ECOLOGICAL CHARACTERISTICS OF PRAWN CULTURE FIELDS IN THE COCHIN AREA

THESIS SUBMITTED

IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF

THE DEGREE OF

DOCTOR OF PHILOSOPHY

OF THE

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

BY

SHEEBA SUSAN MATHEWS

ICAR
भाकृअप

Post-Graduate Programme in Mariculture

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

COCHIN - 682 031, INDIA

JANUARY 1992

DEDICATED TO MY PARENTS

C E R T I F I C A T E

This is to certify that the thesis entitled **"Ecological characteristics of prawn culture fields in the Cochin area"** is the bonafide record of the research work carried out by Kum. Sheeba Susan Mathews, under my guidance and supervision in the Post-graduate Programme in Mariculture, CMFRI, and that no part thereof has been presented for the award of any other degree.

Dr. N. GOPINATHA MENON,
SCIENTIST (SG),
CENTRAL MARINE FISHERIES
RESEARCH INSTITUTE,
COCHIN-682 031.

Cochin-682 031,
January, 1992.

DECLARATION

I hereby declare that this thesis entitled **"Ecological characteristics of prawn culture fields in the Cochin area"** has not previously formed the basis of the award of any degree, diploma, associateship or other similar titles or recognition.

Cochin-682 031,
January, 1992.

SHEEBA SUSAN MATHEWS

C O N T E N T S

		PAGE No
LIST OF TABLES		
LIST OF FIGURES		
PREFACE		i - iv
1.	INTRODUCTION	1 - 15
2.	MATERIAL AND METHODS	16 - 29
3.	RESULTS	
	I. PERENNIAL FIELDS	30 - 58
	II. SEASONAL FIELDS	59 - 82
	III. COCONUT GROVES	83 - 99
	IV. DIURNAL STUDIES	100 - 106
4.	DISCUSSION	107 - 129
5.	SUMMARY	130 - 134
6.	REFERENCES.	135 - 154

** ** **

LIST OF TABLES

Table No.	Title
1.	Seasonal variation of Organic carbon content in the soil.
2a.	Seasonal availability of Phytoplankton - Cherai.
2b.	Seasonal availability of Phytoplankton - Edavanakkad.
2c.	Seasonal availability of Phytoplankton - Vaduthala.
2d.	Seasonal availability of Phytoplankton - Panangad.
3.	Quantitative abundance of Zooplankton.
4.	Seasonal percentage composition of Zooplankton. a. Cherai and b. Edavanakkad.
5.	Seasonal percentage composition of Zooplankton. a. Vaduthala and b. Panangad.
6.	Seasonal prawn/fish production at Panangad.
7.	Comparison of production in the primary, secondary and tertiary trophic levels.
8.	Correlation matrix of various environmental parameters.
9.	Two way Analysis of variance Table.
10.	Seasonal variation of Organic carbon content in the soil.
11.	Seasonal availability of Phytoplankton. a. Cherai and b. Narakkal.
12.	Seasonal availability of Phytoplankton a. Chittoor and b. Mulavukad.
13.	Quantitative abundance of Zooplankton.
14.	Seasonal percentage composition of Zooplankton. a. Cherai and b. Narakkal.
15.	Seasonal percentage composition of Zooplankton. a. Chittoor and b. Mulavukad.
16.	Seasonal prawn/fish production at Mulavukad.

Table No.	Title
17.	Comparison of production in the primary, secondary and tertiary trophic levels.
18.	Correlation matrix of various environmental parameters.
19.	Two way Analysis of Variance Table.
20.	Seasonal variation of Organic carbon content in the soil.
21.	Seasonal availability of Phytoplankton a. Edavanakkad and b. Narakkal
22.	Quantitative abundance of Zooplankton.
23.	Seasonal percentage composition of Zooplankton. a. Edavanakkad and b. Narakkal.
24.	Correlation matrix of various environmental parameters.
25.	Two way Analysis of Variance Table.
26.	Diurnal variation of Chlorophylls and Carotenoids.

LIST OF FIGURES

Fig. No.	Description
1.	Map of Cochin backwater showing the sampling stations.
2.	Zooplankton collecting net
3.	Monthly variation in Rainfall.
	PERENNIAL FIELDS
4-8.	Monthly variations in Atmospheric and Water temperature, pH, Salinity, Total alkalinity and Dissolved oxygen.
9-12.	Monthly variations in Nitrate, Nitrite and Ammonia-Nitrogen, Reactive phosphorus and Silicate-silicon.
13.	Monthly variation in primary production.
14.	Monthly variation in Chlorophyll and Carotenoid concentration
15-16	Monthly percentage composition of zooplankton.
	SEASONAL FIELDS
17-21	Monthly variations in Atmospheric and Water temperature, pH, Salinity, Total alkalinity and Dissolved oxygen.
22-25	Monthly variations in Nitrate, Nitrite and Ammonia-Nitrogen, Reactive phosphorus and Silicate-silicon.
26.	Monthly variation in Primary production.
27.	Monthly variations in Chlorophyll and Carotenoid concentration.

28-29. Monthly percentage composition of zooplankton

COCONUT GROVES

30-34. Monthly variations in Atmospheric and water temperature, pH, Salinity, Total alkalinity and Dissolved oxygen.

35-38. Monthly variations in Nitrate, Nitrite and Ammonia-Nitrogen, Reactive phosphorus and Silicate-silicon.

39. Monthly variation in Primary production.

40. Monthly variations in Chlorophyll and Carotenoid concentration.

41. Monthly percentage composition of Zooplankton.

DIURNAL STUDIES

42-47. Diurnal variations in various hydrobiological parameters.

48. Relationship between Tide level, pH and Dissolved oxygen.

P R E F A C E

Ever increasing human population, continually expanding demand for protein rich fishery products, stagnating coastal fish production, risk-prone, capital-intensive, technology-oriented deep sea resource exploitation coupled with the need to generate more employment opportunities for rural traditional fishermen created an awareness among scientists, policy makers, fish farmers and enterpreneurs to evolve new strategies to convert the vast derelict swamps and low lying water bodies adjacent to backwaters and coastal zones into productive fish farms at a comparatively low cost, cheap & locally available technologies with a sure high yield in return. In addition to this the ever increasing fuel cost and operational cost in the capture fisheries sector poses doubts of profitability. In view of all these factors it is generally felt that the traditional extensive fish culture practice with minimum inputs is a more attractive, feasible and economically viable solution to increase yield than to concentrate more on an already stagnating capture fisheries or to venture into uncertain deep sea exploitation with higher inputs.

As shrimp is a valuable export commodity with great potentials, there were intense efforts to increase the yield rapidly for the last several years which resulted in overexploitation of this resource from the coastal waters. Therefore, the most rational proposition to achieve high production is to intensify the brackishwater prawn farming in the light of the locally available cheap technologies. Hence, the brackishwater prawn culture is considered as a priority area in our Fisheries Plan Schemes. Out of 1.7 million hectares of estuaries, backwaters, mangrove swamps and numerous lagoons along the coastline suitable for culture operation, at present, only a fraction of it is utilized for prawn farming.

The available domestic, traditionally adopted technology is already found to be cheap and produces promising harvests. However, the changing ecological characteristics of the culture system is all the more vital to achieve high yield rates than the technology itself. In view of the importance of this factor on the growth and production potential of organism at different trophic levels, for the past one decade several short term studies have been conducted on this aspect. Most of these studies were confined either to short periods of time or in a limited area. A detailed study on the primary, secondary and tertiary production in different culture systems along with the various ecological parameters is currently lacking. Therefore, inorder to fill the above lacuna an attempt is made to investigate thoroughly the various ecological parameters, both abiotic and biotic, of perennial and seasonal culture fields and canals in between coconut plantations along Cochin area lying adjacent to Vembanad lake during different seasons of 1988 to 1990 period. I hope that the results of this study will be of use to brackishwater prawn/fish farmer to suitably modify their pond management practices inorder to achieve a profitable harvest year round.

This thesis comprises of chapters such as Introduction, Material and Methods, Results, Discussion, Summary and References. INTRODUCTION includes aspects such as the importance of prawn farming, nature of ecosystems, details of relevant work carried out by other workers and the

purpose of taking up the present work. In MATERIAL AND METHODS, location of sampling stations, frequency of sampling, techniques of sampling and preservation of sample are dealt with. Methods of analyses of various physico-chemical and biological parameters are also included in this chapter. RESULTS deal with monthly/seasonal/diurnal variation of these environmental parameters. The chapter on DISCUSSION explains the results of the present study and discussed and compared with earlier work on this subject. The gist of the whole research work is mentioned in SUMMARY. Last part of the thesis is the REFERENCES which consist of the work of various authors mentioned in the text.

I wish to express my deep sense of gratitude to my Supervising Guide Dr. N. Gopinatha Menon, Scientist SG, CMFRI, for his valuable guidance, constant encouragement and whole hearted support throughout the period of study and in the preparation of the manuscript. My thanks are also due to Dr. P.S.B.R. James, Director, CMFRI, for the excellent facilities provided to carry out this research. I am indebted to Dr.A. Noble, Principal Scientist, CMFRI, for his encouragement. My sincere thanks are also due to Shri. G.S.Daniel Selvaraj and Shri.V.Kunjukrishna Pillai, Scientists, CMFRI, for critically going through the manuscript and their help during the various stages of my work. I am grateful to Ms. T.S. Naomi, Scientist, CMFRI, for helping me in the identification of zooplankton. I am indebted to Dr. K.S. Scariah and Shri.T.V.Sathianandan, Scientists, CMFRI, for their help in the statistical analyses of the data. I am also thankful to Shri. D.S. Rao, Principal Scientist, CMFRI, for his timely help in sanctioning transport facilities during my field work. I am much obliged to Shri. A.K.V. Nasser, Scientist, CMFRI, for his prompt help during the computer analysis. My thanks are also due to Ms. Prathibha Rohit, Scientist, CMFRI, for her encouragement and support throughout the work.

Timely technical help rendered by Shri. A. Nandakumar, V.K. Balachandran, M. Ayyappan Pillai and K. Balachandran are gratefully acknowledged. I am thankful to Shri. M.J. John for the clerical and administrative help rendered during the tenure of this programme. My thanks are also due to Shri. K.J. Mathew and V.N. Surendran, motor drivers for their assistance during field trips.

My sincere thanks are due to my colleagues: K. Preetha, Santhi Thirumani, Saji Chacko and V. Baskaran; Seniors; Dr. Kuldeep Kumar Lal and V.R. Suresh, Juniors: Tessy K.L., C. Vasudevappa, and G. Prasad. I would like to extend my thanks to all Junior Research Fellows, especially C. Regunathan, P. Anil Kumar, S. Ani, U. Ganga and N.P. Ani Kumari for their sincere help during different stages of this thesis preparation. I am thankful to my friends Ms. Ranjitha R. Kammath, Sini Sara Philip, Steffy Saleena Ponnan and Soli Jacob for their timely help during various stages of my research work.

I would like to thank Shri. M.S. Babu, Sudarsan, Sabu and Chinnappan for their help during the collection of data and in diurnal studies. I am thankful to Ms. K.G. Isha, and V.B. Padmaja for typing this thesis.

Finally I acknowledge the Indian Council of Agricultural Research for providing me with the Senior Research Fellowship to carry out my research work on mariculture.

INTRODUCTION

Prawns form a prominent export commodity and account for 57% by quantity and 79% by value in the total marine products export. Prawn fishery also plays a vital role in providing livelihood for thousands of families by way of providing employment opportunities. During the past few years the annual landing of prawns is observed to be stagnating despite increasing fishing pressure. It forms about 11.3% of the total marine fish production in India. During 1990, the total yield was estimated at 2.16 million tonnes (CMFRI Annual Report, 1990-'91). About 67.35% of the total prawn production is by the penaeid group which is of great export value. Penaeid prawns form a substantial fishery along the southwest coast of India. Estuaries and backwaters also form fishing ground for this group. However, the exploitation of this resource from the shallow coastal waters is currently facing several problems due to overharvest of juveniles and sub-adults of commercially important penaeid prawns, regional and social problems of mechanised and non-mechanised sectors together exploiting the same grounds etc. Hence there has been a general awakening to find out ways and means for augmenting prawn production through coastal aquaculture.

World production of farmed shrimp is estimated to be 6,33,000 metric tons (Fish Farming International, 1991). Out of which India's share is only 5%. The shallow estuarine muddy bottom and tidal marshes are of particular importance to the fish farmers, since they are regarded as

(1) the most fertile area, their biological production rating as high as 20 times that of open sea (Iverson, 1976) and (2) rich grounds for naturally available seeds of commercially important prawns. Apart from this they form the breeding grounds of various species of marine and estuarine finfishes and shellfishes. An estimated 17,00,000 hectares of cultivable brackishwater areas are available in the coastal sector. Out of this only 30,000 hectares lying in the coastal belt of Kerala, Karnataka and West Bengal are being used for prawn and fish farming (Silas et al., 1983).

In Kerala, the total brackishwater areas including the lower reaches of rivers, the brackishwater lakes and adjacent low lying fields and mangrove swamps is estimated at about 2,43,000 hectares. About 50% (1,21,600 ha) of the total water logged areas could be utilized for prawn farming (Anon, 1978). But only about 5,117 hectares of low lying fields are at present utilized for the traditional prawn and fish farming in Kerala (Rao, 1980). Traditional shrimp culture is practised in these fields adjacent to backwaters in the districts of Ernakulam, Kottayam, Trichur and Alleppey. These fields are categorised into two types viz, 'seasonal' and 'perennial'.

A traditional system of prawn farming in paddy fields popularly known as prawn filtration is prevalent in more than 4,500 hectares of low lying coastal brackishwater fields adjoining the Vembanad lake (Muthu, 1978). These seasonal fields vary in size from less than 0.5 to more than 10 hectares (George and Suseelan, 1983) which are confluent with Vembanad lake through canals and are subjected to tidal influence. This traditional farming system involves the entrapment of juvenile prawns brought in by the incoming tidal water and allowed them to grow for 2-3 months with periodic harvesting at regular intervals. This is a seasonal operation carried out during November-April period. In the remaining period (June-September) water in these fields become almost freshwater thereby making the system unsuitable for prawn/fish culture. But during this period a variety of paddy called 'pokkali' which is tolerant to salinity upto 6-8‰ is grown in these fields. This is a short term crop lasting for about 90-100 days.

Soon after the paddy harvest, the fields are leased out to prawn farmers for a period of five months from mid November to mid April. The lessee prepares the field for the operation by repairing the bund, fixing the sluice gate for the regulation of water flow and such other work. Paddy stumps and straw left out the field are allowed to decay in the field itself and it provides a good organic manure for the growth of algal pasture including periphyton.

Stocking is done by letting in tidal water into the fields during high tide. Along with tidal water juvenile prawns/fishes from the adjoining backwater areas enter the field. They are attracted into the fields by keeping a light at the sluice gate during night. When the tidal water started receding during low tide, a closely tied screen made of bamboo or arecanut is inserted across the sluice gate and water is let out trapping all the juvenile prawns/fishes that have entered the field. This sort of entrapment is continued at every high tide throughout the period of operation. Harvesting known as filtration, begins from mid December by operating a conical net fixed at the sluice gate during low tide. Filtration is done at dawn or dusk for 5-8 days around every new moon and full moon period (locally known as 'Thakkom') during which maximum tidal amplitude is experienced. The final harvesting, locally known as 'Kalakkipiditham' or 'Kettukalakkal' will be done at the end of the season by operating sluice net, cast net and also by hand picking.

In addition to 'pokkali 'fields, there are relatively deeper brackish-water impoundments which are not suitable for growing paddy. The size of these fields range from 2 to 75 hectares (George and Suseelan, 1983) and are called perennial fields ('Varshakkettu' in Malayalam). These fields are used for growing prawns throughout the year. The method of stocking and harvesting are similar to those adopted in the case of seasonal fields. Since such areas are deeper, the bottom portion of the water column will be saline making it suitable for the growth and survival of prawn during monsoon period also.

The penaeid prawn belonging to the genera *Penaeus* and *Metapenaeus* spawn in the sea, but the post larvae enter the estuaries and backwater areas in large number and serve as natural nursery ground for juveniles. In traditional culture operation, these naturally occurring post larvae and juveniles are trapped in the tidal impoundments are allowed to grow for shorter periods before they are caught. In India, this type of prawn culture is practised in the brackishwater bheries of West Bengal and paddy fields adjoining Vembanad lake in Kerala (Muthu, 1978).

The present area of investigation includes the prawn culture fields adjacent to Cochin backwater. The Cochin backwater (09° 58'N 76° 28'E) is a shallow semi-enclosed body of water of tropical estuary. A narrow gut, about 450 M wide forms its main connection with the Arabian sea and this region is subjected to regular tidal influence. It is a catchment basin for several rivers such as Periyar, Pamba and Muvattupuzha which empty either into Vembanad lake or into Cochin backwater, which extends in the form of shallow brackishwater lagoon. Except at Cochin, these backwaters are essentially shallow with mean depth of about 3.5 metres. Along the main channel near the Cochin harbour, the depth is 10-14 metres which is maintained for navigational purposes. The inflow of freshwater, particularly during monsoon months is considerably high and the influx of this large scale freshwater run off extends far beyond the harbour mouth during this period (Silas and Pillai, 1975). The continual discharge of freshwater and the inflow of seawater into the estuary brings about dynamic conditions which make the backwater extremely interesting and ecologically an intriguing environment. The Vembanad lake and the connected backwaters around Cochin are well known for its role as a nursery ground for important fishery resources of this area. The fishery resources mainly depend on the magnitude of primary and secondary production which inturn are influenced by various physical, chemical and biological factors.

The hydrography of backwater is largely influenced by two main factors: the short term changes induced by tides and seasonal changes brought about by the monsoons. During the last few years, considerable research work have been done on the physico-chemical and biological parameters of different estuaries of India. Cochin backwater is one of the well studied system in India. Some of the pioneering studies were that of Ramamirtham and Jayaraman (1963) and Cherian (1967). Tides in Cochin backwater are of mixed semidiurnal type with maximum range of about 1 metre. Two high and two low water marks occur each day with an appreciable difference in range and time (Qasim and Gopinathan, 1969). The various environmental factors such as temperature, salinity, dissolved oxygen, nutrients, alkalinity and chlorophyll are generally influenced by tidal rhythm. The difference in almost all these parameters are more marked at the surface than at the bottom. Effects of tidal currents on hydrography is reported by Pillai et al. (1973) and Ramaraju et al. (1979). Tide and diurnal influence on zooplankton is described by Madhupratap and Rao (1979). Udayavarma et al. (1981) worked on the seasonal variation in current and salinity around Willingdon Island.

Meteorologically three seasons can be observed, viz. premonsoon (January-May), monsoon (June-August) and postmonsoon (September-December) in this area (Wellershaus, 1971). During premonsoon no salinity stratification was noticed. As monsoon approaches this condition changes quickly in accordance with the influx of freshwater from rivers. Thus the stratification persists throughout the monsoon period. Josanto (1971; 1975) studied the bottom salinity characteristics and the factors that influence the salt penetration in Vembanad lake. Diurnal variation of physicochemical parameters of this backwater was studied by Shynamma and Balakrishnan (1973). Apart from this, emphasis has also been given on aspects such as hydrographic features and water quality (Saraladevi et al., 1979), changing ecology of the backwater (Qasim and Madhupratap, 1981), seasonal variation of temperature and salinity (Lakshmanan et al., 1982), estuarine characteristics of lower reaches of river Periyar (Sankaranarayanan et al., 1986) and distribution of salinity and silicate in the Cochin estuary (Anirudhan and Nambisan, 1990).

The abundant animal life of estuaries depend on the phytoplankton, marsh grasses and submerged plants for most of their food. All these plants require a continual supply of nutrients for rapid growth. The source of nutrients are land run off, sediments and sea water that move upstream (Hobbie, 1976). The nutrients determine the potential fertility of water masses (Harvey, 1955) and therefore it is important to study the distribution and characteristics in different geographical locations and seasons. The behaviour of nutrients during estuarine mixing may vary from one estuary to another and even within one estuary it may vary seasonally depending upon environmental conditions such as precipitation, change in river flow, biological activity etc. Studies on the nutrients and their distribution characters were conducted by Sankaranarayanan and Qasim (1969), Joseph (1974), Manikoth and Salih (1974), Sankaranarayanan et al. (1984) and Lakshmanan et al. (1987).

The synthesis of organic compounds from inorganic constituents of water is termed primary production which is effected almost entirely by the photosynthetic activity of plants with traces of organic matter formed by chemosynthesis. Chlorophyll containing plants, by making use of light energy are able to combine these simple substances to synthesise complex organic molecules. This is termed gross primary production. Exclusive studies on primary production were made by Qasim et al. (1969), Qasim (1973), Nair et al. (1975), Pillai et al. (1975) and Qasim (1979) from these waters.

The relation between nutrients and productivity, species abundance and pigment concentration has been studied by Sundarraj and Krishnamurthy (1975), Subramaniam and Venugopalan (1978), Regunatha Reddy (1984) and Kannan and Krishnamurthy (1985). Concentration of Chlorophyll is a useful and a simple tool for estimating phytoplankton standing crop and is now more frequently used than the cell number or cell volume method. Their distribution in relation to environmental parameters and season, diurnal variation and relationship with nutrients have been well studied. The important contributions were that of Dehadrai and Bhargava (1972) Bhargava (1973), Bhargava and Dwivedi (1976), Bhattathiri and Devassy (1978) and Nittala and Nageswara Rao (1989).

Considerable knowledge has been gained in recent years on the distribution, abundance, ecology and adaptations of phytoplankton in Cochin backwater with emphasis on the importance of primary production (Gopinathan 1972; Qasim et al., 1972; Devassy and Bhattathiri, 1974; Gopinathan et al., 1974; Pillai et al., 1975; Joseph and Pillai, 1975; Kumaran and Rao, 1975; Gopinathan, 1975; Qasim, 1980; Gopinathan et al., 1984; Jayalakshmi et al., 1985).

Zooplankton are one of the most important constituents among the secondary producers. Studies on the zooplankton secondary production were conducted by Menon et al. (1971) on total biomass and faunistic composition of zooplankton; Subharaju and Krishnamurthy (1972) on the ecological aspects of production; Haridas et al. (1973) on salinity, temperature, oxygen and zooplankton biomass, Goswami et al. (1977) on zooplankton production, Haridas et al. (1980) on annual variation in zooplankton, Nair (1980) on production and assimilation of zooplankton in the estuarine and nearshore waters; Selvakumar et al. (1980) on seasonal variation in secondary production; Bhunia and Chaudhary (1981) on the seasonal abundance and biomass; Nair et al. (1981) on biomass and composition of zooplankton; Goswami (1985) on secondary production and zooplankton abundance; Shanmugham et al. (1986) on biomass composition of zooplankton and Srinivasan et al. (1988) on biomass and seasonal distribution of planktonic tintinids.

Although the interaction between plant and animal population are difficult to elucidate, the grazing rate of herbivorous zooplankton is certainly one of the factors which regulates the size of the standing stock of phytoplankton and therefore influences the production rate. In all aquatic ecosystems, zooplankton plays an important role in the transfer of energy at the secondary trophic level. A number of studies have already been conducted on some problems related to food chain (Qasim, 1970), production of different trophic levels (Bhattathiri et al., 1976; Qasim, 1977), zooplankton and Trichodesmium phenomenon (Nair et al., 1980), empirical relationship between phytoplankton and zooplankton biomass (Vijayalakshmi, 1984) and biomass relationship between phytoplankton and zooplankton (Pant et al., 1984). Considerable work, both qualitative and quantitative, have been done on the plankton of Indian coastal waters, especially in the Cochin backwater in recent years. The pioneering attempt of making a quantitative study of plankton of this region was by George (1958) who enumerated the more common groups and brought to light the relationship between the seasonal changes of zooplankton population and some of the environmental parameters. Variability is a characteristic feature of plankton distribution. To a certain extent the interaction of the prevailing physicochemical parameters are responsible for spatial difference in abundance and diversity of zooplankton. Such variations are well pronounced in an estuarine habitat which undergoes considerable fluctuations in its physico-chemical characteristics. Important aspects covered about zooplankton in general were on the biomass and faunistic composition (Menon et al., 1971), distribution in space and time (Nair and Tranter, 1971; Rao et al., 1975), seasonal changes in their population (Wellershaus, 1974), composition and variation in abundance (Madupratap and Haridas, 1975; Madhupratap et al., 1977), their dynamics (Silas and Pillai, 1975), ecology (Madhupratap, 1978), their role in the fisheries development (Balachandran and Peter, 1987), ecological affinity (Sharma, 1987), their status and strategy (Madhupratap, 1987) and their fluctuation in the estuarine waters (Maya, 1991).

Soil plays a major role in determining the production of animals present in that system. Benthic algae, which form the major food organism for brackishwater fish and prawns, derive their nutrients either directly from the soil or the soil water interphase and accordingly productivity in such system depends on the nature and properties of the soil. Among the soil parameters, the important ones are soil nutrients, organic matter and grain size. In this context, the important studies were that of Balasubrahmanyan (1961) on the properties of bottom sediments, Josanto (1971) on the grain size distribution of sediments, Murthy and Veerayya (1972) on the organic matter, Sankaranarayanan and Panampunnayil (1979) on the organic carbon, nitrogen and phosphorus, Remani et al., (1981) on the sediments of a retting yard, Mallik and Suchindan (1984) on the sedimentological aspects and Jagtap (1987) on the seasonal distribution of organic matter.

In view of the importance of backwaters for large scale culture of fish and shellfish, a number of studies have been made on the ecology and allied aspects of culture systems adjacent to it. Brackishwater aquaculture is expanding at a rapid pace in many areas along the Indian coast. This has acquired the status of an industry with the recent developments in technically feasible and economically viable fish culture systems assuming sizeable profits with low risks and short term operational investments. Maintainance of healthy aquatic environment and production of sufficient food organisms in ponds are the two factors of prime importance for successful prawn culture operations. A knowledge of the biotic and abiotic factors affecting the cultivable species of fish/shellfish is a prerequisite for their culture. Among the physicochemical factors influencing aquatic productivity, pH, alkalinity, dissolved gases like oxygen, carbon dioxide and dissolved organic nutrients like nitrogen and phosphorus are considered to be important.

Successful management of an aquaculture system depends on a constant supply of basic nutrients necessary for the optimal growth of the cultured species. The constant supply of nutrients depends heavily on rapid recycling, which is one of the most important factors of maximising production in pond culture. Phosphates and nitrates play a significant role in production of aquatic organisms especially micro- and macro- plants and rely on biochemical processes of recycling for their conversion into a form available to the organism involved. The supply of nutrients is also dependent on the fertility of the underlying soil and soft sediment which provides living environments for bottom organisms.

The growth of plankton and aquatic macrophytes is known to be critical for augmenting fish production in pond culture, especially as most fish raised in warm water pond in less developed nations are dependent largely upon natural foods. Phytoplankton is utilized by the primary consumers (zooplankton) which serve as a major food source for wide variety of organism including fish. The phytoplankton growth and its ecological factors in fish ponds have concerned fish farmers the world over. Lin (1970) stated that many Chinese carp farmers judge the water quality of fish ponds by their colour, the degree of greenness reflects the abundance of phytoplankton. Species composition of phytoplankton in fish pond is important because different taxa of planktonic algae present different diet values in various developmental stages of fish or prawn (Banerjea and Ghosh, 1963; Nagarajaiah and Gupta, 1985; Gomathi, 1990).

Zooplankton population and biomass in brackishwater culture system is also well studied. Biotic factors that influence zooplankton communities include "bottom-up" (Producer or resource controlled) parameters such as phytoplankton biomass and productivity and "top-down" (consumer controlled) parameters such as vertebrate and invertebrate predation pressure (Mc Queen et al., 1986). Studies on the zooplankton production from these culture systems were that of Banerjee and Pakrasi (1986) on the biomass production of newly constructed brackishwater impoundments, Suseela et al. (1987) on the zooplankton and macrobenthos in brackishwater fish farm and Legendre et al. (1987) on zooplankton population and biomass in brackishwater aquaculture ponds.

Physical and chemical properties of pond water are more or less the reflection of the bottom soil in normal ponds which are not influenced by external factors. The major chemical factors of importance are pH, nutrients, organic carbon etc. Importance of soil in brackishwater aquaculture systems has been emphasized by Djajadiredja and Poernoma (1972). Productivity of a pond depends upon its soil and water. Productivity in terms of fish production mainly depends upon agriculturally rich soil and water essential for good growth of related biological organisms of that medium. Soil nutrients and their role in plankton production are well studied (Banerjea and Ghosh, 1963; Banerjea, 1967; Banerjee and Banerjee, 1975; Mollah et al., 1979; Chattopadhay and Mandal, 1980; Chattopadhay and Chakkraborti, 1986; Pradeep and Gupta, 1986).

Culture of penaeid prawns in brackishwater earthern ponds is becoming increasingly popular in the tropical and subtropical regions. In India it is of traditional nature and is mainly prevalent along Kerala and West Bengal. But our understanding of the pond ecology in relation to prawn production is still limited. Earliest work on the paddy field prawn fishery is that of Menon (1954) in the Travancore area. After that George et al. (1968) made an observation on paddy field prawn filtration in Kerala. Extensive studies on the traditional culture systems were made only after 1970s. Among that the important contributions were that of George (1974), George (1975), Paulinose et al., (1981) Prasad (1982), Balachandran et al. (1982) Gopinathan et al. (1982), Sankaranarayanan et al. (1982). Ravindran (1983), Gilbert and Pillai (1986), Nasser (1986), Reddy (1986), Singh (1987), Gopalakrishnan et al., (1988) Nair et al. (1988), Devapiriyan (1990) and Joshi (1990)

Apart from general ecological studies, due importance was also given for the economics of prawn culture. In this context the noteworthy contributions were that of George (1978) on the economics of traditional prawn culture practices, Gopalan et al. (1978) on the economics of an improved method of paddy field shrimp culture, Gopalan and Purushan (1981) on the present status of brackishwater shrimp culture, Sathyadas et al.,

(1989) on the economic evaluation of paddy-prawn integrated farming, Ajith Kumar (1990) on the analysis of factor-product relationship in prawn farming and Nasser and Noble (1991) on the economics of prawn culture in Vypeen.

Prawn culture by traditional method forms an important occupation for the people in these areas, especially in the Vypeen island. Though short term studies have been made on various aspects of prawn culture field and its ecology, a study of detailed nature covering perennial, seasonal, fields and canals between coconut plantation is lacking from these areas. This study will also enable to assess the relative productivity of different systems during different seasons and the influence of the environment on the production potentials. Therefore the present study is taken upto throw more light on the ecological characteristics of these fields with special emphasis on its primary, secondary and tertiary production.

MATERIAL AND METHODS

LOCATION OF STATIONS

Ten stations were selected for regular sampling. Among this, four each are perennial and seasonal fields and the rest canals in between rows of coconut plantations. Of these stations, nine are scattered in the northern and one in the southern side of Cochin barmouth. These stations lie within a distance of 20-50 Km from the barmouth. Out of the four perennial fields, two are located in the Vypeen island, one in Vaduthala and the other in Panangad. Among the seasonal fields, two are in the Vypeen island and one each in Chittoor and Mulavukad. Both the canals of coconut plantations are located in the Vypeen island (Fig. 1).

Perennial fields are large and comparatively deeper where prawn culture is practised throughout the year. In the present study, the selected fields were at Cherai and Edavanakkad (Vypeen island),Vaduthala and Panangad. Cherai field is having an area of 4 acres with a depth of 1 metre and Edavanakkad has an area of 8 acres and a mean depth of 1.5 metres. Vaduthala and Panangad having area of 4 and 28 acres respectively with a mean depth of 1.5 metres. Seasonal fields are shallow and smaller where prawn culture is practised only for 5 months (December-April). These fields are located at Cherai and Narakkal (Vypeen island), Chittoor and Mulavukad. All fields except Chittoor have an area of 4 acres and the latter has 1 acre. Coconut groves are located in Edavanakkad and Narakkal,

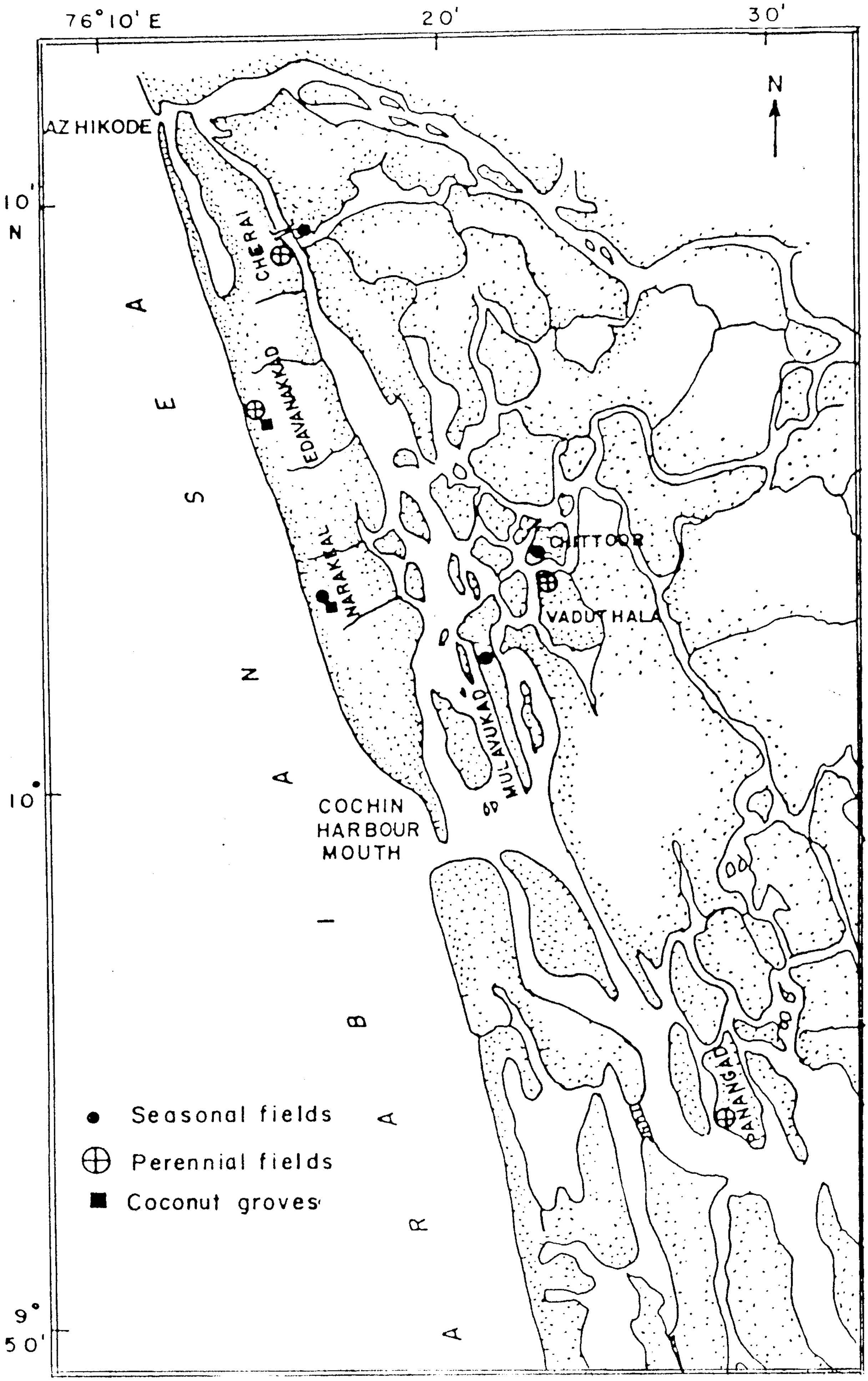


Fig. 1. Map of Cochin backwater showing the sampling stations.

having an area of 50 and 80m^2 (average depth of 1 M) respectively.

SAMPLING FREQUENCY

Regular fortnightly sampling was conducted from all these stations during every new moon and full moon days for a period of two years from 1988-90. Since prawn culture is being practised only for five months in the seasonal fields, data could be collected only during this period. For the convenience of covering distance in minimum period, the stations in the Vypeen islands were sampled on the same day and the rest in the next day. The time for the sampling was from 0800 hrs to 1200 hrs.

From all stations water and plankton samples were collected fortnightly and sediment samples seasonally. Water samples were analysed for temperature, pH, dissolved oxygen, salinity, alkalinity, nutrients and chlorophylls. Sediment samples were analysed for organic carbon content only. Composite samples were taken for water and sediments. Water samples were collected in 250 ml plastic bottles for pH, salinity, alkalinity and nutrients and in 1 litre bottle for chlorophyll estimation. Before drawing the sample, the bottles were washed with the ambient water. The samples were preserved in an ice box till they were analysed in the lab. The data were classified for premonsoon (February-May) monsoon (June-September) and postmonsoon (October-January) months.

METEOROLOGICAL PARAMETERS

Monthly rainfall data were collected from the Meteorology Department, Government of India's local data recording centre at Cochin Air Port.

AIR TEMPERATURE

This was measured using a 0-50°C high precision thermometer. Air temperature was recorded prior to the collection of water samples.

