01 at station 5).

The variation in density of gastropods was positively influenced by dissolved oxygen (r = 0.4175, p<0.05 at station 3), pH (r = 0.4512, p<0.05 at station 1), turdbidity (r= 0.4278, p<0.05 at station 1), COD (r = 0.4458, p<0.05 at station 2 and r = 0.6313, p<0.01 at station 6) and negatively influencecd by temperature (r = -0.4277, p<0.05 at station 3 and r = -0.4424, p<0.05 at station 6), conductivity (r = -0.4817, p<0.05at station 3), ammonium (r = -0.4900, p<0.05 at station 6), nitrite (r = -0.4267, p<0.05 at station 3) and chloride (r = -0.5912, p<0.01 at station 6) of river water. At station 4, gastropods reflected only postive relation with chloride (r = 0.4090, p<0.05).

Correlation between major groups and sediment parameters (Tables 9-14):

Sediment temperature showed a negative correlation with Gastropoda (r = -0.4804, p<0.05 at station 3 and r = -0.4706, p<0.05 at station 6), Polychaeta (r = -0.4724, p<0.05 at station 2) and Crustacea (r = -0.4175, p<0.05 at station 1). Sediment pH also showed a negative relation with Gastropoda (r = -0.5339, p<0.01 at station 3), Polychaeta (r = -0.4706, p<0.05 at station 6) and Oligochaeta (r = -0.5163, p<0.01 at station 5). Phosphate had a negative influence on the density of Gastropoda only (r = -0.4377, p<0.05 at station 2). Nitrite of sediment revealed a highly negative relation with Polychaeta (r = -0.5412, p<0.01 at station 5). Nitrate exhibited a negative influence on Oligochaeta (r = -0.4144, p<0.05 at station 5) and positive on Polychaeta (r = 0.5436, p<0.01 at station 1) and Gastropoda (r = 0.5184, p<0.01 at station 3).

Correlation between the water parameters and species (Tables 9-14) :

The variation in the density of the regularly occurring species exhibited significant correlation with the water quality as follows.

N. oligobranchia exhibited significant correlation at station 3 only being positive with temperature (r = 0.7892, p<0.01), hardness (r = 0.5617, p<0,01), dissolved oxygen (r = 0.4274, p<0.05), BOD (r = 0.4379, p<0.05) and negatively related with turbidity (r = -0.5265, p<0.01) and lead (r = -0.4728, p<0.05).

Table 9. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station1 [total benthos (Tb), Polychaeta (Pol), Crustacea (Cru), Gastropoda (Gas), *T. lineata* (Tl), *T. scabra* (Ts) and *T. tuberculata* (Tt)].

Physico-chemical Variable	Biotic Components						
	Tb	Pol	Cru	Gas	Tl	Ts	Tt
WATER							
Temperature							-0.6413**
pH	0.4629*			0.4512*			
Conductivity							0.7339**
Turbidity	0.4123*			0.4278*			
Total Alkalinity		-0.5264**					0.5263**
Hardness					-0.4110*		0.5733**
DO							0.5231**
BOD						0.4214*	
Chloride							0.4856**
Nitrate		-0.4942*					0.7551**
SEDIMENT							
Temperature			-0.4175*				-0.6791**
Phosphate							0.4709*
Nitrite							0.4533*
Nitrate		0.5436**					0.4527*

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 10. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station 2 [total benthos (Tb), Polychaeta (Pol), Crustacea (Cru), Gastropoda (Gas), *T. lineata* (Tl) and *T. scabra* (Ts)].

Physico-chemical Variable	Biotic Components					
	Tb	Pol	Cru	Gas	Tl	Ts
WATER						
Temperature		-0.4415*				
Turbidity	0.4971*		0.5853**		0.4204*	
COD				0.4458*		
Chloride	-0.4646*					
Nitrite					0.4260*	
SEDIMENT						
Temperature		-0.4724*				
Phosphate				-0.4377*		-0.4903*

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 11. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station 3 [total benthos (Tb), Polychaeta (Pol), Crustacea (Cru), *N. oligobranchia* (Nol), *N. fauveli* (Nf), *D. aestuarina* (Da), *T. scabra* (Ts)].

Physico-chemical Variable	Biotic Components							
	Tb	Pol	Cru	Gas	Nol	Nf	Da	Ts
WATER								
Temperature	-0.4555*			-0.4277*	0.7892**	-0.6489**	-0.5368**	-0.4328*
Conductivity	-0.5213*			-0.4817*				-0.4873*
Turbidity		-0.5996**			-0.5265**	-0.6814**		
Total Alkalinity			0.5804**			0.7779**		
Hardness			0.4328*		0.5617**	0.6879**	0.4352*	
DO	0.4665*	0.5838**		0.4175*	0.4274*	0.7444**	0.5947**	0.4122*
BOD					0.4379*			
Phosphate							-0.4075*	
Nitrite	-0.4434*			-0.4267*				
Nitrate						-0.4747*		
Lead		-0.5857**			-0.4728*	-0.5452**	-0.5214**	
SEDIMENT								
Temperature	-0.5072*			-0.4804*		-0.5334**	-0.4605*	-0.4820*
pH	-0.5480**			-0.5539**			-0.4216*	-0.5443**
Phosphate							0.4273*	
Nitrate	0.5613**			0.5184**				0.5333**

'*' = Significance level at 0.05

'**' = Significance level at 0.01

Table 12. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station 4 [total benthos (Tb), Polychaeta (Pol), Oligochaeta-*L. hoffmeisteri* (Lh), Crustacea (Cru), Gastropoda (Gas), *T. scabra* (Ts)].

Physico-chemical Variable	Biotic Components					
	Tb	Pol	Cru	Gas	Lh	Ts
WATER						
pH		0.6032**				
Turbidity			0.4926*		-0.4174*	
Hardness		-0.4138*				
Chloride				0.4090*		0.5404**
Phosphate	0.5475**				0.5490**	
Chromium						0.4087*
Lead						0.5266**

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 13. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station 5 [total benthos (Tb), Polychaeta (Pol), Oligochaeta-*L. hoffmeisteri* (Lh), Crustacea (Cru), *N. oligobranchia* (Nol), *N. fauveli* (Nf), *D. aestuarina* (Da), *T. lineata* (Tl)].

Physico-chemical Variable	Biotic Components							
	Tb	Pol	Cru	Nol	Nf	Da	Lh	Tl
WATER								
Temperature							-0.6321**	-0.4965*
Conductivity			-0.4085*		0.4236*			0.4231*
Total Alkalinity								0.4317
Hardness					0.4644*			
BOD		0.4075*			0.5370**	0.5771**		
Phosphate								-0.4973*
Nitrite			-0.5369**					
Chromium								-0.5540**
SEDIMENT								
Temperature				-0.4241*				-0.5211**
pH	-0.4386*						-0.5163**	
Nitrite	-0.4869*	-0.5412**		-0.5668**	-0.4748*	-0.4974*	-0.5430**	
Nitrate							-0.4144*	

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 14. Correlation between physico-chemical parameters and biotic components in number per metre square (no./m^2) at station 6 [total benthos (Tb), Polychaeta (Pol), Crustacea (Cru), Gastropoda (Gas), *N. oligobranchia* (Nol), *N. fauveli* (Nf), *D. aestuarina* (Da), *S. edwardsi* (Se), *A. francesiae* (Af)].

Physico-chemical Variable	Biotic Components								
	Tb	Pol	Cru	Gas	Nol	Nf	Da	Se	Af
WATER									
Temperature	-0.5204**			-0.4424*					-0.4442*
pH						-0.5829**	-0.4596*		
Turbidity								0.5012*	
Total Alkalinity			0.5228*					0.7338**	
Hardness			0.4090*					0.6620**	
DO	0.4163*	0.4625*				0.4698*			
BOD			-0.4060*						
COD	0.5023*			0.6313**					0.6103**
Chloride	-0.5050*			-0.5912**					-0.6067**
Ammonium	-0.5392**			-0.4900**					-0.5636**
Lead	-0.4395*								
SEDIMENT									
Temperature	-0.4688*			-0.4706*					-0.4696
pH	-0.4771*	-0.4706*					-0.4089*		
Phosphate					0.6476**				
Nitrite	-0.4865*					-0.4632*			-0.4290*

'*' = Significance level at 0.05

'**' = Significance level at 0.01

N. fauveli had positive relation with alkalinity ($r = 0.7779$, $p<0.01$ at station 3), hardness ($r = 0.6879$, $p<0.01$ at station 3 and $r = 0.4644$, $p<0.05$ at station 5), dissolved oxygen ($r = 0.7444$, $p<0.01$ at station 3 and $r = 0.4698$, <0.05 at station 6), conductivity ($r = 0.4236$, $p<0.05$ at station 5) and BOD ($r = 0.5370$, $p<0.01$ at station 5), while negative correlation with temperature ($r = -0.6489$, $p<0.01$ at station 3), pH ($r = -0.5829$, $p<0.01$ at station 6), turbidity ($r = -0.6814$, $p<0.05$ at station 3), nitrate ($r = -0.4747$, $p<0.05$ at station 3) and lead ($r = -0.5452$, $p<0.01$ at station 3) was observed.

D. aestuarina showed significant positive effect of BOD ($r = 0.5771$, $p<0.01$ at station 5), hardness ($r = 0.4352$, $p<0.05$ at station 3), dissolved oxygen ($r = 0.5947$, $p<0.01$ at station 3) and negative effect of pH ($r = -0.4596$, $p<0.05$ at station 6), temperature ($r = -.05368$, $p<0.01$ at station 3), phosphate ($r = -0.4075$, $p<0.05$ at station 3) and lead ($r = -0.5214$, $p<0.01$ at station 3).

L. hoffmeisteri was positively correlated with phosphate ($r = 0.5490$, $p<0.01$ at station 4) and negaively with turbidity ($r = -0.4174$, $p<0.05$ at station 4) and temperature ($r = -0.6321$, $p<0.01$ at station 5).

S. edwardsi had significant positive correlation with turbidity ($r = 0.5012$, $p<0.05$), alkalinity ($r = 0.7338$, $p<0.01$) and hardness ($r = 0.6620$, $p<0.01$) at station 6 only.

The abundance of *T. lineata* showed a significant positive relation with turbidity ($r = 0.4204$, $p<0.05$ at station 2), conductivity ($r = 0.4231$, $p<0.05$ at station 5), alkalinity ($r = 0.4317$, $p<0.05$ at station 5) and nitrite ($r = 0.4260$, $p< 0.05$ at station 2) while a negative relation was found with temperature ($r = -0.4965$, $p<0.05$ at station 5), hardness ($r = -0.4110$, $p<0.05$ at station 1), phosphate ($r = -0.4973$, $p<0.05$ at station 5) and chromium ($r = -0.5540$, $p<0.01$ at station 5).

T. scabra was positively correlated with dissolved oxygen ($r = 0.4122$, $p<0.05$ at station 3), chloride ($r = 0.5404$, $p<0.01$ at station 4), BOD ($r = 0.4214$, $p<0.05$ at station 1), chromium ($r = 0.4087$, $p<0.05$ at station 4), lead ($r = 0.5266$, $p<0.01$ at station 4) and negatively correlated with conductivity and temperature ($r = -0.4873$, $p<0.05$; $r = -0.4328$, $p<0.05$ respectively at station 3).

T. tuberculata had positive relation with conductivity ($r = 0.7339$, $p<0.01$), alkalinity ($r = 0.5263$, $p<0.01$), dissolved oxygen ($r = 0.5231$, $p<0.01$), hardness ($r = 0.5733$, $p<0.01$) chloride ($r = 0,4856$, $p<0.01$), nitrate ($r = 0.7551$, $p<0.01$), and negative correlation with only water temperature ($r = 0.6413$, $p<0.01$) at station 1.

A. francesiae exhibited significant positive relationship with COD ($r = 0.6103$, $p<0.01$), and negative relationship with temperature ($r = -0.4442$, $p<0.05$), chloride ($r = -0.6067$, $p<0.01$) and ammonium ($r = -0.5636$, $p<0.01$) at station 6.

Correlation between sediment parameters and species (Tables 9-14) :

The temperature of sediment had negative influence on *T. scabra* ($r = -0.4820$, $p<0.05$ at station 3), *T. lineata* ($r = -0.5211$, $p<0.01$ at station 5), *T. tuberculata* ($r = -0.6791$, $p<0.01$ at station 1), *A. francesiae* ($r = -0.4696$, $p<0.05$ at station 6), *N. oligobranchia* ($r = -0.4241$, $p<0.05$ at station 5), *D. aestuarina* ($r = -0.4605$, $p<0.05$ at station 3) and *N. fauveli* ($r = -0.5334$, $p<0.01$ at station 3).

The pH of sedimant had negative effect on the abundance of *T. scabra* ($r = -0.5443$, $p<0.01$ at station 3), *D. aestuarina* ($r = -0.4216$, $p<0.05$ at station 3 and $r = -0.4089$, $p<0.05$ at station 6) and *L. hoffmeisteri* ($r = -0.5163$, $p<0.01$ at station 5).

Sediment nitrite exhibited positive influence on the occurrence of *T. tuberculata* ($r = 0.4533$, $p<0.05$ at station 1) only and negative influence on *A. francesiae* ($r = -0.4290$, $p<0.05$ at station 6), *N. oligobranchia* ($r = -0.5668$, $p<0.01$ at station 5), *D. aestuarina*($r = -0.4974$, $p<0.05$ at station 5), *N. fauveli* ($r = -0.4748$, $p<0.05$ at station 5 and ($r = -0.4632$, $p<0.05$ at station 6) and *L. hoffmeisteri* ($r = -0.5430$, $p<0.01$ at station 5).

Nitrate showed a positive relationship with the variation in density of *T. tuberculata* ($r = 0.4527$, $p<0.05$ at station 1) and *T. scabra* ($r = 0.5333$, $p<0.01$ at station 3) and a negative relationship with the density of *L. hoffmeisteri* ($r = -0.4144$, $p<0.05$ at station 5).

Phosphate was noted to have a positive influence on the density of *T. tuberculata* ($r = 0.4709$, $p<0.05$ at station 1), *N. oligobranbchia* ($r = 0.6476$, $p<0.01$ at station 6) and *D. aestuarina* ($r = 0.4273$, $p<0.05$ at station 3) while it acted negatively on *T. scabra* ($r = -0.4903$, $p<0.05$ at station 2).

Stepwise multiple regression analysis

Stepwise multiple regression technique was adopted to know which of the physico-chemical parameters affect the abundance of benthos (Total benthos, groups and species) and also to what extent. The following tables (15-20) present the partial regression coefficient (βj) corresponding to each independent variable i.e. physico-chemical parameters which are supposed to be included in final regression equation. The partial regression coefficient (β) determines the expected change in density of total benthos/groups/species caused by the unit increase/decrease of the corresponding independent variables, other variables remaining unchanged. The tables also present coefficient of determination (R^2) for each species/group/total benthos, which measures their percent variation explained by the independent variables used in the final equation. The accuracy of the regression equations was tested with R^2 and the F value.

Multiple regression analysis of physico-chemical parameters and total benthos (no. m^2):

At station 1, among all the physico-chemical parameters, only pH bore linear relationship with the density of total benthos (no./m^2) and explained about 21% variation in their density. At station 2, three parameters - turbidity, COD and sediment temperature were important in influencing the density of total benthos and jointly explained 55% of the variation in number of benthos per meter square. About 65% variation is explained jointly by conductivity of water, sediment pH and linearly affected by phosphate and sediment nitrite respectively. At station 6, ammonium pH, temperature of water strongly contributed to the reduction of total benthos per meter square. These factors along with COD explained 73% of variation in total benthic density at station 6 (Tables 15-20).

Multiple regression analysis of physico-chemical parameters and groups/species (no. m^2):

Among the major groups studied at station 1, the abundance of Gastropoda per meter square was influenced by pH, phosphate, sediment pH, sediment organic carbon which jointly explained 63% of variation in gastropod density. Nitrate and sediment temperature strongly contributed to the reduction of crustaceans explaining 34% of variation in their density, while sediment nitrate linearly affected the density of polychaetes at this station. The variations in density of the regularly occurring species at station 1 viz., *T. lineata, T. scabra* and *T. tuberculata* were caused by pH, nitrate, chloride, conductivity, BOD and COD of water and nitrite and organic carbon of sediment (Table 15).

At station 2, alkalinity, turbidity and COD of water explained about 51% variation, sediment temperature explained 22% variation and turbidity explained 34% variation in the density of Gastropoda, Polychaeta and Crustacea respectively. The abundance of *T. lineata* and *T. scabra,* the regularly occurring species of this station was influenced by alkalinity, turbidity, lead and COD (Table 16).

About 55% of the variation in density of Gastropoda, 71% of Polychaeta and 83% of Crustacea was explained respectively by conductivity and sediment pH, alkalinity only in case of Polychaeta and dissolved oxygen, alkalinity, COD and organic carbon in case of Crustacea at station 3. The species such as *T. scabra, S. edwardsi,. N. oligobranchia, N. fauveli* and *D. aestuarina* at this station were influenced by conductivity, hardness, turbidity, alkalinity, dissolved oxygen, BOD, COD, and temperature of water and also sediment pH, sediment phosphate and organic carbon (Table 17).

At station 4, chloride in case of Gastropoda, Nitrite, Nitrate and pH in case of Polychaeta, turbidity in case of Crustacea and phosphate for Oligochaeta explained respectively about 17%, 78%, 24% and 30% variation in their densities. *L. hoffmeisteri* and *T. scabra* were influenced by phosphate and chloride of water at this station (Table 18).

At station 5, sediment nitrite bore a linear relationship with Polychaeta explaining about 29% variation in its density, temperature of water accounted for 40% variation in Oligochaeta density, nitrite of water explained 29% variation in crustacean density while gastropods failed to reveal any relation with physico-chemical parameters at this station. The abundance of the species such as *T. lineata, N. oligobranchia, N. fauveli* and *D. aestuarina* was influenced by phosphate, ammonium BOD and chromium of water and nitrite and temperature of sediment. *T. scabra* did not reveal any relationship with physico-chemical parameters of this station (Table 19).

Table 15. Multiple regression analysis between benthos and physico-chemical parameters at station 1 (ßj = partial regression coefficients of the j^{th} parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	pH	896.9999*	366.2376	-5238.0787	2996.7532	0.2142*
Polychaeta	Sediment nitrate	1.3369**	0.4400	-4.8158	3.0526	0.2955**
Crustacea	Nitrate	-44.4430*	18.8662			
	Sediment temperature	-29.1981**	8.7521	978.5891**	285.24	0.3468
Gastropoda	pH	1314.5675**	339.7698			
	Phosphate	2562.1540**	882.1426			
	Sediment pH	-1277.9908**	430.3944			
	Organic carbon	-4330.5711**	959.9413	3378.8363	2928.9911	0.6345**
Thiara lineata	pH	767.6305**	240.4205			
	COD	13.8317*	5.4572			
	Organic carbon	-1644.4208**	443.1482	-4363.4469*	2065.5463	0.5814**
Thiara scabra	BOD	11.0595*	5.0736	562.5164**	62.9853	0.1776*
Thiara tuberculata	Nitrate	20.2654	9.7802			
	Chloride	6.6699*	2.5991			
	Conductivity	0.3617**	0.0968			
	Sediment Nitrite	71.2198**	17.4093	-239.9516**	45.7680	0.8522**

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 16. Multiple regression analysis between benthos and physico-chemical parameters at station 2 (ßj = partial regression coefficients of the j[th] parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	Turbidity	2.3054**	0.5411			
	COD	6.4670**	2.0070			
	Sediment temperature	-27.8037*	12.5835	1059.4967**	345.4468	0.5591**
Polychaeta	Sediment temperature	-3.6081*	1.4353	116.3603**	40.8276	0.2231*
Crustacea	Turbidity	0.7002**	0.2068	-43.3479	29.2966	0.3425**
Gastropoda	Alkalinity	1.5563*	0.6839			
	Turbidity	1.8325**	0.5172			
	COD	5.9804**	1.7947	-127.3792	224.4514	0.5157*
T. lineata	Alkalinity	0.4229**	0.1451			
	Lead	80.9381**	19.9128	63.8020	43.6106	0.4736**
T. scabra	Turbidity	1.0120*	0.4078			
	COD	5.4358**	1.5902	139.1341	83.2189	0.4282**

'*' = Significance level at 0.05

'**' = Significance level at 0.01

Table 17. Multiple regression analysis between benthos and physico-chemical parameters at station 3 (ßj = partial regression coefficients of the j^{th} parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	Conductivity	-1.0243*	0.3770			
	Sediment pH	-653.8316**	177.3614			
	Sediment nitrate	57.1058	29.8991	5676.9997**	1409.7398	0.6478**
Polychaeta	Alkalinity	0.5196**	0.0701	-80.6819**	18.4650	0.7139**
Crustacea	Alkalinity	0.1940**	0.0236	32.7465**	8.2953	0.8257**
	Dissolved oxygen	-10.1907**	1.8392			
	COD	-0.3279**	0.0806			
	Organic carbon	-22.4604**	6.5655			
Gastropoda	Conductivity	-1.3085**	0.3890			
	Sediment pH	-769.7392**	200.0805	6857.9502**	1524.7098	0.5495**
Nephtys	Alkalinity	0.3842**	0.0635			
oligobranchia	BOD	3.7706*	1.5577	-87.5864**	17.4693	0.7050**
Namalycastis	Alkalinity	0.0553**	0.0109			
fauveli	Water temperature	-0.6329**	0.1928	14.4814	7.2330	0.7382**
Dendronereis	Conductivity	-0.0154*	0.0066			
aestuarina	Dissolved oxygen	5.5704**	1.1018			
	Sediment Phosphate	2.8957**	0.6105	-26.3206**	7.3818	0.7015**
Sesarma	Alkalinity	0.1942**	0.0228			
edwardsi	Dissolved oxygen	-10.2510**	1.7811			
	COD	-0.3489**	0.0780			
	Organic carbon	-21.5547**	6.3581	33.1918**	8.0334	0.8368**
Thiara scabra	Conductivity	-1.2332**	0.2557			
	Hardness	-4.2256**	1.3872			
	Turbidity	-1.7462**	0.4238			
	Sediment pH	-750.3269**	143.7651	7372.4484**	1179.8395	0.7697**