WATER TEMPERATURE

The thermometer that was used for recording air temperature, was used for measuring water temperature. Temperature was recorded by immersing the thermometer upto 5 cm deep in the water column.

pH

The pH was determined using Toshniwal pH meter model CAT. No.CL.47. The instrument was calibrated with pH buffers 4.0, 7.0 and 9.2. The samples collected for salinity were utilised for pH determination before salinity analysis. After taking the pH meter reading, the *in situ* pH was calculated using the formula (Anon, 1975)

$$\text{pH } \textit{in situ} = \text{pH measured} + 0.0118\,(t_2 - t_1),$$

Where t1 = temperature *in situ*; t2 = measurement temperature.

SALINITY

Salinity was determined by the classical Mohr titration method (Strickland and Parsons, 1968). For determining salinity, ten millilitres of water sample was titrated against the silver nitrate solution with potassium chromate as indicator. Care was taken to arrive at the exact end point colouration in all the samples and for every set of titration. Silver nitrate was standardised using standard seawater supplied by the Oceanography Institute, Copenhagen. Each sample was titrated 2 to 3 times and the mean value was taken. Salinity of the sample was calculated using the following formula,

$$S(\text{‰}) = \frac{V_1 S}{V_2}$$

Where, V_1 is volume of silver nitrate for titrating 10 ml of the sample and V_2 is the volume of silver nitrate used for titrating 10 ml of standard sea water, S = Salinity of standard seawater.

TOTAL ALKALINITY

The amount of acid required to titrate the base in water is a measure of alkalinity of water. It was determined using the following procedure. To a 100 ml sample about 4-8 drops of methyl orange indicator solution was added and titrated with standard sulphuric acid solution until the colour of the solution changes from yellow to faint orange. The volume of sulphuric acid was measured. Total alkalinity was calculated using the following equation,

$$\text{Total alkalinity (mg/l as Ca } CO_3) = \frac{T.N.50000}{S}$$

Where T = Volume in millilitres of sulphuric acid;

N = Normality of sulphuric acid;

S = Volume in millilitres of samples.

DISSOLVED OXYGEN

Water samples were collected using a standard 125 ml 'Corning' bottle with glass stopper for the estimation of dissolved oxygen. Only column water was taken from these stations as the difference between the surface and the bottom water was found to be very little. Traditional Winkler method with azide modification was used for the determination of dissolved oxygen content (Anon, 1975). The procedure of this method is as follows. To a sample in 125 ml bottle, 2 ml of manganous sulphate solution and 2 ml of alkali-iodine-azide solution were added. The bottle was stoppered to prevent air bubbles. The solution was mixed by shaking the bottle several times and the precipitate was allowed to settle. To this 2 ml of concentrated sulphuric acid was added and shaken thoroughly until the precipitate was completely dissolved.

From this 100 ml of the sample was taken into a 250 ml beaker and titrated with standard sodium thiosulphate (6.3 g/l) solution to a pale straw colour. About 5 drops of starch indicator solution was added to this and titrated until blue colour disappeared. The dissolved oxygen concentration was estimated by using the formula:

$$\text{Dissolved oxygen (mg/l)} = \frac{(T).\ (N).\ 8000}{S}$$

Where, T = Volume in millilitre of sodium thiosulphate;

N = Normality of sodium thiosulphate;

S = Volume in millilitres of sample.

NUTRIENTS

Water samples for nutrients were collected in a 250 ml narrow mouthed plastic bottle and kept in an ice box till the analyses were carried out. Using an ECIL Senior Spectrophotometer model GS 865 D with a wave length range of 200-930 nM, intensities of colours developed in these analyses were measured.

a. Nitrate-Nitrogen: Nitrate-Nitrogen was estimated by the method of Morris and Riley as described by strickland and Parsons (1968) with slight modification. To a sample of 50 ml 2 ml of buffer reagent (Phenol solution + sodium hydroxide solution) was added and with rapid mixing 1 ml of reducing agent (copper sulphate + hydrazine sulphate) was also added. The flask was kept in dark for 20 hours and later this sample was mixed with 2 ml of acetone. After two minutes interval 1 ml each of sulphanilamide solution and NNED were added and mixed thoroughly. After 10 minutes the absorption was measured at a wave length of 543 nM in the spectrophotometer. Standard nitrate stock solution was prepared at different concentrations and the values were plotted. Standard graph was plotted in a graph sheet. Concentration of nitrate is expressed in µg at./l.

b. Nitrite-Nitrogen: Nitrite-Nitrogen was estimated by the method of Morris and Riley as described by Strickland and Parsons (1968). In to a conical flask 50 ml of water sample was poured and mixed with 1 ml of sulphanilamide solution. After 2 minutes, but not later than 8 minutes 1 ml of NNED was also added and mixed thoroughly. The extinction was measured at 543 nM. Standard graph was prepared by using standard nitrite solution and nitrite concentration is expressed in µg at/l.

c. Ammonia-Nitrogen: Ammonia was determined following the phenol-hypochlorite method (Solarzano, 1969). This method consisted of the addition of 2 ml of phenol solution, 2 ml of sodium nitroprusside solution and 5 ml of oxidising reagent to 50 ml of sample as well as blank. After each addition the sample was mixed thoroughly. The colour was allowed to develop at room temperature for one hour and the absorbance was measured against the blank at 640 nM. Standard ammonia solution was prepared at different concentrations and the graph was plotted. Ammonia is expressed in µg at/l.

d. Reactive phosphorus: The method given by Murphy and Riley, as described by Strickland and Parsons (1968) was used for the determination of reactive phosphorus. To a 100 ml sample 10 ± 0.5 ml of mixed reagent (Molybdic acid, ascorbic acid and trivalent antimony) was added and mixed.

The resulting complex heteropoly acid was reduced in situ to a blue solution. After 5 minutes, preferably within 2-3 hours the extinction of the solution was measured at 885 nM. For standard phosphorus, different concentrations of potassium dihydrogen phosphate was made and the graph was plotted. Phosphate is expressed in μg at/l.

e. Silicate-Silicon: Dissolved silicon of the sample was estimated by using the method of Mullin and Riley (1955). To a sample of 25 ml, 10 ml of molybdate solution [prepared by dissolving 4.0 g of ammonium molybdate in 300 ml of distilled water and 12 ml of concentrated hydrochloric acid (12 N)] was added. After 10 minutes, 15 ml of reducing agent (consisted of metol + oxalic acid + sulphuric acid) was added to the sample. The solution was allowed to stand for 2 hours to complete the reduction. The absorbance was measured against the blank at 810 nM. Standard graph was prepared by using the standard silicate solution and silicate is expressed in μg at/l.

SEDIMENT ANALYSIS

Sediment samples were collected with the help of a Van Veen grab. The grab was lowered into the water from a height using a polypropylene rope. The grab was hauled up once it penetrated the bottom. Composite samples were taken and kept air tight in a polythene bag. The samples were dried in a hot air oven at 100°C for 24 hours and later cooled to room temperature. They were labelled properly and stored in a dessicator for further analysis. The samples were analysed only for organic carbon.

ORGANIC CARBON

Organic carbon was determined using the chromic acid method as described by Walkley and Black (1934). The procedure of this method is as follows:

The Dried sample was ground in an agate mortar and passed through a 0.5mm non-ferrous sieve. A carefully weighed amount of powdered sample was placed in a 500 ml conical flask. With a pipette exactly 10 ml of 1 N dichromate solution was added. This was mixed carefully by swirling. To this 20 ml of concentrated sulphuric acid was added and mixed by gently rotating the flask. The mixture was allowed to react for 20-30 minutes. the sample was diluted to 200 ml with distilled water and to this 10 ml of concentrated phosphoric acid was added. The sample was back titrated with 0.4 N ferrous ammonium sulphate solution using 1 ml of diphenylamine indicator. End point was the appearance of a brilliant green colour from an initial turbid blue colour. Along with sample, distilled water blank was also analysed. The percentage of organic carbon content was calculated using the following equation.

$$\text{Percentage carbon} = \frac{3.95}{g}\left(1 - \frac{T}{S}\right)$$

Where, g = Sample weight in gram; S = ml of ferrous ammonium sulphate used for the blank and T = ml of ferrous solution used for sample titration.

PRIMARY PRODUCTION

Oxygen technique (Gaarder and Gran, 1927) was used for the estimation of primary production. In this method, composite samples were collected in 125 ml 'Corning' bottle with glass stopper. These bottles were categorised into three groups, viz, initial bottle (IB), light bottle (LB) and dark bottle (DB). The dark bottles were painted black and wrapped in aluminium foil.

Initial dissolved oxygen concentration was determined by fixing the initial bottle with winkler A and winkler B. The light and dark bottles were kept in the lab under fluorescent light for a period of three hours. In the dark bottle only respiration takes place, whereas in the light bottle both photosynthesis and respiration take place. The difference in the oxygen content between light and dark bottle was taken as gross production. Primary production was calculated as follows:

$$\text{Production (mg C)} = \frac{O_2(\text{mg}) \times 0.375}{PQ}$$

Where PQ (Photosynthetic quotient) is taken as 1.25.

Assuming that photosynthesis has taken place 10 hours a day, then primary production per day can be calculated as follows:

$$\text{Primary production (mgC/m}^3\text{/day)} = \frac{O_2(\text{mg}) \times 0.375 \times 1000 \times 10}{1.25 \times A}$$

Where, A = Number of hours of incubation.

PHYTOPLANKTON

About 50 litres of water was filtered through the bolting silk (No.25 with mesh size 60 μM) and the samples were collected in a 250 ml plastic bottle and fixed with 4% formalin for later qualitative studies.

CHLOROPHYLL AND CAROTENOID DETERMINATION

The method followed by Jeffrey and Humphrey (1975) as described by Parsons et al. (1984) was used for chlorophyll and carotenoid estimation. A known volume of sample was poured into a millipore filtering equipment containing a membrane filter paper. Sample was filtered under 1/2 atmosphere pressure vacuum. To this 3-5 drops of magnesium carbonate solution was added while filtering. Filter was drained thoroughly and was placed in a 15 ml glass vial. To this 10 ml of 90% acetone was added. This was allowed to stand overnight in a dark container in a refrigerator. The contents of each tube was centrifuged for 5-10 minutes at 2000 rpm. The supernatant solution was decanted into the spectrophotometer cell and extinction was measured at different wave lengths (750, 664, 647, 630, 510 and 480 nM). Each extinction was corrected for a turbidity blank by subtracting the 750 nM from 664, 647, and 630 nM absorptions. The 510 nM and 480 nM absorbance were corrected by subtracting 2X and 3X 750 nM absorbance respectively. The amount of pigment in the original sample was determined using the equation given below.

For chlorophylls:

(Ca) Chlorophyll-a = $11.85\,E_{664} - 1.54\,E_{647} - 0.08\,E_{630}$

(Cb) Chlorophyll-b = $21.03\ E_{647} - 5.43\ E_{664} - 2.66\ E_{630}$

(Cc) Chlorophyll-c = $24.52\ E_{630} - 1.67\ E_{664} - 7.60\ E_{647}$

For Plant carotenoids:

Plant carotenoids (Cp) = $7.6\ E_{480} - 1.49\ E_{510}$

Where E stands for absorbance at different wave lengths obtained above and Ca, Cb, Cc and Cp are the amount of chlorophyll a, b, c and carotenoids (μg/ml) if a 1 cm light cuvette is used.

Then mg chlorophyll or carotenoid/m^3 = $\frac{C \times v}{V \times 10}$

Where V = Volume of sample in litre, C is the substituted value for Ca, Cb, Cc and Cp in the above equation, v = volume of acetone in ml (μg/l $\equiv$ mg/m^3).

SECONDARY PRODUCTION

Secondary production was estimated by collecting the zooplankton by using a 1.5 M long plankton net (Fig. 2). This conical plankton net has mouth diameter of 0.30 metres; the anterior part of the net is connected to the ring by a 30 cm long canvas followed by 1 M long No.3 grade (mesh size 0.33 mm) bolting silk. The cod end of this net is attached to a small bucket of 10 cm long with the help of a 20 cm long canvas. The net was towed for about 5 minutes covering a distance of 20 metres. Most of the samples were collected in the bucket, but those which remained in the inner wall of the net was removed by turning the net inside out

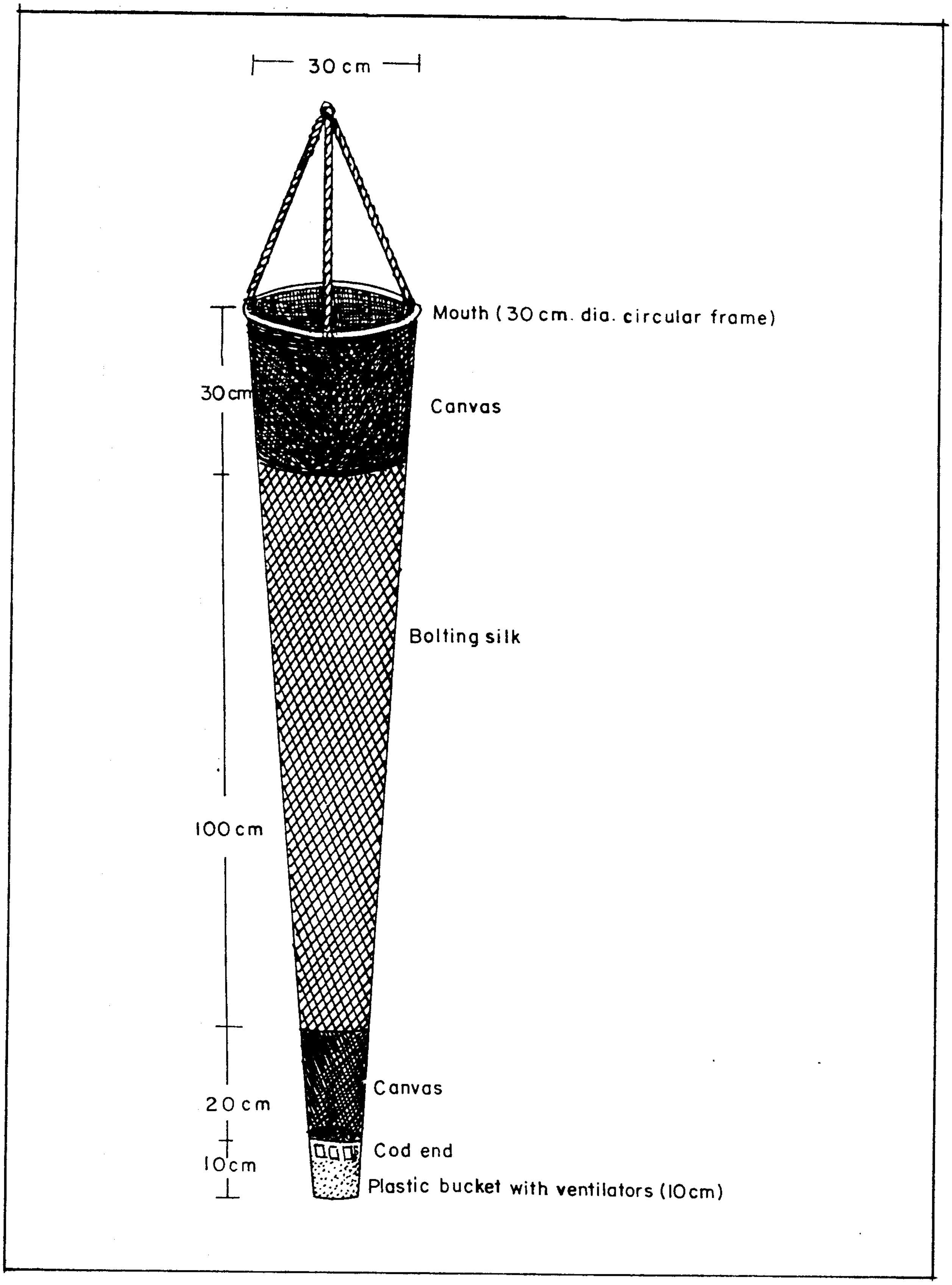


Fig. 2. Zooplankton collecting net

and washing it in a wide mouthed receiving jar containing about 1 litre of ambient water. An approximate measurement of the plankton was attempted using the formula $\pi r^2 d$. Where r = radius of the net aperture; d = distance of tow assuming that the net could filter all the water in its path. The total water column sampled at each station was estimated as 1.414 m^3. The numbers per 1.414 m^3 were raised to 100 m^3 for the convenience of estimation.

Immediately after collection, the plankton were fixed in 4% formalin for later qualitative and quantitative analyses. Plankton were identified upto group/generic level wherever possible.

Total zooplankton biomass was determined from formalin preserved samples and the volume was determined in a zooplankton volume determiner.

TERTIARY PRODUCTION

For estimating tertiary production fortnightly data were collected for a period of two years from a perennial field, whereas only 10 months data could be collected from the seasonal field. Harvesting was not regular in the case of coconut groves. Generally harvest took place during new moon and full moon and data pertaining to prawn/fish production were collected at the time of harvest. At the time of harvest the catch was sorted into different species of prawns and fishes. The quantity of each species landed was also noted at the time of harvest.

DIURNAL STUDIES

In order to find out the variation in the environmental parameters, diurnal studies were conducted at Edavanakkad perennial field during full moon, mid lunar and new moon days. In each lunar phase, the observations started at 06 00 hrs and completed at 06 00 hrs on the next day. Tide level was measured by fixing a graduated pole in the pond. Samples were collected at every two hours and they were analysed for temperature, salinity, pH, total alkalinity, dissolved oxygen, nutrients, chlorophylls and zooplankton.

STATISTICAL ANALYSES

In order to understand the relationship between the various physico-chemical and biological parameters of water, their values were subjected to computer analysis for the estimation of correlation coefficient, 'r'. The significance of correlation coefficient 'r' of different parameters such as water temperature, pH, salinity, total alkalinity, dissolved oxygen, primary production and zooplankton numbers were tested at 5% level.

Similarly to test the effect of treatments of these above mentioned environmental parameters of each system, two way Analysis of Variance (ANOVA) technique was employed and the F value was taken at 5% and 1% level respectively. In ANOVA tables, stations were considered as 'treatment' and seasons as 'replicate'.

RESULTS

The results of various environmental parameters studied during the period December 1988 to November 1990 are given below.

The rainfall data collected during this period showed a total of 2962 mm during 88-89; out of this 14% was recorded during premonsoon, 63% during southwest monsoon and 23% in postmonsoon period, whereas in 89-90, the total rainfall was 2371 mm with the seasonal percentage recorded as 26, 56 and 18 respectively (Fig.3).

I. PERENNIAL FIELDS

TEMPERATURE

The atmospheric temperature of the four perennial stations studied showed monthly variation ranging from 24.5°C (August '90, Panangad) to 31.5°C (March '89, Edavanakkad), whereas water temperature ranged between 26.8 (November '90, Cherai) to 36.0°C (April '90, Vaduthala). In these perennial stations, generally the premonsoon season showed higher values than monsoon and postmonsoon (Fig.4).

The correlation coefficients (r) were found to be significant at 5% level between water temperature and total alkalinity (0.335) at Cherai. In Vaduthala water temperature showed significant relationship with dissolved oxygen (0.416) and zooplankton number (0.365).

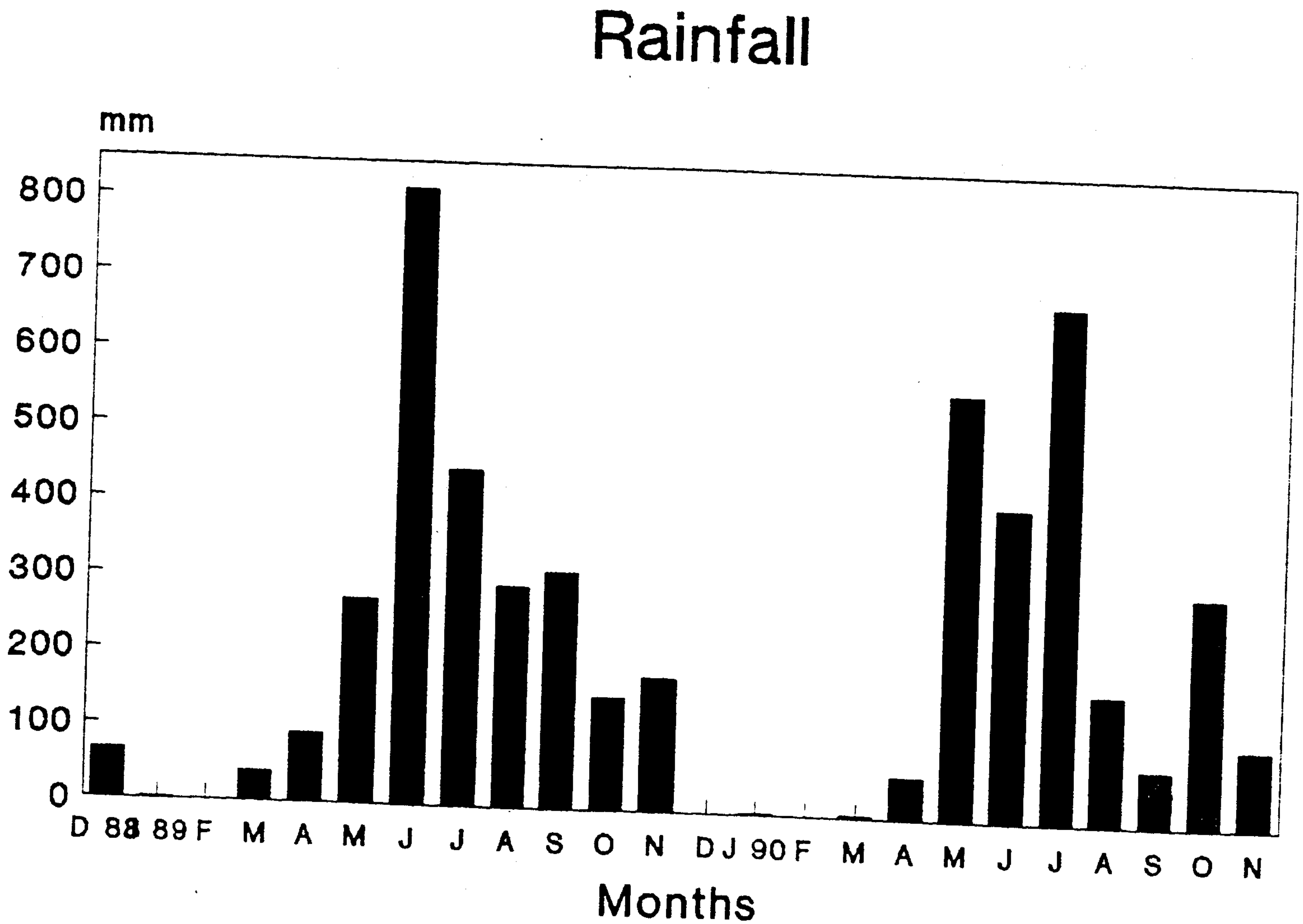


Fig. 3. Monthly variation in Rainfall

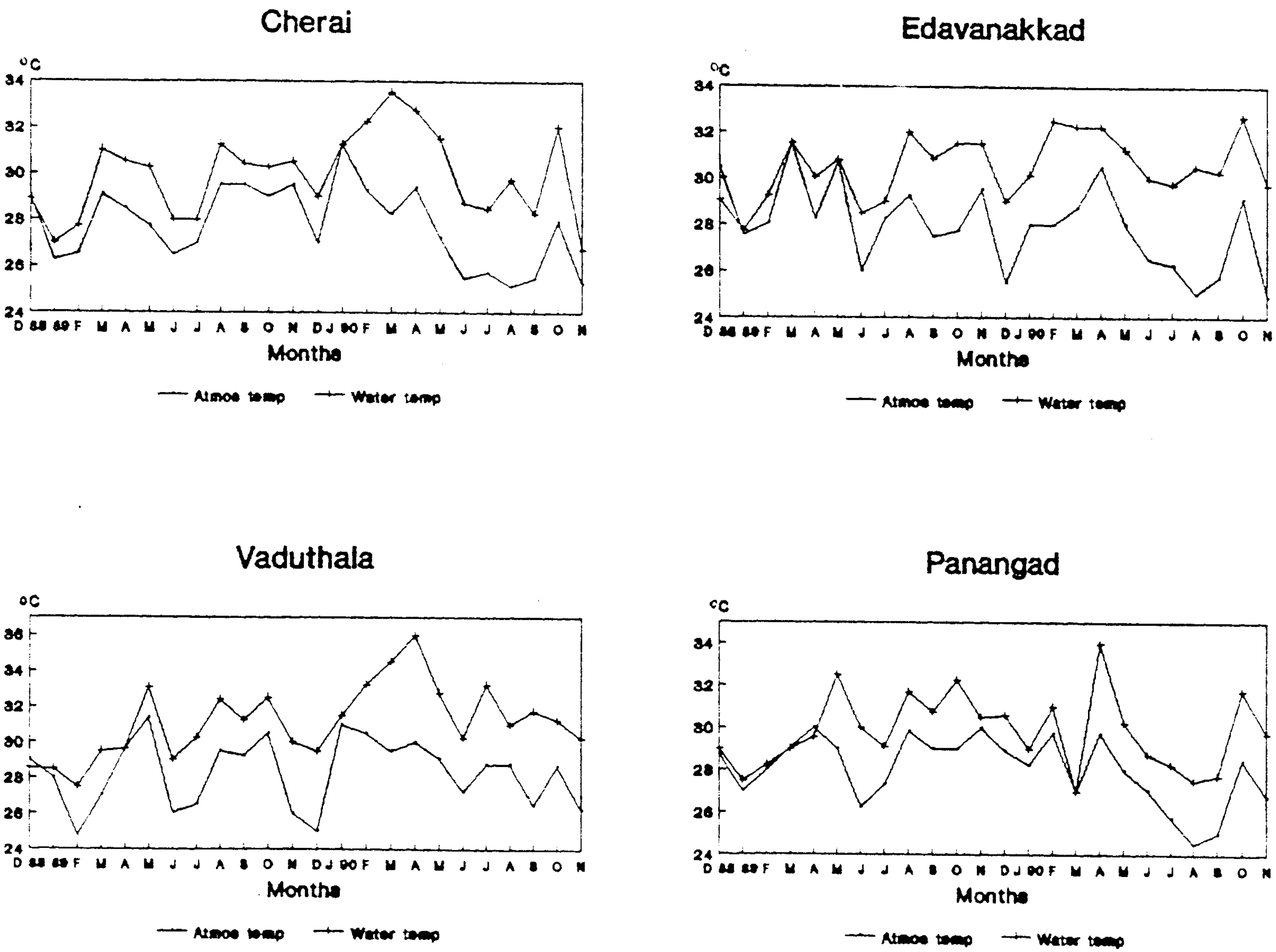


Fig. 4. Monthly variation in Atmospheric and Water temperature

It is evident from the two way ANOVA Table (Table-9) that there was significant variation in temperature among stations ($P < 0.05$), but showed highly significant variation over seasons ($P<0.01$).

pH

The monthly variation of pH in four stations is shown in Fig. 5. In all stations, pH values were generally on the alkaline side. However, slightly acidic values were recorded from these stations during July & September '89 and October '90 (Cherai), July '89 (Edavanakkad); July, November and December '89 and July, August and September '90 (Vaduthala) and July & November '89 and August '90 (Panangad). The pH ranged between 6.0 and 9.2. In these stations, the water was found to be more alkaline during premonsoon season.

In Cherai, pH showed a significant correlation with salinity (0.343); whereas it showed significant relationship with dissolved oxygen (0.487) and primary production (0.361) in Vaduthala, as seen from Table-8. In Panangad, both salinity (0.323) and alkalinity (0.368) showed significant correlation with pH.

Two way ANOVA Table (Table-9) showed that there was no significant variation in pH among the stations, but showed significant variation over seasons ($P < 0.05$).

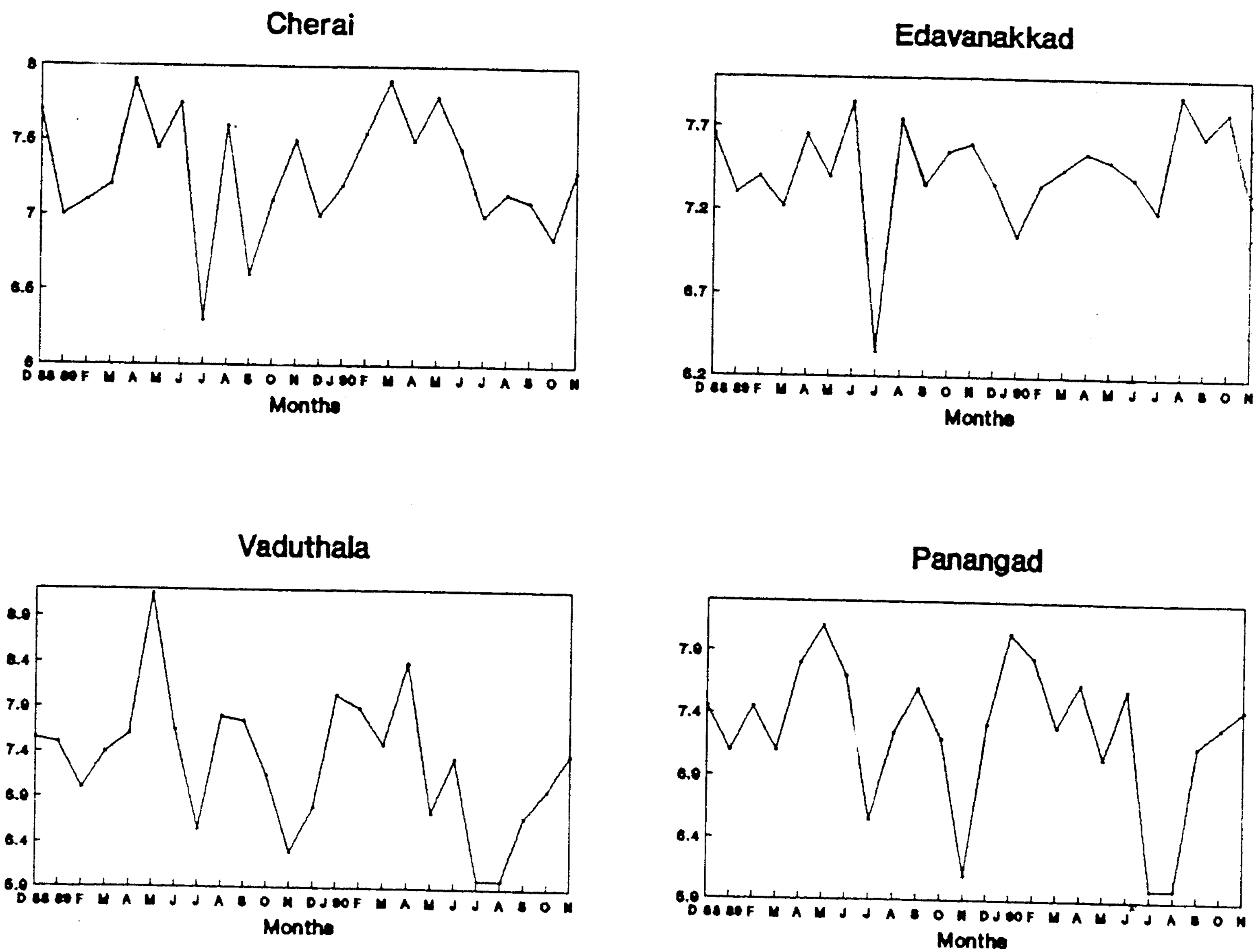


Fig. 5. Monthly variation in pH

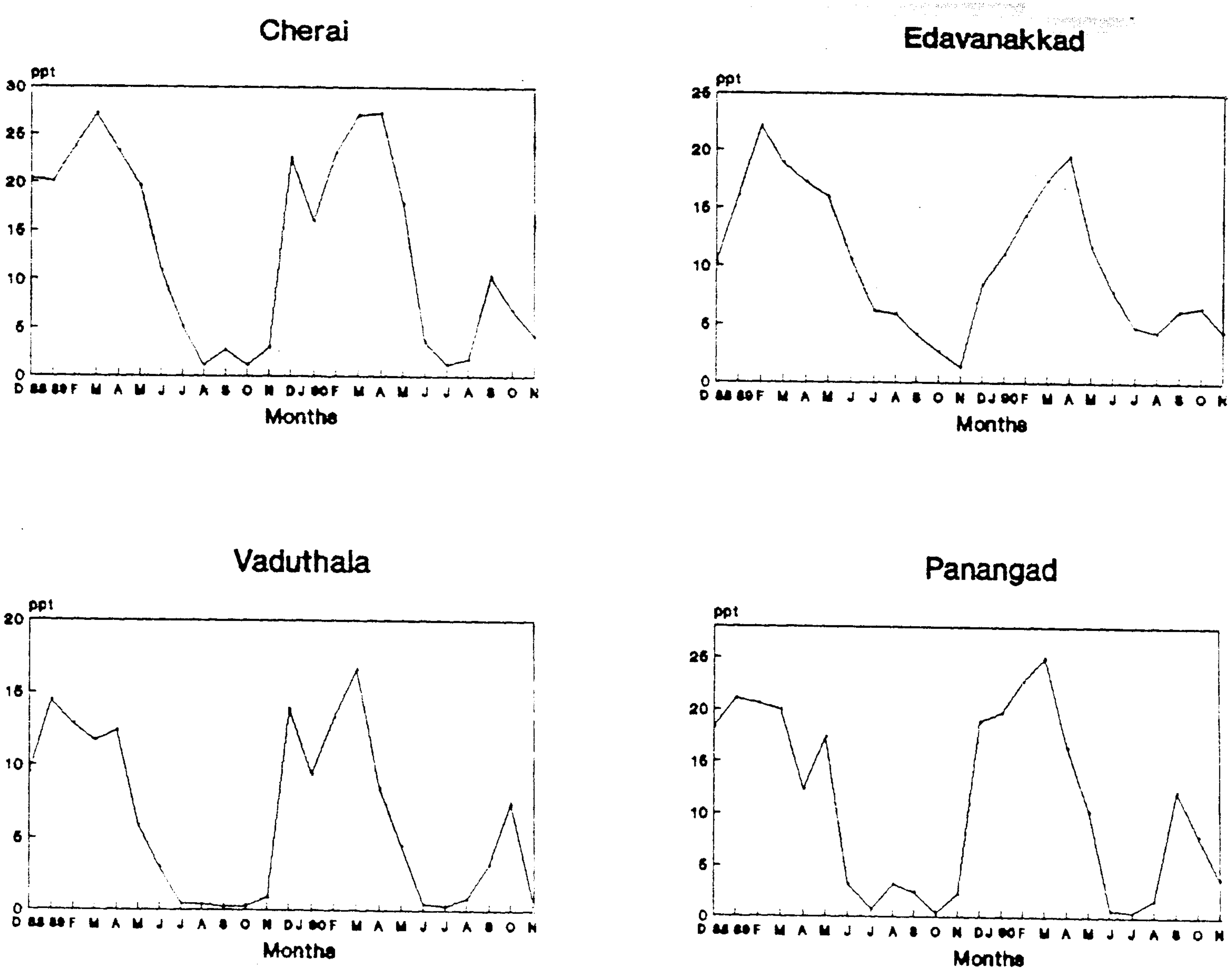


Fig. 6. Monthly variation in Salinity

SALINITY

Sharp seasonal salinity variations were recorded in different seasons throughout the perennial fields. In general, salinity varied from 0.28‰ (September '89, Vaduthala) to 27.23‰ (Cherai, April '90). Low values were invariably recorded during monsoon in all the stations and there was no marked variation in the salinity values between the two years (Fig.6).

It is seen from Table-8 that salinity showed a significant positive correlation with primary production (0.358) and pH (0.343) at Cherai. Similarly significant relationship was noticed between salinity and alkalinity at Vaduthala (0.447) and Panangad (0.896).

The ANOVA Table showed that there was no significant variation in salinity among the stations. However, highly significant variation over seasons ($P < 0.01$) was noticed (Table-9).

TOTAL ALKALINITY

This hydrographic parameter showed high values in all the four stations. Alkalinity varied from 10 mg/l (Panangad) during November '89 to 130 mg/l (Edavanakkad) during June '90. In Cherai and Panangad, the premonsoon season showed higher alkalinity values; however, no definite trend was discernible in Edvanakkad and Vaduthala stations (Fig. 7).