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 18. Multiple regression analysis between benthos and physico-chemical parameters at station 4 (ßj = partial regression coefficients of the j[th] parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	Phosphate	7606.6236**	2478.7256	6499.0009**	2009.8577	0.2997**
Polychaeta	pH	30.2230**	9.4901			
	Nitrite	-9.8960*	4.4154			
	Nitrate	5.3991**	0.9235	-241.4065**	72.9024	0.7856**
Oligochaeta (*L. hoffmeisteri*)	Phosphate	7645.2918**	2481.4677	6407.6923**	2012.0811	0.3014**
Crustacea	Turbidity	0.2108*	0.0794	-24.7296	13.1332	0.2426*
Gastropoda	Chloride	0.5034*	0.2394	22.5946	12.8035	0.1672*
T. scabra	Chloride	0.3521**	0.1168	1.2570	6.2493	0.2920**

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 19. Multiple regression analysis between benthos and physico-chemical parameters at station 5 (ßj = partial regression coefficients of the j[th] parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	Sediment Nitrite	-143.4830*	54.8791	220.8128**	39.7941	0.2370*
Polychaeta	Sediment Nitrite	-96.6649**	32.0217	125.0111**	23.2197	0.2928**
Oligochaeta	Water temperature	-1.1585**	0.3028	36.6512**	8.7352	0.3995**
Crustacea	Nitrite	-14.8567**	4.977	7.6823**	1.9386	0.2882**
D. aestuarina	BOD	3.8945**	1.1751	-18.4115	10.8187	03329**
N. fauveli	BOD	2.5568**	0.8563	-79631	7.8841	0.2883**
N. oligobranchia	Ammonium	68.0017**	15.2551			
	Chromium	-130.3186*	48.8541			
	Sediment temperature	11.0349**	3.0786			
	Sediment Nitrite	-164.2080**	31.5972	-199.4866*	71.6407	0.6701**
T. lineata	Phosphate	-7.4070*	2.9381			
	BOD	0.8409**	0.2898			
	Chromium	-19.7095*	7.4660	9.1969**	2.9396	0.5788**

'*' = Significance level at 0.05
'**' = Significance level at 0.01

Table 20. Multiple regression analysis between benthos and physico-chemical parameters at station 6 (ßj = partial regression coefficients of the j[th] parameter of faunal density, S.E. = standard error, R^2 = coefficient of determination).

Dependent Variable (Y)	Independent Variables (X)	ßj	S.E.	Constant	S.E.	R^2
Total benthos	Water temperature	-16.7534*	6.2133	2264.3430**	648.2030	0.7301**
	pH	-190.3197*	75.7881			
	Ammonium	-179.4981*	71.6469			
	COD	4.8190**	1.1340			
Polychaeta	Chrominm	-197.8535**	83.6991	865.7204**	239.3826	0.4032**
	Sediment pH	-91.0742**	31.3204			
Crustacea	Alkalinity	0.2140**	0.0643	-40.5994	23.7001	0.5517**
	Turbidity	0.1214*	0.0475			
	BOD	-2.2145*	0.8298			
Gastropoda	COD	5.4802**	0.9851	14.2999	41.0385	0.6461**
	Lead	-76.2721**	19.8985			
N. oligobranchia	COD	0.6558*	0.2933			
	Sediment Phosphate	12.8075**	2.8992	-25.2955	17.7501	0.5309**
N. fauveli	pH	-61.8470**	19.1112			0.4759**
	Sediment nitrite	-31.8623*	13.6401	573.2316**	156.3844	
D. aestuarina	pH	-32.9910*	13.5912	300.7969*	112.2992	0.21122*
S. edwardsi	Alkalinity	0.2482**	0.0467	-35.3977*	15.2997	0.6281**
	BOD	-1.3512*	0.6005			
A. francesiae	Ammonium	-222.9402**	48.1502	68.0358	43.3072	0.6894**
	COD	4.3033**	0.8582			

'*' = Significance level at 0.05
'**' = Significance level at 0.01

COD and lead jointly caused about 65% variation in density of Gastropoda at station 6 whereas chromium and sediment pH strongly contributed to the reduction in density of Polychaeta. About 55% variation in crustacean density was governed by alkalinity, BOD and turbidity of water. Among the fairly occurring species at this station *N. fauveli* was influenced by pH and sediment nitrite; COD and sediment phosphate were responsible for the density variation in *N. oligobranchia;* pH of water for *D. aestuarina;* alkalinity and BOD for *S. edwardsi* and COD and ammonium for *A. francesiae* (Table 20).

Analysis of Variance (ANOVA - 2 way)

The variation in density of major groups of benthic organisms along with species occurring in abundance as well as their interaction was studied by two way ANOVA with respect to different stations and seasons assumed as premonsoon (March - June), monsoon (July - October) and postmonsoon (November - February). The densities of groups and species were transformed to log (x + 1).

Two way ANOVA of density values of benthic groups, such as Polychaeta, Crustacea and Gastropoda in relation to stations and seasons showed significant difference only with respect to stations ($F = 22.164$, $P < 0.01$ in Polychaeta; $F = 3.815$, $P < 0.01$ in Crustacea and $F = 44.832$, $P < 0.01$ in Gastropoda) while Oligochaeta reflected significant difference in both stations ($F = 1158.352$, $P < 0.01$) and seasons ($F = 7.490$, $P < 0.01$), and also their interaction ($F = 6.080$, $P < 0.01$) (Table 21).

Among the species (Table 21) significant differences only with respect to stations were observed in *D. aestuarina* ($F = 37.620$, $P < 0.01$); *N. fauveli* ($F = 31.967$, $P < 0.01$); *S. edwardsi* ($F = 3.374$, $P < 0.05$), *T. lineata* ($F = 91.743$, $P < 0.01$) and *T. scabra* ($F = 48.463$, $P < 0.01$) while *A. francesiae* reflected significant variation both in relation to station ($F = 21.727$, $P < 0.01$) and season ($F = 0.014$, $P < 0.05$). The abundance of *N. oligobranchia* and *T. tuberculata* was observed to have strong difference in relation to station ($F = 14.541$, $P < 0.01$ and $F = 69.150$, $P < 0.01$ respectively) and also 2 way interaction with season and station ($F = 2.081$, $P < 0.05$ and $F = 4.651$, $P < 0.01$ respectively). *L. hoffmeisteri* on the other hand, revealed significant variation both in relation to station ($F = 1158.352$, $P < 0.01$ and season ($F = 7.490$, $P < 0.01$) as well as in their interaction ($F = 6.080$, $P < 0.01$).

The nature of interactions and relationship between the abiotic and biotic factors of the present riverine ecosystem revealed the effect of more than one abiotic factor on the benthic fauna as observed by correlation and multiple regression analysis. This relationship between abiotic and biotic factor is not simple. The following discussion deals with the observations of one factor in relation to other with reference to their influence on each other. In the present study, the temperature of water and sediment was negatively correlated with total number of benthos, polychaetes *(N. fauveli, D. aestuarina)* and gastropods (*T. lineata, T. scabra, T. tuberculata, A. francesiae*), while oligochaetes *(L. hoffmeisteri)* were negatively related with only water temperature and crustaceans with only sediment temperature. Various authors have emphasized the importance of temperature in effecting the distribution of invertebrates (Ward, 1975; Logan and Maurer, 1975). Sharma (1986) reported a negative correlation of water temperature and total benthic organisms giving support to the present study. The polychaete, *N. oligobranchia,* on the other hand, showed a high positive influence of water temperature. Ansari and Parulekar (1993) reported a similar positive effect of temperature on polychaetes, particularly when their breeding takes place (Cantelmo, 1978). The analysis of Plante and Downing (1989) suggests that temperature should have a positive effect on secondary production.

The pH of water was found to exert a positive influence on total benthic population at station 1 which mainly consisted of gastropods. The Gastropoda as a group and its species *T. lineata* were highly influenced by pH as also observed by multiple regression analysis (Table 15). Exclusion of gastropods and other taxa from streams low in pH, has been reported elsewhere (Sutcliffe and Carrick, 1973; Townsend, Hildrew and Francis, 1983). However, the negative influence of sediment pH on gastropods *(T. scabra)* and oligochaetes *(L. hoffmeisteri)* corroborated the study of Adholia *et al.* (1990).

Conductivity of water also acted negatively on the gastropod population (Table 11) which is in conformity with the finding of Adholia *et al.* (1990). Turbidity of water had positively influenced the total number of gastropod and crustacean population and negatively the polychaetes and oligochaetes. Crayton and Sommerfeld (1979) reported that the abundant quantity of aquatic organisms and species richness appeared to be influenced by high turbidity. Sharma (1986) found a negative relation although low between turbidity and total benthos.

Total alkalinity reflected a significant positive relationship with the abundance of Polychaeta *(N. fauveli, F. oligobranchia),* Crustacea *(S. edwardsi)* and Gastropoda *(T. lineata)* (Table 16 and 17). High alkalinity accelerates the zoobenthos population as reported by Dutta (1978). Sarkar (1989) reported a positive relation between alkalinity and mollusc population.

Hardness showed a positive relation with Crustacea *(S. edwardsi)* and Polychaeta *(N. fauveli, N. oligobranchia and D. aestuarina)* while it acted as a negative factor on the abundance of polychaetes at station 4 (Table 12) and gastropods, and *T. scabra* (Table 17) and *T. lineata* (Table 9). Okland (1990) found hardness to explain most of the differences in gastropod distribution.

Dissolved oxygen positively influenced the faunal abundance viz., Total benthos, Polychaeta *(N. fauveli, N. oligobranchia, D. aestuarina)* and Gastropoda *(T. scabra, T. tuberculata).* This parameter of water has been reported by Gaufin (1958) to effect the distribution of invertebrates. Sarkar (1989) and Adholia *et al.* (1990) reported the positive relation between dissolved oxygen and mollusc. However, results of multiple

Table 21. Analysis of variance (2 way) of various benthic groups and species of the study area. (SS - Sum of squares, MS - Mean square, '*' indicates significance level at 0.05, '**' indicate significance level at 0.01).

Groups/ species	Station DF=5	Season SF=2	Station x Season DF=10	Residual	Total
POLYCHAETA					
SS(MS)	25.594(5.119)	0.211(0.105)	4.413(0.441)	12.471(0.231)	42.689(0.601)
F value	22.164**	0.456	1.991		
N. oligobranchia					
SS(MS)	16.733(3.347)	0.896(0.448)	4.790(0.479)	12.428(0.230)	34.849(0.491)
F value	14.541**	1.948	2.081*		
N. fauveli					
SS(MS)	18.044(3.609)	0.431(0.215)	1.887(0.189)	6.096(0.113)	26.458(0.373)
F value	31.967**	1.909	1.672		
D. aestuarina					
SS(MS)	18.833(3.767)	0.227(0.113)	2.003(0.200)	5.407(0.100)	26.470(0.373)
F value	37.620**	1.132	2.000		
OLIGOCHAETA					
L. hoffmeisteri					
SS(MS)	158.345(31.669)	0.410(0.205)	1.662(0.166)	1.476(0.027)	161.893(2.280)
F value	1158.352**	7.490**	6.080**		
CRUSTACEA					
SS(MS)	8.371(1.674)	0.251(0.125)	4.318(0.432)	23.697(0.439)	36.637(0.516)
F value	3.815**	0.286	0.984		
S. edwardsi					
SS(MS)	5.222(1.044)	1.169(0.585)	3.556(0.356)	16.714(0.310)	26.661(0.376)
F value	3.374*	1.889	1.149		
GASTROPODA					
SS(MS)	31.514(6.303)	0.422(0.211)	2.787(0.279)	7.592(0.141)	42.315(0.596)
F value	44.832**	1.501	1.982		
T. lineata					
SS(MS)	59.068(11.814)	0.005(0.003)	2.475(0.247)	6.954(0.129)	68.502(0.965)
F value	91.743**	0.020	1.922		
T. scabra					
SS(MS)	54.916(10.983)	1.170(0.585)	1.970(0.197)	12.238(0.227)	70.294(0.990)
F value	48.463**	2.581	0.869		
T. tuberculata					
SS(MS)	30.989(6.198)	0.402(0.201)	4.168(0.417)	4.840(0.090)	40.399(0.569)
F value	69.150*	2.241	4.651**		
A. francesiae					
SS(MS)	21.059(4.212)	1.808(0.904)	2.391(0.239)	10.468(0.194)	35.726(0.503)
F value	21.727**	0.014*	1.234		

regression analysis revealed the negative effect of dissolved oxygen on Crustacea at station 3. Sharma (1986) found dissolved oxygen acting negatively on total benthic population. Similar finding was also reported by Prabha Devi and Ayyakkannu (1989). Ansari (1974), however, reported that the enrichment of dissolved oxygen did not have any effect of the fauna on Vembanad lake.

BOD and COD exhibited a positive influence on the abundance of *N. oligobranchia*, and *T. lineata* while *D. aestuarina* was positively related with BOD only. The pollution tolerant nature of these organisms was also reported by several workers (Subba Rao and Mitra, 1982; Datta Munshi *et al.*, 1989; Sarala Devi *et al.*, 1991). The crustacean (*S. edwardsi*) population, however, decreased with increased BOD and COD (Table 17 and 20).

Chloride negatively affected the population of total benthic organisms, gastropods and *A. francesiae* at station 6 while positively affected the abundance of *T. tuberculata* and *T. scabra*. Adholia *et al.* (1990) found a significant positive relation in one station and low negative relation in another station between chloride and total benthic organisms.

Among the nutrients, the phosphate content of water highly influenced the abundance of oligochaetes (*L. hoffmeisteri*) and also the total benthic organisms (Table 18) which is in conformity with the findings of Adholia *et al.* (1990). It is believed that the influence of phosphate, direct or indirect, is considerable in influencing the growth of oligochaetes (Mandal and Moitra, 1975). Sediment phosphate positively affected the abundance of *D. aestuarina* and *N. oligobranchia* as sediment phosphorus acts as a nutrient for them (Datta Munshi *et al.*, 1989) whereas it had negative influence on gastropod population (Table 10). Adholia *et al.* (1990) also reported a negative effect of sediment phosphate on molluscan population. Ammonium and nitrite of water generally acted as a negative factor in the abundance of bottom fauna. Sediment nitrite, however, positively affected the density of *T. tuberculata*. Shetty *et al.* (1988) found enrichment of bottom fauna due to nitrite of water. Nitrate of water positively affected *T. tuberculata* while nitrate of sediment highly affected the total benthic organisms, Polychaeta, Gastropoda and species like *T. tuberculata* and *T. scabra*. Datta Munshi *et al.* (1989) reported nitrogen as a nutrient for polychaete abundance. Ghosh and Banerjee (1996) found a positive relation with sediment nitrogen, phosphorus and total benthic organism. Heavy metals usually acted negatively on the faunal distribution.

The relationship between the benthic abundance and organic carbon percentage had been studied by many workers (Mandal and Moitra, 1975; Prabha Devi and Ayyakkannu, 1989; Ghosh and Banerjee, 1996). But it is still unknown as to how much of the labile organic carbon is utilized by benthic animals (Patra *et al.*, 1990). In the present study, though the mean value of organic carbon content was high at station 1 dominated by gastropods, the multiple regression analysis showed a negative effect of organic carbon on gastropods. When organic matter and particularly humic substance exceed a given threshold, they start to inhibit mollusc development (Aho, 1966; Okland, 1990). Harkantra *et al.* (1980) observed a steady decrease in benthic animals when organic carbon is high (>4%). In this study the crustaceans were also negatively influenced by organic carbon. This negative relation of organic carbon on these organisms may be due to bacterial decomposition and decline in available oxygen, which in turn may result in the decline of population.

The analysis of variance revealed that the faunal composition in the present study had significant spatial variations. The significant difference in season observed in case of oligochaetes, corroborated the study of Sarkar (1989). Harris *et al.* (1992) also reported highly significant differences in population density of benthic macroinvertebrates between sampling stations and seasons in course of their study on the ecology of the La Trobe river in Australia.

From the foregoing accounts, it is possible to predict which species will be the most abundant under given condition and time at a given place. For example, polychaetes might have flourished with higher alkalinity as found at station 3 where as oligochaetes were abundant in high phosphate content, crustaceans in greater trubidity and gastropods in pH as observed at stations 4, 6 and 1 respectively. However, in addition to the synergistic effects of the abiotic factors, the biotic interactions are also of overriding importance in determining the faunal abundance.

CONCLUSION

The overall assessment of the Hugli river water quality within the study stretch in and around Calcutta city revealed that the station 4, located below the sewage discharge point of Tolly's nullah, is maximally polluted as evidenced from physico-chemical characteristics of water. However, sewage inputs at station 4 have not suppressed the pH level of water indicating high buffering capacity of the river. The sedimentological characteristics though have profound influence on the bottom biota, played a limited role in judging the quality of the station.

The variation in the abundance of bottom fauna was mainly influenced by a number of abiotic factors such as temperature, dissolved oxygen, nutrients, composition of sediment and its organic carbon content, substratum type and food supply from detritus as well as the reproductive periodicity of the major invading species thereby indicating the interdependence of abiotic and biotic factors in the riverine environment.

The benthic community study of this riverine ecosystem also confirmed the polluted condition of station 4 as it harboured the pollution indicator tubificid - *L. hoffmeisteri* in huge nunbers (more than 99% of total bottom fauna) but had the lowest diversity of species. The diversity indices of station 4 also indicated the most deteriorated condition of this station compared to other stations. However, river Hugli was found to be capable of rapid recovery which occurred at station 5 about 100m distance from station 4 in the present study, thus reflecting auto-purification potential of this river system.

SUMMARY

This research work presents the results of observation made monthly (May 1995 to April 1997) on intertidal macrobenthic fauna of Hugli river in and around Calcutta metropolis at six selected stations (Dakshineswar, Bagbazar, Kidderpore Taktaghat, Kidderpore Doighat, Kidderpore Jettyghat and Shivpur) along with water and sediment quality status of these stations.

Both qualitative and quantitative studies were conducted on the macrobenthos from the above mentioned stations using nets, sieve and sampler while water and sediment characteristics comprising a total of twenty four parameters were analyzed using standard methods (APHA, 1989; Jackson, 1973; Piper, 1966) and photometer SQ 118.

Among the selected stations, except for station 4 (Kidderpore Doighat-located at the outfall region of Tolly's nullah) there were no specific point source of pollution other than small drainages and human activities in the bathing ghat, burning ghat, waste dumping, defaecation etc.

The water quality status at station 4 evidently showed very high values of alkalinity (200-650mg/1), hardness (90-302.6 mg/1), conductivity (271.8-1400 μmhos/cm), chloride (12-135 mg/1), phosphate (0.1-1.6 mg/1), ammonium (0.13-3.7 mg/1) and nitrite (0.13-2.63 mg/1) of water compared to the other stations. However, the discharge of sewage from Tolly's nullah has not suppressed the pH of water (7.58-8.4) at this station.

The dissolved oxygen concentration at station 4 reflected a poor value as low as 0.4 mg/l and it never exceeded 3 mg/l for most part of the year. This low dissolved oxygen value along with higher load of BOD (up to 51.3 mg/1) and COD (up to 179.68 mg/1) than the other stations (BOD upto 21.7 mg/1 and COD up to 99.4 mg/1) reflected a stressful condition of this station.

Among the heavy metals, except for zinc (0-2.6 mg/1), the values of chromium (0.01-0.49 mg/1) and lead (0.08-2.91 mg/1) at all the station failed to meet the drinking water standards prescribed by WHO.

The sedimentological characteristics varied little from station to station. Sediment texture, however, showed considerable variation in having very less percentage of sand (6.28%) at station 1 compared to the other stations (14.21-24.94%) which might have influenced the occurrence and distribution of benthic fauna.

The macrozoobenthic fauna is comprised of a total of 44 species belonging to Gastropoda (18 species), Polychaeta (8 species) and Crustacea (7 species) as the major

groups. Oligochaeta, on the other hand, constituted the major and dominant group at station 4 only. The other groups recorded were Bivalvia and Pisces, which were occasionally encountered while the insect larvae were seasonal in occurence. Station 4 had the lowest number of species (only 12) while station 6 harboured the highest (33) species diversity.

The total benthos density was highest at station 4 (21,147 no./m^2) mainly due to oligochaetes. Inspite of this high density of benthos, biomass reflected a considerably poor value (0.95-20.18 gm/m^2) indicating stressed condition. At the other stations the density of total benthos and biomass varied from 28 to 3409 no./m^2 and 1.03 to 542.56 gm/m^2 respectively.

The four numerically dominant groups viz., Polychaeta, Oligochaeta, Crustacea and Gastropoda exhibited prominent spatial variations. Polychaetes were found mainly at stations 3, 5 and 6 and negligibly at stations 2 and 4. Oligochaetes were found at station 4 only and rarely at station 5 while crustaceans and gastropods occurred at all the stations.

Among the species only nine species were of regular occurrence, viz., *N. oligobranchia, N. fauveli* and *D. aestuarina* (at stations 3, 5 and 6), *L. hoffmeisteri* (at station 4 only), *S. edwardsi* (at stations 3 and 6), *T. lineata* (at stations 1, 2 and 3), *T. scabra* (at stations 1, 2, 3 and 5), *T. tuberculata* (at station 1 only) and *A. francesiae* (at station 6 only). The peak population of these species (viz., *N. fauveli* and *D. aestuarina* in February-March, *N. oligobranchia* in March-April, *L. hoffmeisteri* in December, *S. edwardsi* in February, April, *T. lineata* in June-July, *T. scabra* in November - December, *T. tuberculata* in February and *A. francesiae* in November) occurred due to increased breeding activity. The trough occurred mostly during monsoonal rain which might be due to habitat disturbance thereby decreasing the density of benthic population.

Highest value of index of dominance (0.84 to 0.99) and lowest values of Margalef's diversity index (0.45 to 1.49), Shannon - Weiner's index (0.007-0.44) and evenness index (0.004 to 0.27) were recorded at station 4 reflecting the deteriorating condition of health of aquatic ecosystem. On the other hand, low values of dominance (0.17-0.61) and high values of diversity indices viz., Margalef's index (1.97-6.26), Shannon-Weiner's-index (1.55-2.99) and evenness index (0.51-0.93) at station 6, signify a larger number of species contributing to the benthic community at this station. The values fell between these two extremes at the other stations.

The statistical relationship between abiotic factors and biotic components of each station revealed the importance of more than one abiotic factor such as temperature, phosphate, nitrite, nitrate, etc., which acted jointly in controlling the benthic-population in this riverine ecosystem.