Alkalinity showed significant correlation with primary production (0.406) and water temperature (0.335) at Cherai; at Vaduthala the relationship

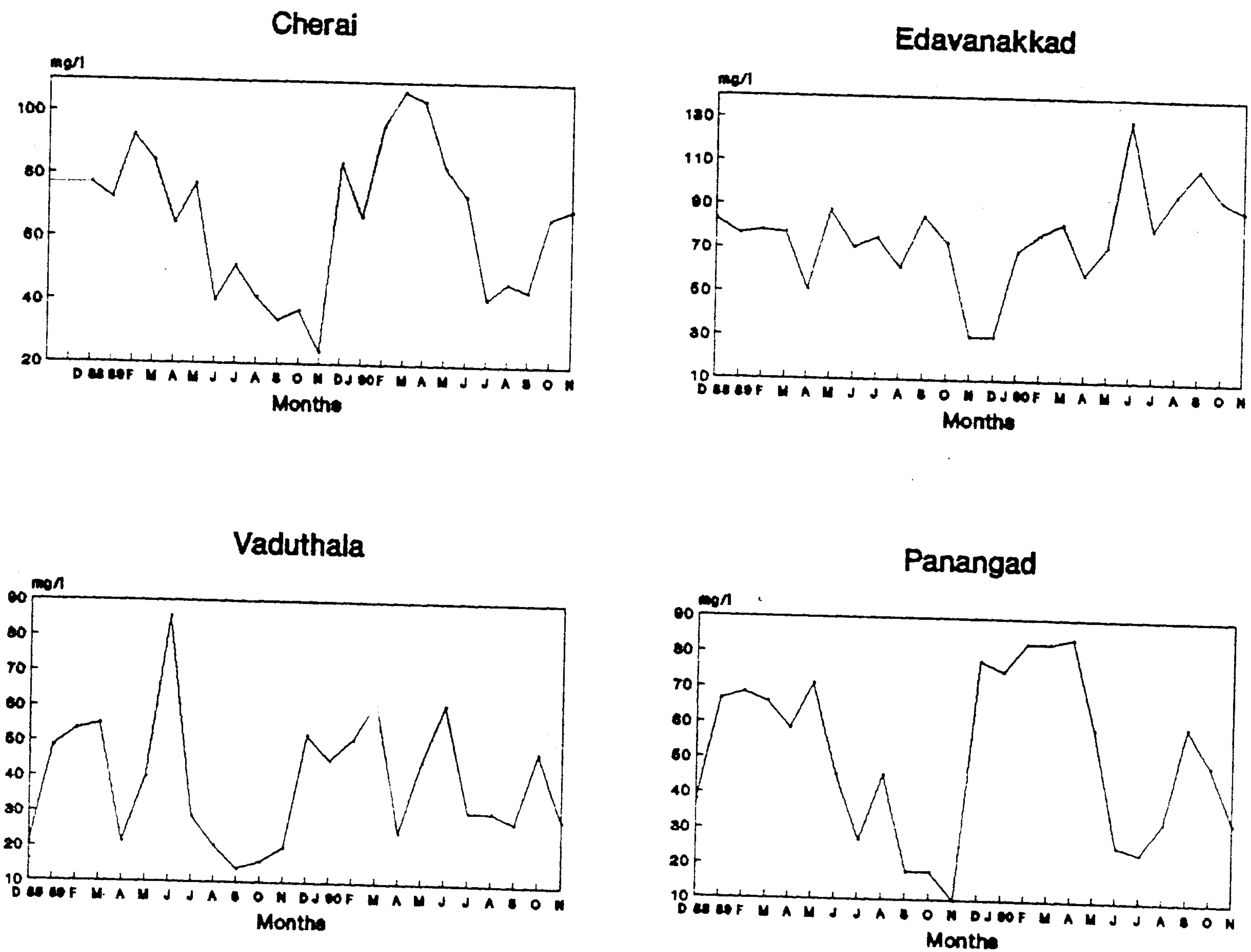


Fig. 7. Monthly variation in Total Alkalinity

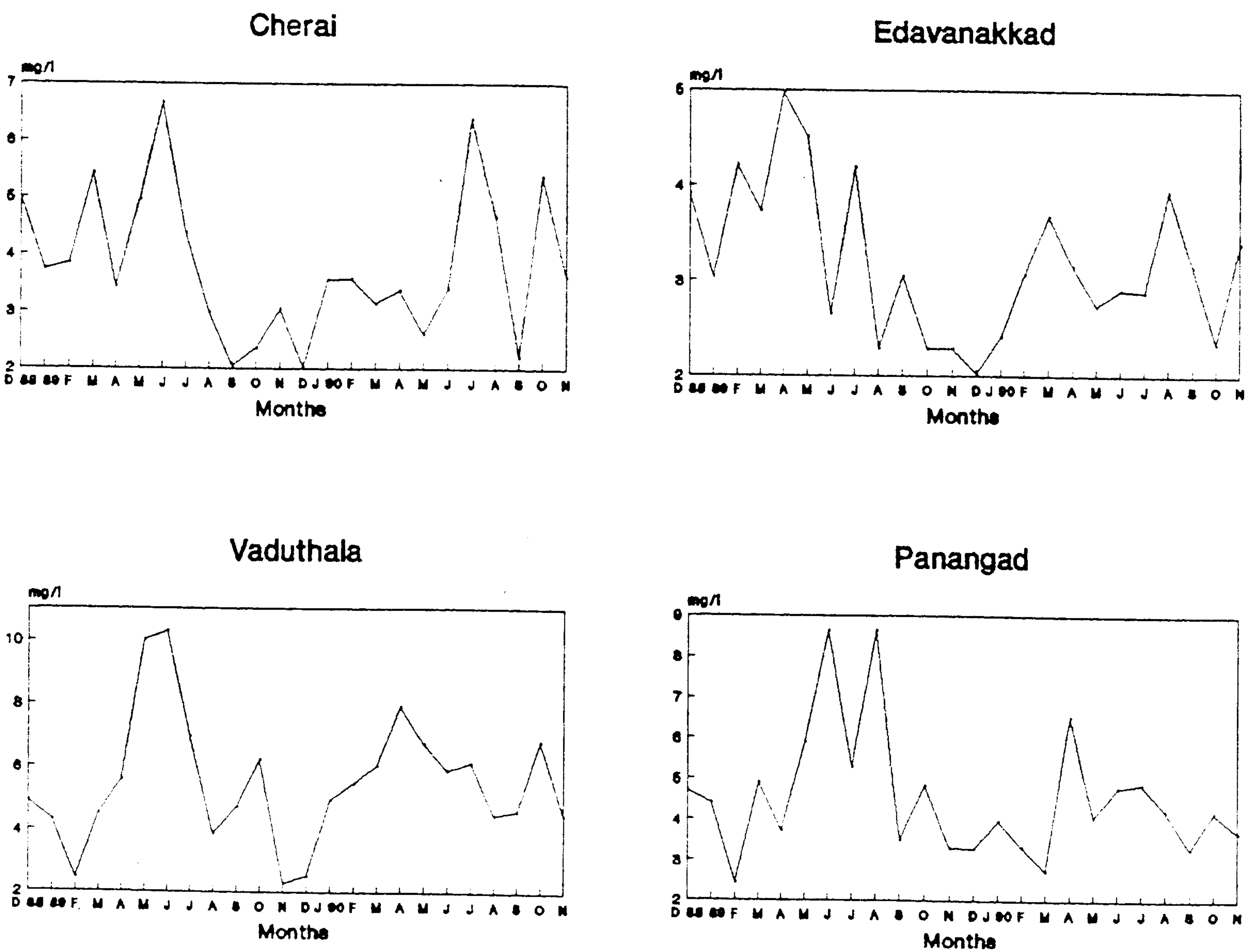


Fig. 8. Monthly variation in Dissolved Oxygen

was with salinity (0.447) and in Panangad both pH (0.368) and salinity (0.896) showed significant relationship with alkalinity as seen from Table-8.

ANOVA Table (Table-9) showed significant variation in alkalinity in different stations ($P < 0.05$), whereas the variation was insignificant over seasons.

DISSOLVED OXYGEN

The dissolved oxygen concentration in the perennial fields varied from 2.03 to 10.29 mg/l (Fig. 8). The highest value of 10.29 mg/l was recorded from Vaduthala in July '89, whereas the lowest value (2.03 mg/l) was noticed in Cherai and Edavanakkad during December '89. In general, the monsoon season recorded higher dissolved oxygen content than premonsoon and postmonsoon.

As seen from Table-8, dissolved oxygen exhibited significant relationship with primary production (0.312), water temperature (0.416) and pH (0.487) at Vaduthala.

It can be seen from the ANOVA Table (Table-9) that there was no significant variation in dissolved oxygen concentration among the stations and over the seasons.

NITRATE AND NITRITE-NITROGEN

Monthly variations of Nitrate-N and Nitrite-N in the four perennial fields are shown in Fig.9. The concentration of Nitrate-N fluctuated from 0.15 (Cherai, April '89) to 27.8 μg at/l (Vaduthala, June '90); whereas Nitrite-N varied from 0.003 (Cherai, April '89) to 3.38 μg at/l (Vaduthala, January '90). The peak concentration of Nitrate-N (27.8 μg/l) was recorded in Vaduthala during June '90. Invariably in all the four stations, high values of Nitrate-N was found during monsoon and postmonsoon seasons. Nitrite-N concentration as well as its seasonal fluctuation was generally low during the study period. Relatively higher values of Nitrite-N were observed in all stations during January to November '90.

ANOVA Table (Table-9) showed that the variation in the concentration of Nitrate-N was significant ($P < 0.05$) among the stations and was not significant over seasons. Similarly, the variation in Nitrite-N concentration was highly significant ($P < 0.01$) among the stations while no significant variation was noticed over different seasons.

AMMONIA-NITROGEN

The concentration of Ammonia-N fluctuated from as low as 1.88 to as high was 164.93 μg at/l (both at Cherai) without any definite trend of distribution during different months (Fig. 10).

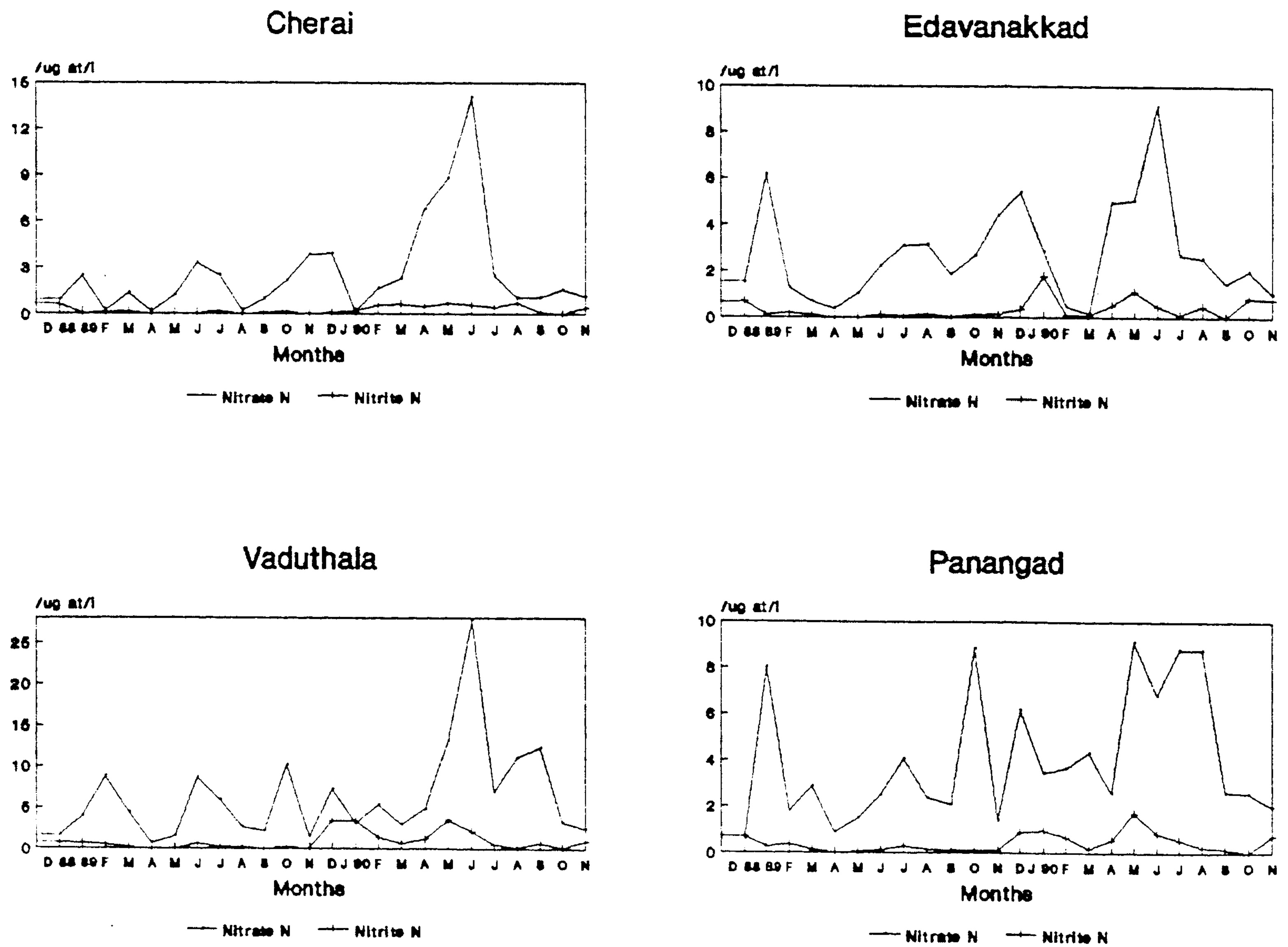


Fig. 9. Monthly variations in Nitrate and Nitrite-nitrogen

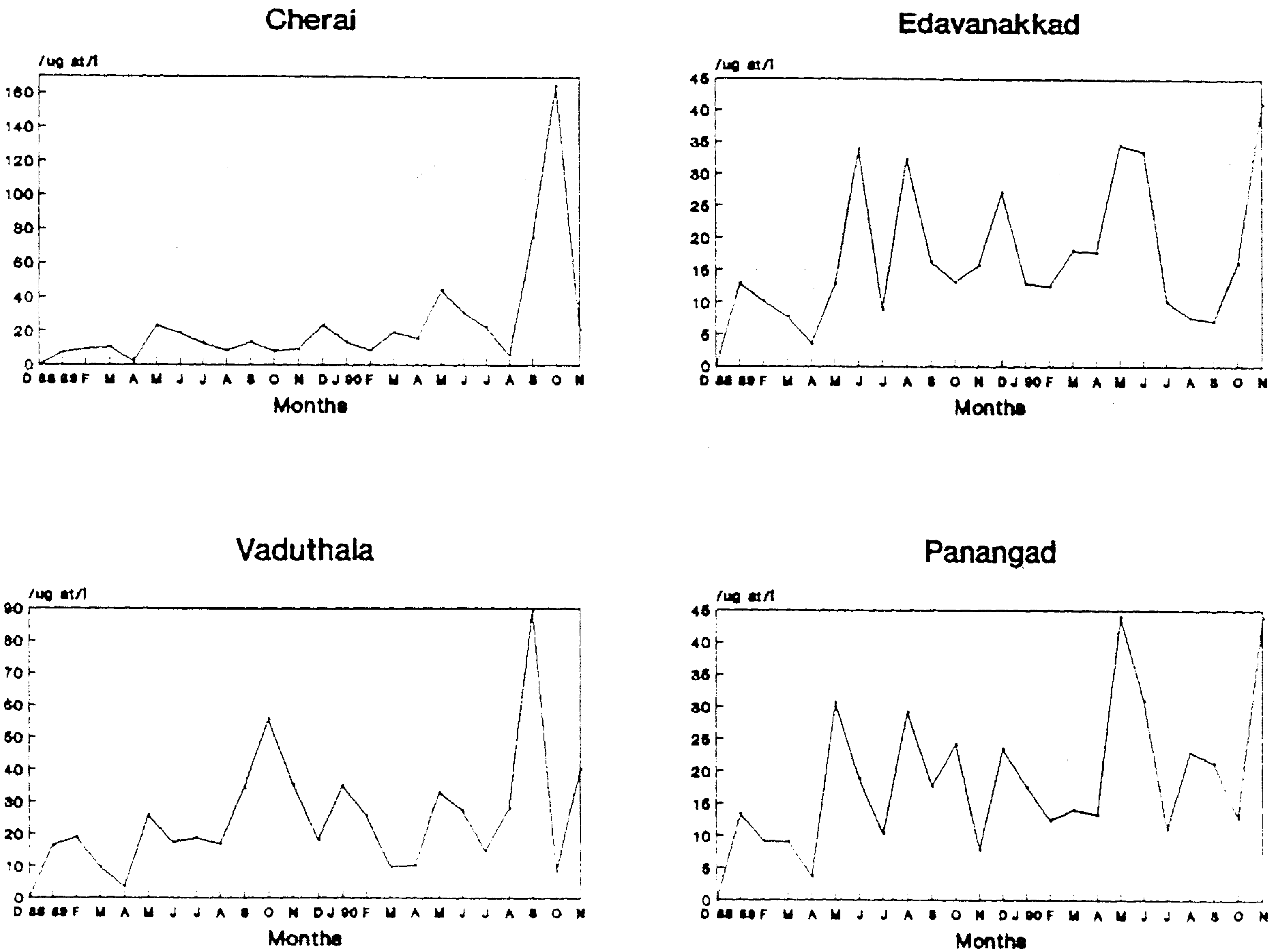


Fig. 10. Monthly variation in Ammonia-Nitrogen

REACTIVE PHOSPHORUS

The seasonal trends in distribution of reactive phosphorus in the perennial stations are shown in Fig. 11. The month-wise distribution of this nutrient showed wide fluctuation from zero to 15.5 μg at/l with the lowest value recorded in Panangad during November '89 and the highest in Edavanakkad during May '90. In general, reactive phosphorus concentration was high during premonsoon and low in monsoon months.

It can be seen from the ANOVA (Table-9) that the variation in the concentration of reactive phosphorus was significant ($P < 0.05$) among the stations and over the seasons.

SILICATE-SILICON

The silicate values ranged from 3 to 160 μg at/l in the perennial fields. The highest concentration was found in Edavanakkad and Vaduthala during April and May '89 respectively. No clear demarcation of seasonal trends in the concentration of silicate was discrenible in any of the stations studied (Fig. 12).

Two way ANOVA (Table-9) showed that the variation in the silicate concentration was not significant from station to station and over seasons.

ORGANIC CARBON CONTENT OF THE SEDIMENT

Seasonal variation of organic carbon is given in Table-1. In '88-89,

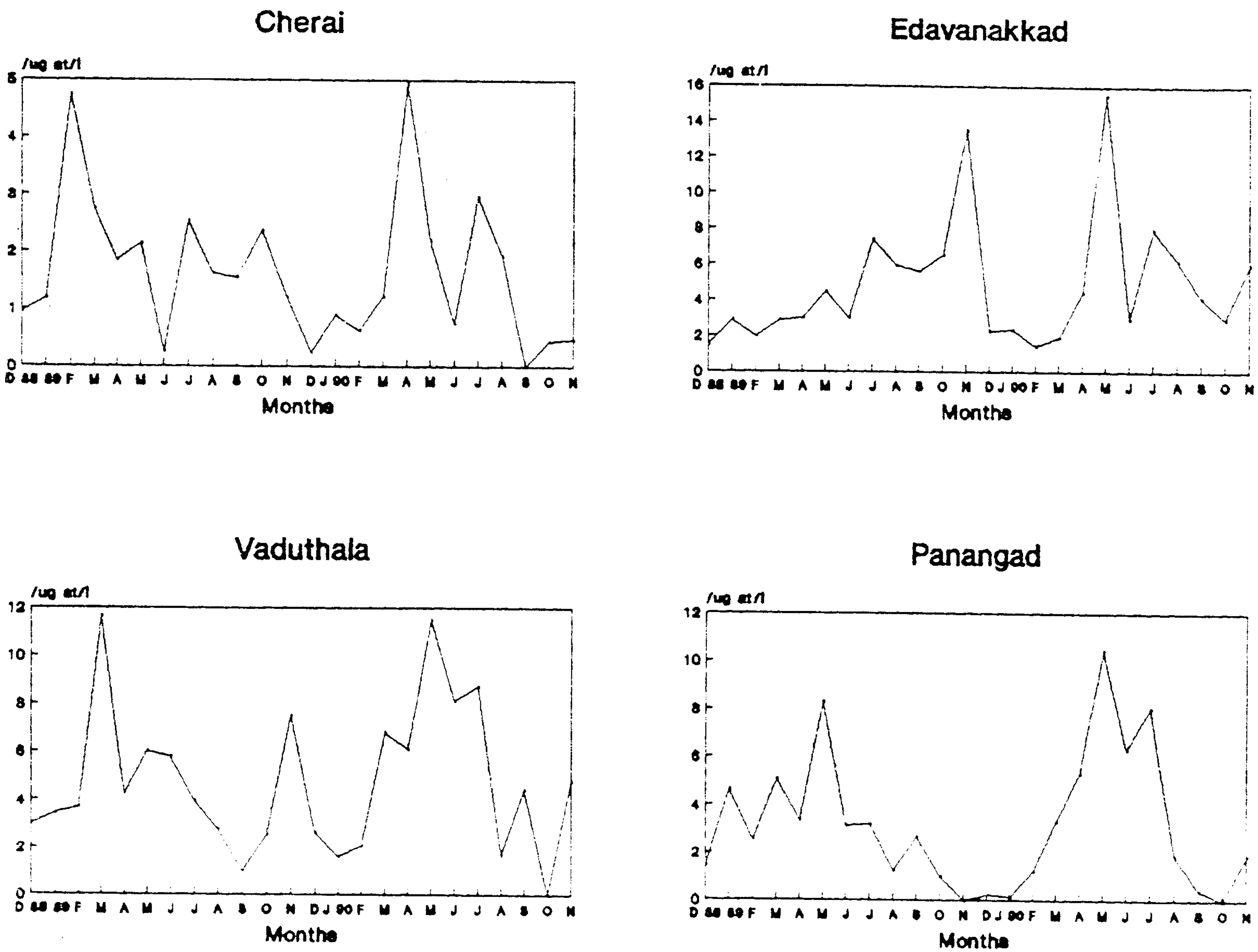


Fig. 11. Monthly variation in Reactive phosphorus

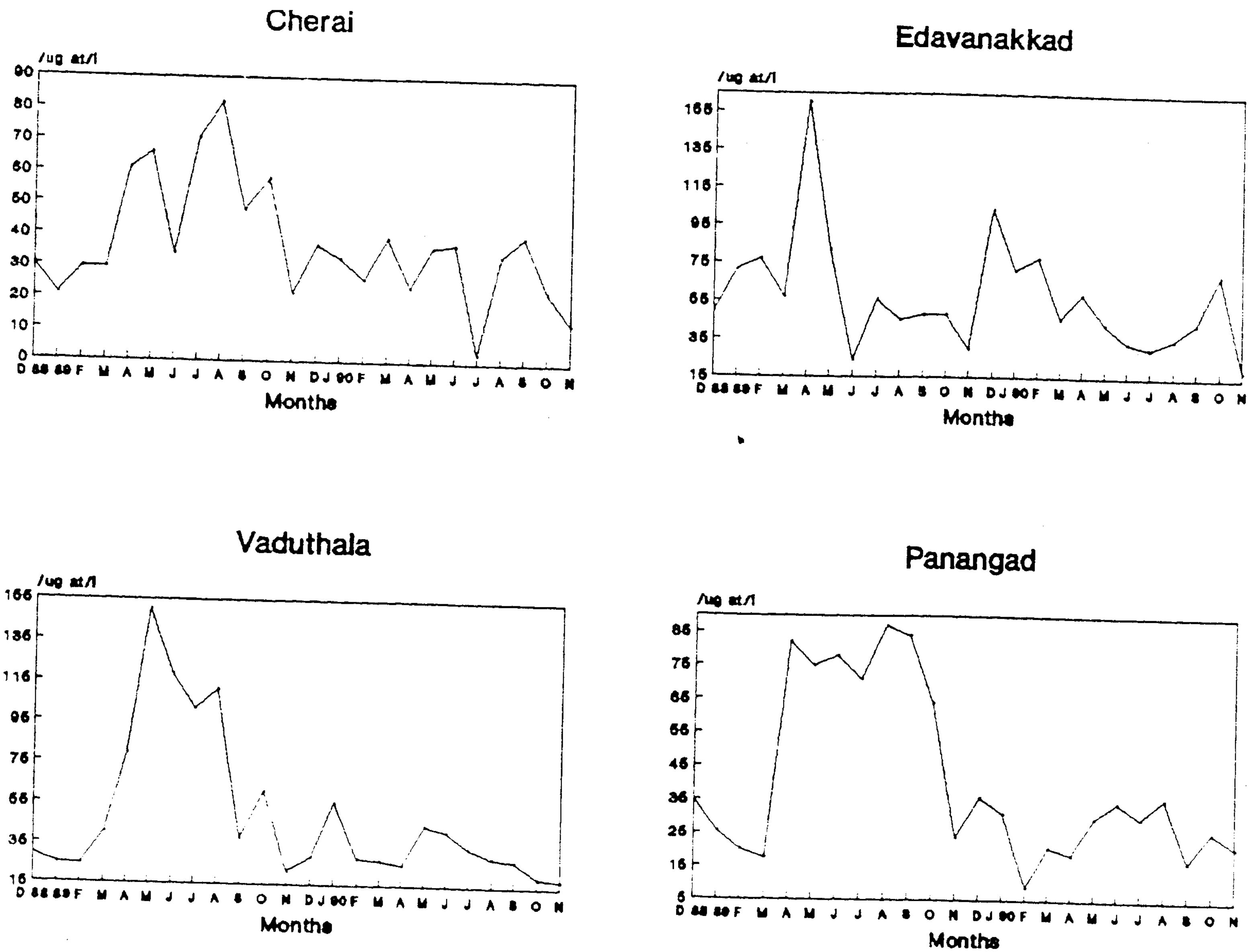


Fig. 12. Monthly variation in Silicate-silicon

high values were recorded during postmonsoon in all stations. However, the values never exceeded 2%. Low values were recorded during monsoon at Cherai and Panangad and premonsoon at Edavanakkad and Vaduthala. In 89-'90 period, higher values were recorded during premonsoon at Cherai (3.64%) and monsoon months at Vaduthala (3.28%).

Table-1. Seasonal variation of organic carbon content in the sediment (%)

Station	Premonsoon 88-89	Premonsoon 89-90	Monsoon 88-89	Monsoon 89-90	Postmonsoon 88-89	Postmonsoon 89-90
Cherai	1.01	3.64	0.12	0.23	1.88	0.69
Edavanakkad	1.55	1.07	1.78	0.51	1.95	0.54
Vaduthala	1.84	2.52	1.88	3.28	1.98	0.67
Panangad	1.31	1.41	1.19	1.98	1.60	1.12

ANOVA Table (Table-9) showed that there was no significant variation in the organic carbon content of the soil from station to station and in different seasons.

PRIMARY PRODUCTION

The rate of primary production in the perennial fields of Cherai, Edavanakkad, Vaduthala and Panangad are given month-wise in Fig. 13. Among the four stations studied, the highest productivity was recorded in Vaduthala (9186 $mgC/m^3/day$) during May '89. In Cherai, the

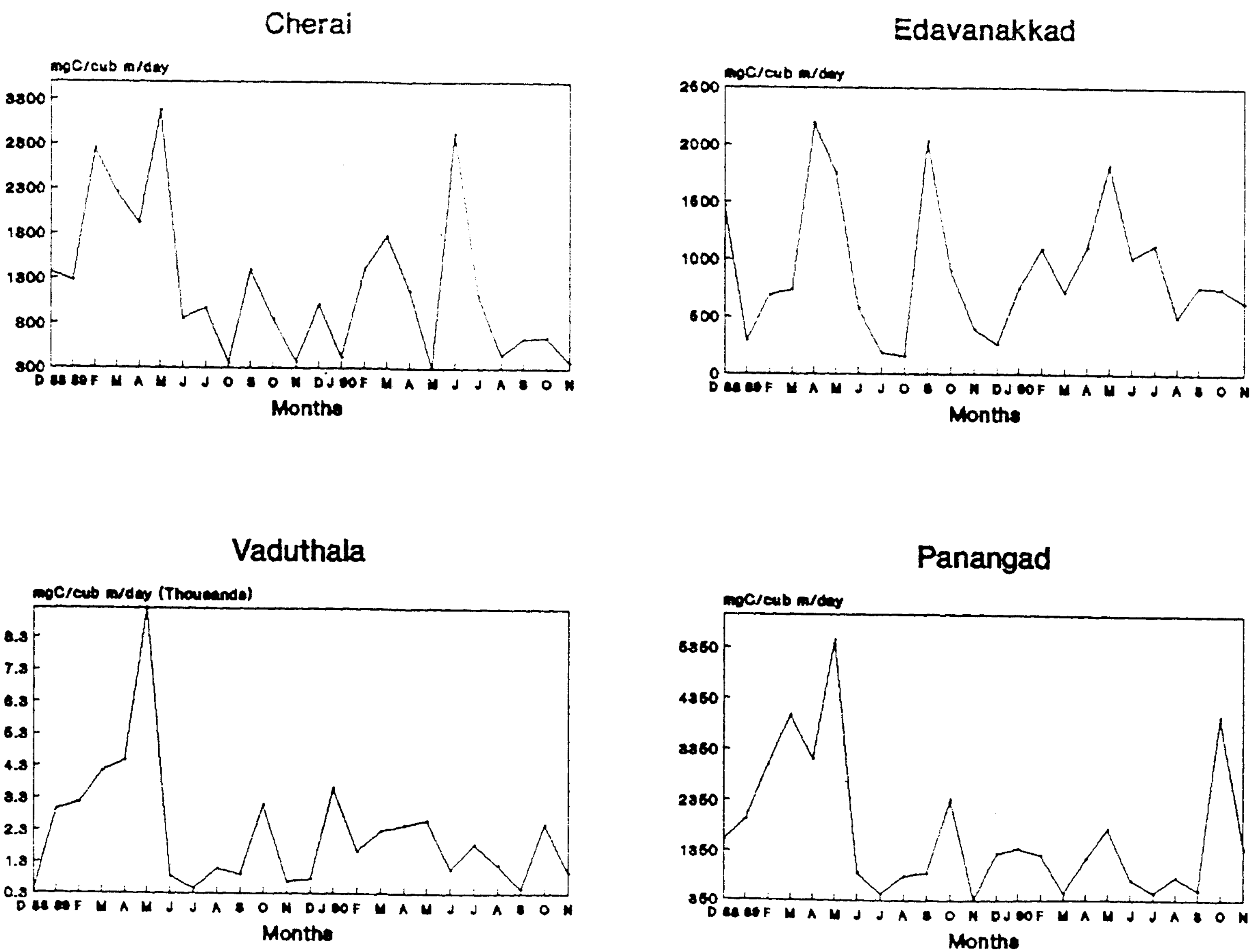


Fig. 13. Monthly variation in Primary production

productivity ranged from 310 to 3170 mgC/m^3/day with the peak values observed in May '89 and June '90. In Edavanakkad, the values varied from 156 to 2184 mgC/m^3/day with several crusts and dips. Similarly, in Panangad field, the productivity fluctuated from 375 to 5500 mgC/m^3/day without showing any seasonal trend.

Primary production showed significant positive correlation with salinity (0.358) and alkalinity (0.406) at Cherai, with pH (0.361) and dissolved oxygen (0.312) at vaduthala as shown in Table-8.

Two way ANOVA Table (Table-9) showed that the variation in primary production among the stations was not significant, whereas it was significant over seasons ($P < 0.05$).

PHYTOPLANKTON COMPOSITION

Cherai: The availability of important phytoplankton genera is given in Table-2a. It consisted of members of three classes, viz., Bascillariophyceae (diatoms), Myxophyceae (blue green algae) and dinophyceae (dinoflagellates). Diatoms were dominant throughout the study period and represented by mostly *Diploneis robustus*, *Navicula* sp and *Pleurosigma* sp. In the above genera *Pleurosigma* was abundant throughout the seasons. Members of the Class Myxophyceae (*Lyngbya* and *Synechocystis*) and Dinophyceae (*Peridinium*) were also present in this water body. The genera *Lyngbya*

Table-2a. Seasonal availability of phytoplankton components - Cherai.

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Amphora lineolata	X	R	X
A. ostrearia	R	C	X
Coscinodiscus sp.	X	C	X
Diploneis robustus	C	A	C
D. smithi	C	C	X
Grammatophora undulata	X	R	X
Gyrosigma sp.	C	A	R
Lyngbya sp	X	R	X
Navicula sp.	C	A	C
Nitzschia sp.	X	A	R
N. closterium	C	X	X
Peridinium sp.	X	R	X
Pleurosigma sp.	A	A	A
Rhizosolenia sp.	X	R	X
Stephanopyxis palmeriana	X	C	X
Surerella exima	X	R	R
Synechocystis sp.	R	X	X
Thalassionema nitzschiocoides	X	R	X
Thalassiosira subtilis	X	C	X
Tropidoneis lepidoptera	C	C	X

*A - Abundant; C - Common; R - Rare; X - Not observed.

Table-2b. Seasonal availability of Phytoplankton components - Edavanakkad.

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Amphora ostrearia	X	X	R
Coscinodiscus sp.	R	R	X
Diploneis robustus	R	A	X
Euglena sp.	R	X	X
Gyrosigma sp.	R	C	R
Navicula sp.	X	X	C
Nitzschia sp.	X	A	X
Peridinium sp.	X	R	X
Pleurosigma sp.	C	C	A
Skeletonema costatum	R	X	X
Surerella exima	R	R	X
Stephanophyxis palmeriana	X	R	X
Tropidoneis lepidoptera	X	R	X

*A - Abundant; C - Common; R - Rare; X - Not observed.

and Peridinium occurred during monsoon and Synehocystis in premonsoon season.

Edavanakkad: Diatoms were the most dominant component almost throughout the period. Phytoplankters belonging to the classes Euglenophyceae and Dinophyceae occurred in less numbers. Pleurosigma sp occurred throughout the season with particular abundance during postmonsoon. Navicula and Gyrosigma were common during postmonsoon and monsoon respectively Euglena and Peridinium were the rare components in this station (Table-2b).

Vaduthala: As in other perennial fields, diatoms were the dominant constituents of phytoplankton followed by Chlorophyceae and Dinophyceae. Green algae like Chlamydomonas and Pandorina and dinoflagellate (Peridinium) occurred during monsoon. None of the genera were abundant in all seasons except Skeletonema costatum which was abundant in premonsoon. Species such as Navicula and Nitzschia sp were common in this water body during monsoon season (Table-2c).

Panangad: As seen from Table-2d, it is evident that the diatoms were the major item of phytoplankters followed by Dinophyceae. Pleurosigma occurred throughout the seasons while Skeletonema costatum and Navicula were abundant during postmonsoon, premonsoon and monsoon respectively. Diploneis, Gyrosigma and Thalassiosira were encountered during postmonsoon season.

Table-2c. Seasonal availability of phytoplankton components - Vaduthala.

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Biddulphia sp.	R	X	X
Coscinodiscus sp.	X	R	R
Cymbella marina	X	R	R
Chlamydomonas sp.	X	C	X
Diploneis robustus	R	C	X
D. smithi	X	R	X
Gyrosigma sp.	R	R	X
Navicula longa	X	R	X
Navicula sp.	R	C	X
Nitzschia closterium	R	C	X
Nitzschia sp.	R	C	X
Pandorina sp.	X	R	X
Peridinium sp.	X	A	X
Pleurosigma sp.	X	C	R
P. elongatum	X	R	X
Rhizosolenia sp.	X	X	R
Skeletonema costatum	A	X	R
Stephanopyxis palmeriana	X	X	R
Synedra ulna	X	R	X
Thalassionema nitzschicoides	X	R	X
Thalassiosira subtilis	X	R	X
Tropidoneis lepidoptera	R	X	R

*A - Abundant; C - Common; R - Rare; X - Not observed.

Table-2d. Seasonal availability of phytoplankton components - Panangad.

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Amphora lineolata	X	R	X
Coscinodiscus sp.	A	C	X
Cymbella marina	X	R	X
Diploneis robustus	X	R	C
D. smithi	X	X	R
Gyrosigma sp.	X	C	C
Grammatophora undulata	X	R	X
Navicula sp.	X	A	R
Nitzschia longissima	X	R	X
Nitzschia sp.	R	C	X
Peridinium sp.	R	C	X
Pleurosigma sp.	C	C	C
P. elongatum	X	R	X
Skeletonema costatum	A	X	A
Stephanopyxis palmeriana	R	R	X
Syndera ulna	X	R	X
Thalassiosira subtilis	X	R	C

*A - Abundant; C - Common; R - Rare; X - Not observed.

CHLOROPHYLLS AND CAROTENOIDS

The percentage concentration of chlorophyll - a,b,c and carotenoids is shown below:

Station	Chlorophyll-a	Chlorophyll-b	Chlorophyll-c	Carotenoids
Cherai	47	10	15	28
Edavanakkad	37	16	17	30
Vaduthala	49	10	11	30
Panangad	46	14	17	23

Concentration of chlorophyll-a,b,c and carotenoids in the different perennial stations during December '88 to November '90 is shown in Fig.14 a & b. The concentration of chlorophyll-a accounted for 47% (Cherai), 37% (Edavanakkad), 49% (Vaduthala) and 46% (Panangad) of the total chlorophylls. It ranged from 0.68 (Edavanakkad, April '90) to 169.7 mg/m^3 (Vaduthala,April '90) without a steady seasonal distribution pattern; whereas in these perennial fields the seasonal concentration of chlorophyll-b fluctuated from 0 to 61.07 mg/m^3 in Edavanakkad where it formed 16% of the total plant pigment concentration. The fluctuation of chlorophyll-b also showed no definite seasonal trend. Chlorophyll-c also showed the same trend of distribution (0 to 54.86 mg/m^3) and constituted 11% of the total plant pigment. The premonsoon season indicated relatively higher concentration of chlorophyll-c.