With respect to the pollution, station 4 was maximally polluted where the pollution indicator tubificid worm-*L. hoffmeisteri* contributed over 99% to the total benthic fauna. However, the widely used Shannon-Weiner index value revealed that all other stations are moderately polluted throughout the year.

An indication of recovery tendency of the pollution at station 4 was observed at station 5 located at about 100m downstream as revealed from the rise in dissolved oxygen (up to 6.9 mg/1), lowering of BOD (1.9-15.1 mg/1), COD (14.54-73-04 mg/1), and rise in number of species (25). The pollution indicator worm *L. hoffmeisteri* was also recorded rarely at station 5 where it was a member of a complex community rather than an indicator species. The Shannon-Weiner diversity value (1.5 to 2.76) at this station was also increased indicating the self-purification capacity of the river.

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APPENDICES

Appendix 1-23. Physico-chemical characteristics at six selected station (May 1995-April 1997).

Appendix 1. Water temperature (^{0}C)

Months	Water temperature (^{0}C) at station nos.					
	1	2	3	4	5	6
May(1995)	33.0	33.0	37.5	30.0	32.4	33.5
June	29.5	32.0	32.5	35.0	29.9	28.5
July	30.0	31.0	30.5	32.5	30.4	30.0
August	29.0	30.6	33.5	33.5	31.0	32.0
September	29.0	31.0	31.5	32.5	32.0	31.5
October	30.5	34.7	32.0	31.5	30.0	30.0
November	27.0	27.1	28.0	28.0	26.0	30.0
December	24.7	25.8	21.2	22.0	22.3	23.8
January(1996)	24.8	21.7	24.1	22.4	22.5	22.8
February	25.2	26.0	25.2	26.4	24.2	25.3
March	27.5	27.8	30.2	30.8	30.5	29.5
April	29.9	29.8	34.0	34.0	31.4	32.2
May	33.1	31.5	33.7	34.6	32.8	32.6
June	29.4	32.1	30.3	30.4	30.5	30.5
July	30.0	29.7	30.4	31.1	29.0	31.5
August	31.4	30.0	28.9	28.5	32.6	30.6
September	31.0	29.4	31.5	30.5	32.0	35.5
October	29.0	34.3	28.8	29.4	34.4	29.4
November	27.1	26.7	29.0	28.1	24.9	27.2
December	26.0	25.0	26.0	26.0	22.3	20.7
January(1997)	25.0	23.0	20.4	20.6	27.0	23.5
February	25.0	24.0	24.0	25.0	25.0	28.0
March	26.5	29.3	25.9	26.7	26.4	31.5
April	28.8	29.0	29.6	29.8	27.4	35.0

Appendix 2. pH

Months	pH at station nos					
	1	2	3	4	5	6
May(1995)	8.1	8.3	8.5	8.05	8.2	8.8
June	8.1	8.2	8.4	8.0	8.3	8.5
July	8.2	8.0	8.3	8.2	7.9	8.01
August	7.4	8.0	8.61	8.2	8.0	8.3
September	8.9	8.2	8.0	8.3	8.05	8.1
October	8.89	8.1	8.1	8.0	8.2	8.6
November	8.1	8.4	8.1	7.8	8.1	8.1
December	7.8	8.0	8.2	8.0	8.0	8.3
January(1996)	8.05	8.4	8.1	7.9	8.4	8.4
February	8.45	8.0	8.3	7.9	8.3	8.3
March	8.1	8.4	8.4	7.6	7.7	8.4
April	8.4	8.2	8.4	7.8	8.5	8.6
May	8.1	8.5	8.6	7.75	8.2	8.16
June	8.5	8.0	8.4	7.8	8.7	8.5
July	8.2	7.2	8.1	8.0	7.7	8.0
August	7.2	7.9	8.6	8.4	7.8	8.5
September	8.7	8.0	8.2	8.3	8.01	7.98
October	8.9	8.3	8.1	7.58	8.2	8.8
November	7.9	8.34	8.07	7.65	8.0	8.0
December	7.69	8.0	8.05	7.61	8.05	8.05
January(1997)	8.15	8.16	8.32	7.58	7.86	8.07
February	8.35	8.2	8.2	7.72	7.68	7.78
March	8.1	7.95	8.41	7.6	8.05	8.06
April	7.84	8.2	8.01	7.66	8.16	7.88

Appendix 3. Conductivity (μmhos/cm)

Months	Conductivity at station nos.					
	1	2	3	4	5	6
May(1995)	191	328	718	697	568	472
June	205	285	360	490	292	276
July	250	301	276	360	274	222
August	195	210	281	650	251	332
September	198	250	297	599	250	321
October	210	166	590	610	420	178
November	285	290	240	330	310	310
December	370	270	110	320	412	410
January(1996)	399	140	540	520	470	400
February	498	380	400	570	450	460
March	410	400	450	1400	800	430
April	480	360	520	770	650	480
May	209	352	742	803	572	508
June	215	315	450	510	308	324
July	210	319	328	359.9	346	198
August	210	314	279	630	269	268
September	282	274	399	703	266	301
October	330	174	686	728	452	262
November	315	160.6	266	394	169.8	289
December	594	231	166	271.8	462	390
January(1997)	501	367	376	798	555	402
February	462	420	377	916	463	432
March	410	418	381	1100	633	195.1
April	458	460	433	475	449	462

Appendix 4. Turbidity (N. T. U.)

Months	Turbidity at station nos.					
	1	2	3	4	5	6
May(1995)	61	79	127	170	208	272
June	196	113	167	154	66	87
July	349	351	400	293	285	394
August	113	102	320	224	192	237
September	145	163	345	169	198	260
October	132	100	92	125	389	166
November	135	100	182	136	115	400
December	78	103	34	41	50	264
January(1996)	95	93	189	176	147	215
February	84	60	101	162	300	400
March	97	102	159	264	194	341
April	83	89	85	206	161	245
May	61.1	100	73	198	270	317
June	210	103	177	207	80	276
July	341	361	400	185	295	281
August	109	116	161	182	196	244
September	139	108	345.01	159	204	156
October	99	152	172	127	400	287
November	107	113	81	81	89	168
December	95	97	50	90	82	132
January(1997)	125	43	93	106	114	175
February	108	54	56	73	179	118
March	99	82	67	86	101	238
April	55	91	74	66	97	80

Appendix 5. Total Alkalinity (mg/1)

Months	Alkalinity at station nos.					
	1	2	3	4	5	6
May(1995)	310	230	270	360	350	300
June	150	220	220	290	241	200
July	140	180	170	200	290	210
August	140	160	200	300	230	200
September	200	150	160	250	200	190
October	250	330	220	250	390	220
November	260	250	190	200	300	250
December	300	240	260	270	320	330
January(1996)	290	240	230	430	300	310
February	300	290	310	380	330	350
March	300	280	340	650	440	380
April	350	290	300	400	380	370
May	290	210	250	300	390	310
June	170	221	180	300	240	230
July	160	190	150	250	300	230
August	180	200	230	300	220	200
September	210	230	160	251	210	280
October	210	350	250	390	430	270
November	280	300	200	260	300	230
December	380	240	350	420	340	250
January(1997)	300	300	330	490	390	300
February	300	330	380	460	380	350
March	301	350	380	600	400	390
April	360	290	350	390	390	410

Appendix 6. Hardness (mg/1)

Months	Hardness at station nos.					
	1	2	3	4	5	6
May(1995)	87.0	92.5	122.0	119.0	121.0	99.0
June	79.1	77.0	91.9	125.0	90.0	85.0
July	77.4	85.0	77.0	90.0	91.0	66.0
August	99.7	91.0	124.6	195.8	89.0	89.0
September	100.0	89.0	134.0	131.0	100.1	106.8
October	97.0	110.0	131.0	147.0	189.0	94.9
November	147.5	124.6	106.8	124.6	160.2	142.4
December	195.8	146.6	106.8	160.2	160.2	160.2
January(1996)	149.1	160.2	178.0	178.0	178.0	178.0
February	176.9	133.9	165.0	182.0	160.2	160.2
March	170.0	141.0	150.0	265.0	194.0	141.0
April	126.0	139.0	120.0	135.0	137.0	150.0
May	93.0	97.5	112.0	121.0	155.0	151.0
June	98.9	105.0	92.1	201.0	102.0	93.0
July	65.0	99.0	73.0	98.0	99.0	80.0
August	110.3	99.0	75.0	146.0	93.0	91.0
September	149.2	110.0	100.0	161.0	81.9	110.0
October	133.0	120.0	115.0	157.0	211.0	95.1
November	152.5	160.0	112.0	150.0	142.0	123.0
December	165.0	153.4	165.0	205.0	138.0	149.0
January(1997)	190.9	130.0	145.0	215.0	152.0	140.0
February	153.1	146.1	213.6	302.6	140.0	160.2
March	190.0	195.8	160.2	302.6	231.4	195.8
April	231.4	143.0	195.8	213.6	178.0	178.0

Appendix 7. Dissolved Oxygen (mg/1)

Months	Dissolved Oxygen at station nos.					
	1	2	3	4	5	6
May(1995)	5.2	4.3	6.0	2.5	2.6	4.3
June	5.5	5.8	4.4	1.0	4.2	5.0
July	4.0	4.6	5.0	1.5	4.01	4.4
August	4.5	4.0	4.9	0.4	5.0	4.0
September	5.0	5.3	4.5	3.3	4.3	4.5
October	4.5	4.3	4.6	3.0	2.51	4.7
November	5.1	5.3	5.2	1.8	4.5	4.7
December	6.3	5.5	6.9	3.6	5.3	6.6
January(1996)	5.9	5.2	5.8	3.3	5.5	5.7
February	6.0	5.8	6.5	4.5	5.6	6.1
March	5.8	5.3	5.9	0.9	2.5	4.4
April	5.3	5.5	5.4	1.8	4.3	5.5
May	5.19	4.1	5.0	2.2	2.4	4.0
June	4.7	6.0	5.8	2.0	4.4	5.8
July	4.5	4.7	5.0	1.7	4.0	4.0
August	4.7	4.0	5.0	2.4	4.6	4.2
September	5.0	5.6	5.1	3.0	4.7	4.5
October	5.0	4.5	5.3	1.7	2.5	4.5
November	5.3	5.0	5.2	2.8	5.5	5.3
December	6.0	5.5	7.0	3.8	6.9	8.0
January(1997)	5.1	7.0	7.0	3.5	6.2	7.0
February	5.5	6.2	7.5	4.5	6.0	7.0
March	6.2	5.5	7.4	0.7	5.6	4.6
April	6.5	5.7	4.8	3.0	5.9	5.5

Appendix 8. BOD (mg/1)

Months	BOD (mg/1) at station nos.					
	1	2	3	4	5	6
May(1995)	16.3	14.3	8.01	33.0	7.1	14.9
June	16.9	14.6	6.2	25.2	6.7	8.1
July	2.6	4.1	8.4	17.1	6.1	8.2
August	4.7	7.2	3.5	23.4	5.3	6.4
September	6.5	6.3	4.8	21.0	6.1	8.4
October	5.4	9.7	3.1	32.0	8.2	8.3
November	14.0	11.0	2.8	12.3	5.3	12.5
December	3.8	10.6	11.9	28.2	8.2	16.3
January(1996)	3.3	3.4	3.01	27.4	11.5	4.7
February	11.8	7.1	2.7	31.5	11.7	4.1
March	12.2	5.2	5.3	48.7	10.9	11.5
April	15.9	4.4	8.1	8.6	4.1	2.8
May	21.7	17.7	8.0	37.01	10.9	15.3
June	17.1	15.4	7.8	26.8	7.3	20.3
July	20.1	5.9	7.6	26.9	7.9	18.0
August	5.3	8.8	2.5	24.6	4.7	1.0
September	9.5	7.7	5.2	29.0	9.9	9.6
October	8.6	10.3	4.9	26.0	11.8	7.7
November	20.01	19.0	3.2	13.7	6.7	15.5
December	6.2	13.4	12.1	37.8	11.8	17.7
January(1997)	4.7	4.6	3.0	36.6	14.5	6.5
February	16.2	2.9	3.3	34.5	12.3	4.9
March	13.8	6.8	6.7	51.3	15.1	14.5
April	3.4	5.6	9.9	13.4	1.9	1.6

Appendix 9. COD (mg/1)

Months	COD (mg/1) at station nos.					
	1	2	3	4	5	6
May(1995)	39.6	39.0	56.68	179.68	21.98	21.1
June	55.0	41.02	21.58	141.1	18.26	27.92
July	45.9	20.2	19.68	23.26	14.98	29.2
August	16.78	26.8	24.8	46.68	73.04	29.98
September	14.94	30.0	14.5	41.1	22.12	30.84
October	10.0	33.2	62.94	66.16	24.06	38.16
November	48.14	66.6	54.78	46.4	47.04	56.84
December	28.0	43.2	31.0	58.1	40.18	35.36
January(1996)	30.1	13.56	37.4	44.34	56.44	16.9
February	36.0	14.58	21.58	19.96	34.01	12.0
March	36.52	19.92	18.1	36.6	21.5	63.08
April	13.62	16.0	15.8	11.62	21.0	26.56
May	70.4	43.04	42.3	102.52	14.54	18.74
June	24.2	36.98	17.78	64.74	31.7	38.48
July	52.1	13.0	10.28	13.26	18.22	40.76
August	13.1	33.2	28.44	52.92	33.2	49.7
September	31.06	36.4	17.5	78.9	26.0	27.48
October	9.92	34.8	46.62	60.0	42.58	41.52
November	47.86	99.4	38.14	49.8	33.32	95.88
December	68.28	58.8	49.0	30.58	32.94	36.88
January(1997)	25.9	15.6	40.6	23.66	26.56	15.1
February	37.04	15.42	32.42	32.04	34.0	10.0
March	33.48	32.08	11.9	61.4	28.5	41.04
April	9.62	23.84	17.4	28.38	23.0	19.78

Appendix 10. Chloride (mg/1)

Months	Chloride at station nos.					
	1	2	3	4	5	6
May(1995)	15.6	8.5	11.7	27.9	44.0	24.7
June	17.9	7.1	9.9	75.6	10.01	22.59
July	18.1	6.2	8.01	27.1	9.1	20.1
August	16.6	9.4	7.5	52.5	36.0	27.5
September	20.8	5.0	24.3	15.0	11.9	34.0
October	15.0	8.0	8.0	30.0	50.9	17.0
November	19.2	10.0	14.0	70.0	31.0	18.0
December	15.0	6.0	10.0	12.0	13.0	25.0
January(1996)	20.0	9.0	21.0	23.0	21.0	25.0
February	22.0	10.01	12.0	31.0	23.0	28.0
March	17.5	12.0	11.0	135.0	40.0	27.0
April	13.0	9.5	14.0	23.0	45.0	25.0
May	14.4	9.5	6.3	28.0	46.0	25.3
June	18.0	6.9	10.0	78.4	10.0	23.0
July	21.9	7.8	8.0	30.9	10.9	29.9
August	17.4	8.6	10.5	55.5	40.01	28.5
September	15.2	8.0	21.7	19.0	12.1	32.0
October	12.0	7.9	11.0	59.0	59.1	22.0
November	12.8	4.0	9.0	63.0	15.0	10.0
December	25.0	6.0	10.0	40.0	17.0	19.0
January(1997)	20.0	6.0	10.0	46.0	19.0	21.0
February	21.9	10.0	9.0	62.0	18.0	30.0
March	18.5	15.0	10.0	74.0	22.0	37.0
April	15.0	14.5	15.0	20.0	17.0	23.0

Appendix 11. Phosphate (mg/1)

Months	Phosphate at station nos.					
	1	2	3	4	5	6
May(1995)	0.1	0.08	0.1	0.2	0.2	0.2
June	0.01	0.3	0.09	0.1	0.09	0.1
July	0.2	0.1	0.3	0.2	0.08	0.3
August	0.09	0.21	0.2	0.79	0.5	0.2
September	0.1	0.1	0.2	0.7	0.3	0.3
October	0.2	0.1	0.1	0.99	0.8	0.1
November	0.5	0.02	0.3	0.8	0.1	0.1
December	0.7	0.17	0.1	1.0	0.4	0.01
January(1996)	0.4	0.1	0.19	1.1	0.2	0.3
February	0.3	0.09	0.1	0.4	0.19	0.31
March	0.16	0.03	0.09	0.4	0.11	0.3
April	0.1	0.07	0.1	0.15	0.1	0.2
May	0.3	0.12	0.1	0.6	0.2	0.2
June	0.07	0.3	0.1	1.1	1.1	0.7
July	0.2	0.3	0.3	0.6	0.12	0.9
August	0.1	0.2	0.8	0.8	0.5	1.4
September	0.5	0.5	0.4	0.7	0.5	1.2
October	0.6	0.1	0.7	1.0	1.6	1.3
November	0.5	0.18	0.3	1.2	0.5	0.3
December	0.9	0.23	0.3	1.4	0.2	0.05
January(1997)	0.4	0.1	0.2	0.4	0.21	1.1
February	0.3	0.31	0.1	1.6	0.2	0.36
March	0.24	0.37	0.1	0.4	0.7	0.7
April	0.1	0.13	0.3	0.25	0.3	1.0

Appendix 12. Ammonium (mg/1)

Months	Ammonium at station nos.					
	1	2	3	4	5	6
May(1995)	0.14	0.21	0.11	1.7	0.65	0.47
June	0.20	0.31	0.08	0.56	0.19	0.59
July	0.03	0.25	0.14	1.9	0.24	1.05
August	0.07	0.01	0.22	1.7	0.07	1.21
September	0.15	0.04	0.28	2.0	0.16	0.51
October	0.01	0.19	0.07	2.6	0.59	0.71
November	0.06	0.2	0.07	1.7	0.20	0.18
December	0.01	0.1	0.17	0.48	0.13	0.11
January(1996)	0.04	0.2	0.23	0.56	0.22	0.15
February	0.07	0.28	0.25	1.9	0.18	0.49
March	0.16	0.22	0.27	1.0	0.45	0.56
April	0.20	0.36	0.42	2.3	2.1	0.53
May	0.28	0.29	0.11	2.5	0.75	0.49
June	0.2	0.3	0.12	0.96	0.19	0.65
July	0.11	0.47	0.16	2.1	0.28	1.1
August	0.15	0.05	0.36	3.7	0.07	1.19
September	0.16	0.04	0.34	3.6	0.18	0.75
October	0.01	0.2	0.15	2.8	0.67	0.79
November	0.06	0.32	0.07	1.7	0.22	0.18
December	0.09	0.5	0.17	0.7	0.25	0.27
January(1997)	0.08	0.34	0.31	0.56	0.24	0.21
February	0.03	0.2	0.43	2.7	0.18	0.63
March	0.2	0.62	0.27	1.4	0.6	0.76
April	0.1	0.7	0.15	0.13	1.0	0.13

Appendix 13. Nitrite (mg/1)

Months	Nitrite at station nos.					
	1	2	3	4	5	6
May(1995)	0.9	0.42	0.29	0.21	0.5	0.28
June	0.15	0.22	0.37	0.51	0.2	0.10
July	0.39	0.15	0.33	0.53	0.47	0.34
August	0.069	0.30	0.41	0.38	0.45	0.37
September	0.27	0.06	0.12	0.28	0.4	0.36
October	0.15	0.11	0.15	0.20	0.67	0.19
November	0.19	0.41	0.39	0.40	0.4	0.34
December	0.07	0.4	0.15	0.20	0.37	0.50
January(1996)	0.1	0.41	0.51	0.52	0.27	0.48
February	0.53	0.3	0.07	0.14	0.47	0.79
March	0.3	0.10	0.13	0.26	0.34	0.7
April	0.28	0.19	0.13	0.27	0.44	0.51
May	0.15	0.54	0.17	0.34	0.5	0.63
June	0.18	0.4	0.10	0.21	0.22	0.16
July	0.39	0.39	1.16	0.77	0.2	0.62
August	0.07	0.3	0.63	2.63	0.39	0.61
September	0.19	0.24	0.12	0.26	0.38	0.13
October	0.35	0.15	0.26	0.23	0.57	0.62
November	0.2	0.20	0.19	0.43	0.2	0.22
December	0.01	0.2	0.15	0.30	0.22	0.04
January(1997)	0.5	0.3	0.20	0.22	0.18	0.09
February	0.39	0.31	0.11	0.13	0.12	0.19
March	0.29	0.36	0.11	0.15	0.44	0.28
April	0.18	0.43	0.42	0.45	0.36	0.36

Appendix 14. Nitrate (mg/1)

Months	Nitrate at station nos.					
	1	2	3	4	5	6
May(1995)	2.3	2.5	6.0	5.09	1.9	5.9
June	1.6	3.6	3.2	1.7	2.2	2.0
July	1.2	4.9	11.3	6.9	5.3	5.7
August	1.1	3.01	1.5	1.0	5.2	3.8
September	1.9	1.4	7.41	8.4	7.4	4.9
October	2.2	1.1	1.4	1.8	4.19	1.4
November	2.9	2.4	1.4	6.7	1.2	3.4
December	4.4	2.41	1.1	1.2	4.1	4.51
January(1996)	3.9	1.7	6.3	2.1	5.1	5.1
February	5.5	2.6	1.23	1.35	1.0	6.9
March	2.4	2.2	6.3	2.3	4.7	3.2
April	1.9	2.3	4.3	3.0	1.2	2.8
May	1.7	6.3	5.0	5.0	2.1	6.2
June	1.0	2.6	5.8	1.1	2.0	14.6
July	1.21	6.5	12.3	1.0	9.3	10.4
August	1.7	3.0	2.7	5.6	4.4	5.9
September	1.3	2.0	9.39	8.0	8.0	6.0
October	3.2	2.9	2.0	1.81	4.2	4.3
November	3.1	1.9	5.0	4.1	2.1	10.7
December	3.1	2.59	1.2	1.5	3.2	5.49
January(1997)	3.3	1.0	2.1	4.1	1.5	6.9
February	4.7	2.8	1.0	1.1	2.8	3.5
March	3.8	4.1	2.4	2.3	5.5	1.8
April	3.0	3.7	2.9	2.5	1.2	2.7

Appendix 15. Chromium (mg/1)