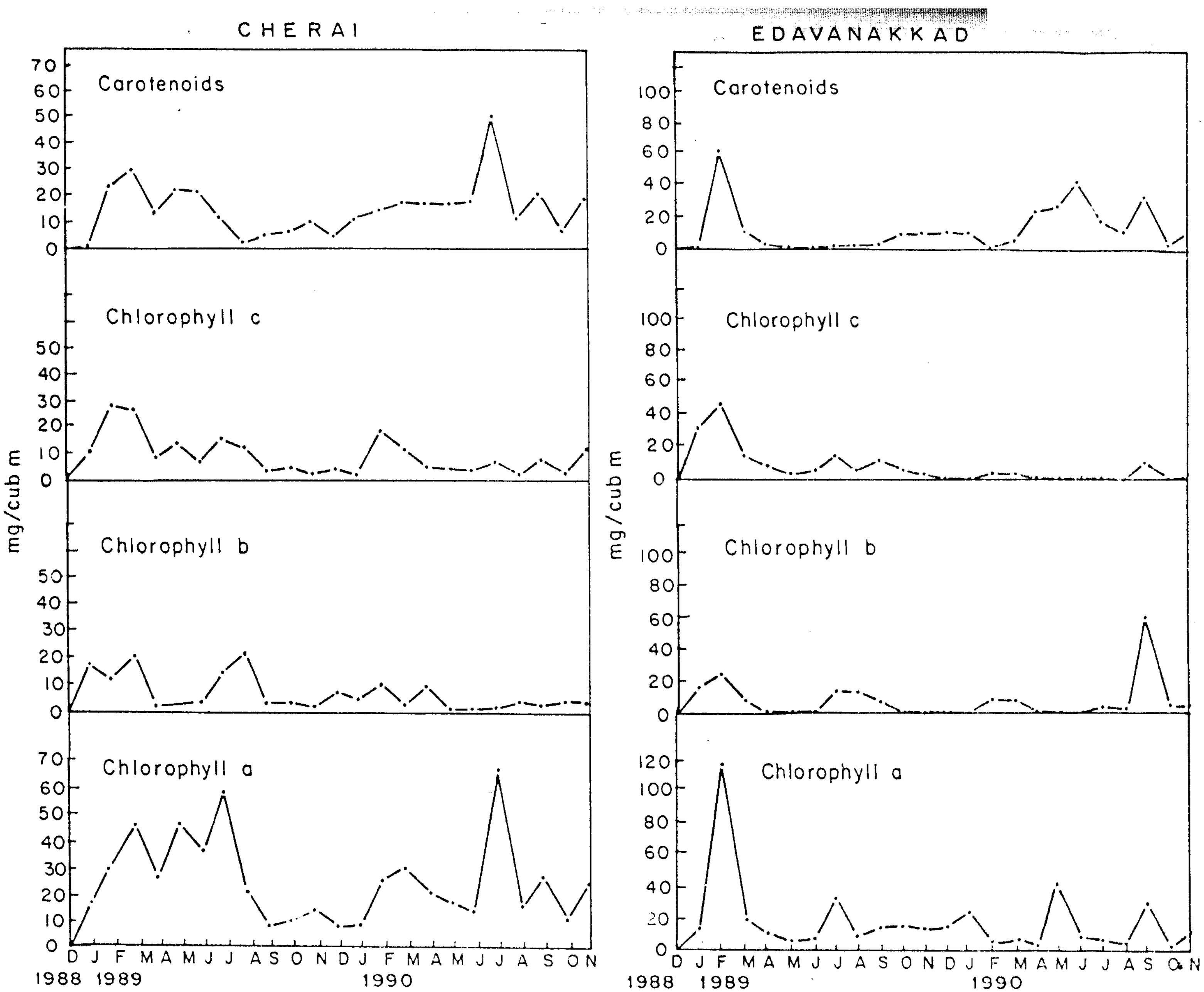


Fig. 14a . Monthly variation in Chlorophyll and Carotenoid concentration

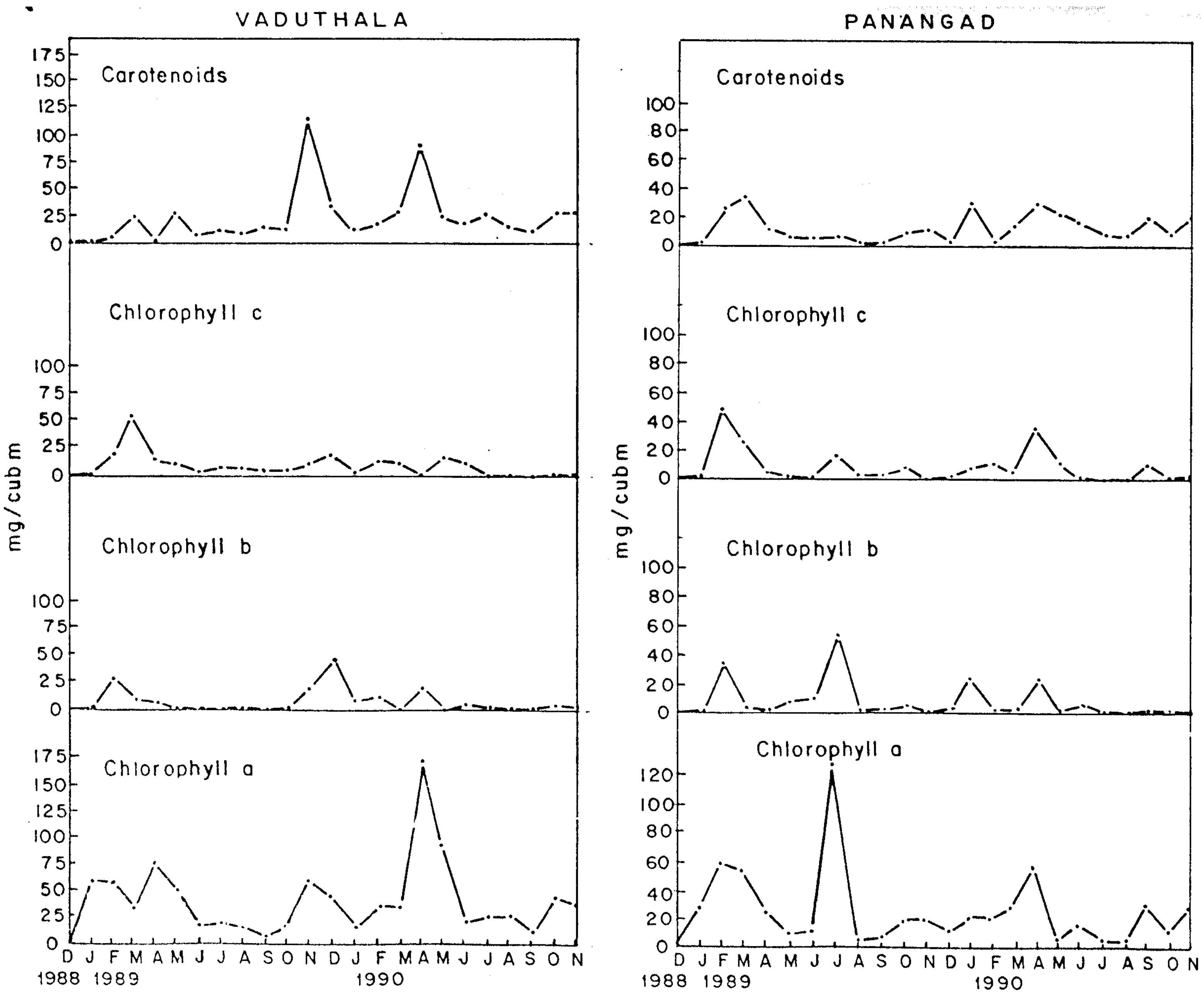


Fig. 14b. Monthly variation in Chlorophyll and Carotenoid concentration

Carotenoids varied from 0 to 116.69 mg/m^3 (Vaduthala) with no regular pattern of monthly distribution and it formed 30% of the plant pigment in the same station.

From the ANOVA Table (Table-9), it is clear that Chlorophylls (a, b & c) did not show any significant variation among the stations and over seasons while the variation in the concentration of carotenoid was significant ($P < 0.05$) among the stations and with seasons.

QUANTITATIVE ABUNDANCE OF ZOOPLANKTON

Table-3 shows the seasonal variation of zooplankton biomass.

Cherai: Low biomass value (1698 Nos and 4 ml/100 m^3) was recorded during postmonsoon in 1988-89 and high value of 100 ml/100 m^3 (30761 Nos) was observed in premonsoon; whereas in 89-90, the biomass varied from 40 ml in monsoon season to 1000 ml/100 m^3 in postmonsoon. Premonsoon was the next productive season with 56116 numbers and 200 ml/100 m^3.

Edavanakkad: This station also showed high biomass values both by number (159404) and by volume (150 ml) during premonsoon in 88-89. However, in 89-90, the highest number (566794) and volume (850 ml) were noticed during postmonsoon. In both years, the lowest biomass values were recorded during monsoon.

<u>Vaduthala:</u> The biomass values during the two year period was found to be high in premonsoon season. In 88-89, the second highest biomass value was during postmonsoon with 25 ml/100 m^3 (5268 Nos); whereas in 89-90, both postmonsoon and monsoon showed the same biomass value in terms of volume (100 ml), while their numbers fluctuated widely (23834 and 36819).

<u>Panangad:</u> This station showed different trends in the fluctuation of biomass during 88-89 and 89-90. In 88-89, plankton biomass showed peak value of 100 ml/100 m^3 (32003 Nos) during monsoon. Lowest value (45 ml/100m^3) was recorded during postmonsoon, whereas in 89-90, postmonsoon recorded higher value of 100 ml (29667 Nos) per 100 m^3 than during premonsoon (500 ml and 17222 Nos) and monsoon (25 ml and 9193 Nos).

Table-3. <u>Quantitative abundance (Nos/Vol. per 100 m^3) of zooplankton.</u>

Season	Cherai		Edavanakkad		Vaduthala		Panangad	
	Nos.	Vol. (ml)	Nos	Vol. (ml)	Nos	Vol. (ml)	Nos	Vol. (ml)
1988-89								
Premonsoon	30761	100	159404	150	300058	300	19377	50
Monsoon	9195	20	38507	50	6758	15	32003	100
Postmonsoon	1698	4	33948	100	5268	25	4805	45
1989-90								
Premonsoon	56116	200	135999	250	45546	150	17222	50
Monsoon	18318	40	29669	45	36819	100	9193	25
Postmonsoon	310007	1000	566794	850	23834	100	29667	100

Zooplankton number showed statistically significant relationship with water temperature (0.365) and primary production (0.317) at Vaduthala (Table-8).

The two way Analysis of Variance (Table-9) showed that the zooplankton biomass did not exhibit any significant variation among the stations and with seasons.

QUALITATIVE COMPOSITION OF ZOOPLANKTON

Cherai: The monthly percentage occurrence and seasonal percentage composition of important zooplankton in the perennial field of Cherai is shown in Fig. 15a and Table-4a. Copepods were the most dominant component of the zooplankton almost throughout the period of study from December '88 to November '90. Their percentage composition fluctuated from 6.8 in July '90 to 100 in December '88. Generally, this group had high abundance during premonsoon and postmonsoon seasons. Numerically, copepods accounted for 92.8% of the total zooplankton production of this station. The next dominant component was mysids, contributing to about 2.6% of the total zooplankton production. Mysids were generally abundant during the premonsoon season. However, unusual abundance of this group was recorded during July '90 forming 69.2% of the total plankton production. Nauplii, especially of copepods, formed 1.1% of the total zooplankton during monsoon season. Ostracods were the next important (0.9%) planktonic component with their abundance during monsoon season. The less abundant plankton

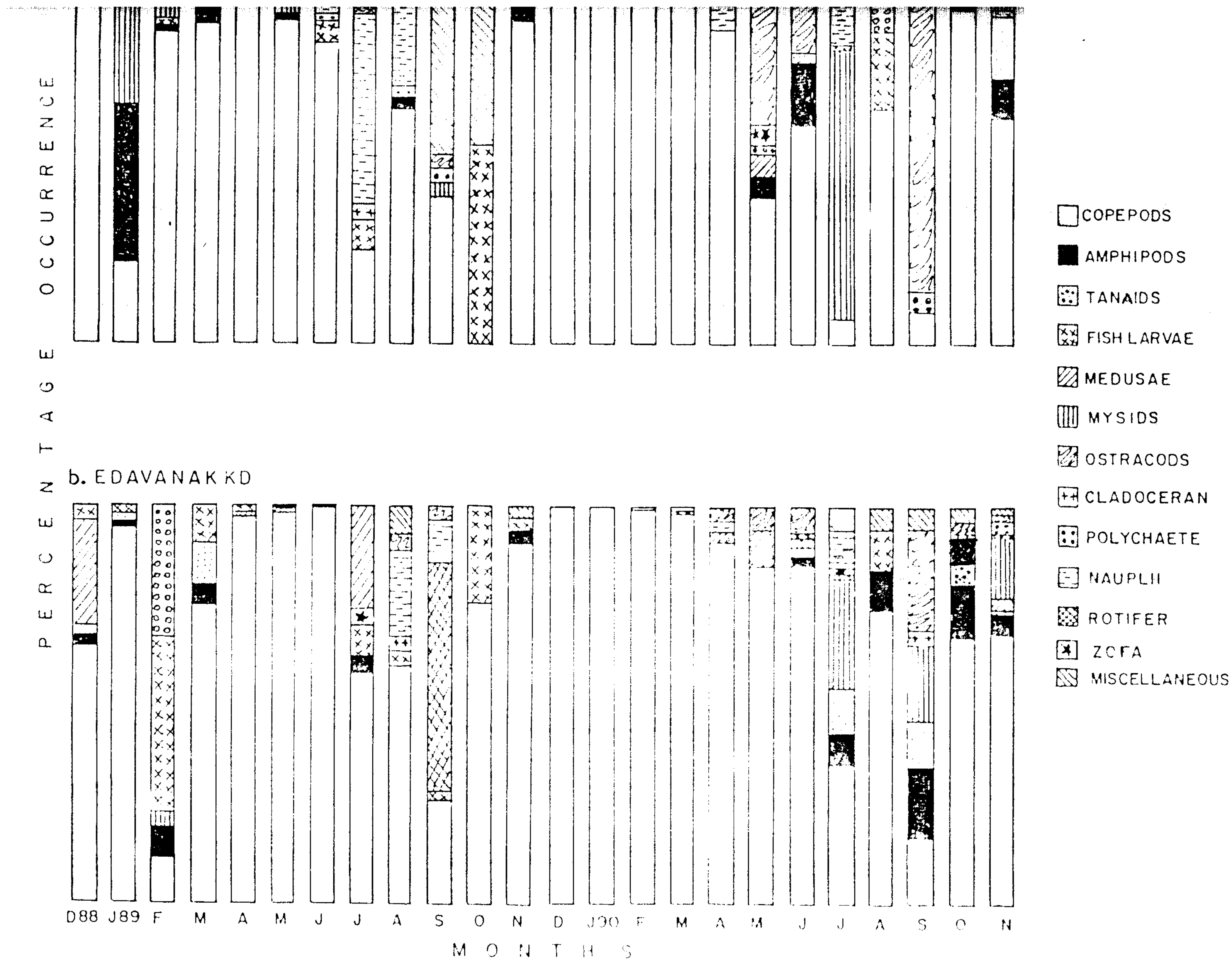


Fig. 15. Monthly percentage composition of zooplankton at a. Cherai and b. Edavanakkad.

Table-4a. Seasonal percentage composition of zooplankton

a. Cherai

Group	1988 - 89			1989 - 90		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
Copepod	81.39	15.19	3.42	14.86	0.80	84.33
Amphipod	70.37	7.43	22.19	11.09	25.92	62.98
Tanaid	100.00	-	-	-	5.02	94.88
Fish larvae	46.13	38.50	15.38	8.03	8.03	83.94
Mysid	85.37	4.89	9.79	2.19	92.70	5.11
Medusae	100.00	-	-	100.00	-	100.00
Polychaete	82.66	17.34	-	21.01	47.39	31.59
Cladoceran	50.00	50.00	-	-	-	-
Zoea	-	100.00	-	100.00	-	-
Nauplii	3.94	68.07	-	5.25	94.75	-
Rotifer	-	100.00	-	100.00	-	-
Ostracod	-	100.00	-	27.72	70.30	1.99
Miscellaneous	17.64	76.46	5.91	-	59.97	40.03

b. Edavanakkad

Group	Pre-Monsoon (1988 - 89)	Monsoon (1988 - 89)	Post-Monsoon (1988 - 89)	Pre-Monsoon (1989 - 90)	Monsoon (1989 - 90)	Post-Monsoon (1989 - 90)
Copepod	71.05	15.68	13.26	18.46	2.70	78.85
Amphipod	24.93	18.74	56.32	4.34	51.08	44.58
Tanaid	29.00	-	71.00	11.68	62.38	25.94
Medusae	38.17	-	61.83	71.77	11.77	16.46
Mysid	83.25	-	16.75	3.04	66.43	30.53
Fish larvae	66.66	11.45	21.90	40.06	34.96	24.98
Polychaete	88.85	-	11.15	28.53	23.82	47.64
Zoea	-	100.00	-	-	-	-
Ostracod	-	100.00	35.72	52.39	11.89	-
Nauplii	-	100.00	-	7.72	92.28	-
Miscellaneous	8.57	85.69	5.74	-	66.72	33.28

groups recorded from this station were amphipods (0.7%), fish larvae (0.4%), tanaids (0.4%) and polychaetes (0.4%).

Edavanakkad: In this station, zooplankton groups occurred throughout the year with high concentration during December to April. Copepods were the most abundant (96.3%) component of the zooplankton. Their percentage composition varied from 12 in February '89 to 100 in December '89. Among the other zooplankton items, medusae formed the important component (0.8%) with their abundance during postmonsoon and premonsoon months. Fish larvae occurred throughout the period of study. They formed 0.5% of the total plankton production. They occurred frequently during postmonsoon and premonsoon seasons. The less abundant planktonic groups recorded from this station were amphipods (peak during monsoon), ostracods (monsoon), tanaids (pre and postmonsoon), nauplii (monsoon) etc. (Fig. 15b. and Table-4b)

Vaduthala: In this station, zooplankton was abundant during premonsoon and monsoon seasons. Similar to other perennial fields, here also copepods formed the major component accounting for 65.5% of the total plankton biomass. Its monthly percentage composition fluctuated from zero (October-November 89) to 100 (December 89). Peak occurrance of copepod was noticed during premonsoon months. In this station, rotifers (9.9%) were the next important plankton component though it occurred only during few months. The highest concentration was during May '89. Tanaids (8.2%)

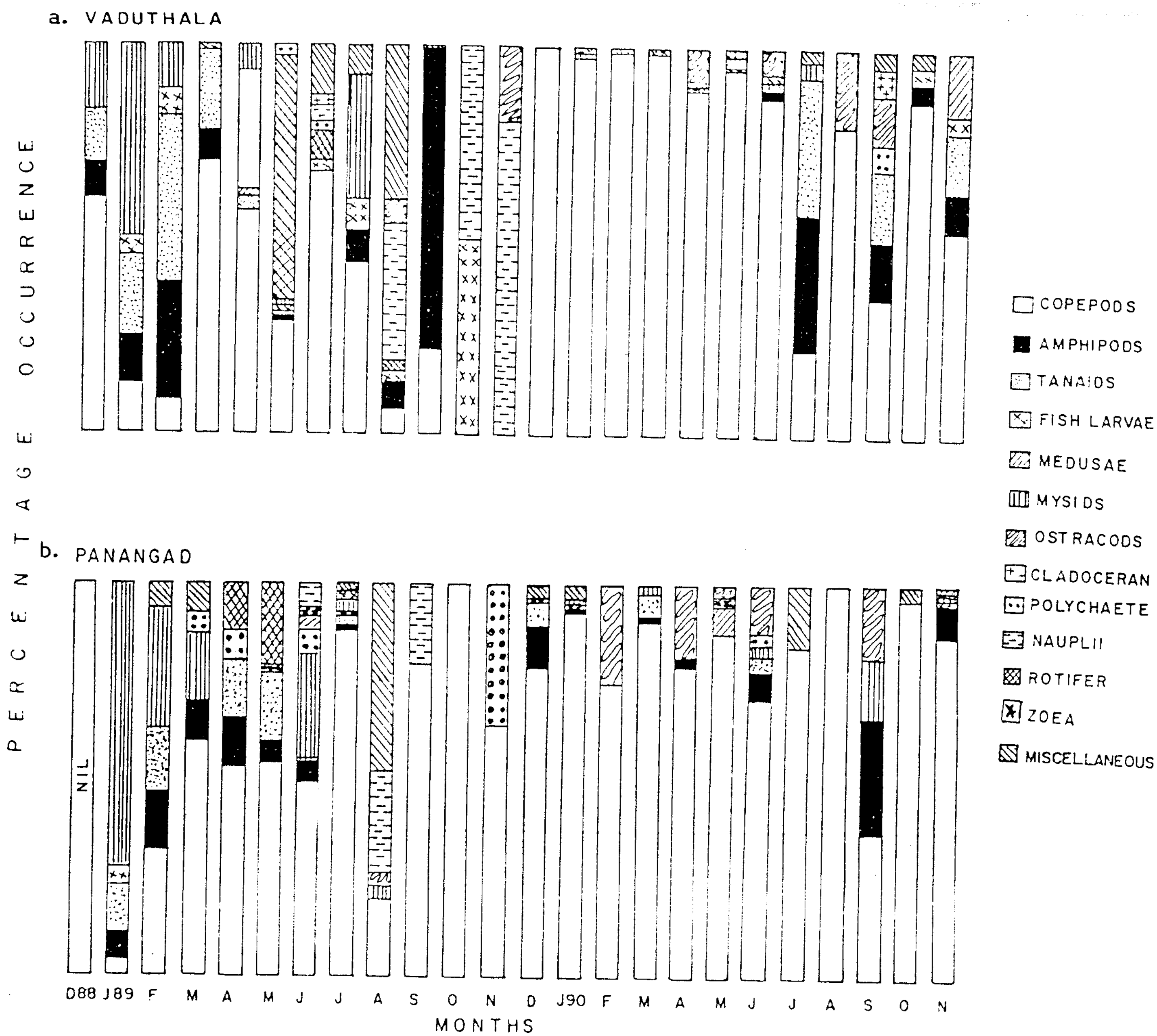


Fig. 16 . Monthly percentage composition of zooplankton at a. Vaduthala and b. Panangad

Table-5. Seasonal percentage composition of zooplankton

a. Vaduthala

Group	1988 - 89			1989 - 90		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
Copepod	72.00	16.47	11.53	50.92	18.30	30.77
Amphipod	49.08	25.49	25.44	1.56	94.94	3.49
Tanaid	69.33	-	30.67	0.75	95.13	4.12
fish larvae	42.05	31.69	26.30	29.46	23.46	47.09
Medusae	100.00	-	-	83.29	-	16.71
Mysid	44.91	8.17	46.93	-	76.46	23.54
Rotifer	98.06	1.94	-	-	-	-
Polychaete	75.00	25.00	-	-	-	-
Nauplii	-	76.18	23.82	-	-	-
Ostracod	-	71.38	28.63	37.07	62.93	-
Cladoceran	-	100.00	-	-	100.00	-
Miscellaneous	-	100.00	-	-	74.27	25.73
b. Panangad						
Copepod	27.14	69.36	3.49	31.56	12.55	55.89
Amphipod	64.59	8.21	27.39	8.10	27.02	64.87
Tanaid	76.35	13.65	10.00	22.23	22.23	55.54
Fish larvae	11.16	66.67	22.17	-	-	-
Mysid	21.18	35.77	43.04	12.54	37.46	50.00
Polychaete	41.69	58.30	-	-	27.25	72.75
Medusae	100.00	-	-	100.00	-	-
Rotifer	93.19	6.81	-	-	-	-
Zoea	100.00	-	-	100.00	-	-
Ostracod	-	100.00	-	53.36	41.33	5.32
Cladoceran	-	100.00	-	-	-	-
Nauplii	-	100.00	-	-	100.00	-
Miscellaneous	15.77	84.23	-	-	50.00	50.00

and amphipods (7.4%) were the other dominant plankton occurred throughout the period of study with their abundance during monsoon. Mysids occurred only during few months and accounted for 3.2% of the total plankton production. They were abundant during premonsoon months. Ostracods, nauplii and cladocerans were also recorded from this station although the latter was highly seasonal in occurrence (Fig.16a and Table-5a).

Panangad: Postmonsoon season was highly productive for zooplankton biomas in this station followed by premonsoon (Fig.16b and Table-5b). Copepods occurred throughout the period of study and formed 73.8% of the total plankton biomass. Its seasonal percentage contribution ranged from 4.4 (January '89) to 100 (October '89 and August '90). The peak abundance was in premonsoon and monsoon seasons. Mysids also occurred almost throughout the period though in less numbers and accounted for 5.3% of the total plankton production. Amphipods (4.4%) and tanaids (4.6%) occurred almost throughout the period and both had their abundance during premonsoon season. The less common plankton items were polychaetes, rotifers, ostracods nauplii and fish larvae and all of them showed highly restricted seasonal abundance.

TERTIARY PRODUCTION

Data could be collected only from one perennial field (Panangad). The seasonal variation in production (Kg) is shown in Table-6.

Table-6. Seasonal prawn/fish production (Kg) at Panangad perennial farm (11.5 ha) during 1988-90 (production/ha is indicated in parenthesis)

Group/Species	1988 - 89			1989 - 90		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
Penaeus indicus	1868 (162.43)	814 (70.78)	996 (86.60)	683 (59.39)	84 (7.30)	180 (15.65)
Metapenaeus dobsoni	3840 (333.91)	1678 (145.91)	1550 (134.78)	330 (28.70)	800 (69.57)	850 (73.91)
M. monoceros	926 (80.52)	559 (48.61)	470 (40.87)	43 (3.74)	115 (10.0)	30 (2.61)
Total prawn	6634 (576.87)	3051 (265.30)	3016 (262.26)	1056 (91.83)	999 (86.87)	1060 (92.17)
Total fish	305 (26.52)	178 (15.48)	180 (15.65)	654 (56.87)	153 (13.3)	290 (25.22)
Total Production	6939 (603.39)	3229 (280.78)	3196 (277.91)	1710 (148.70)	1152 (100.17)	1350 (117.39)
Total production for the year	13364 (1162.087)			4212 (366.26)		
Total prawn production	(1114.43)			(270.87)		

During '88-89, a total production (fish and prawn) of 13364 Kg was obtained from the Panangad perennial farm of 11.5 ha. In the total production, finfishes formed about 663 Kg. (4.96%) and prawns 12701 Kg. (95.04%). Of the total prawn production, the major share was contributed by Metapenaeus dobsoni (55.65%) and was dominant throughout the study period. Its maximum production was obtained during premonsoon followed by the monsoon and postmonsoon.

Penaeus indicus was the next dominant (28.96%) prawn component of production. It formed 3678 Kg and the peak production was realised during pre monsoon whereas the production during postmonsoon was comparatively low (966 Kg) when the monsoon accounted for the least production (814 Kg.)

M. monoceros was next in abundance and contributed about 15.39% of the prawn production. Like the other two species, their maximum production (926 Kg) was noticed during premonsoon while the postmonsoon accounted for the least production.

About 4212 Kg. of fish and prawn were harvested during 89-90 from this field. The production during this period was much less compared to 88-89 period. Out of the total production, the share of pre and post monsoon was more or less equal (1056 and 1060 Kg respectively) whereas the monsoon season recorded a production of 999 Kg.

Prawns formed about 73.96% of the total production and the dominant species contributed to production was M. dobsoni, which formed about

63.56% of the total prawn. Its production was high during postmonsoon (850 Kg), followed closely by a production figure of 800 Kg. in monsoon while premonsoon season contributed only 330 Kg.

P. indicus was next in abundance (30.40%) of total prawn harvest and the maximum and minimum production were noticed during premonsoon (683 Kg) and monsoon (84 Kg) respectively.

Among the three species of prawns, M. monoceros accounted for only 6.04% of the total prawn production. Monsoon showed high production (115 Kg), whereas the production was only 43 and 30 Kg respectively during premonsoon and postmonsoon.

The total finfish yield during this period was 1097 Kg. (26.04% of the total production) and the maximum production was recorded during premonsoon (654 Kg) followed by postmonsoon (290 Kg) and monsoon (153 kg).

In both years the finfish species harvested from this perennial field consisted of Liza parsia, Etroplus suratensis, E. maculatus, Tachysurus maculatus and Ambassis sp Apart from these, occasional occurrence of mud-crab Scylla serrata was also noticed.

COMPARISON OF PRODUCTION IN THE PRIMARY, SECONDARY AND TERTIARY TROPHIC LEVELS.

Table - 7 shows the comparison among the primary, secondary and tertiary production.

Table-7. Comparison of production (g/100 m^3) in the primary, secondary and tertiary trophic levels in the Panangad field

(Values within parentheses indicates their percentage in primary production)

Production	1988 - 89			1989 - 90		
	Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
Primary	1570	313	627	476	264	804
Secondary	50 (3.18)	100 (31.95)	45 (7.18)	50 (10.50)	25 (9.40)	100 (1.24)
Tertiary	60 (3.82)	28 (8.95)	27 (4.31)	15 (3.15)	10 (3.79)	12 (1.49)

In this field secondary production of zooplankton ranged from 25 to 100 g/100m^3. It was noticed that about 1.24 to 10.50% of the primary production is utilized in the secondary level. However, very high percentage (31.95%) was also recorded during monsoon. In the tertiary level, production was much less and fluctuated from 10 - 60 g/100m^3 forming about 1.49 to 8.95% of the total primary production. In general, the production in the three trophic levels was not consistant over seasons and years.

COASTAL FLORA AND OTHER UNIQUE FEATURES

Cherai: The coastal flora consisted of *Excoccaria agallocha*, *Abrus pricatorius*, *Crotalaria retusa* and *Acanthus ilicifolius*. Of this, *E. agallocha* was present throughout the study period. Its inflorescence was noticed in May and fruit formation in June. Occurrence of *A. ilicifolius* was scattered and its flowering season was in April. Other two species were present only for a few months.

No bloom of phytoplankton species had been recorded from this water body during the period of study.

Edavanakkad: Excoccaria agallocha was the dominant floral component present in the margin of pond during the period 88-90. Its flowering season and fruit formation were in May and June respectively. Monsoon months were characterised by the occurrance of mangrove fern, Acrostichum aureum. They borne sporophylls in premonsoon months of April and May.

Infestation of large sized jelly fishes were noticed during premonsoon months (April and May).

Vaduthala: This station also showed the dominance of Excoccaria agallocha throughout the year. Here also its inflorescence and fruit formation were noticed in May and June respectively. Other than this, the flora consisted of Acrostichum aureum, Abrus pricatorius, Thespesia populnea and Hygrophila angustifolia. Out of this, H. angustifolia was present only during December and January.

Peak premonsoon and early monsoon months showed the occurrence of green alga, Enteromorpha intestinalis in the water. No phytoplankton bloom had been recorded from here.

Panangad: Very few plants were recorded from the margin of this field. However, scatterd occurrence of Acanthus ilicifolius was noticed throughout the year and its flowering season was found to be in April.

During the study period, jelly fish infestation of the farm was noticed in early premonsoon. Similarly Enteromorpha intestinalis (Green alga) was found in February and May

Table-8. Correlation matrix of various environmental parameters

Wat. temp.	pH	Salin.	Alkal.	Diss. Oxygen	Prim. prod.	Zoopl. No.
Cherai						
1.000						
0.211	1.000					
0.264	*0.343	1.000				
*0.335	0.279	0.781	1.000			
-0.062	0.002	-0.015	-0.062	1.000		
-0.063	0.095	*0.358	*0.406	0.126	1.000	
0.059	-0.145	0.066	-0.007	-0.045	-0.102	1.000
Edavanakkad						
1.000						
0.214	1.000					
0.124	-0.022	1.000				
0.139	0.028	0.068	1.000			
0.039	-0.345	0.299	0.122	1.000		
0.035	0.116	0.163	-0.040	0.156	1.000	
-0.189	-0.264	0.004	-0.239	-0.042	0.042	1.000
Vaduthala						
1.000						
0.288	1.000					
-0.069	0.272	1.000				
-0.117	0.171	*0.447	1.000			
*0.416	*0.487	-0.189	0.280	1.000		
0.149	*0.361	0.208	0.098	*0.312	1.000	
*0.365	0.104	0.098	0.238	0.293	*0.317	1.000
Panangad						
1.000						
0.122	1.000					
-0.104	*0.323	1.000				
-0.045	*0.368	*0.896	1.000			
0.033	0.199	-0.133	0.065	1.000		
-0.039	0.300	0.303	0.282	-0.006	1.000	
0.087	0.131	-0.102	0.043	0.223	-0.016	1.000

* Significant at 5% level.

Table-9. Two way Analysis of Variance (ANOVA) Tables showing the level of significance in variation of different parameters among stations and over seasons.

Source	D.F.	SUM. SQR	MEAN SQR	F. VAL.	REMARKS
Water temperature:					
Treat	3	2.701	0.900	7.63	SIG (5%)
Replic	2	6.409	3.205	27.16	HI.SIG (1%)
Error	6	0.708	0.118		
pH:					
Treat	3	0.033	0.011	0.43	N.S.
Replic	2	0.307	0.153	5.94	SIG (5%)
Error	6	0.155	0.026		
Salinity:					
Treat	3	90.740	30.247	3.89	N.S.
Replic	2	406.977	203.488	26.16	HI.SIG (1%)
Error	6	46.677	7.779		
Total alkalinity:					
Treat	3	3133.07	1046.357	6.97	SIG (5%)
Replic	2	1043.754	521.877	3.47	N.S.
Error	6	901.129	150.188		
Dissolved oxygen:					
Treat	3	10.061	3.354	1.53	N.S.
Replic	2	6.958	3.479	1.58	N.S.
Error	6	13.182	2.197		
Nitrate-N:					
Treat	3	28.567	9.522	5.94	SIG (5%)
Replic	2	7.454	3.727	2.32	N.S.
Error	6	9.622	1.604		
Nitrite-N:					
Treat	3	0.860	0.287	10.98	HI.SIG (1%)
Replic	2	0.094	0.047	1.80	N.S.
Error	6	0.157	0.026		
Reactive phosphorus:					
Treat	3	16.081	5.360	8.75	SIG (5%)
Replic	2	8.883	4.441	7.25	SIG (5%)
Error	6	3.674	0.612		
Silicate-silicon:					
Treat	3	974.063	324.688	1.43	N.S.
Replic	2	263.156	131.578	0.58	N.S.
Error	6	1363.149	227.191		
Primary production:					
Treat	3	2157968.000	719322.700	3.68	N.S.
Replic	2	3702728.000	1851364.00	9.48	SIG (5%)
Error	6	1171642.000	195273.700		
Chlorophyll-a:					
Treat	3	942.174	314.058	2.28	N.S.
Replic	2	482.170	241.085	1.75	N.S.
Error	6	825.394	137.566		
Chlorophyll-b:					
Treat	3	13.638	4.546	0.19	N.S.
Replic	2	10.674	5.337	0.22	N.S.
Error	6	145.06	24.177		
Chlorophyll-c:					
Treat	3	28.193	9.398	0.39	N.S.
Replic	2	105.857	52.929	2.17	N.S.
Error	6	146.437	24.406		
Carotenoids:					
Treat	3	192.327	64.109	5.90	SIG (5%)
Replic	2	116.049	58.024	5.34	SIG (5%)
Error	6	65.239	10.872		
Zooplankton biomass:					
Treat	3	13.674	4.558	1.07	N.S.
Replic	2	20.960	10.480	2.46	N.S.
Error	6	25.578	4.263		
Organic carbon:					
Treat	3	1.225	0.408	0.94	N.S.
Replic	2	0.558	0.279	0.64	N.S.
Error	6	2.617	0.436		

II. SEASONAL FIELDS

As the prawn culture activity is limited to five months in the seasonal fields, hydrobiological data were collected only during the five months period from December-April of 1988-89 and 1989-90.

TEMPERATURE

Monthly variation of atmospheric as well as water temperature is shown in Fig.17. Atmospheric temperature varied from 24°C (December '89, Narakkal) to 31.5°C (January, '90, Cherai). Variation in water temperature was high compared to atmospheric temperature, the range of the former being 26.5-36.0°C. Invariably the water temperature was above 33.0°C in all stations and premonsoon months showed higher values than postmonsoon.

The correlation coefficient (r) values (Table -18) showed significant relationship at 5% level between water temperature and pH (0.591) at Cherai; whereas the relationship was significant with dissolved oxygen (0.559) and zooplankton number (0.661) at Chittoor.

Two way ANOVA Table (Table-19) showed that variation in water temperature was not significant among stations, on the other hand it was highly significant over seasons ($P < 0.01$).