Months	Chromium at station nos.					
	1	2	3	4	5	6
May(1995)	0.02	0.12	0.22	0.16	0.33	0.35
June	0.21	0.02	0.17	0.32	0.061	0.03
July	0.10	0.02	0.07	0.08	0.05	0.18
August	0.01	0.01	0.07	0.08	0.45	0.20
September	0.06	0.01	0.07	0.13	0.41	0.21
October	0.01	0.01	0.02	0.01	0.29	0.01
November	0.09	0.17	0.18	0.21	0.01	0.09
December	0.01	0.11	0.01	0.02	0.01	0.48
January(1996)	0.01	0.42	0.23	0.19	0.10	0.35
February	0.07	0.13	0.04	0.01	0.17	0.27
March	0.03	0.10	0.03	0.12	0.17	0.20
April	0.06	0.08	0.1	0.02	0.08	0.26
May	0.04	0.12	0.05	0.13	0.21	0.19
June	0.22	0.06	0.08	0.11	0.06	0.19
July	0.09	0.05	0.29	0.23	0.09	0.43
August	0.03	0.17	0.30	0.15	0.37	0.46
September	0.02	0.15	0.071	0.11	0.49	0.48
October	0.20	0.10	0.20	0.22	0.37	0.49
November	0.21	0.06	0.35	0.20	0.17	0.14
December	0.09	0.07	0.10	0.19	0.14	0.05
January(1997)	0.19	0.10	0.26	0.19	0.21	0.21
February	0.06	0.03	0.09	0.16	0.10	0.08
March	0.07	0.10	0.09	0.19	0.25	0.32
April	0.02	0.14	0.01	0.02	0.18	0.26

Appendix 16. Lead (mg/1)

Months	Lead at station nos.					
	1	2	3	4	5	6
May(1995)	0.66	0.37	0.17	0.57	1.0	0.81
June	0.72	0.52	0.71	0.71	0.35	0.7
July	0.42	1.7	1.1	0.95	2.5	1.9
August	0.12	0.66	1.0	0.77	0.6	0.6
September	0.33	0.63	1.41	0.91	0.9	2.91
October	0.42	0.49	1.3	0.8	1.1	1.41
November	0.51	0.23	1.1	2.69	0.61	0.9
December	0.44	0.32	0.39	0.83	0.32	0.19
January(1996)	0.62	0.3	0.35	0.56	0.9	0.17
February	0.57	0.43	0.2	0.8	0.69	0.15
March	0.78	0.4	0.3	2.0	0.9	2.2
April	0.4	0.59	0.2	0.7	0.6	1.3
May	0.74	0.43	0.23	0.63	0.8	0.8
June	0.88	0.68	0.09	0.89	0.45	1.3
July	0.58	2.1	1.5	1.5	2.7	2.9
August	0.08	0.74	1.6	0.63	1.2	2.6
September	0.47	0.77	1.4	0.9	1.3	2.9
October	0.78	0.51	1.9	1.2	1.7	1.79
November	0.49	0.37	0.9	2.91	0.6	0.3
December	0.56	0.48	0.41	0.77	0.68	0.59
January(1997)	0.78	0.5	0.45	0.64	1.3	0.23
February	0.63	0.77	0.6	0.4	0.7	0.45
March	0.82	0.6	0.4	0.8	1.1	1.1
April	1.8	0.6	0.8	0.5	0.8	0.5

Appendix 17. Zinc (mg/1)

Months	Zinc at station nos.					
	1	2	3	4	5	6
May(1995)	-					
June						
July						
August			0.03	0.28		0.05
September						
October	0.01	0.01	0.09	0.01		
November	-	0.02				0.19
December						
January(1996)						
February						
March						
April	-					
May	-				0.07	
June						
July				2.6	0.51	0.19
August				0.10	0.14	
September	-					
October					0.07	
November	-			0.45		0.13
December	0.01				0.06	
January(1997)	-	0.05			0.12	
February						
March		0.12	0.22	0.26	0.19	0.19
April			0.15	0.13	0.19	0.13

Appendix 18. Sediment temperature (^0C)

Months	Sediment temperature at station nos.					
	1	2	3	4	5	6
May(1995)	33.0	32.3	40.0	33.0	37.4	35.8
June	28.5	30.0	32.5	29.0	33.0	28.0
July	29.5	31.0	30.5	30.6	30.0	28.5
August	30.0	30.6	34.0	33.0	34.6	30.0
September	29.0	31.0	31.5	31.7	33.0	31.5
October	31.0	31.0	32.0	32.0	32.0	28.5
November	28.0	26.1	28.0	28.0	28.0	28.0
December	26.5	23.9	21.8	22.8	25.0	24.1
January(1996)	24.0	21.8	23.2	23.7	24.0	26.0
February	24.6	24.6	27.5	29.3	30.0	27.5
March	27.5	26.5	33.2	33.2	29.2	29.6
April	28.4	29.5	34.0	34.0	24.7	32.1
May	32.9	34.2	37.5	35.3	37.8	33.5
June	30.2	30.0	30.4	32.9	31.1	29.8
July	28.5	28.9	31.6	33.0	29.4	31.8
August	30.1	30.8	29.0	28.9	35.0	31.1
September	31.0	29.0	31.5	31.3	37.0	33.0
October	27.6	31.5	29.5	31.7	32.0	27.9
November	28.0	26.0	29.0	28.0	26.3	28.0
December	26.0	25.1	26.0	26.0	23.5	20.2
January(1997)	22.7	23.0	24.1	22.8	25.6	23.5
February	24.2	24.0	27.0	25.0	27.0	31.0
March	26.5	29.0	26.5	26.8	26.4	31.5
April	28.8	28.5	29.6	29.8	27.4	35.0

Appendix 19. Sediment pH

Months	Sediment pH at station nos.					
	1	2	3	4	5	6
May(1995)	7.71	8.0	7.6	7.3	7.7	8.1
June	7.7	8.1	7.9	8.0	8.0	7.9
July	7.57	8.0	7.9	7.6	7.6	7.3
August	7.4	7.41	8.0	8.1	7.31	8.2
September	7.4	7.4	7.2	7.29	7.4	7.4
October	8.2	7.31	7.3	7.31	7.61	8.0
November	7.4	7.3	7.6	7.8	6.8	7.1
December	7.5	7.3	7.4	7.3	7.4	7.3
January(1996)	7.46	7.6	7.4	7.7	7.5	7.4
February	7.4	7.81	7.1	7.9	7.1	7.4
March	7.9	7.6	7.4	6.6	7.6	7.2
April	7.8	7.67	7.7	6.3	7.8	7.8
May	7.7	7.6	7.8	7.3	7.5	8.3
June	7.9	7.5	7.9	7.6	7.8	7.7
July	7.63	8.0	7.7	7.6	7.6	7.31
August	7.41	7.4	8.4	8.3	7.3	8.6
September	8.2	7.38	7.2	7.3	7.2	7.2
October	8.4	7.3	7.22	7.3	7.6	7.8
November	7.4	7.27	7.28	7.28	7.24	7.57
December	6.44	7.24	7.13	6.74	7.33	7.44
January(1997)	7.4	7.17	7.41	7.35	7.43	7.43
February	7.4	7.51	7.75	7.59	7.31	7.44
March	7.3	7.65	7.47	7.59	7.26	7.37
April	7.37	7.53	7.54	7.45	7.7	7.42

Appendix 20. Sediment Phosphate (mg/1)

Months	Sediment Phosphate at station nos.					
	1	2	3	4	5	6
May(1995)	4.2	4.17	4.1	3.3	5.5	4.81
June	1.7	4.4	4.0	3.9	4.2	4.9
July	2.1	5.1	3.2	2.1	4.3	2.2
August	4.3	4.2	1.9	1.7	3.4	3.3
September	2.9	1.87	3.1	3.7	2.5	5.1
October	5.0	10.0	3.0	4.2	4.21	7.5
November	2.0	1.0	5.0	5.0	5.7	8.4
December	12.0	3.1	1.3	8.8	4.8	7.1
January(1996)	3.7	5.0	6.9	4.9	2.0	4.2
February	6.1	5.2	9.2	9.1	9.2	9.1
March	3.21	5.0	3.9	4.0	3.9	3.9
April	5.0	4.1	4.0	3.0	5.3	2.0
May	3.8	4.2	3.5	2.7	4.3	4.8
June	1.5	4.2	3.6	4.1	3.8	4.1
July	1.9	4.1	2.8	2.0	4.1	1.8
August	5.7	2.0	2.1	2.3	2.6	2.7
September	4.1	3.3	3.1	3.3	3.5	3.9
October	2.0	2.4	4.0	4.2	4.2	4.1
November	3.0	1.2	3.8	2.1	1.7	4.0
December	3.7	3.3	1.6	2.9	4.3	3.1
January(1997)	4.5	4.5	1.1	1.1	4.1	3.5
February	9.0	3.6	2.8	3.9	4.8	4.5
March	3.2	4.4	1.4	4.7	5.1	6.1
April	2.4	3.9	3.3	3.2	4.0	4.1

Appendix 21. Sediment Nitrite (mg/1)

Months	Sediment Nitrite at station nos.					
	1	2	3	4	5	6
May(1995)	0.91	0.61	0.71	0.99	1.35	0.97
June	0.88	0.71	0.97	1.9	0.89	1.2
July	0.59	0.89	0.99	0.81	0.76	1.27
August	0.6	0.8	0.12	0.34	0.78	1.16
September	0.73	2.15	0.57	0.99	0.71	1.49
October	0.54	1.49	1.14	1.3	0.82	0.78
November	0.72	2.56	1.49	1.5	0.63	0.64
December	0.09	0.44	1.62	1.65	0.45	0.81
January(1996)	0.08	0.93	0.74	0.78	0.34	0.43
February	2.13	0.9	0.84	0.52	0.42	1.35
March	0.41	0.10	0.13	0.26	0.34	0.70
April	0.86	0.92	0.75	0.93	1.0	0.48
May	0.9	0.77	0.70	1.1	1.37	1.3
June	0.92	0.7	1.1	1.98	0.95	1.08
July	0.61	1.3	0.91	0.69	0.68	1.37
August	0.74	1.0	2.3	0.99	0.8	1.07
September	0.77	0.10	0.53	1.1	0.79	0.62
October	0.92	0.3	0.09	0.35	0.86	0.72
November	0.68	0.3	1.02	0.26	0.15	0.27
December	0.05	0.56	0.17	0.32	0.04	0.25
January(1997)	0.02	0.09	0.20	0.29	0.18	0.08
February	1.99	0.7	0.25	0.47	0.12	0.47
March	0.4	0.94	0.66	0.42	0.22	0.53
April	0.56	0.88	0.35	0.40	0.52	0.64

Appendix 22. Sediment Nitrate (mg/1)