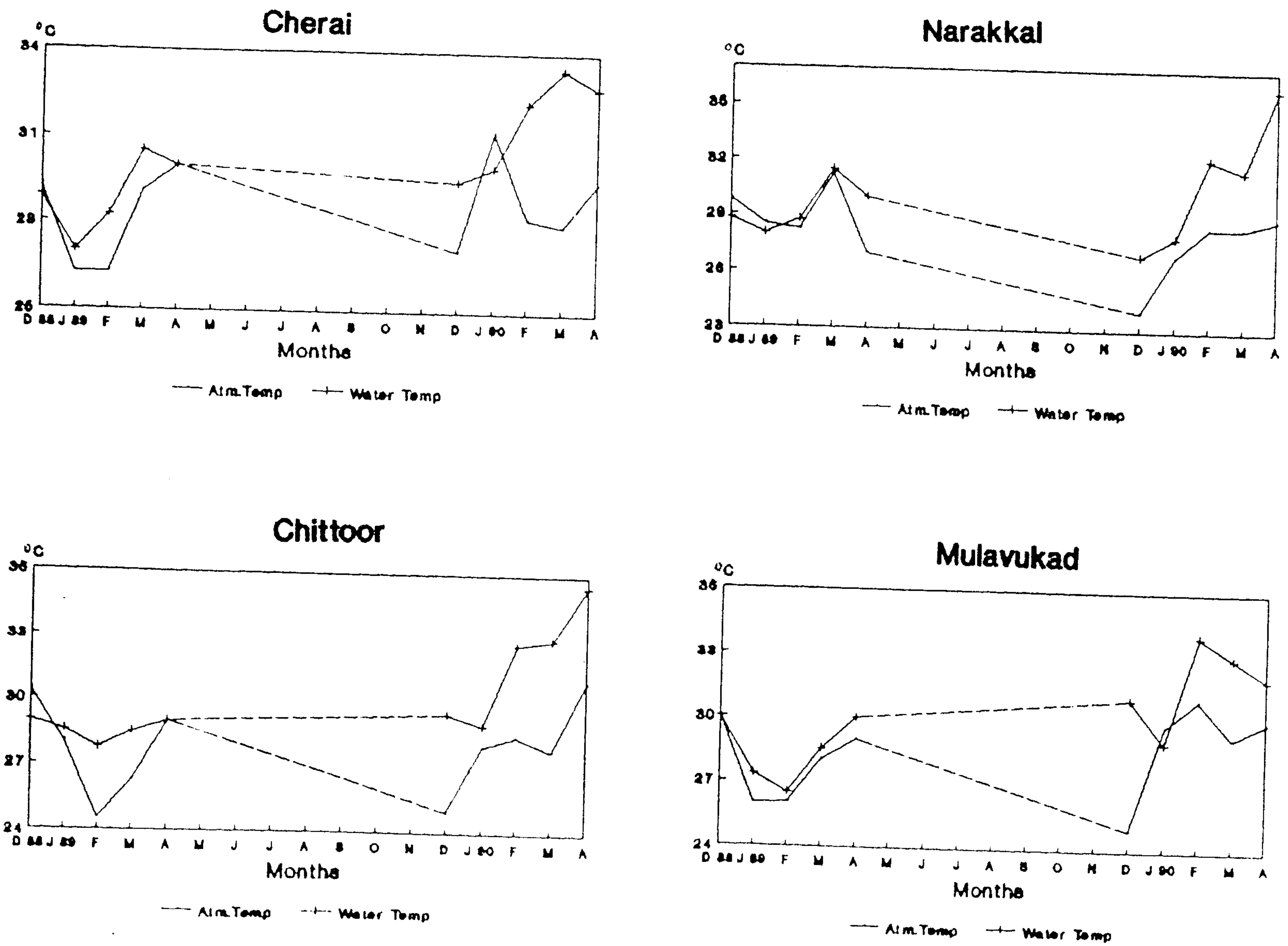


Fig. 17. Monthly variations in Atmospheric and Water temperature

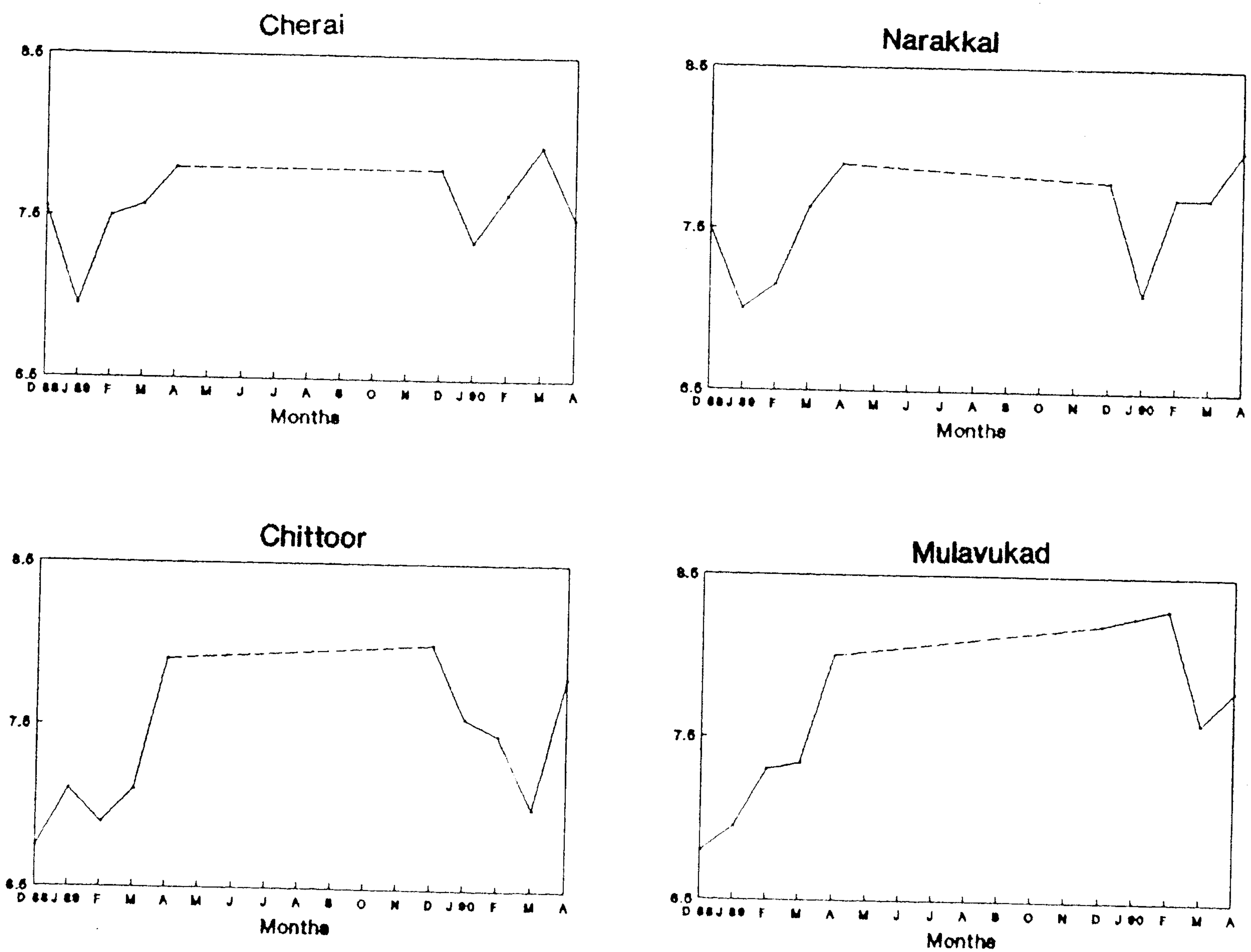


Fig. 18. Monthly variation in pH

pH

Fig.18 gives the monthly variation in pH at different seasonal fields. In general, the water was more alkaline than acidic. The pH values varied from 6.75 (Chittoor) to 8.25 (Mulavukad). Premonsoon showed higher values than postmonsoon during 88-89 in all stations, whereas in 89-90 higher values were recorded during postmonsoon.

pH showed a significant positive relationship with alkalinity (0.587) at Cherai and with alkalinity (0.675) and dissolved oxygen (0.566) in Narakkal, while it showed a significant negative correlation with primary production in Chittoor (-0.518) and Mulavukad (-0.503) as seen from Table-18.

The variation in pH was not significant among stations and with seasons as seen from the two way ANOVA Table (Table-19).

SALINITY

Salinity ranged from 4.9‰ (Chittoor) to 28.5‰ (Cherai) in the seasonal fields during 88-90 period. In all stations, premonsoon recorded higher salinity values than postmonsoon (Fig.19).

A significant positive correlation of salinity was noticed with alkalinity (0.704) and zooplankton number (0.656) at Cherai and the relationship was with primary production ~~production~~ (0.512) at Mulavukad (Table-18).

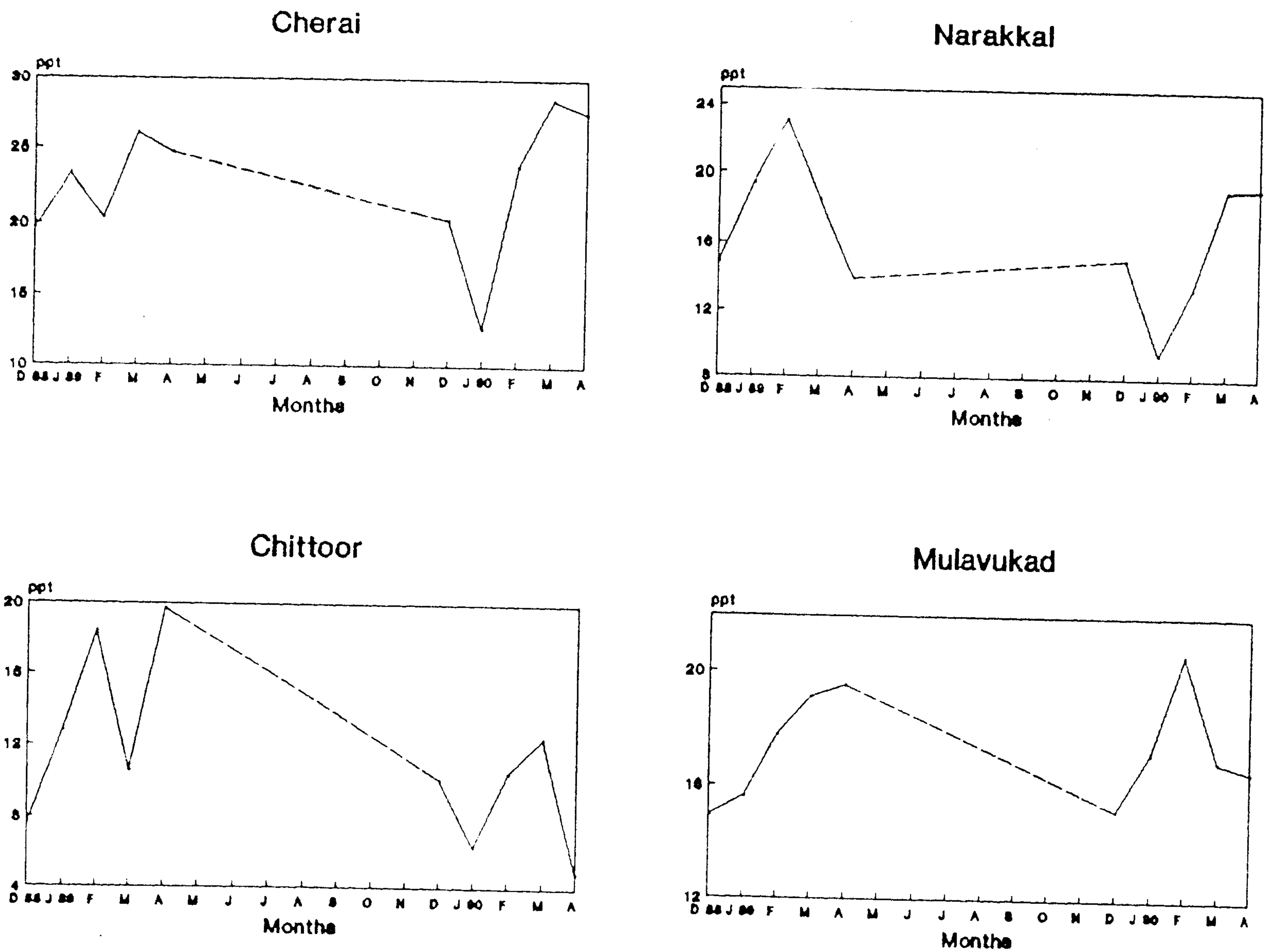


Fig. 19. Monthly variation in salinity

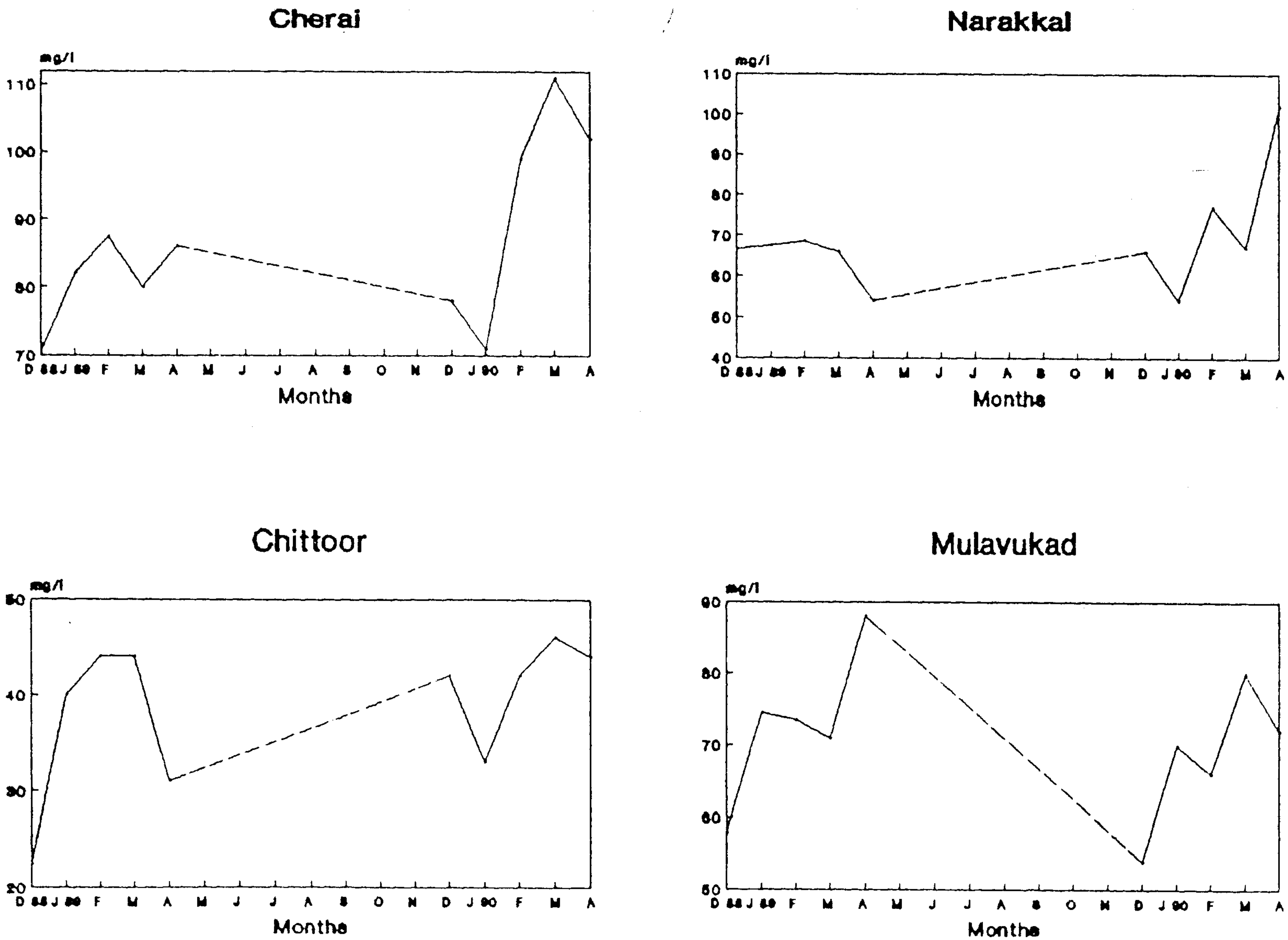


Fig. 20. Monthly variation in Total Alkalinity

Two way ANOVA Table (Table-19) showed that the variation in salinity was not significant among stations and with seasons.

TOTAL ALKALINITY

Alkalinity was found to be high in all stations except at Chittoor. In Chittoor, the values ranged from 22.5 (December 88) to 45 mg/l (March '89); whereas in the other stations, it varied between 54 (Narakkal, April '89) and 111 mg/l (Cherai, March '90) without showing any remarkable seasonal pattern of distribution. However, slightly high values could be noticed in premonsoon (Fig. 20).

With zooplankton, alkalinity showed a significant negative correlation (-0.516) at Cherai, along with pH (0.587) and salinity (0.704); whereas in Narakkal, a significant positive correlation (0.675) was noticed between alkalinity and pH (Table-18).

ANOVA Table (Table-19) showed highly significant variation ($P < 0.01$) in alkalinity among stations and significant ($P < 0.05$) variation over seasons.

DISSOLVED OXYGEN

The dissolved oxygen fluctuated from 2.75 to 4.7 mg/l in Cherai, 1.4 to 5.95 mg/l in Narakkal, 1.27 to 5.34 mg/l in Chittoor and 3.0 to 6.66 mg/l in Mulavukad. In all stations higher values were recorded during premonsoon season (Fig.21).

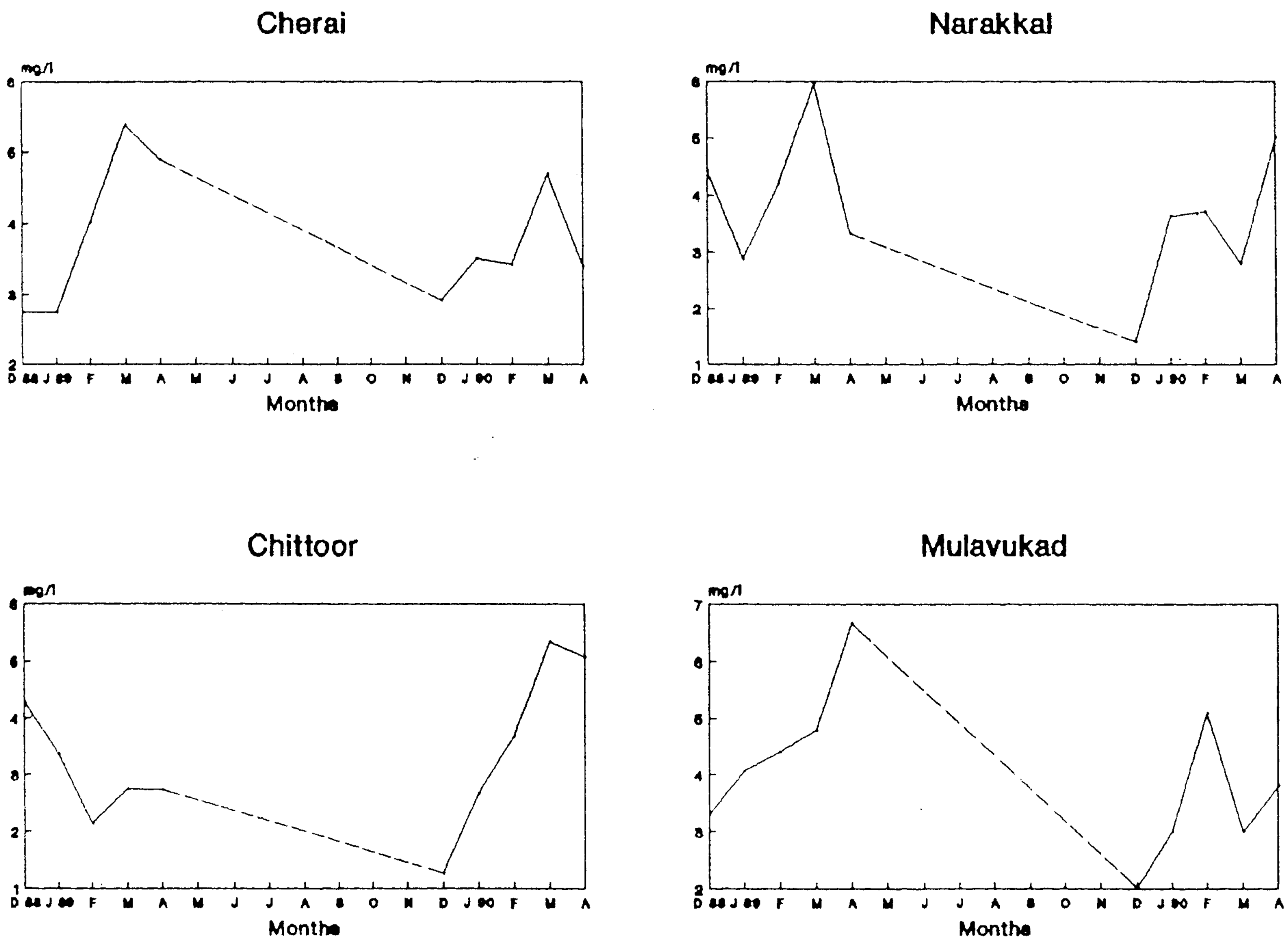


Fig. 21. Monthly variation in Dissolved Oxygen

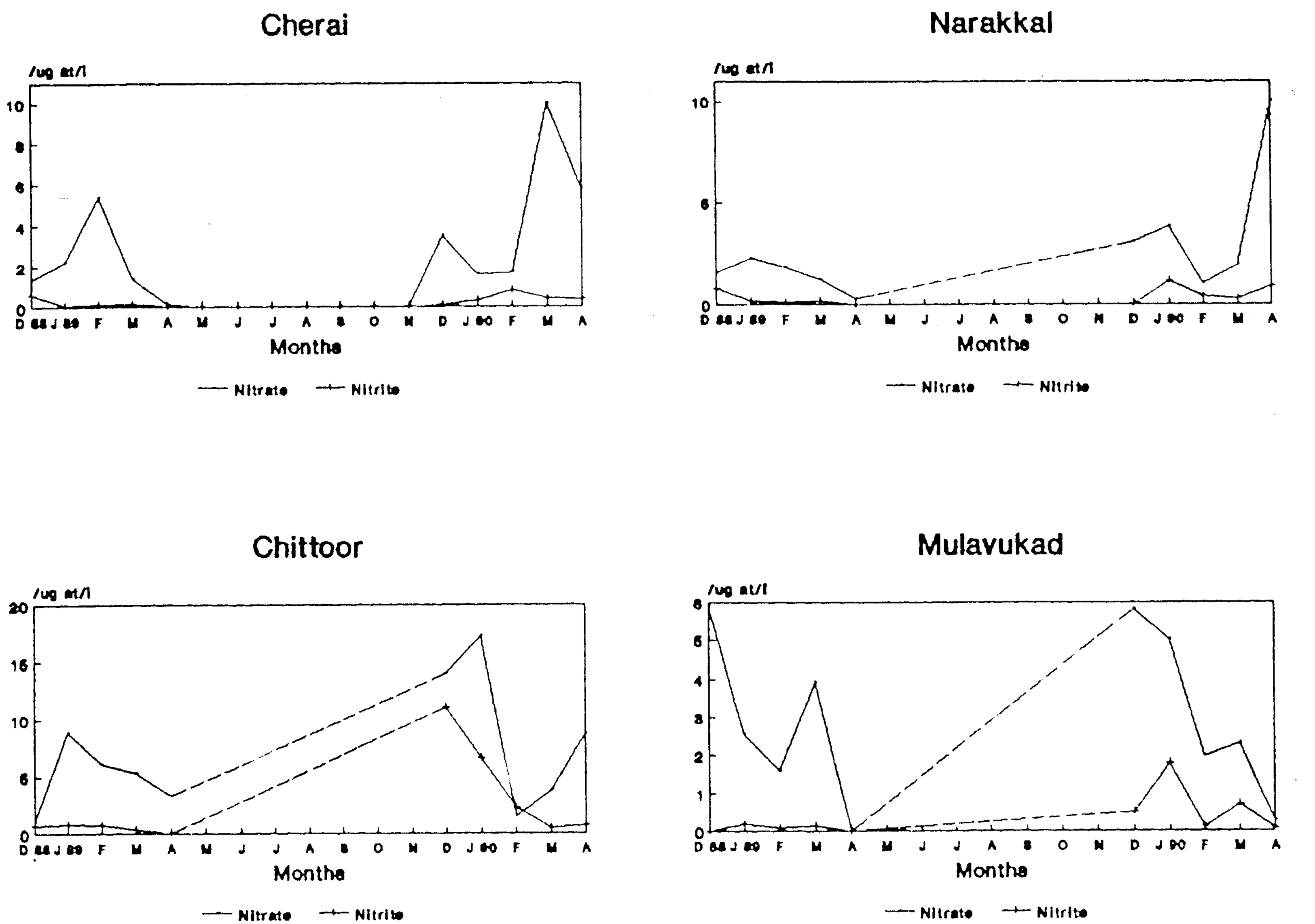


Fig. 22. Monthly variation in Nitrate and Nitrite-Nitrogen

Dissolved oxygen showed significant relationship with pH (0.566) and primary production (0.593) at Narakkal, whereas in Chittoor it showed significant correlation with water temperature (0.559) and zooplankton (0.519) as seen from Table-18.

Analysis of Variance (Table-19) showed that the variation in the concentration of dissolved oxygen was not significant among stations and was significant with seasons ($P < 0.05$).

NITRATE AND NITRITE-NITROGEN

All seasonal fields showed high Nitrate-N values. The values ranged from 0.15 (Cherai, April '89) to 22.5 μg at/l (Narakkal) and seasonal fluctuation was not prominent in these fields; whereas Nitrite-N showed very low values in all stations. However, exceptionally high value of 11.1 μg at/l was recorded from Chittoor (December '89). During 88-89, the seasonal variation of Nitrite-N was pronounced with high values recorded in post-monsoon (Fig. 22).

The variation in the concentration of both Nitrate and Nitrite-N was not significant either between stations or with seasons (Table-19).

AMMONIA-NITROGEN

Ammonia-N concentration was high in almost all stations as shown in Fig.23. It ranged from a minimum of 1.96 (Mulavukad, April '89) to

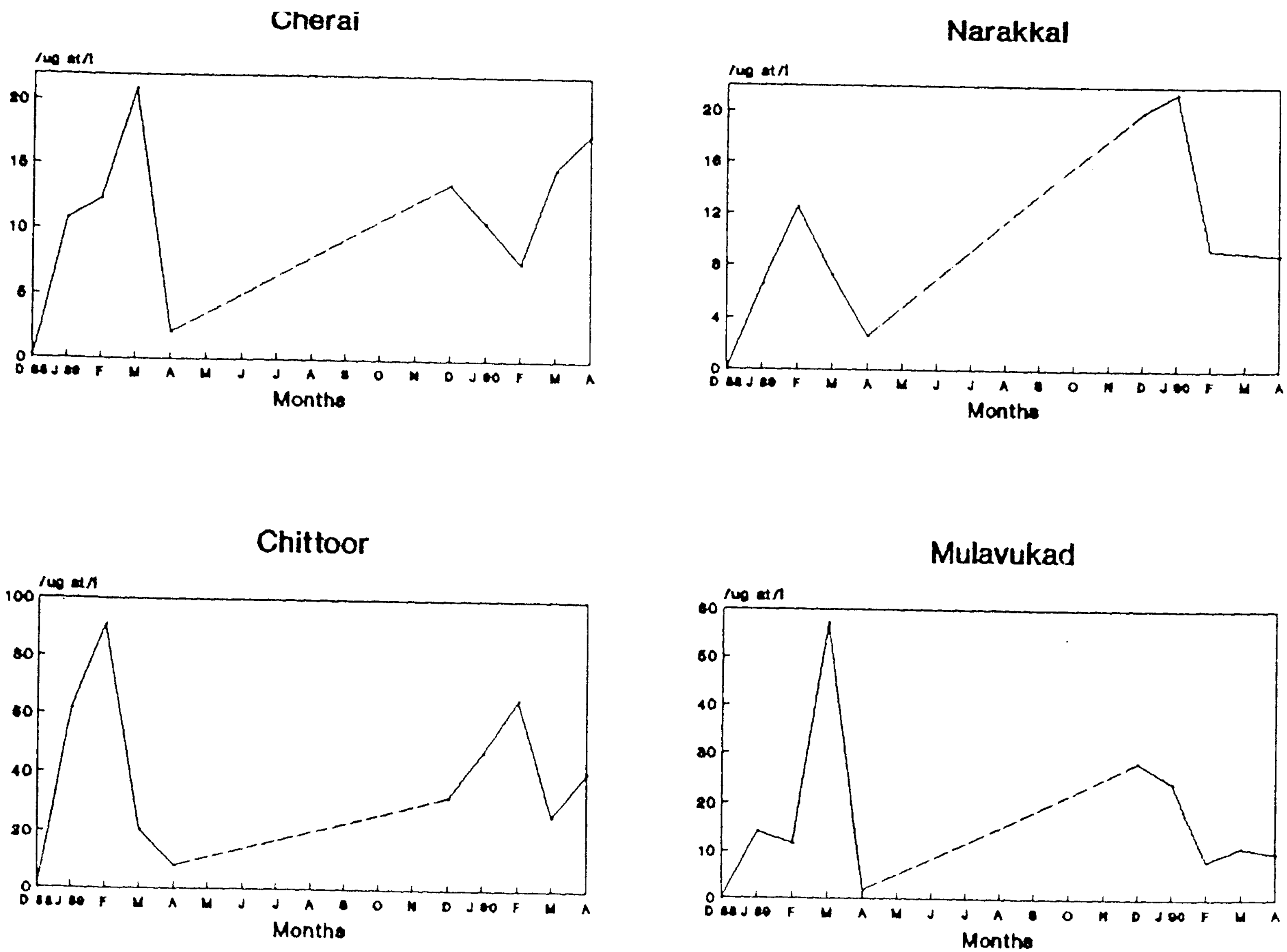


Fig. 23. Monthly variation in Ammonia-Nitrogen

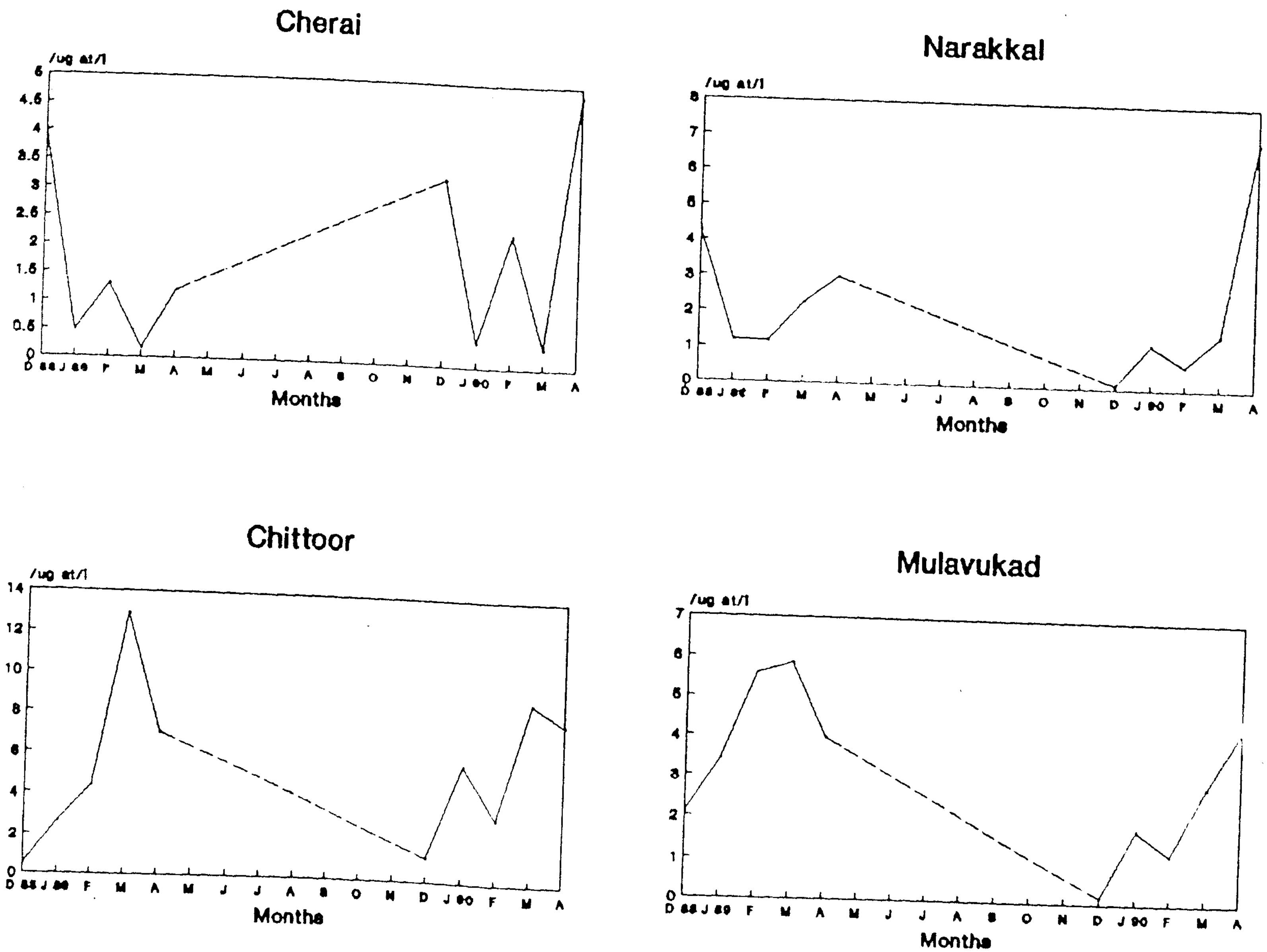


Fig. 24. Monthly variation in Reactive Phosphorus

a maximum of 91.04 µg at/l (Chittoor, February '89). There was no uniform trend in the seasonal fluctuation in different seasonal fields.

REACTIVE PHOSPHORUS

Concentration of phosphorus was more or less uniform in all stations except at Chittoor where fairly high value (12.88 µg at/l) was recorded (Fig.24). The monthly range was 0.18-4.83 µg at/l (Cherai), 0.13 - 4.24 µg at/l (Narakkal), 0.5 - 22.88 µg at/l (Chittoor) and 0.2 - 5.87 µg at/l (Mulavukad). Seasonal variation was not remarkable as the high and low values were observed during both premonsoon and postmonsoon months in two different years.

The two way ANOVA Table (Table-19) showed that the variation was not significant in the concentration of phosphate over stations and with seasons.

SILICATE-SILICON

The distribution of Silicate-silicon is shown in Fig. 25. The range in concentration was 15.52-53.0 µg at/l (Cherai), 15-196 µg at/l (Narakkal), 26-68 µg at/l (Chittoor) and 4-48 µg at/l (Mulavukad). There was no definite seasonal variation in its concentration during pre and postmonsoon period.

There was no significant variation in the concentration of silicate from station to station and with seasons as seen from the ANOVA Table (Table-19).

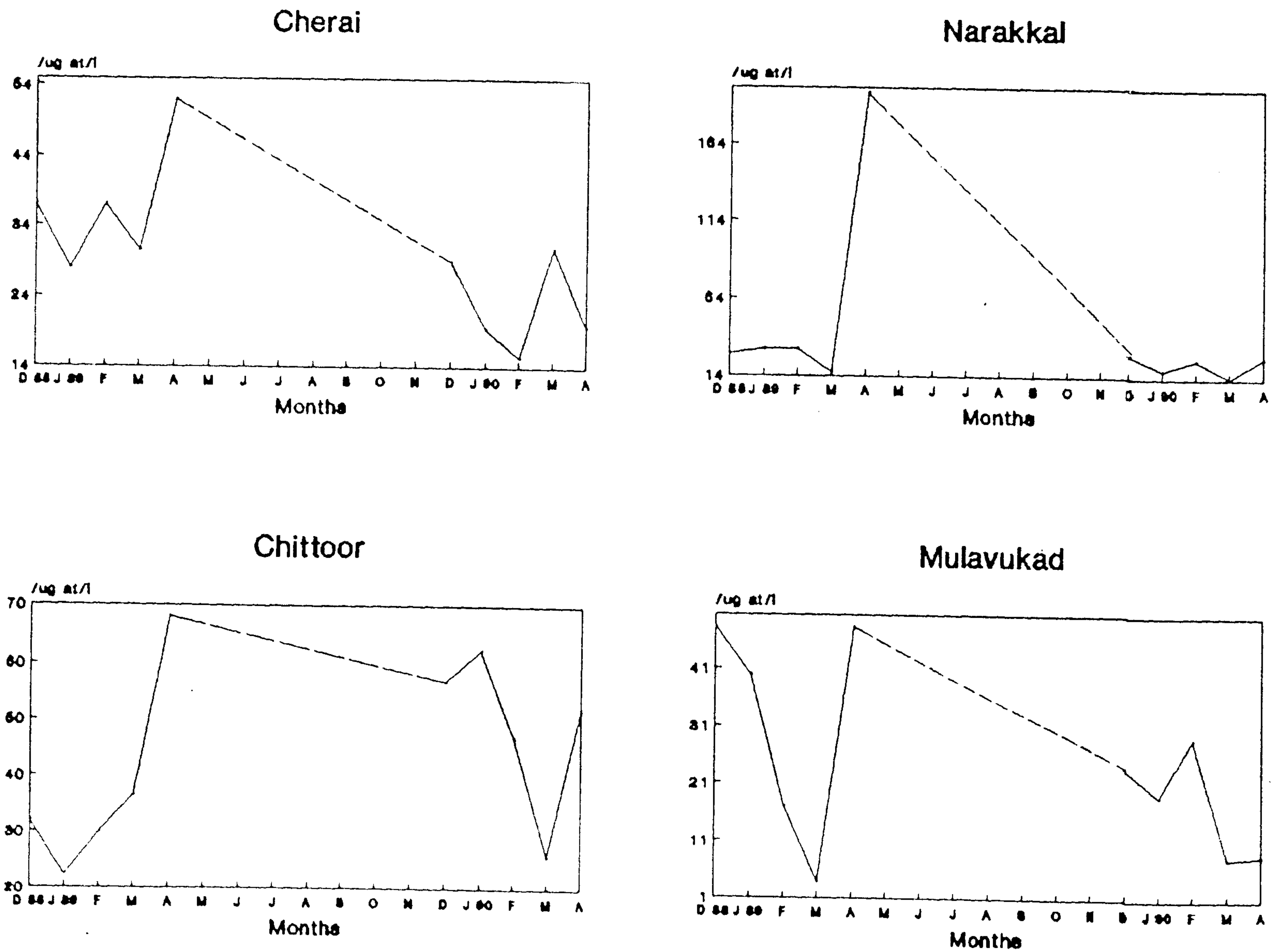


Fig. 25. Monthly variation in Silicate-silicon.

ORGANIC CARBON CONTENT OF THE SEDIMENT

Data on seasonal variation of organic carbon content of sediment are presented in Table-10.

Table-10. Seasonal variation of organic carbon content in sediment (%).

Season	Premonsoon 88-89	Premonsoon 89-90	Postmonsoon 88-89	Postmonsoon 89-90
Cherai	2.41	3.20	2.80	1.94
Narakkal	3.23	2.54	3.68	1.82
Chittoor	3.79	3.79	3.92	1.45
Mulavukad	3.43	3.47	3.65	2.00

High organic carbon content was recorded in the postmonsoon season of 88-89. On the other hand, in 89-90, high values were observed in the premonsoon period. Of the four seasonal fields, Chittoor field showed the highest percentage of organic carbon in the bottom sediment.

ANOVA Table (Table-19) showed that the variation in the organic carbon content of the sediment was not significant among stations and with seasons.

PRIMARY PRODUCTION

In general, high primary production values were obtained from all these stations, particularly during premonsoon season (Fig.26). The minimum

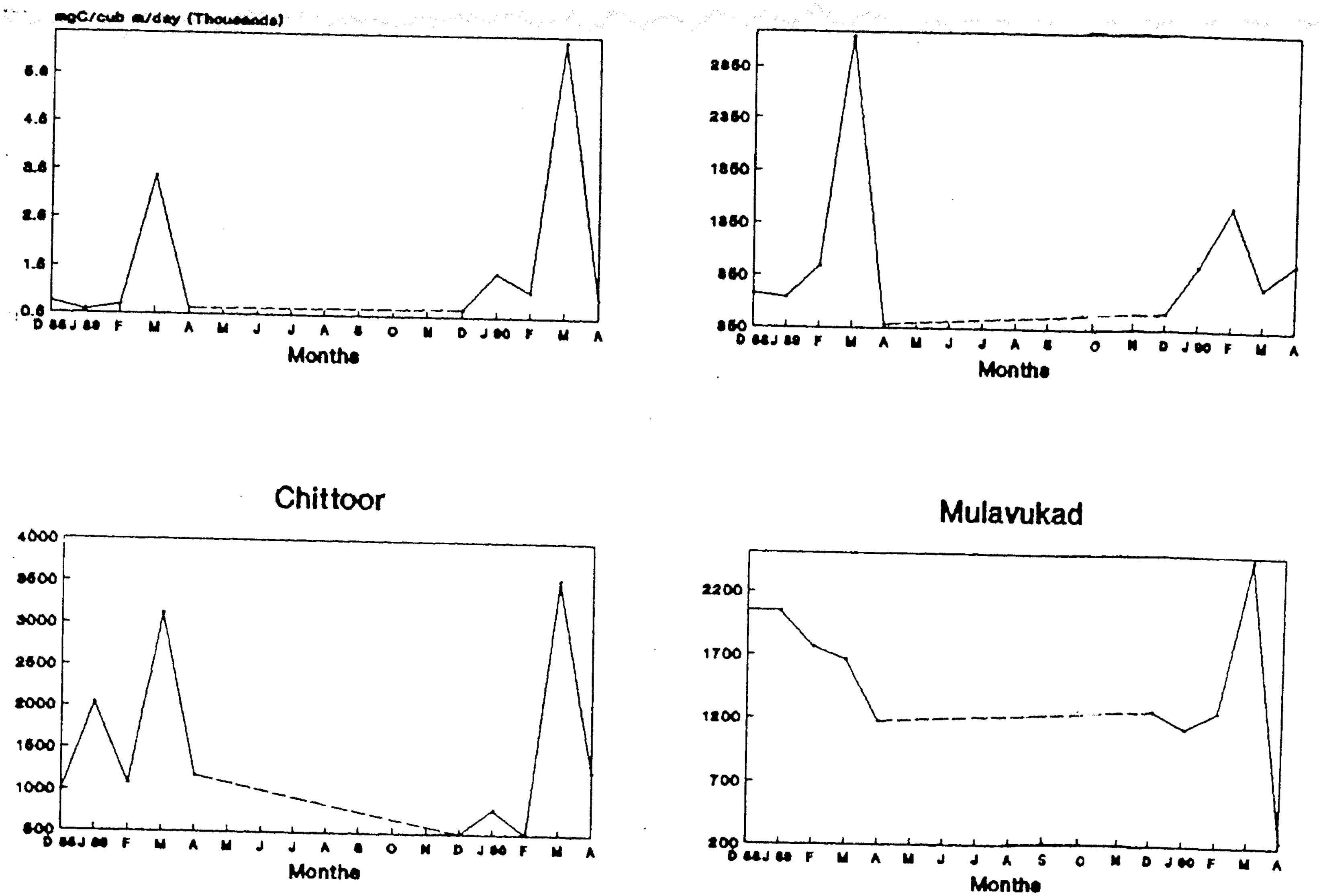


fig. 26. Monthly variation in Primary production

and maximum values were 675-6378 mgC/m^3/day in Cherai,390-3150 mgC/m^3/day in Narakkal, 510-3560 mgC/m^3/day in Chittoor and 250-2465 mgC/m^3/day in Mulavukad.

Primary production showed significant positive correlation with dissolved oxygen (0.593) in Narakkal and a negative relationship was noticed with pH (-0.518) in Chittoor; whereas in Mulavukad, primary production showed significant negative relationship with pH (-0.503) and positive correlation with salinity (0.512) as seen from Table-18.

It is evident from the ANOVA Table (Table-19) that the variation in primary production was not significant from station to station and with seasons.

PHYTOPLANKTON COMPOSITION

Cherai: The seasonal availability of different species of phytoplankton is given in Table-11a. In this station the phytoplankton comprised exclusively of diatoms. *Coscinodiscus* and *Pleurosigma* occurred during pre and postmonsoon; whereas *Gyrosigma* was common in postmonsoon and *Diploneis robustus* and *Navicula* in premonsoon.

Narakkal: Similar to Cherai seasonal field, the phytoplankton of Narakkal also consisted exclusively of diatoms. *Gyrosigma* occurred abundantly in both the seasons (Table-11b).

Table-11. Seasonal availability of phytoplankton components

a. Cherai

Phytoplankton	Premonsoon	Postmonsoon
Amphora ostrearia	R	X
Biddulphia sp.	R	X
Coscinodiscus sp.	C	A
Diploneis robustus	C	X
Gyrosigma sp.	X	C
Navicula sp.	C	X
Nitzschia sp.	R	X
Pleurosigma sp.	C	A
Rhizosolenia sp.	R	X
Stephanophyxis palmeriana	R	X
Tropidoneis lepidoptera	R	X

b. Narakkal

Phytoplankton	Premonsoon	Postmonsoon
Amphora ostrearia	R	X
Coscinodiscus sp.	C	C
Diploneis robustus	C	C
D. smithi	R	X
Grammatophora undulata	X	R
Gyrosigma sp.	A	A
Navicula sp.	X	A
Nitzschia closterium	X	R
Pleurosigma sp.	C	A
Tropidoneis lepidoptera	X	R

*A - Abundant; C - Common; R - Rare; X - Not observed.

Table-12. Seasonal availability of phytoplankton components.

a. Chittoor

Phytoplankton	Premonsoon	Postmonsoon
Amphora ostrearia	R	X
Coscinodiscus sp.	A	X
Gyrosigma sp.	C	X
Navicula sp.	C	R
N. longa	R	X
Nitzschia sp.	C	X
N. closterium	A	X
Pleurosigma sp.	C	R

b. Mulavukad

Phytoplankton	Premonsoon	Postmonsoon
Amphora lineolata	R	X
A. ostrearia	R	X
Coscinodiscus sp.	C	A
Navicula sp.	R	C
Nitzschia ap.	R	X
Peridinium sp.	R	X
Pleurosigma sp.	C	A
Skeletonema costatum	X	C
Stephanopyxis palmeriana	R	X

*A - Abundant; C - Common; R - Rare; X - Not observed.

Chittoor: Diatoms were the major component throughout the period of study. Species such as Nitzschia closterium and Coscinodiscus sp. were abundant during premonsoon. Only a few genera were recorded during postmonsoon (Table-12a).

Mulavukad: In addition to the dominant occurrence of diatoms, Dinophyceae (Peridinium) was also noticed in this station during premonsoon. It may be seen from the Table-12b that species such as Coscinodiscus sp, Navicula sp. and Pleurosigma sp. occurred during pre and postmonsoon months.

CHLOROPHYLLS AND CAROTENOIDS

The percentage composition of chlorophyll-a,b,c and carotenoids in the four seasonal fields are given below.

Station	Chlorophyll-a	Chlorophyll-b	Chlorophyll-c	Carotenoids
Cherai	41	14	20	25
Narakkal	39	6	24	31
Chittoor	42	13	12	33
Mulavukad	46	12	18	23

All stations showed very high chlorophyll-a concentration. Its concentration reached upto 116.96 mg/m^3 in Mulavukad (February '89). The concentration ranged from 7.65-73.66 mg/m^3, 5.27 to 85.47 mg/m^3, 4.26 to 80.12 mg/m^3 and 20.19 to 116.96 mg/m^3 respectively in Cherai, Narakkal, Chittoor

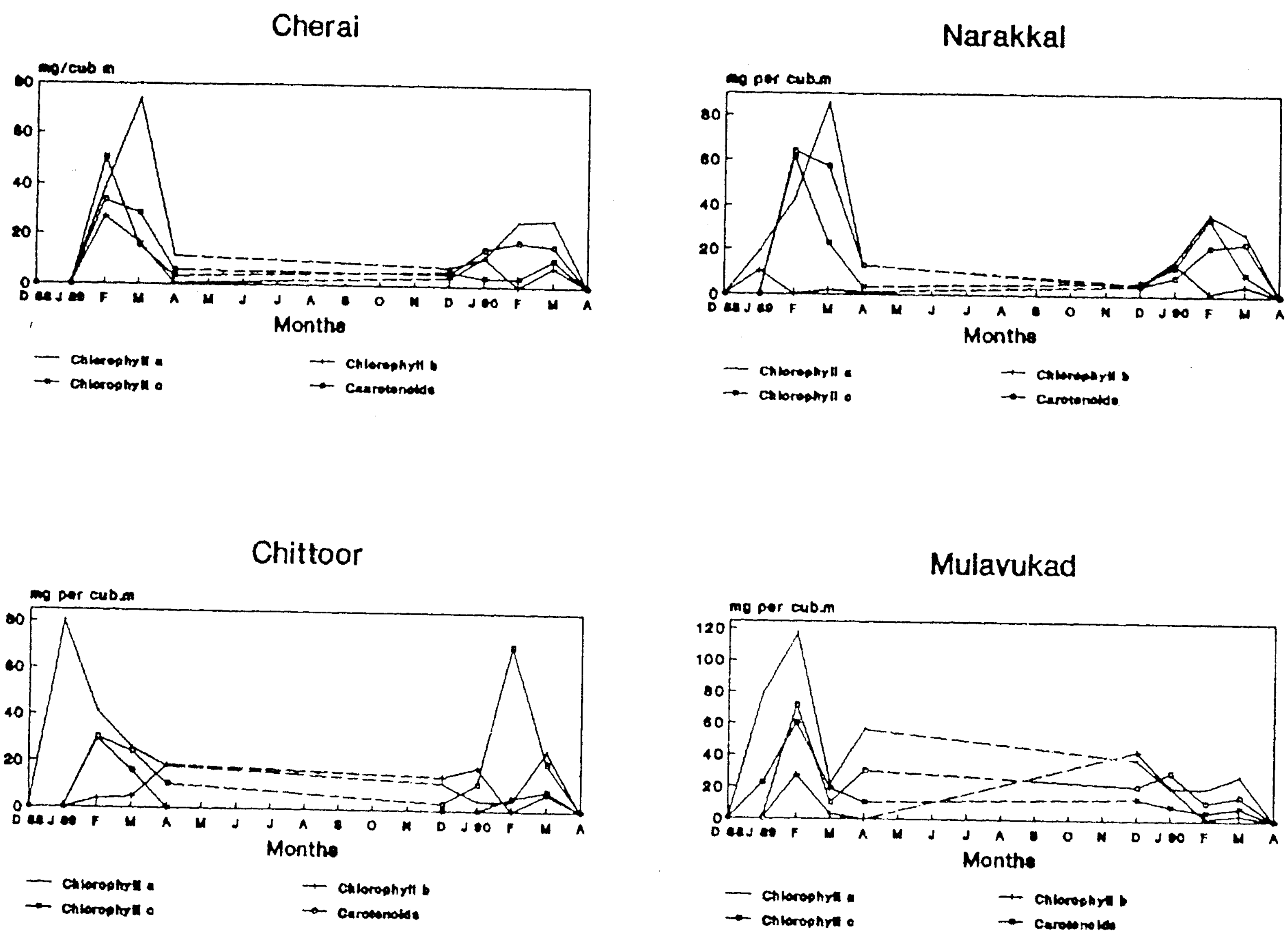


Fig. 27. Monthly variations in Chlorophylls and Carotenoids

and Mulavukad. In almost all stations high values were recorded during premonsoon.

Chlorophyll-b concentration was comparatively less than that of chlorophyll-a in all stations. It ranged from 0 to 26.88 mg/m^3 (Cherai) 0 to 14.45 mg/m^3 (Narakkal), 0 to 18.56 mg/m^3 (Chittoor) and 0 to 42.98 mg/m^3 (Mulavukad). In all stations, postmonsoon indicated high values than premonsoon. On the other hand, chlorophyll-c concentration was much higher than that of chlorophyll-b and less than that of chlorophyll-a. In all stations, it ranged from a minimum of 0 to a maximum of 50.25 mg/m^3 (Cherai), 0 to 61.48 mg/m^3 (Narakkal), 0 to 29.38 mg/m^3 (Chittoor) and 0 to 60.28 mg/m^3 (Mulavukad). Carotenoids also showed high values next to chlorophyll-a. Its concentration ranged between 0 and 33.52 mg/m^3 in Cherai, 0 and 64.10 mg/m^3 in Narakkal, 0 and 70.78 mg/m^3 in Chittoor and 0 and 71.72 mg/m^3 in Mulavukad. Premonsoon recorded high carotenoid contents in these fields (Fig. 27).

Chlorophyll-a,b and carotenoid concentration did not show any significant variation from station to station and with seasons, whereas in the case of chlorophyll-c the variation was not significant among stations and was significant ($P < 0.05$) with seasons (Table-19).

QUANTITATIVE ABUNDANCE OF ZOOPLANKTON

Seasonal variation of zooplankton biomass is shown in Table-13.

Cherai: In 88-89, the plankton biomass values were 25 $ml/100m^3$ (4279 Nos) and 900 $ml/100m^3$ (33840 Nos) during postmonsoon and premonsoon respectively, whereas in 89-90, the biomass showed wide fluctuation from 22631 numbers and 80 ml/100m^3 to 230092 numbers and 1500 ml/100m^3 during premonsoon and postmonsoon seasons respectively.

Narakkal: The entire study period was characterised by the high biomass values during premonsoon. Among the two years of observation, premonsoon of 89-90 showed the maximum biomass value with 79139 Nos. and 500 ml/100m^3, whereas the biomass fluctuated from 3041 numbers (20 ml) per 100 m^3 to 5480 numbers (30 ml) per 100 m^3 in the postmonsoon seasons.

Chittoor: This field also showed high biomass value in premonsoon and low in postmonsoon. In 88-89, the plankton biomass values were 15 ml or 3783 Nos/100 m^3 and 200 ml or 10609 Nos/100 m^3 respectively for postmonsoon and premonsoon; while during 89-90, the biomass ranged from 8486 numbers or 100 ml (postmonsoon) to 20668 numbers or 150 ml/ 100 m^3 (premonsoon).

Mulavukad: The zooplankton biomass was much less in this station compared to the other seasonal fields. The highest numberical abundance was recorded in the postmonsoon of 89-90 (27440 Nos/100 m^3 amounting to 15 ml/100 m^3 only); whereas in the premonsoon the biomass was 50 ml/100 m^3 although the numerical abundance was only 20580.

Zooplankton number showed significant correlation with salinity (0.656) and alkalinity (-0.516) at Cherai and with water temperature (0.661) *at Chittoor (Table-18).*

The variation in zooplankton biomass was not significant among stations and with seasons as seen from the ANOVA Table (Table-19).

Table-13. Quantitative abundance (Nos/Vol per 100 m³) of zooplankton

Season	Cherai Nos.	Cherai Vol. (ml)	Narakkal Nos.	Narakkal Vol. (ml)	Chittoor Nos	Chittoor Vol. (ml)	Mulavukad Nos	Mulavukad Vol. (ml)
1988-89								
Premonsoon	33840	100	70298	185	10609	200	6435	25
Postmonsoon	4279	25	5480	30	3783	15	1840	10
1989-90								
Premonsoon	22631	80	79139	500	20668	150	20580	50
Postmonsoon	230092	1500	3041	20	8486	100	27440	15

QUALITATIVE COMPOSITION OF ZOOPLANKTON

Cherai: Fig. 28a shows the monthly percentage occurrence and Table-14a the seasonal percentage composition of zooplankton. The most dominant zooplankton component was copepods and their percentage composition ranged from 19.5 (January, 89) to 99.8 (February, 90). Its abundance was high during premonsoon in 88-89 and during postmonsoon in 89-90. Copepods formed about 98.86% of the total zooplankton. The next dominant component was mysids forming about 0.43% of the total plankton and were abundant during premonsoon in 88-89, whereas they were totally absent in 89-90. The next important group was amphipod whose maximum abundance was found in January '89. In 88-89, amphipods were more common during pre-

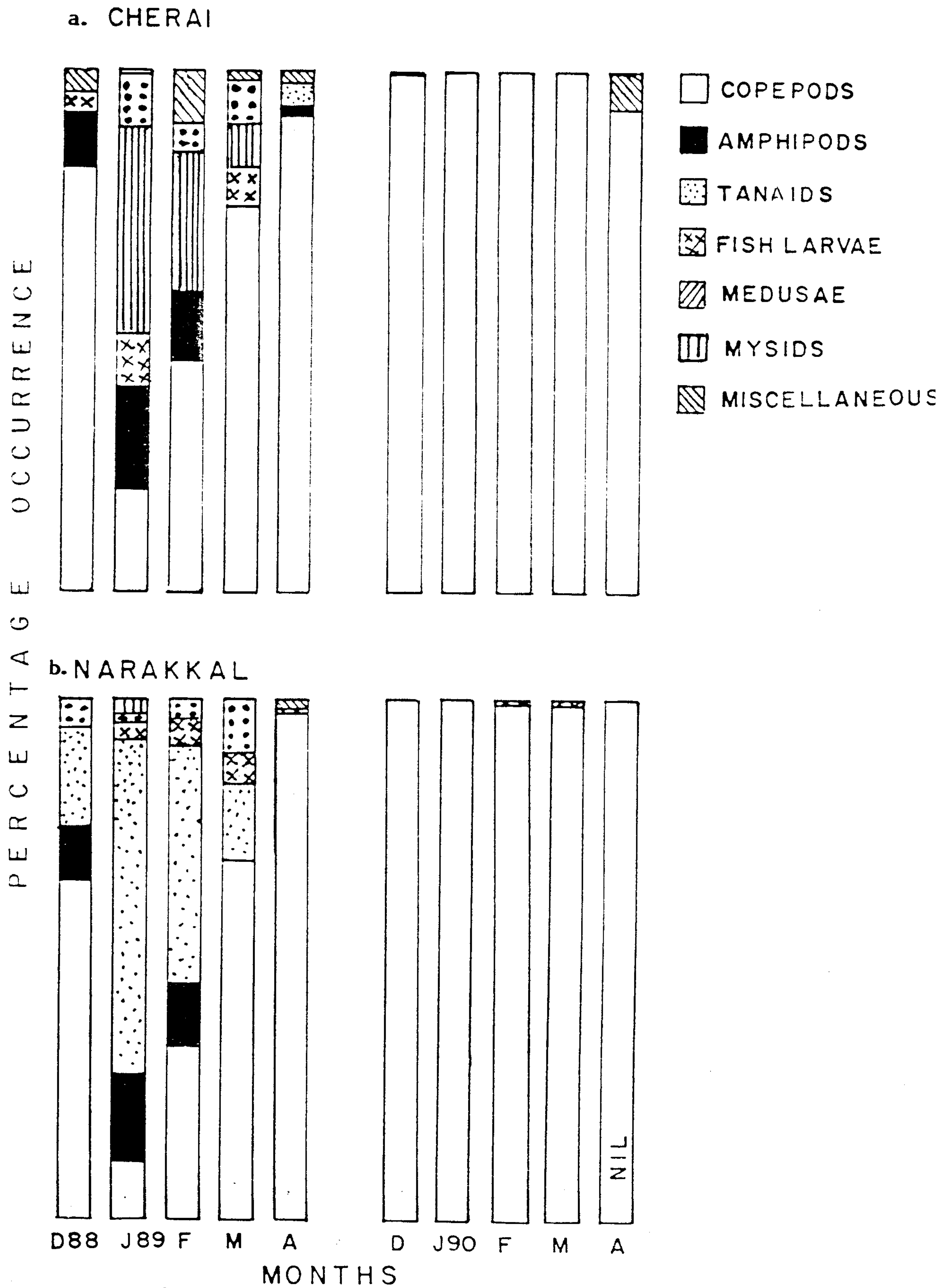


Fig.28. Monthly percentage composition of Zooplankton at a. Cherai and b. Narakkal.

Table-14. Seasonal percentage composition of zooplankton

a. Cherai

Group	1988 - 89		1989 - 90	
	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon
Copepod	90.72	9.38	8.94	91.06
Amphipod	62.52	37.48	-	100.00
Tanaid	100.00	-	-	-
Fish larvae	40.11	59.89	-	100.00
Mysid	77.14	22.82	-	-
Lucifer	75.00	25.00	-	-
Polychaete	60.00	40.00	-	-
Medusae	100.00	-	-	-
Miscellaneous	100.00	-	50.00	50.00

b. Narakkal

Copepod	98.02	1.98	96.27	3.73
Amphipod	29.47	70.53	-	-
Tanaid	33.61	66.39	-	-
Fish larvae	81.85	18.15	100.00	-
Polychaete	60.00	40.00	-	-
Mysid	-	100.00	100.00	-
Ostracod	-	-	100.00	-
Miscellaneous	100.00	-	100.00	-

monsoon than postmonsoon; whereas this group occurred only during post-monsoon of 89-90. Polychaetes were recorded only during 89-90 with their abundance during premonsoon. The less abundant planktonic groups were fish larvae and tanaids. In general the number of planktonic groups were more during 88-89 than 89-90.

Narakkal: This station was also characterised by the presence of more planktonic groups during 88-89 when compared to 89-90. Fig. 28b shows the monthly percentage occurrence and Table-14b depicts the seasonal percentage composition of the plankton. Copepods were the dominant plankton component throughout the period of study except January and February 89. They formed about 94.54% of the total zooplankton and their abundance was high during premonsoon. The next abundant group was tanaids (2.79% of the plankton) and were represented in all months during 88-89. Generally tanaids were abundant during postmonsoon. Amphipods also formed a small percent (0.76) of the plankton and their percentage was more in postmonsoon. Apart from this, other planktonic forms such as polychaetes, fish larvae and mysids formed about 0.22%, 0.83% and 0.09% respectively of the total zooplankton.

Chittoor: Here also, the period 88-89 was rich in planktonic forms. Copepods were the dominant plankton component in most of the months. They constituted about 73.47% of the total plankton. Maximum abundance was noticed during premonsoon. The next abundant group was tanaids which formed about 8.84% of the plankton. Their abundance was fairly high in premonsoon.

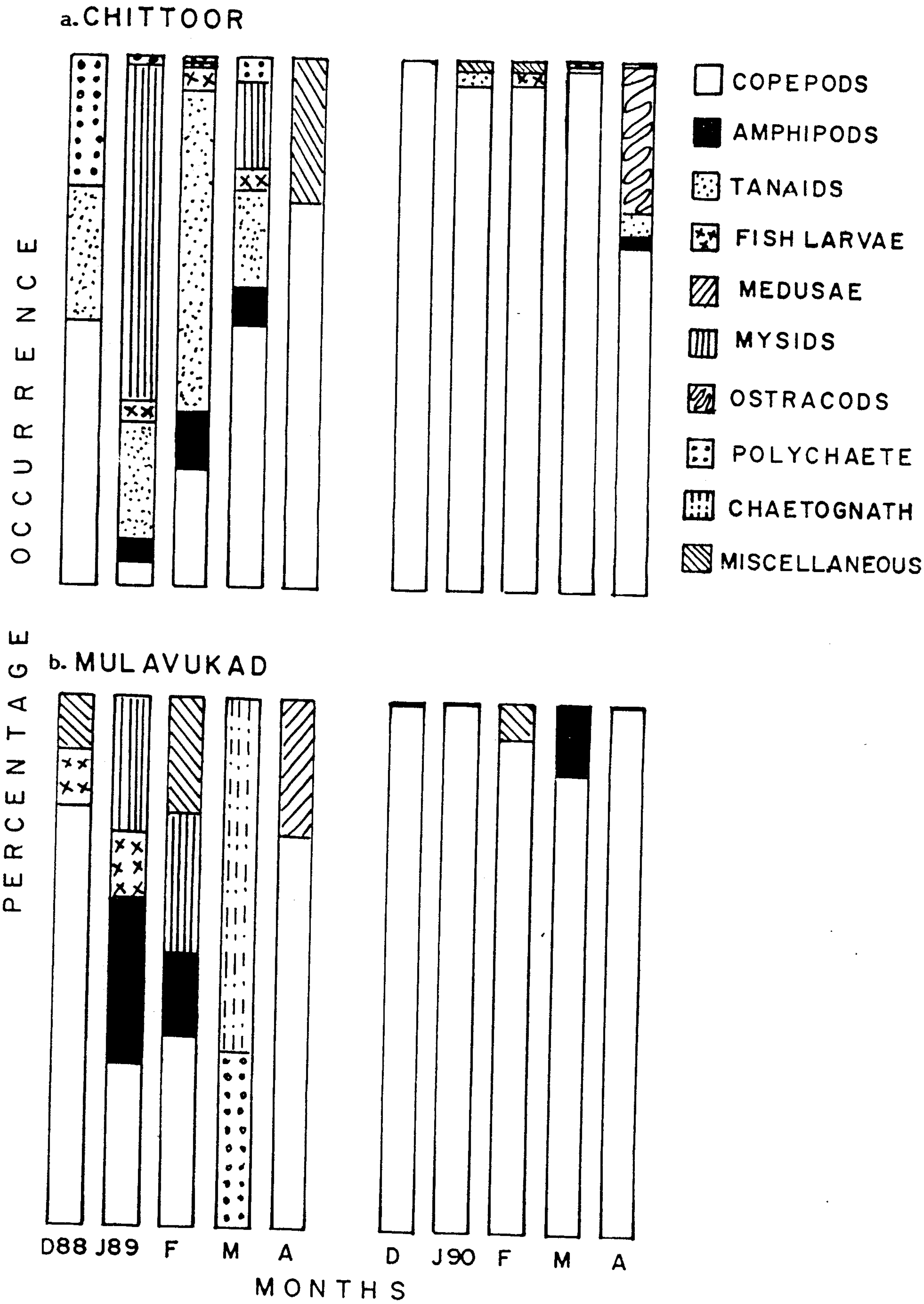


Fig. 29. Monthly percentage of zooplankton at a. Chittoor and b. Mulavukad.

Table-15. Seasonal percentage composition of zooplankton.

a. Chittoor

Group	1988 - 89 Premonsoon	1988 - 89 Postmonsoon	1989 - 90 Premonsoon	1989 - 90 Postmonsoon
Copepod	93.71	6.29	75.67	24.33
Amphipod	81.85	18.15	83.30	16.70
Tanaid	80.35	19.65	66.67	33.33
Fish larvae	67.00	33.00	100.00	-
Mysid	15.78	84.22	-	-
Polychaete	50.00	50.00	100.00	-
Lucifer	100.00	-	-	100.00
Ostracod	-	-	100.00	-
Miscellaneous	100.00	-	100.00	-

b. Mulavukad

Group	1988 - 89 Premonsoon	1988 - 89 Postmonsoon	1989 - 90 Premonsoon	1989 - 90 Postmonsoon
Copepod	79.68	20.32	52.42	47.52
Amphipod	54.00	46.00	58.90	41.10
Fish larvae	-	100.00	-	-
Mysid	71.40	28.60	-	-
Lucifer	-	100.00	-	-
Medusae	100.00	-	-	-
Polychaete	100.00	-	-	-
Chaetognath	100.00	-	-	-
Miscellaneous	100.00	-	50.00	50.00

Mysids followed tanaids and were abundant during the postmonsoon of 88-89 and were totally absent in 89-90. They accounted for 5.17% of the plankton. Amphipods, though recorded in almost all months, their maximum abundance was in premonsoon constituting 2.47% of the total zooplankton from this station. Polychaetes (0.68%), fish larvae (2.26%) and Ostracods (5.17%) were also present among the plankton (Fig. 29a and Table-15a).

Mulavukad: The dominant plankton component was copepods. Their maximum abundance was noticed during premonsoon and this accounted for about 92.02% of the total zooplankton. Amphipods were the next abundant component. They were recorded in almost all months with maximum abundance in premonsoon. Amphipods formed about 2.45% of the zooplankton. Mysids, though recorded only during two months of premonsoon season in the entire period of study, they formed about 1.76 of the plankton. Similarly fish larvae were also recorded only during postmonsoon season of 88-89 and formed about 0.38% of the plankton. Chaetognaths and medusae were recorded only once during the entire study period, contributing 0.25 and 1.63% respectively of the total zooplankton (Fig. 29b and Table-15b).

TERTIARY PRODUCTION

Data on prawn/fish production could be collected only from one seasonal field (Mulavukad). In this field, the prawn production data was limited to five months only (December to April 88-89 and 89-90). The seasonal variation in production and rate of yield is given in Table-16.

Table-16. Seasonal variation in prawn/fish production (Kg) at Mulavukad (1.6 ha). Production/ha is given in parentheses.

Group/Species	1988 - 89		1989 - 90	
	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon
Penaeus indicus	1331 (831.88)	14.0 (8.75)	865 (540.63)	75 (46.88)
Metapenaeus dobsoni	1181 (738.13)	1440 (900)	490 (360.25)	920 (575)
M. monoceros	205 (128.13)	520 (325)	25 (15.63)	250 (156.25)
Total prawn	2717 (1698.13)	1974 (1233.75)	1380 (862.5)	1245 (778.13)
Total fish	1503 (939.38)	25 (16.63)	880 (550)	47 (29.38)
Total production (fish + prawn)	4220 (2637.5)	1999 (1249.38)	2260 (1412.5)	1292 (807.5)
Total production for the year	6219 (3886.88)		3552 (2220)	
Total prawn production	(2931.88)		(1640.63)	

A total production (fish + prawn) of 6219 Kg. was obtained from this seasonal field during 88-89. Out of this the share of finfish was 1528 Kg. (24.57%) and that of prawn was 4691 Kg. (75.43%). Among prawns, Metapenaeus dobsoni was the dominant species with maximum production in postmonsoon (1440 Kg), while the production was 1181 Kg during premonsoon. The percentage of M. dobsoni in total prawn was 55.87%. Penaeus indicus was the next dominant species whose high production was recorded during premonsoon (1331 Kg). It contributed about 28.67% of the total prawn. M. monoceros contributed only 15.46% of the total prawn and its maximum production (520 Kg) was in postmonsoon.

During 89-90, the total production was 3552 Kg. Out of this finfish contributed nearly 927 kg (26.10%) and the rest prawns (2625 Kg, 73.90%). The production was more during premonsoon when compared to postmonsoon. Here also, the dominant species was M. dobsoni, forming about 53.71% of the total prawn, with production of 920 and 490 Kg during postmonsoon and premonsoon respectively. P. indicus showed its maximum production during premonsoon (865 Kg). Of the total prawn, about 35.81% was contributed by P. indicus. The lowest production was recorded by M. monoceros (250 and 25 Kg respectively for postmonsoon and premonsoon) and formed 10.48% of the total prawn yield.

Tilapia mossambica, Etroplus suratensis, E. maculatus, Liza parsia and Ambassis sp. were the major constituents of the fish harvest. Alongwith fishes, stray occurrence of mud crab, Scylla serrata was also noticed.

COMPARISON OF PRODUCTION IN THE PRIMARY, SECONDARY AND TERTIARY TROPHIC LEVELS.

Comparison of production in the primary, secondary and tertiary level (gram per 100m^3) is shown in (Table-17).

Table-17. Comparison of production (g/100 m^3) in the primary, secondary and tertiary trophic levels at Mulavukad.

(Values within parentheses indicate their percentage in primary production).

Production	1988 - 89		1989 - 90	
	Premonsoon	Postmonsoon	Premonsoon	Postmonsoon
Primary	461	204	399	241
Secondary	25 (5.42)	10 (4.90)	50 (12.53)	15 (6.22)
Tertiary	264 (57.26)	125 (61.27)	141 (35.33)	81 (33.61)

It was observed that about 5.42 to 12.53% of the primary production was utilized in the secondary level. Very high tertiary production, ranging from 81 to 264 g with the maximum in premonsoon, was also noticed. Tertiary production accounted for about 33.61 to 61.27% of the primary production. In general, primary, secondary and tertiary production did not follow a steady pattern over seasons and years.

COASTAL FLORA AND OTHER UNIQUE FEATURES

Cherai: The marginal flora consisted mainly of *Acanthus ilicifolius* and *Fimbris stylis*. Of this, *A. ilicifolius* was dominant throughout the study period and their flowering season was found to be in April, whereas F stylis was recorded during early half of postmonsoon season.

Infestation of Enteromorpha intestinalis (green alga) and floating weed (Salvinia sp.) was noticed during late premonsoon months.

Narakkal: The following plants constituted the coastal flora during early half of postmonsoon months. They were Ludwigia sp., Sphaeranthus sp., Eclipta alba and Hygrophila quadrivalvis; whereas the latter part of postmonsoon (January) and early premonsoon months (February) were characterised by the dominance of stag horn (Ceratopteris sp.). Acanthus ilicifolius was the only species present throughout the year. Its flowering season was observed in April. The entire vegetation was in the dried condition during premonsoon months except A. ilicifolius.

Chittoor: The marginal vegetation consisted of mangrove fern (Acrostichum aureum), Fimbris stylis and Ipomoea aquatica. Among this A. aureum was dominant throughout the study period, whereas the other two species ocurred during early and mid part of postmonsoon season.

Heavy infestation of floating weeds such as Salvinia sp.and Eichhornia sp. was noticed during late postmonsoon months.

Mulavukad: Scattered occurrence of only a few species of plants were noticed from this field throughout the study period. These plants were *Acanthus ilicifolius, Thespesia populnea* and *Excoccaria agallocha*. Among this flowering of *A. ilicifolius* was noticed in April.

Table-18. Correlation matrix of various environmental parameters.

Wat. Temp.	pH	Salin.	Alkali.	Diss. oxygen	Prim. Prod.	Zoopl. No.
Cherai						
1.000						
*0.591	1.000					
0.359	0.339	1.000				
0.479	*0.587	*0.704	1.000			
0.430	0.399	0.394	0.276	1.000		
0.079	0.408	0.032	0.066	0.435	1.000	
0.069	-0.438	*0.665	*-0.516	-0.132	-0.196	1.000
Narakkal						
1.000						
0.531	1.000					
0.131	0.171	1.000				
0.490	*0.675	0.416	1.000			
0.266	*0.566	0.221	0.415	1.000		
0.292	0.356	0.173	0.248	*0.593	1.000	
0.383	0.438	-0.253	0.009	0.098	0.004	1.000
Chittoor						
1.000						
-0.041	1.000					
-0.448	-0.261	1.000				
0.017	-0.220	0.243	1.000			
*0.559	-0.204	-0.178	0.291	1.000		
0.047	*0.518	0.139	0.257	0.196	1.000	
*0.661	-0.151	-0.143	0.373	*0.519	-0.246	1.000
Mulavukad						
1.000						
0.367	1.000					
0.017	-0.096	1.000				
-0.001	-0.308	0.349	1.000			
-0.003	0.011	0.039	0.228	1.000		
-0.108	*0.503	*0.512	-0.331	-0.172	1.000	
0.141	0.413	0.151	-0.215	-0.446	-0.179	1.000

* Significant at 5% level

Table-19. Two way Analysis of Variance (ANOVA) Tables showing the level of significance in variation of different parameters among stations and over seasons.