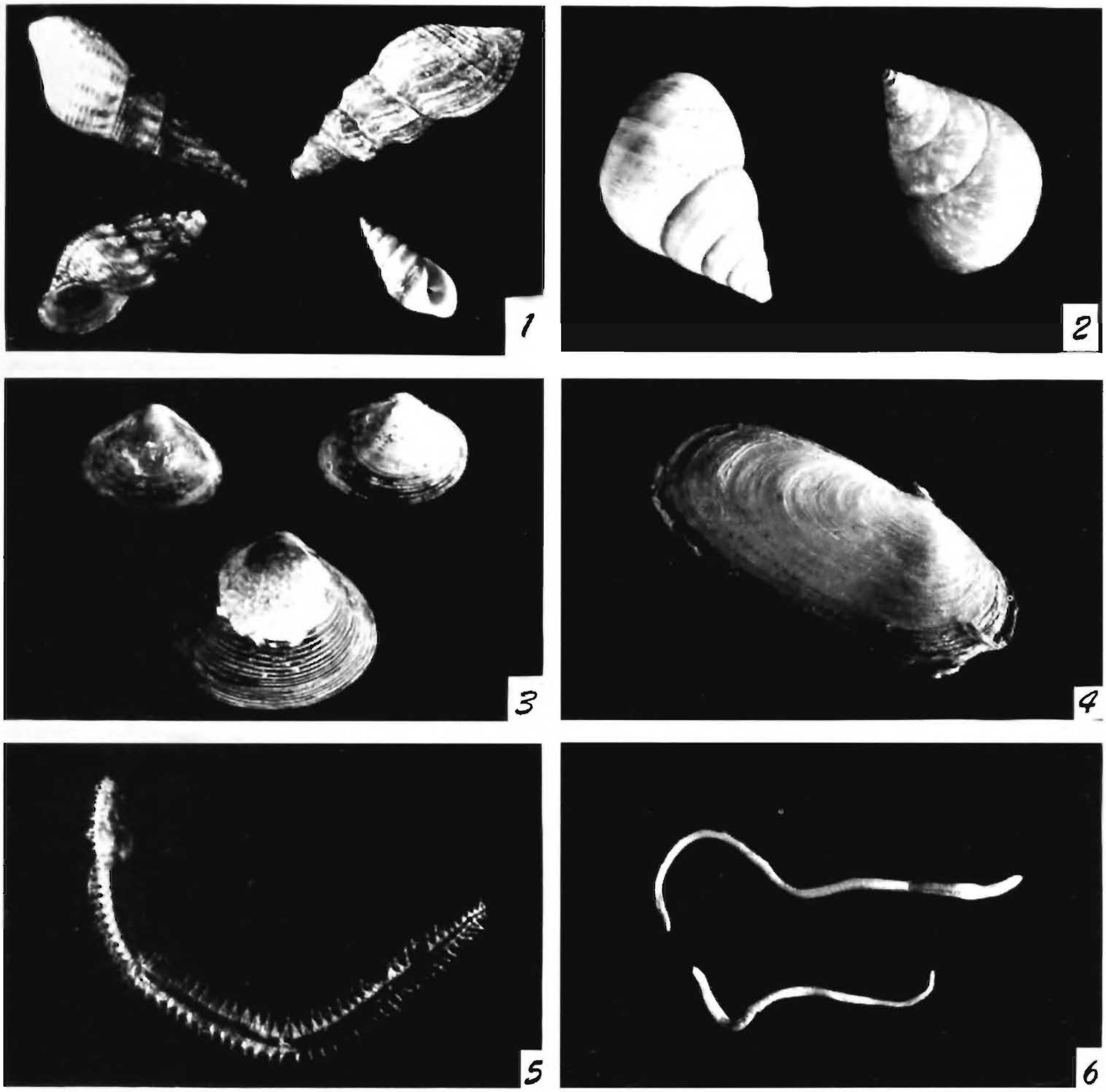
Months	Sediment Nitrate at station nos.					
	1	2	3	4	5	6
May(1995)	7.5	4.5	3.1	7.81	3.6	1.1
June	10.0	3.1	2.9	7.8	2.7	6.6
July	9.0	3.0	2.7	8.9	5.8	1.5
August	10.9	3.51	5.6	2.8	4.6	3.1
September	12.1	8.2	6.5	5.1	8.9	4.6
October	4.9	3.5	3.6	9.0	4.7	4.8
November	3.7	4.1	1.2	1.8	7.4	6.4
December	3.4	3.41	6.2	1.2	1.4	10.5
January(1996)	3.9	1.5	2.6	1.4	6.1	8.9
February	5.0	3.7	2.4	3.4	3.7	6.7
March	2.9	2.2	5.0	1.39	4.9	4.0
April	3.1	2.6	5.1	7.5	3.3	6.0
May	8.5	4.7	2.9	8.99	5.2	2.1
June	9.8	2.9	3.3	9.4	4.3	6.8
July	9.2	3.2	3.1	10.5	7.2	1.9
August	9.1	3.5	7.0	6.1	3.8	4.0
September	9.7	1.3	5.9	4.9	9.1	7.0
October	4.1	2.7	3.8	6.3	6.1	3.8
November	4.5	12.2	9.0	4.3	2.3	6.6
December	2.8	3.59	9.5	4.8	1.41	1.3
January(1997)	5.1	1.2	2.61	1.0	5.4	4.3
February	5.2	4.3	3.9	3.6	3.0	3.6
March	3.3	4.5	5.5	9.0	5.9	3.3
April	2.5	3.4	5.7	7.4	3.0	6.4

Appendix 23. Organic carbon (%)

Months	Organic carbon at station nos.					
	1	2	3	4	5	6
May(1995)	0.51	0.13	0.07	0.09	0.04	0.18
June	0.61	0.9	0.76	0.08	0.24	0.29
July	0.63	0.93	0.2	0.44	0.31	0.24
August	0.72	0.47	0.25	0.33	0.15	0.21
September	0.6	0.52	0.25	0.38	0.22	0.32
October	0.84	0.48	0.51	0.53	0.15	0.39
November	0.89	0.48	0.04	0.45	0.31	0.29
December	0.99	0.41	0.22	0.31	0.16	0.05
January(1996)	0.81	0.39	0.42	0.25	0.28	0.27
February	0.84	0.26	0.57	0.45	0.36	0.51
March	0.78	0.6	0.45	0.42	0.51	0.66
April	0.51	0.2	0.45	0.44	0.45	0.3
May	0.5	0.11	0.05	0.09	0.02	0.99
June	0.53	0.3	0.5	0.04	0.18	0.31
July	0.37	1.47	0.22	0.43	0.23	0.18
August	0.54	0.53	0.29	0.21	0.09	0.27
September	0.7	0.5	0.35	0.42	0.20	0.4
October	0.9	0.47	0.39	0.49	0.21	0.51
November	0.91	0.54	0.02	0.57	0.41	0.31
December	1.5	0.49	0.2	0.3	0.14	0.07
January(1997)	0.8	0.45	0.3	0.35	0.32	0.33
February	0.81	0.34	0.21	0.51	0.21	0.21
March	0.8	0.21	0.18	0.3	0.09	0.12
April	0.63	0.21	0.03	0.06	0.18	0.3

PLATES

PLATE 1



Figs. 1-6. Some common and rarely collected macrobenthos of Hugli river.

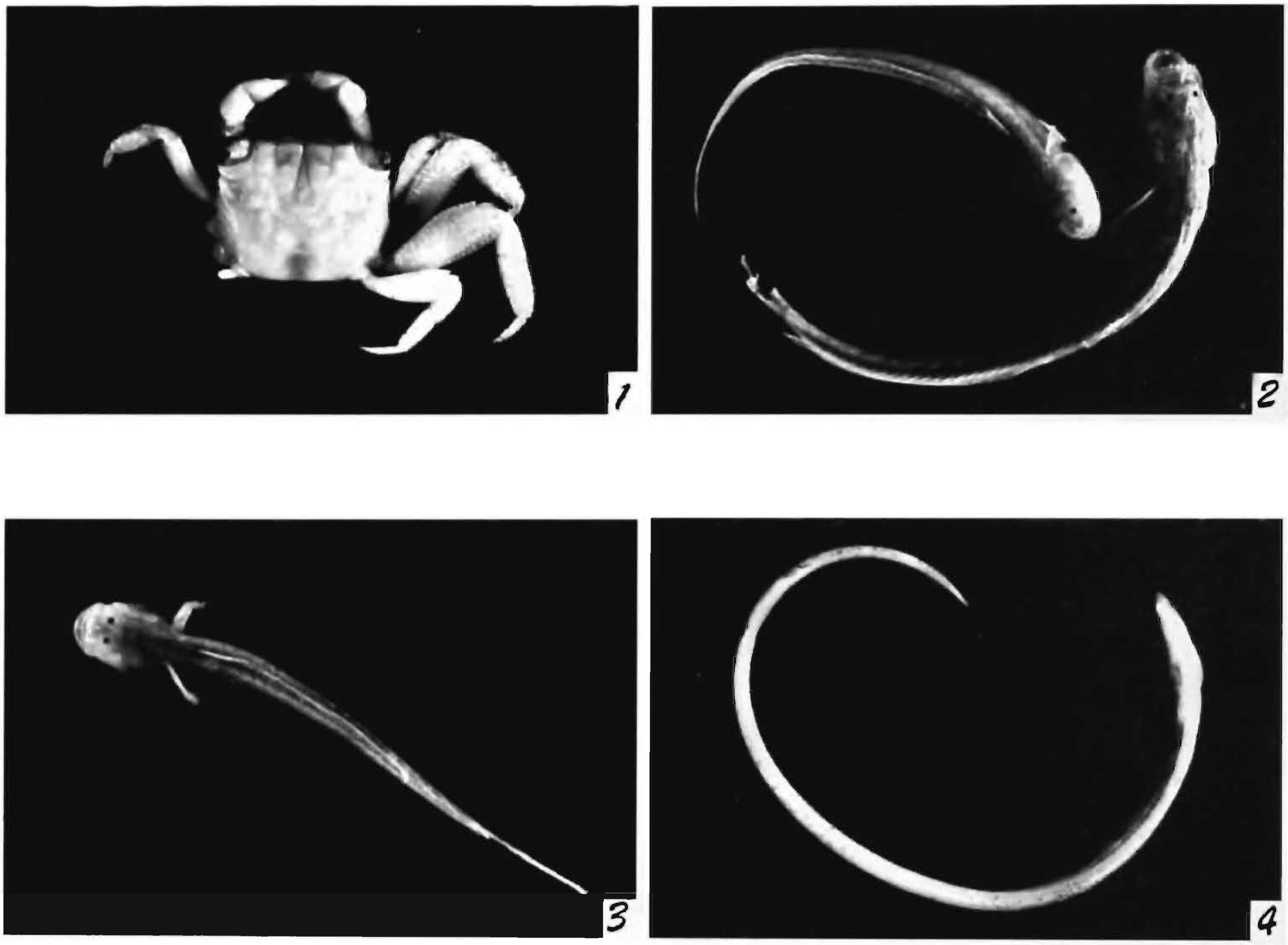
Figs. 1 and 2. Some commonly occurring epibenthos viz., *Thiara* spp. (Fig. 1) and *Assiminea francesiae* (Fig. 2).

Figs. 3 and 4. Rarely occuring infaunal bivalvaes viz., *Corbicula striatella* (Fig. 3) and *Novaculina gangetica* (Fig. 4).

Fig. 5 A common polychaete species *Nephtys oligobranchia*.

Fig. 6. A pollution indicator worm *Limnodrilus hoffmeisteri* abundantly occurring at station 4.

PLATE 2



Figs. 1-4. Some burrowing organisms in the intertidal mudflats of Hugli river.
Fig. 1 *Sesarma edwardsi-a commonly occurring crab.*
Figs. 2-4. Some occasionally occurring intertidal gobiid fishes viz., *Odontamblyopus rubicundus* (**Fig.** 2), *Parapocryptes macrolepis* (Fig. 3) and an unidentified juvenile eel (Fig. 4).