Source	D.F.	SUM. SQR	MEAN SQR	F.VAL	REMARKS
Water temperature					
Treat	3	0.092	0.031	0.12	N.S.
Replic	1	11.139	11.139	44.85	HI.SIG(1%)
Error	3	0.745	0.248		
pH:					
Treat	3	0.122	0.041	1.50	N.S.
Replic	1	0.097	0.097	3.55	N.S.
Error	3	0.082	0.027		
Salinity:					
Treat	3	80.720	20.27	2.73	N.S.
Replic	1	290.28	135.14	25.26	N.S.
Error	3	29.03	5.45		
Total alkalinity:					
Treat	3	2246.488	748.829	47.90	HI.SIG (1%)
Replic	1	255.258	255.258	16.33	SIG (5%)
Error	3	46.902	15.634		
Dissolved oxygen:					
Treat	3	0.309	0.103	1.32	N.S.
Replic	1	1.901	1.901	24.32	SIG (5%)
Error	3	0.235	0.078		
Nitrate-N:					
Treat	3	40.506	13.502	4.06	N.S.
Replic	1	1.232	1.232	0.37	N.S.
Error	3	9.980	3.327		
Nitrite-N:					
Treat	3	7.410	2.470	1.75	N.S.
Replic	1	2.509	2.509	1.78	N.S.
Error	3	4.224	1.408		
Reactive phosphorus:					
Treat	3	11.824	3.941	1.18	N.S.
Replic	1	2.785	2.785	0.84	N.S.
Error	3	10.00	3.333		
Silicate-silicon:					
Treat	3	274.857	91.619	1.50	N.S.
Replic	1	2.029	2.029	0.03	N.S.
Error	3	182.777	60.926		
Primary production:					
Treat	3	982517.000	327505.700	1.50	N.S.
Replic	1	32131.000	32131.000	0.15	N.S.
Error	3	654633.000	218211.000		
Chlorophyll-a:					
Treat	3	67.367	22.456	0.09	N.S.
Replic	1	247.199	247.199	0.94	N.S.
Error	3	786.339	262.113		
Chlorophyll-b:					
Treat	3	34.241	11.414	0.82	N.S.
Replic	1	39.472	39.472	2.84	N.S.
Error	3	41.676	13.892		
Chlorophyll-c:					
Treat	3	74.329	24.776	1.60	N.S.
Replic	1	161.281	161.281	10.41	SIG (5%)
Error	3	46.497	15.499		
Carotenoids:					
Treat	3	213.600	71.200	1.99	N.S.
Replic	1	233.495	233.495	6.52	N.S.
Error	3	107.418	35.806		
Zooplankton biomass:					
Treat	3	35.802	11.802	0.63	N.S.
Replic	1	1.125	1.125	0.06	N.S.
Error	3	55.771	18.590		
Organic carbon:					
Treat	3	0.533	0.178	2.20	N.S.
Replic	1	0.661	0.661	8.18	N.S.
Error	3	0.243	0.081		

III. COCONUT GROVES

TEMPERATURE

The monthly variations in atmospheric and water temperature are depicted in Fig. 30. Atmospheric temperature varied from 24.75°C to 30.65°C and water temperature ranged from 27.0°C to 32.75°C at Edavanakkad and 27.2 to 32.75°C at Narakkal. Premonsoon showed slightly higher water temperature in 89-90.

Correlation coefficient (r) values showed that water temperature exhibited significant reationship with pH (0.353) and zooplankton number (0.378) at Narakkal (Table-24).

From the ANOVA Table (Table-25), it is clear that the variation in temperature between stations was not significant and that of seasons was highly significant ($P < 0.01$).

pH

In general, pH showed alkaline values throughout the study period. However, low values were observed during July. It varied from 6.1 to 8.25 and 6.2 to 8.35 at Edavanakkad and Narakkal respectively. In 88-89, high values were recorded during premonsoon in both stations, whereas in 89-90, monsoon months showed high values (Fig. 31).

III. COCONUT GROVES

TEMPERATURE

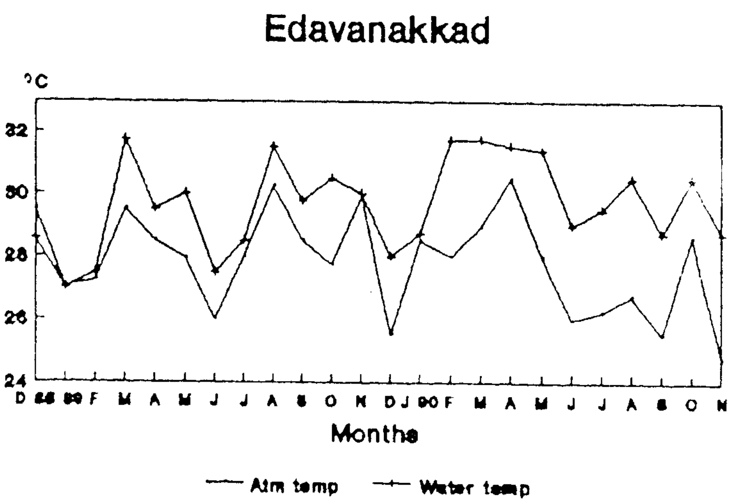
The monthly variations in atmospheric and water temperature are depicted in Fig. 30. Atmospheric temperature varied from 24.75°C to 30.65°C and water temperature ranged from 27.0°C to 32.75°C at Edavanakkad and 27.2 to 32.75°C at Narakkal. Premonsoon showed slightly higher water temperature in 89-90.

Correlation coefficient (r) values showed that water temperature exhibited significant reationship with pH (0.353) and zooplankton number (0.378) at Narakkal (Table-24).

From the ANOVA Table (Table-25), it is clear that the variation in temperature between stations was not significant and that of seasons was highly significant ($P < 0.01$).

pH

In general, pH showed alkaline values throughout the study period. However, low values were observed during July. It varied from 6.1 to 8.25 and 6.2 to 8.35 at Edavanakkad and Narakkal respectively. In 88-89, high values were recorded during premonsoon in both stations, whereas in 89-90, monsoon months showed high values (Fig. 31).



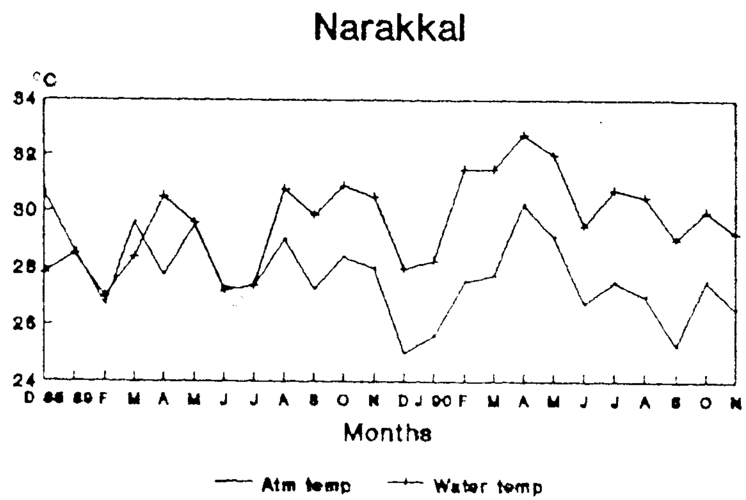


Fig. 30. Monthly variations in Atmospheric and Water temperature

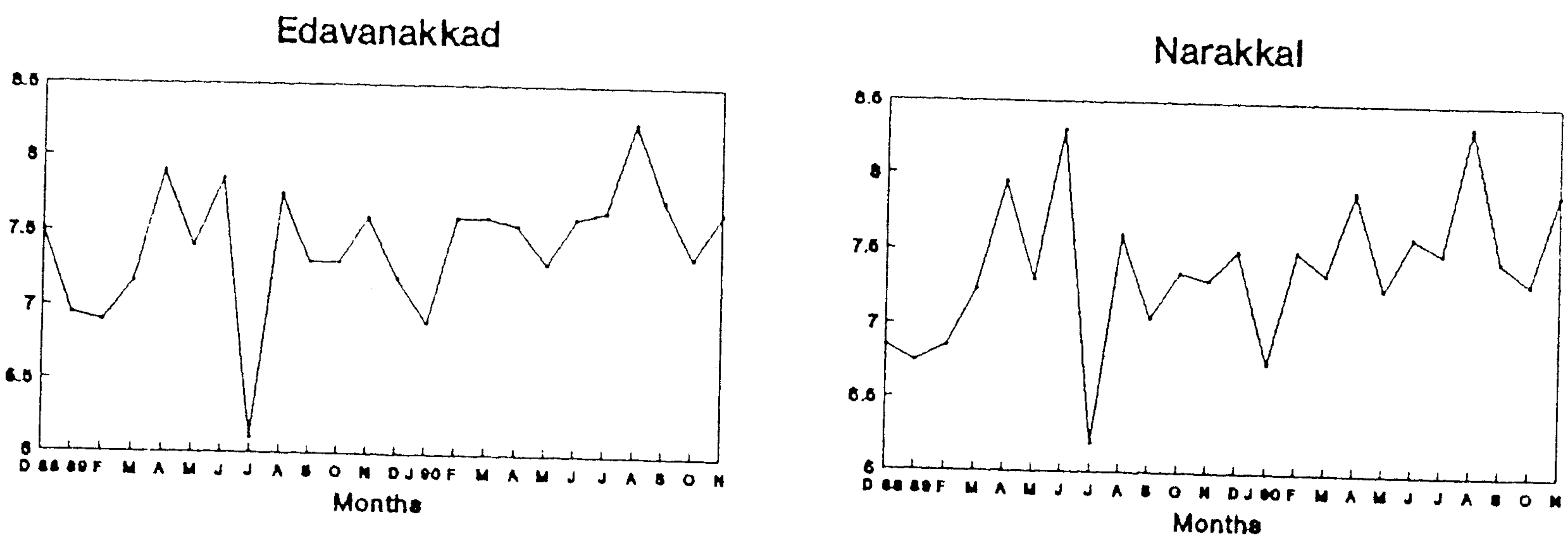


Fig. 31. Monthly variation in pH

pH showed significant correlation with water temperature (0.353) at Narakkal (Table-24).

From the ANOVA Table (Table-25) it is evident that there was no significant variation in pH among stations. However, the variation was significant ($P < 0.05$) over seasons.

SALINITY

Salinity values showed marked seasonal variation (0.96 to 25.25‰) with low values recorded in monsoon and high values in premonsoon. The monthly salinity values at Edavanakkad and Narakkal are shown in Fig.32. At Edavanakkad coconut grove, it ranged from 2.52 to 19.27‰ and at Narakkal, it was 0.96-25.25‰.

Significant relationship (Table-24) was noticed between salinity and zooplankton number (0.345) at Narakkal.

Two way Analysis of Variance (Table-25) showed that there was no significant variation in salinity between stations, but showed significant relationship over seasons (P 0.05).

TOTAL ALKALINITY

High alkalinity values were recorded from this system. The minimum and maximum being 24 and 138 mg/l and 27.25 and 185 mg/l respectively

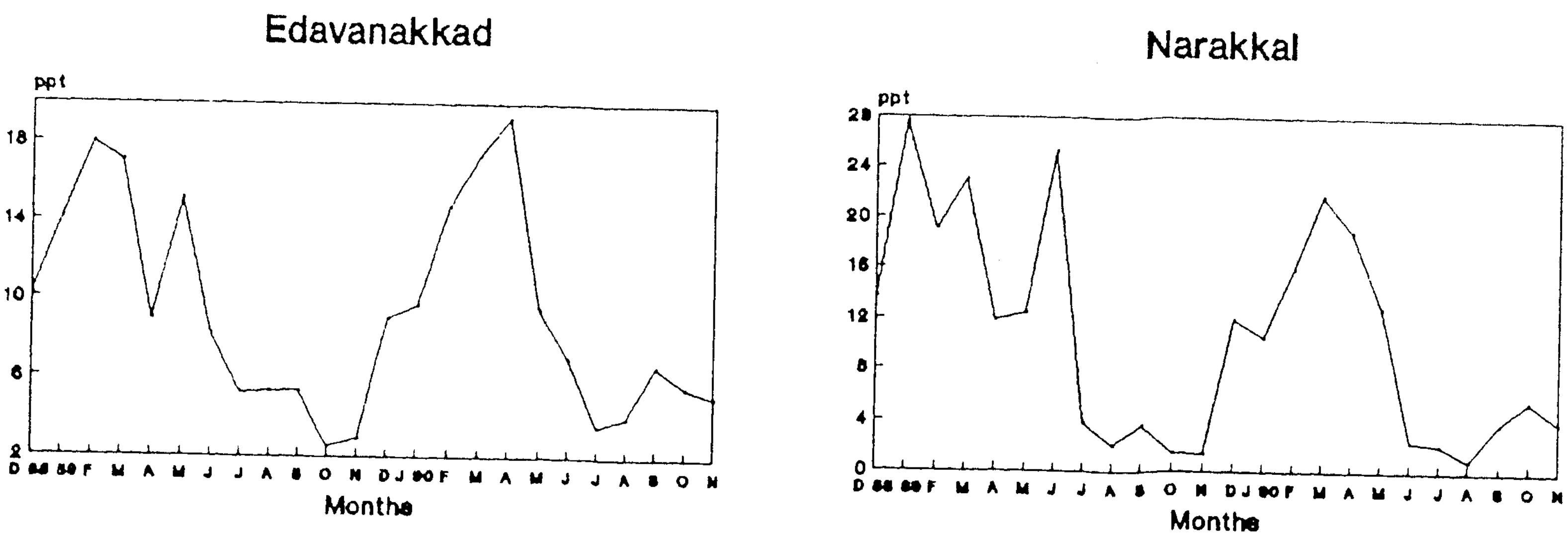


Fig. 32. Monthly variation in salinity.

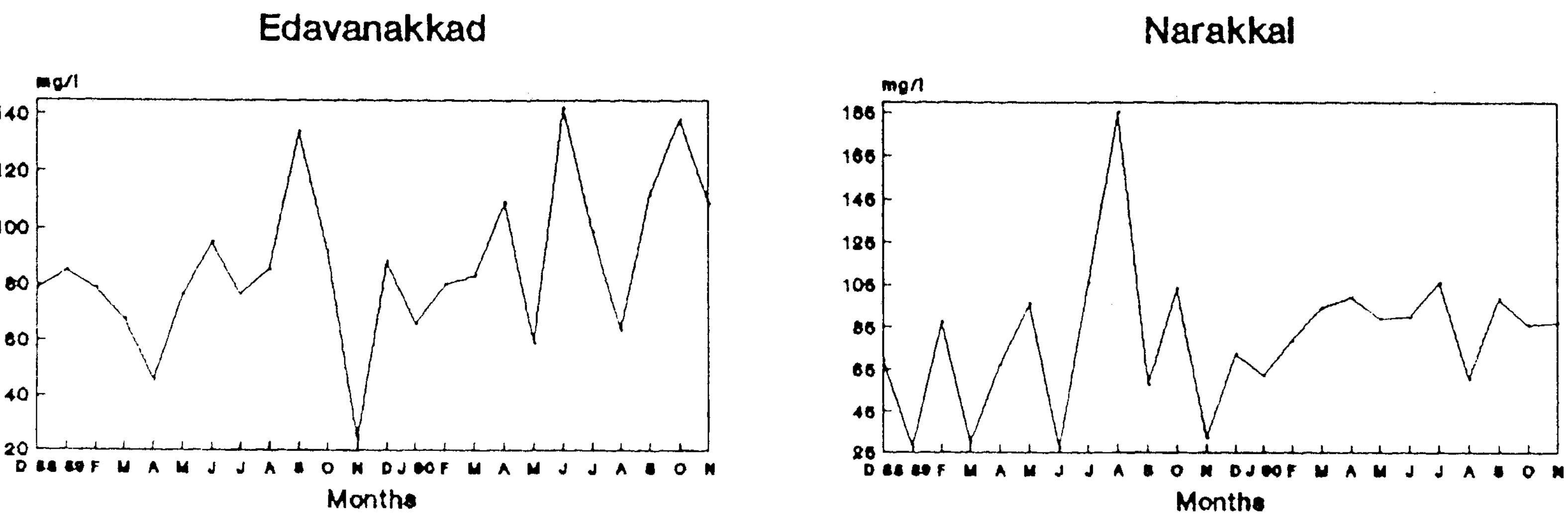


Fig. 33. Monthly variation in Total Alkalinity

for Edavanakkad and Narakkal (Fig. 33). In general, high alkalinity values were recorded during monsoon.

The correlation coefficient (r) values showed significant relationship between alkalinity and zooplankton number (0.305) at Edavanakkad, whereas in Narakkal, the relationship was with primary production (0.313) as shown in Table-24.

It is seen from the ANOVA (Table-25) that there was no significant variation in alkalinity between stations and from season to season.

DISSOLVED OXYGEN

Generally, very low dissolved oxygen concentration was noticed in most of the months. Oxygen content ranged from 1.73 to 5.59 and 1.65 to 5.38 mg/l respectively in Edavanakkad and Narakkal (Fig. 34). In both stations slightly high values were observed during premonsoon in 88-89 and during monsoon in 89-90.

Dissolved oxygen showed a positive correlation with primary production (0.332) at Narakkal (Table-24).

The two way ANOVA Table (Table-25) showed a non-significant variation in dissolved oxygen concentration between stations, while the variation over seasons was significant ($P < 0.05$).

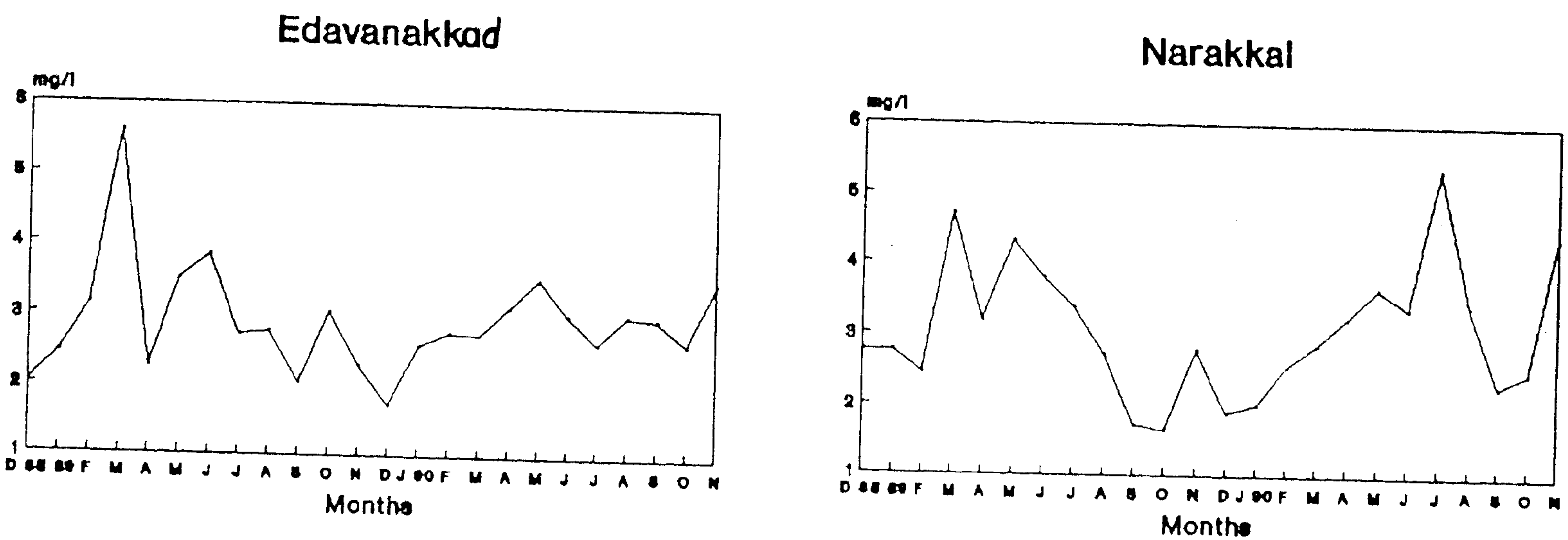


Fig. 34. Monthly variation in Dissolved Oxygen

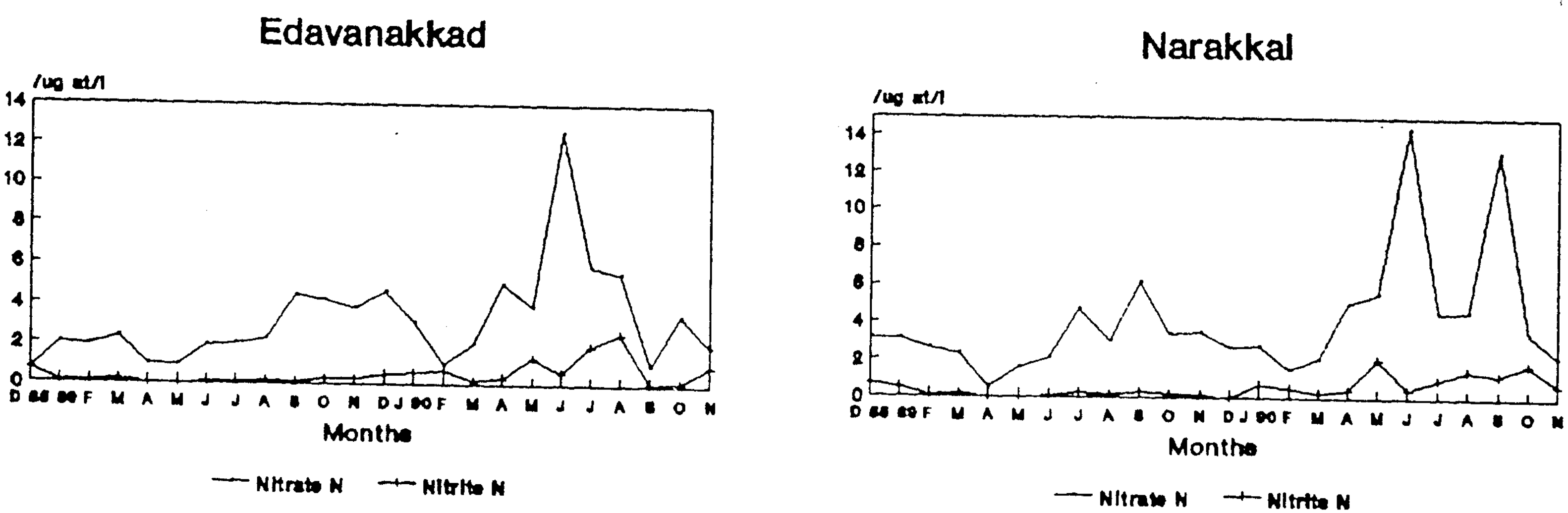


Fig. 35. Monthly variations in Nitrate and Nitrite-Nitrogen

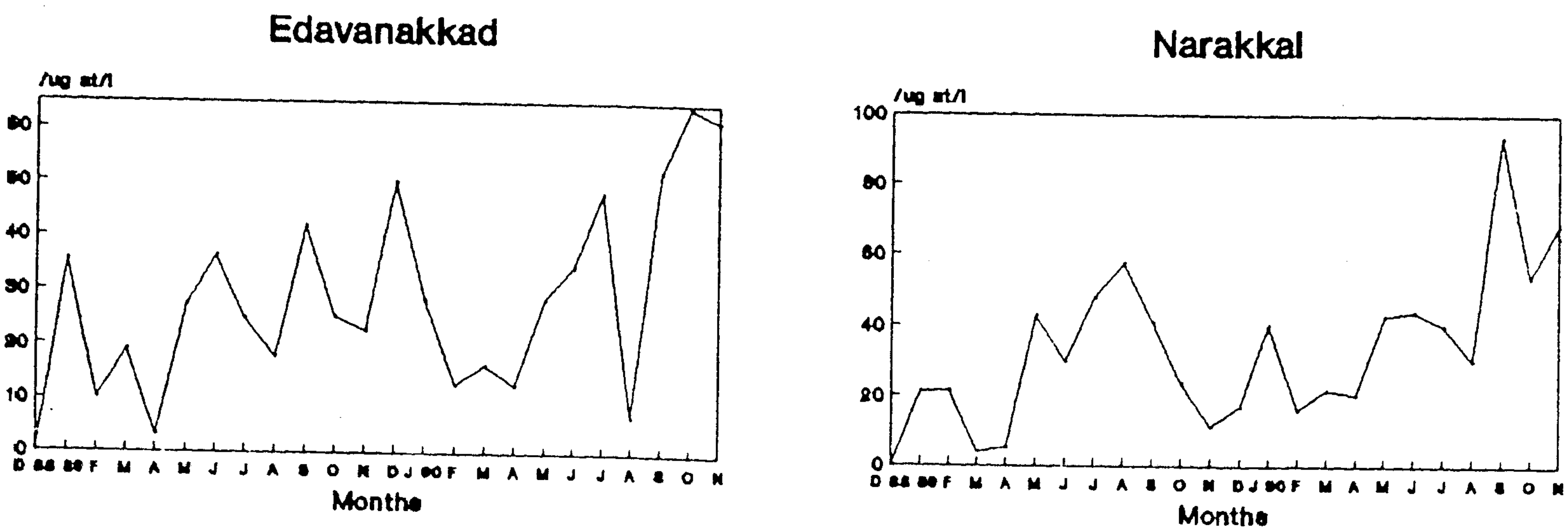


Fig. 36. Monthly variation in Ammonia-Nitrogen

NITRATE AND NITRITE-NITROGEN

Nitrate-N concentration fluctuated from 0.94 to 12.6 μg at/l in Edavanakkad and from 0.53 to 14.4 μg at/l in Narakkal. Comparatively high values were noticed during south-west monsoon and postmonsoon of 88-89 whereas it was high during monsoon in 89-90.

Nitrite-N concentration was less compared to that of Nitrate-N (Fig. 35). It ranged from 0.003 to 2.03 μg at/l at narakkal and 0.007 - 2.55 μg at/l at Edavanakkad. High values were obtained during postmonsoon of 88-89 and monsoon in 89-90 at both stations.

The variation in the concentration of both nitrate and nitrite-nitrogen was not significant between stations and from season to season as seen from the ANOVA Table (Table-25).

AMMONIA-NITROGEN

Very high values of Ammonia-N were recorded in both stations. The minimum and maximum values were 1.01 and 64.71 μg at/l at Edavanakkad and 4.14 and 93.5 μg at/l at Narakkal respectively. Seasonal fluctuation was not consistant in the two years (Fig. 36).

REACTIVE PHOSPHORUS

Phosphorus concentration was also quite high in this system. It ranged from 0 to 11.23 μg at/l at Edavanakkad and 1.0 to 8.48 μg at/l

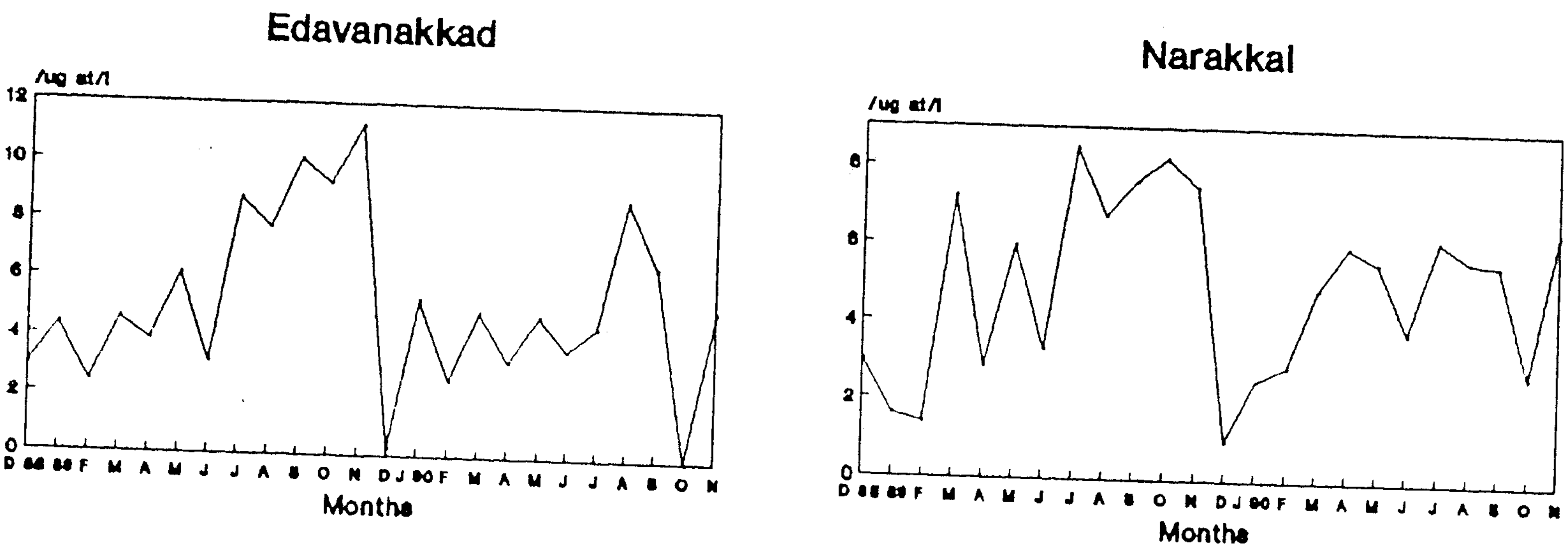
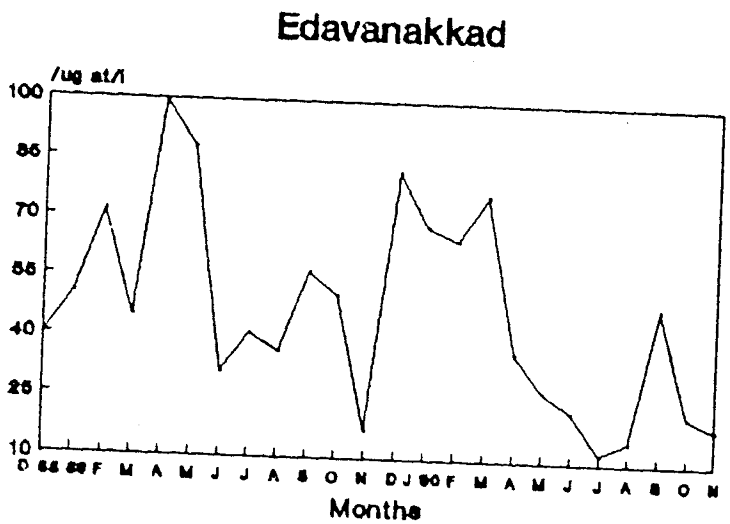


Fig. 37. Monthly variation in Reactive phosphorus



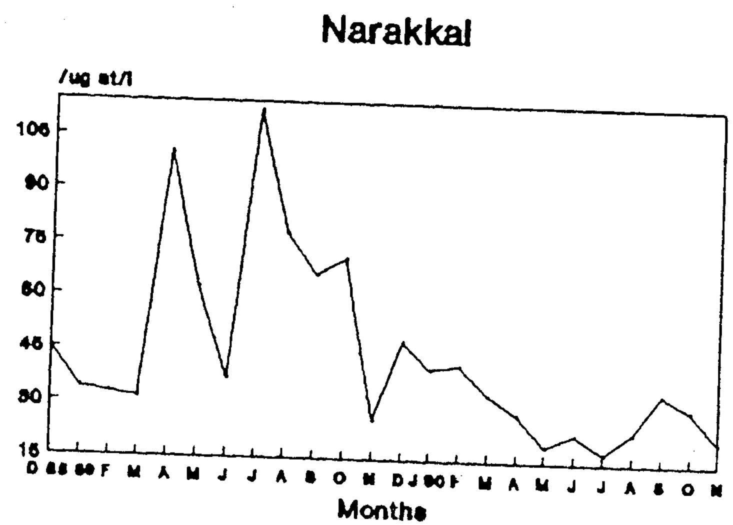


Fig. 38. Monthly variation in Silicate-silicon

at Narakkal (Fig. 37). Seasonal variation was less pronounced.

The ANOVA Table (Table-25) showed that the variations in the concentration of reactive phosphorus with seasons and between stations were not significant.

SILICATE-SILICON

Silicate was also distributed in high concentration. Both stations showed almost similar values and it ranged from 12.5 to 99.5 (Edavanakkad and 18 to 112.5 /ug at/l (Narakkal). Generally, high values were recorded during pre and postmonsoon months (Fig. 38).

The variation in the concentration of siicate was not significant between stations and with seasons (Table-25).

ORGANIC CARBON CONTENT OF THE SEDIMENT

Tabe-20. Seasonal variation of organic carbon content (%)

Station	1988 - 89			1989 - 90		
	Pre monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post Monsoon
Edavanakkad	0.52	0.81	1.08	0.16	1.61	0.99
Narakkal	1.24	1.28	1.52	0.79	3.38	1.67

The seasonal variation in organic carbon content is given in Table-20. The coconut groves at Edavanakkad and Narakkal showed high organic carbon content in the sediment during the postmonsoon of 1988-89, while the monsoon season showed high organic carbon in 89-90. Among the two stations, Narakkal showed the highest value (3.38%) especially during the monsoon of 1989-90.

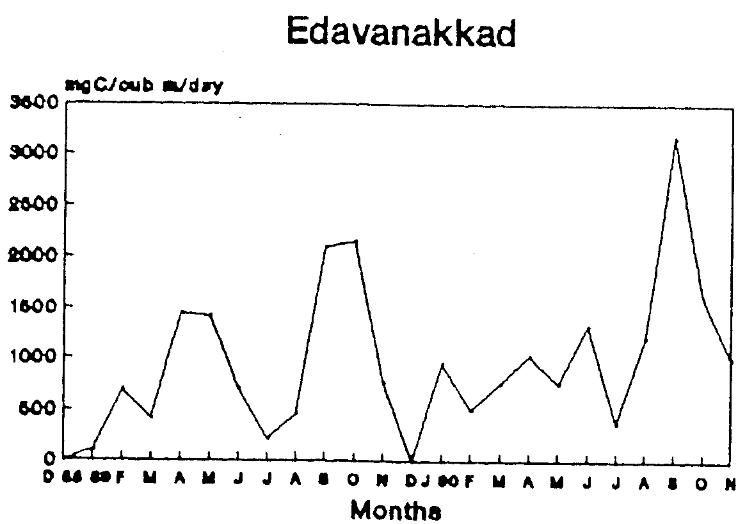
The variation in the organic carbon content of the sediment was not significant between the stations and with seasons (Table-25).

PRIMARY PRODUCTION

Monthly primary production trend of the two stations are shown in Fig. 39. The productivity of this system was found to be comparatively low and values never exceeded 3340 mgC/m^3/day. The production ranged from 105 to 3340 mgC/m^3/day in Edavanakkad and 100 to 2658 mgC/m^3/day in Narakkal with the highest values recorded towards the closure of monsoon season (August-September).

Primary production showed positive correlation with dissolved oxygen (0.332) and a negative relationship with alkalinity (-0.313), at Narakkal (Table-24).

ANOVA Table (Table-25) showed no significant variation in primary production between stations and with seasons.



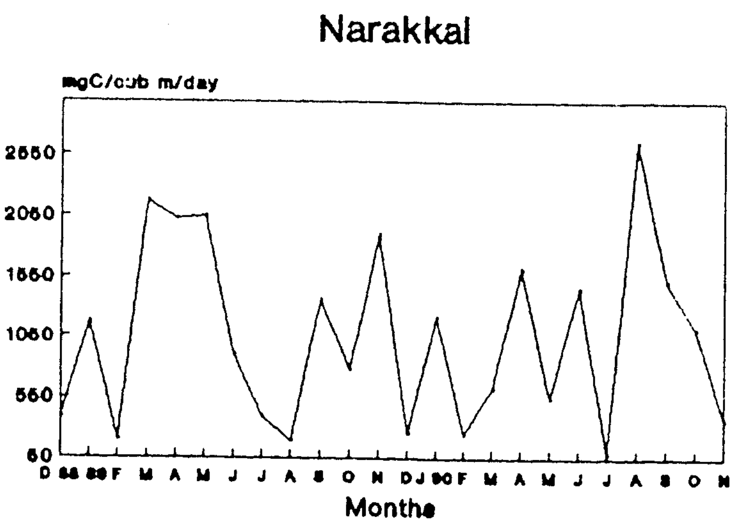


Fig. 39. Monthly variation in Primary production

PHYTOPLANKTON COMPOSITION

Edavanakkad: Diatoms were the major component of the plankton flora in this station. The blue green alga, Oscillatoria was noticed during monsoon. Unlike in seasonal ponds, a large number of genera were represented in Edavanakkad coconut grove throughout the season, the list of which is given in Table-21a.

Narakkal: The phytoplankton were represented by diatoms, green algae, blue green algae and dinoflagellates. Genera such as Coscinodiscus and Navicula were recorded throughout the seasons with the dominance of the former during postmonsoon. During postmonsoon, Pleurosigma and Tropidoneis lepidoptera were abundant in this station (Table-21b).

CHLOROPHYLLS AND CAROTENOIDS

This system showed high chlorophyll-a value and it formed 47% and 48% of the total plant pigment at Edavanakkad and Narakkal respectively It ranged from 0.74 to 135 mg/m^3 at Edavanakkad and 3.16 to 88.23 mg/m^3 at Narakkal. Seasonal variation in the two years was not consistent. Chlorophyll-b values were less compared to that of chlorophyll-a. It formed only 10% of the total plant pigment at both stations. The concentration ranged from 0 to 20.72 mg/m^3 (Edavanakkad) and 0 to 20.02 mg/m^3 (Narakkal). High values were recorded mostly during premonsoon. Chlorophyll-c also showed almost the same pattern of distribution as that of chlorophyll-b. Its percentage composition was only 16 in both the stations. Although seasonal variation was noticed with high concentration in premonsoon, it is not consistent in the two years. High concentration of carotenoid (27% of the total plant pigment) was recorded from this system. The concentration varied from 0.28 to 84.69 and 0 to 33.90 mg/m^3 at Edavanakkad and Narakkal respectively (Fig. 40). Though carotenoids did not follow a steady seasonal trend, slightly high concentration was observed during premonsoon and monsoon.

Table-21a. Seasonal availability of phytoplankton components - Edavanakkad

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Amphora lineolata	X	R	R
A. ostrearia	R	X	R
Cymbella marina	R	R	X
Diploneis robustus	C	R	C
Grammatophora undulata	X	R	X
Gyrosigma sp.	C	C	C
Navicula sp.	C	C	R
N. longa	X	R	X
N. distans	R	X	X
Nitzschia sp.	C	C	R
N. closterium	X	X	C
Oscillatoria princeps	X	C	X
Pinnularia alpina	X	R	R
Pleurosigma sp.	C	C	C
Rhizosolenia sp.	A	X	X
Stephanopyxis palmeriana	R	X	R
Thalassiosira subtilis	X	C	R
Tropidoneis lepidoptera	R	X	R

* A - Abundant; C - Common; R - Rare; X - Not observed.

Table-21b. Seasonal availability of phytoplankton components - Narakkal.

Phytoplankton	Premonsoon	Monsoon	Postmonsoon
Amphora ostrearia	X	X	R
Chlamydomonas sp.	X	C	R
Coscinodiscus sp.	C	R	A
Diploneis robustus	R	R	X
D. smithi	X	R	X
Grammatophora undulata	X	R	X
Gyrosigma sp.	C	X	C
Navicula sp.	C	C	R
Nitzschia sp.	R	C	X
N. panduriformis	R	R	X
N. longissima	X	R	X
Navicula longa	X	R	X
Oscillatoria princeps	X	R	X
Peridinium sp.	R	X	X
Pinnularia sp.	X	R	X
Pleurosigma sp.	X	X	A
P. angulatum	X	R	X
P. elongatum	X	R	X
Skeletonema costatum	C	X	X
Striatula delicatus	X	R	X
Synedra ulna	X	R	X
Thalassionema nitzschicoides	X	R	X
Thalassiothrix sp.	X	R	X
Tropidoneis lepidoptera	X	X	A

*A - Abundant; C - Common; R - Rare; X - Not observed.

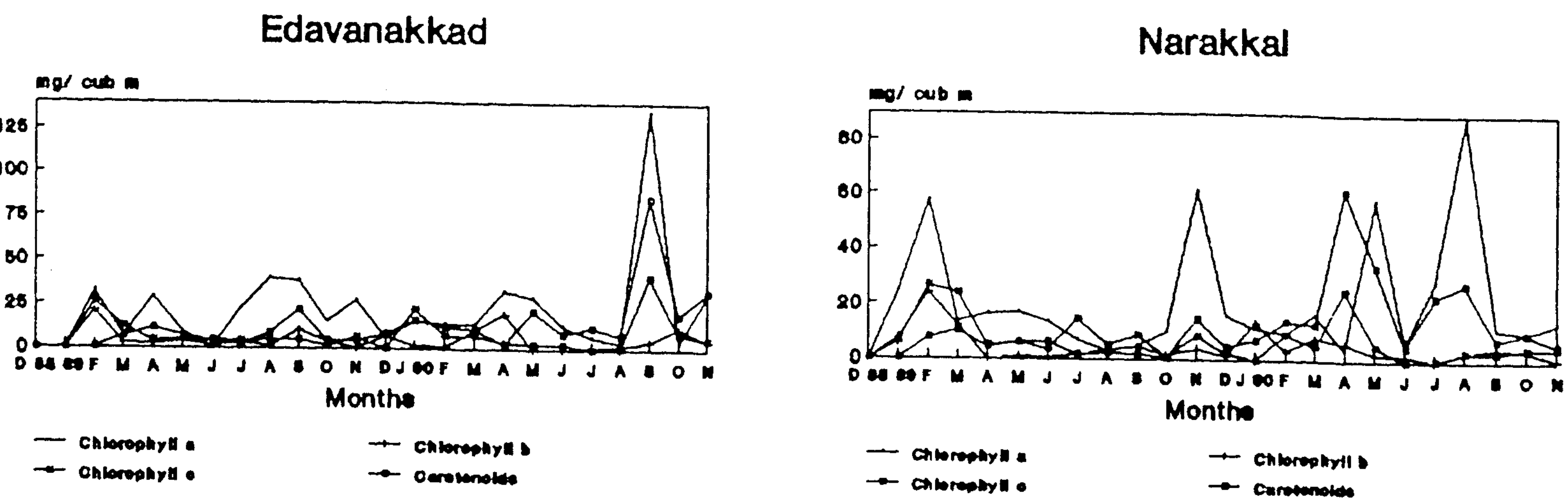


Fig. 40. Monthly variations in Chlorophylls and Carotenoids

In the case of chlorophyll a,b,c and carotenoids, the variation in their concentration was not significant between stations and with seasons (Table-25).

QUANTITATIVE ABUNDANCE OF ZOOPLANKTON

Seasonal variation in the zooplankton biomass of the coconut groves is given in Table-22.

Edavanakkad: Low biomass values were noticed during premonsoon (102544 Nos. or 200 ml/100 m^3. Postmonsoon also showed biomass of 45399 Nos. or 150 ml volume. Whereas in 89-90, a reverse trend, i.e, high values (430974 Nos. or 950 ml) in postmonsoon and comparatively low values (73760 Nos. or 150 ml) in premonsoon, was observed.

Narakkal: Biomass values were high during premonsoon throughout the study period. The values were 150 ml 31684 Nos. and 350 ml 91940 Nos. for 88-89 and 89-90 respectively. The next high biomass value was noticed during monsoon with the values of 100 ml 36309 Nos. in 88-89 and 50 ml 31468 Nos in 89-90. The lowest values were recorded during postmonsoon with 8486 Nos. or 35 ml (88-89) and 11034 Nos. or 25 ml (89-90).

Zooplankton showed a significant negative correlation with alkalinity (-0.308) at Edavanakkad, whereas in Narakkal a positive relationship existed with water temperature (0.378) and salinity (0.345) as seen in Table-24.

Table-22. Quantitative abundance (Nos/Vol. per 100 m^3) of zooplankton

Season	Edavanakkad Nos.	Edavanakkad Vol	Narakkal Nos	Narakkal Vol.
1988-89				
Premonsoon	102544	200	31684	150
Monsoon	39216	40	36309	100
Postmonsoon	45399	150	8486	35
1989-90				
Premonsoon	73760	250	91940	350
Monsoon	27084	35	31468	50
Postmonsoon	430974	950	11034	25

The ANOVA Table (Table-25) showed that the variation in zooplankton biomass was not significant between stations and over seasons.

QUALITATIVE COMPOSITION OF ZOOPLANKTON

Edavanakkad: Monthly percentage occurrence and seasonal percentage composition of important zooplankton groups are shown in Fig. 41a and Table-23a. Copepods were the dominant planktonic group that were recorded almost throughout the study period (Dec. 88 - Nov. 90.) It constituted about 91.6% of the total zoopankton from this station. Seasonally, their maximum abundance was noticed during both pre and postmonsoon. Amphipods, though

Table-23. Seasonal percentage composition of zooplankton

a. Edavanakkad:

Group	1988 - 89			1989 - 90		
	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
Copepod	65.43	15.56	19.00	13.24	2.73	84.19
Amphipod	45.46	18.22	36.32	35.72	35.72	28.56
Tanaid	49.96	6.28	43.77	39.35	24.59	36.06
Fish larvae	97.80	51.92	36.67	40.03	33.33	26.63
Medusae	7.29	6.77	85.94	41.26	35.27	23.46
Ostracod	-	-	-	54.94	42.23	2.83
Polychaete	52.91	11.81	35.27	25.09	74.91	-
Mysid	71.49	14.26	14.26	-	100.00	-
Zoea	-	100.00	-	-	-	-
Rotifer	-	100.00	-	-	-	-
Nauplii	-	79.96	20.04	-	100.00	-
Cladoceran	-	100.00	-	-	-	-
Miscellaneous	-	-	100.00	-	100.00	-

b. Narakkal

Group	Pre Monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
Copepod	53.56	39.27	7.17	72.92	18.47	8.61
Amphipod	36.07	36.07	27.86	36.34	49.34	14.32
Tanaid	11.12	86.77	2.11	37.46	62.37	-
Fish larvae	21.87	16.88	61.25	50.00	35.66	14.34
Medusae	82.56	8.72	8.72	82.56	8.72	8.72
Polychaete	30.28	54.56	15.16	43.00	28.48	28.48
Mysid	83.29	16.71	-	-	96.24	3.76
Ostracod	-	100.00	-	67.70	32.3	-
Rotifer	-	100.00	-	100.00	-	-
Zoea	-	100.00	-	100.00	-	-
Cladoceran	-	100.00	-	-	-	-
Nauplii	-	92.88	7.12	-	100.00	-
Miscellaneous	3.71	92.57	3.72	-	95.82	4.18

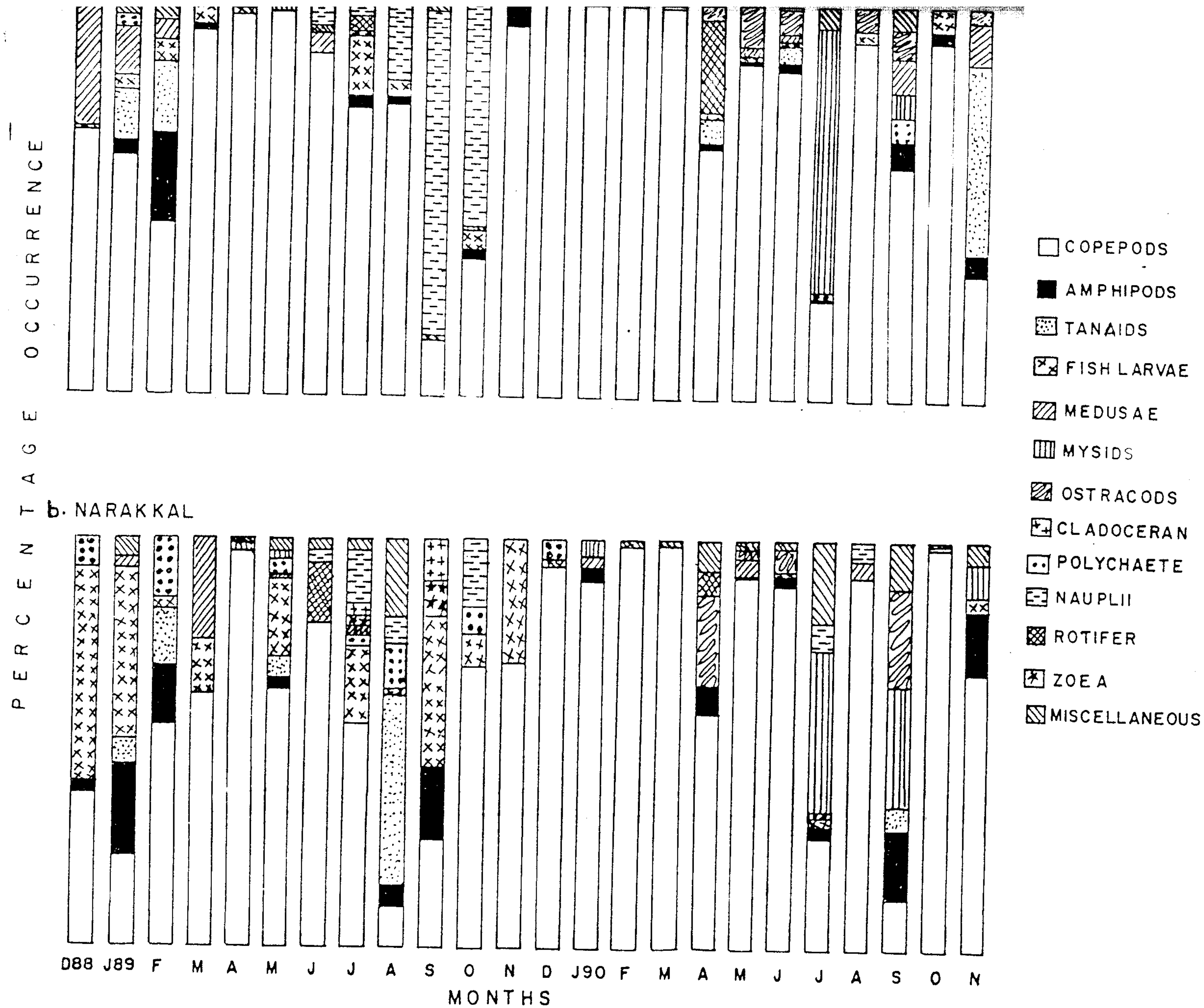


Fig. 41. **Monthly percentage composition of zooplankton at a. Edavanakkad and b. Narakkal.**

recorded throughout the year, their percentage composition among total plankton was only 0.35 and was abundant during premonsoon and monsoon seasons. Tanaids occurred in a few months only. However, relatively high percentage was observed during November '90. They formed about 0.46% of the plankton and their abundance was in premonsoon. Fish larvae (0.75%) were also recorded with the maximum abundance during premonsoon. Medusae formed about 1.97% of the plankton and were abundant during premonsoon and postmonsoon. Apart from this, rotifers and mysids were also present in this system forming about 0.46 and 1.49% respectively of the total plankton. The former was abundant during monsoon while mysids in both premonsoon and monsoon months. The less common groups of plankton from this station were brachyuran zoea, copepod nauplii and cladoceran with percentage composition of 0.02, 2.25 and 0.01% respectively of the total zooplankton. They were abundant during monsoon. Polychaetes (0.13%) were also recorded from this system with their maximum abundance during premonsoon and monsoon.

Narakkal: Copepods (79.16%) were the most abundant component of the zooplankton of this station and their maximum percentage composition was during premonsoon. Fish larvae were the next important group and appeared in almost all months with maximum abundance during postmonsoon and premonsoon. Their share among the plankton was 3.15%. Similarly, amphipods were also recorded throughout the year forming about 2.31% of the plankton and premonsoon and monsoon showed high percentage composition. Mysids were the next important group with high abundance during premonsoon and monsoon and formed about 2.01% of the plankton. Ostracods tanaids, rotifer and medusae were found in a few months only and their percentages in the plankton were 2.53, 3.44, 1.84 and 0.74% respectively. The less abundant groups were polychaetes, zoea and nauplii respectively forming about 1.41%, 0.13% and 1.19% of the plankton (Fig. 41b and Table-23b).

TERTIARY PRODUCTION

As there was no regularity or periodicity in the harvest from these canals, complete catch details could not be collected. Therefore, the tertiary production from this system was not included in the present study.

COASTAL FLORA AND OTHER UNIQUE FEATURES

Edavanakkad: Very few floral components were recorded from the margin of the field. However, the only form present was mangrove fern, *Acrostichum aureum* which was dominant during monsoon and early postmonsoon months. It borne sporophylls during April and May.

Narakkal: Rich coastal flora was present in this fields and the flora consisted mainly of mangrove fern (*Acrostichum aureum*), *Excoccaria agallocha*, *Acanthus ilicifolius* and *Heiratium* sp. Among these, *Heiratium* sp. was dominant during monsoon months and its flowering season was during

November. Similarly, blooming of A. ilicifolius was noticed in April and that of Excoccaria agallocha in May with fruit formation in early monsoon months. Sporophyll bearing mangrove fern was noticed in April and May.

Table-24. Correlation matrix of various environmental parameters.

Wat Temp.	pH	Salin.	Alkl.	Diss. oxygen	Prim. Prod.	Zoopl. No .
Edavanakkad						
1.000						
0.170	1.000					
0.114	-0.004	1.000				
0.132	-0.009	-0.074	1.000			
0.175	0.181	0.111	0.256	1.000		
0.214	0.074	-0.161	0.268	-0.148	1.000	
-0.131	-0.217	-0.091	*-0.305	-0.076	-0.122	1.000
Narakkal						
1.000						
*0.353	1.000					
0.099	-0.100	1.000				
0.031	-0.205	0.119	1.000			
0.276	0.229	-0.036	0.269	1.000		
0.228	0.220	-0.039	*-0.313	*0.332	1.000	
*0.378	0.194	*0.345	0.090	0.129	-0.067	1.000

* Significant at 5% level.

Table-25. Two way Analysis of Variance (ANOVA) Tables showing the level of significance in variation of different parameters between stations and over seasons.

Source	D.F.	SUM. SQR	MEAN SQR	F. VAL.	REMARKS
Water temperature:					
Treat	1	0.014	0.014	1.33	N.S.
Replic	2	4.661	2.331	227.29	HI. SIG (1%)
Error	2	0.021	0.010		
pH:					
Treat	1	0.001	0.001	1.59	N.S.
Replic	2	0.069	0.035	66.53	SIG (5%)
Error	2	0.001	0.001		
Salinity:					
Treat	1	0.023	0.023	0.01	N.S
Replic	2	130.556	65.278	27.30	SIG (5%)
Error	2	4.782	2.391		
Alkalinity:					
Treat	1	39.066	39.066	0.22	N.S.
Replic	2	469.484	234.742	1.33	N.S.
Error	2	351.691	175.846		
Dissolved oxygen:					
Treat	1	0.014	0.014	0.80	N.S.
Replic	2	1.332	0.666	38.02	SIG (5%)
Error	2	0.035	0.018		
Nitrate-N:					
Treat	1	2.496	2.496	6.75	N.S.
Replic	2	10.469	5.235	14.15	N.S.
Error	2	0.740	0.370		
Nitrite-N:					
Treat	1	0.000	0.000	0.02	N.S.
Replic	2	0.116	0.558	18.05	N.S.
Error	2	0.006	0.003		
Reactive phosphorus:					
Treat	1	0.687	0.687	1.85	N.S.
Replic	2	5.243	2.621	7.06	N.S.
Error	2	0.742	0.371		
Silicate-silicon:					
Treat	1	94.963	94.963	1.52	N.S.
Replic	2	34.699	17.350	0.28	N.S.
Error	2	124.851	62.425		
Primary production:					
Treat	1	2562.500	2562.500	0.15	N.S.
Replic	2	43850.500	21925.250	1.29	N.S.
Error	2	33882.500	16941.250		
Chlorophyll-a:					
Treat	1	56.489	56.489	0.21	N.S.
Replic	2	16.444	8.222	0.03	N.S.
Error	2	541.214	270.607		
Chlorophyll-b:					
Treat	1	2.331	2.331	0.38	N.S.
Replic	2	14.848	7.421	1.21	N.S.
Error	2	12.230	6.115		
Chlorophyll-c:					
Treat	1	1.109	3.082	0.11	N.S.
Replic	2	19.322	28.311	0.96	N.S.
Error	2	20.053	10.026		
Carotenoids:					
Treat	1	3.082	3.082	0.08	N.S.
Replic	2	56.622	28.311	0.73	N.S.
Error	2	77.486	38.743		
Zooplankton biomass:					
Treat	1	5.549	5.549	0.50	N.S.
Replic	2	11.337	5.669	0.51	N.S.
Error	2	22.159	11.080		
Organic Carbon:					
Treat	1	0.928	0.923	14.49	N.S.
Replic	2	0.173	0.087	1.35	N.S.
Error	2	0.128	0.063		

IV. DIURNAL STUDIES

Diurnal observations were made on the various environmental parameters from the Edavanakkad perennial field during full moon, mid lunar (half noon) and new moon phases in the month of October, 1990. The diurnal variation of different environmental parameters is given below.

Tide level: It varied from 21-35 cm in full moon phase. In mid lunar phase minimum tide level was noticed with heights ranging from 10-20 cm, whereas maximum tide level was observed during new moon (upto 43 cm) and the range was from 35-43 cm. In general, the variation in the tide level was about 10 cm in these lunar phases(Fig.48).

Atmospheric temperature: Atmospheric temperature varied from a minimum of 24.5° to a maximum of 29.7°C in 24 hrs. Lowest temperature was recorded between 0000 and 0600 hrs and the highest between 0800 and 2000 hrs (Fig. 42a).

Water temperature: Water temperature was high during these periods. It increased gradually and reached a peak in 1600 hrs in different lunar phases (Fig. 42b).

pH: pH was alkaline in full moon and new moon days, whereas in the mid lunar phase, slighty acidic values were noticed during early morning

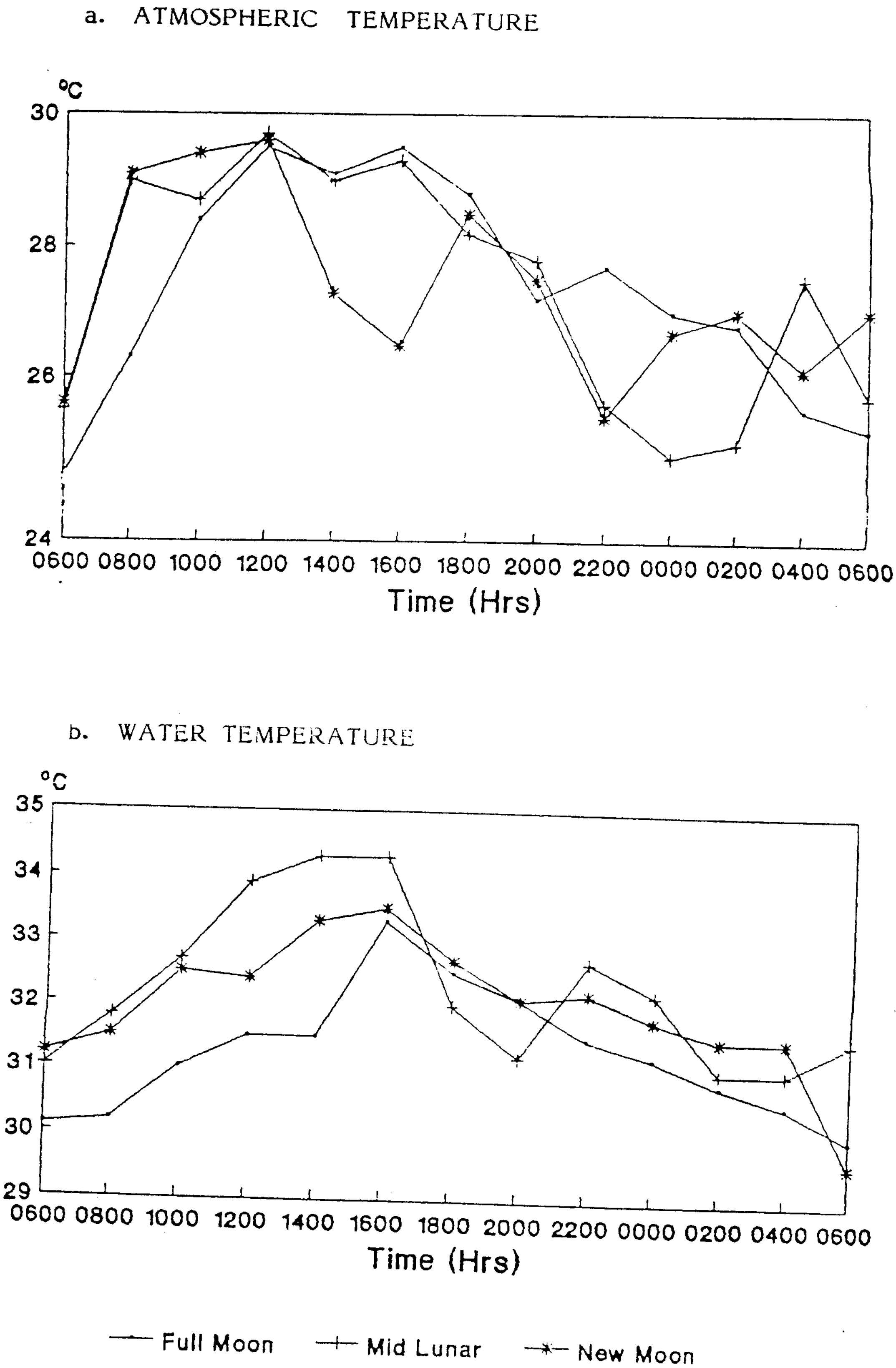
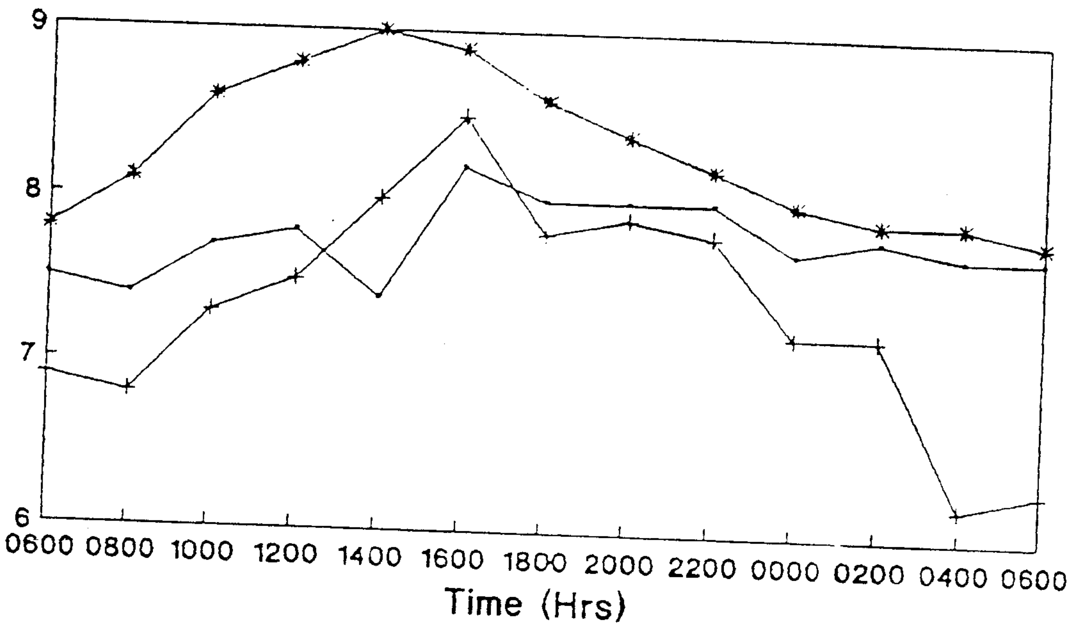


Fig. 42. Diurnal variation in a. Atmospheric and b. Water Temperature

a. pH



b. SALINITY

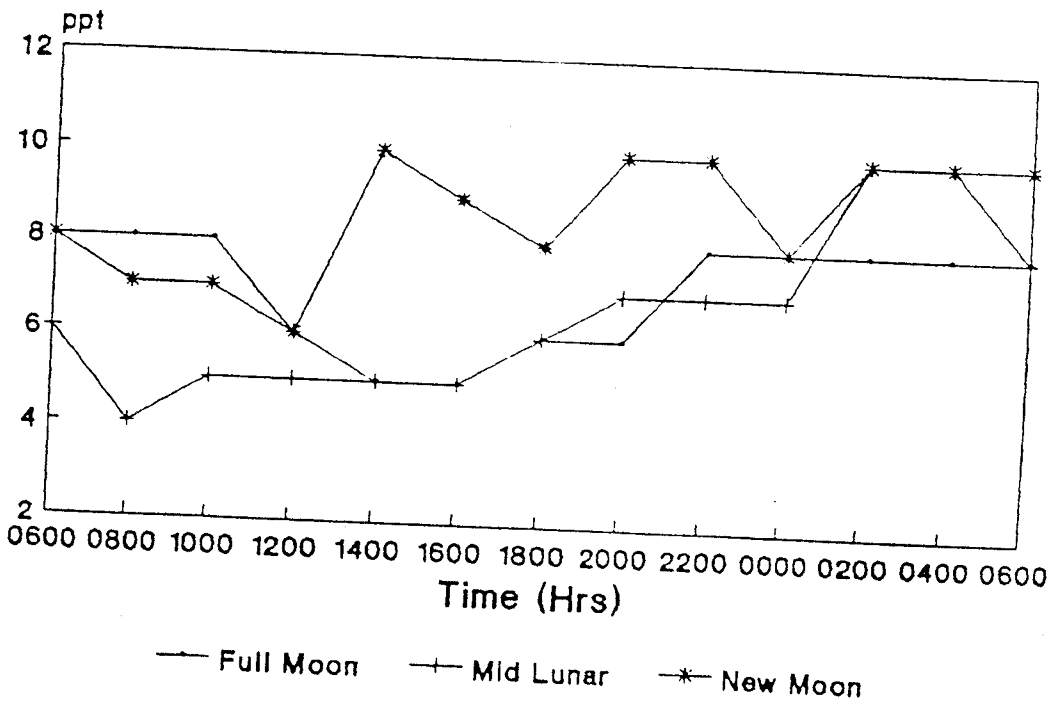


Fig. 43. Diurnal variations in a. pH and b. Salinity

hours. The range was 7.4-8.2, 6.2-8.5 and 7.8-9.0 in full moon, mid lunar and new moon days respectively (Fig. 43a).

Salinity: Very low salinity values were recorded during the different lunar phases. During full moon, it ranged between 5 and 8‰, whereas in mid lunar phase and new moon the range was between 4 and 10‰ respectively (Fig. 43b).

Alkalinity: Very high alkalinity values were recorded during mid lunar period. The general trend is shown in Fig. 44a. It varied between 50 and 102, 68-110 and 56-96 mg/l during full moon, mid lunar and new moon period. Alkalinity did not show any reationship with tide.

Dissolved oxygen: In general, dissolved oxygen concentration was low in different lunar phases except new moon. It ranged from 1.25 to 5.0 mg/l in full moon, 1.25 to 5.25 mg/l in mid lunar and 2.16 to 16.13 mg/l in the new moon (Fig. 44b). High values were recorded at 1600 hrs in both full moon and mid lunar period, whereas it was at 1400 hrs in the new moon. However, lowest values were recorded during early morning hours irrespective of lunar phases.

Nitrate-Nitrogen: Its variation was more or less uniform during full moon and mid lunar phases. The concentration varied from 0.5 to 3.0, 0.5 to 3.0 and 1.3 to 2.2 µg at/l in full moon, mid lunar and new moon period respectively (Fig. 45a).

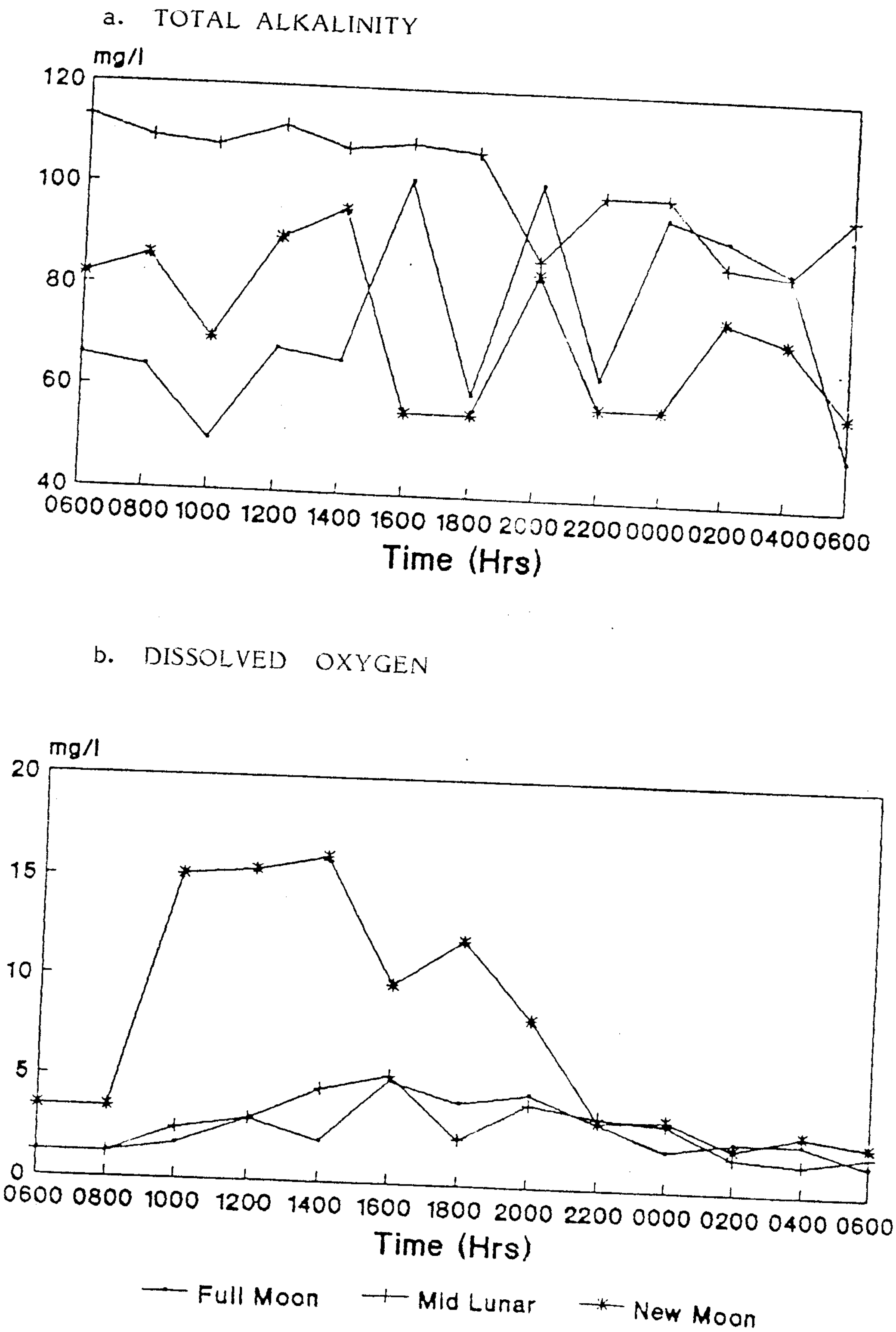
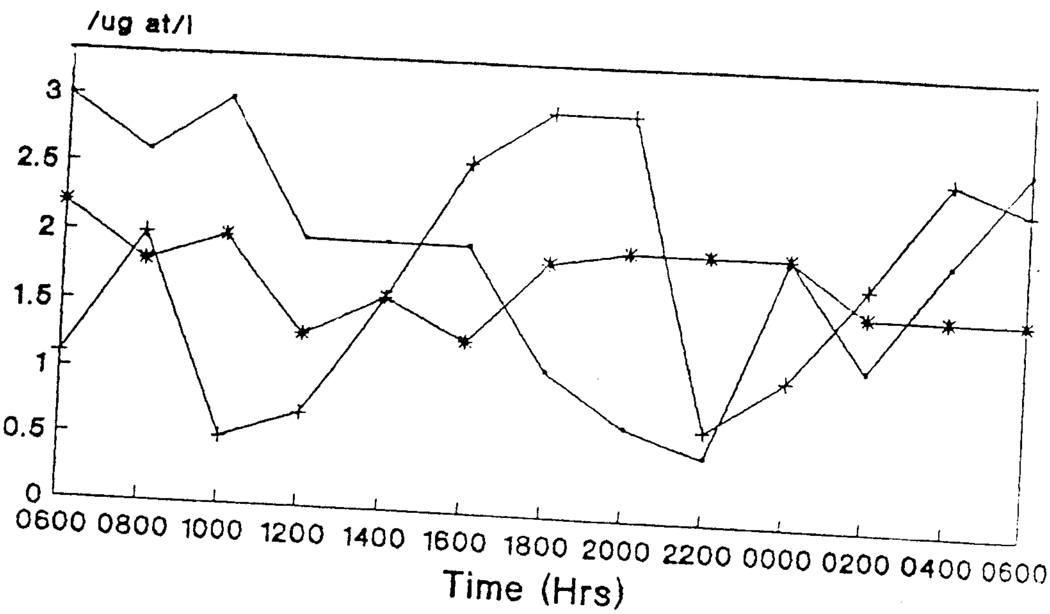


Fig. 44. Diurnal variation in a. Total Alkalinity and b. Dissolved Oxygen

a. NITRATE-NITROGEN



b. NITRITE-NITROGEN

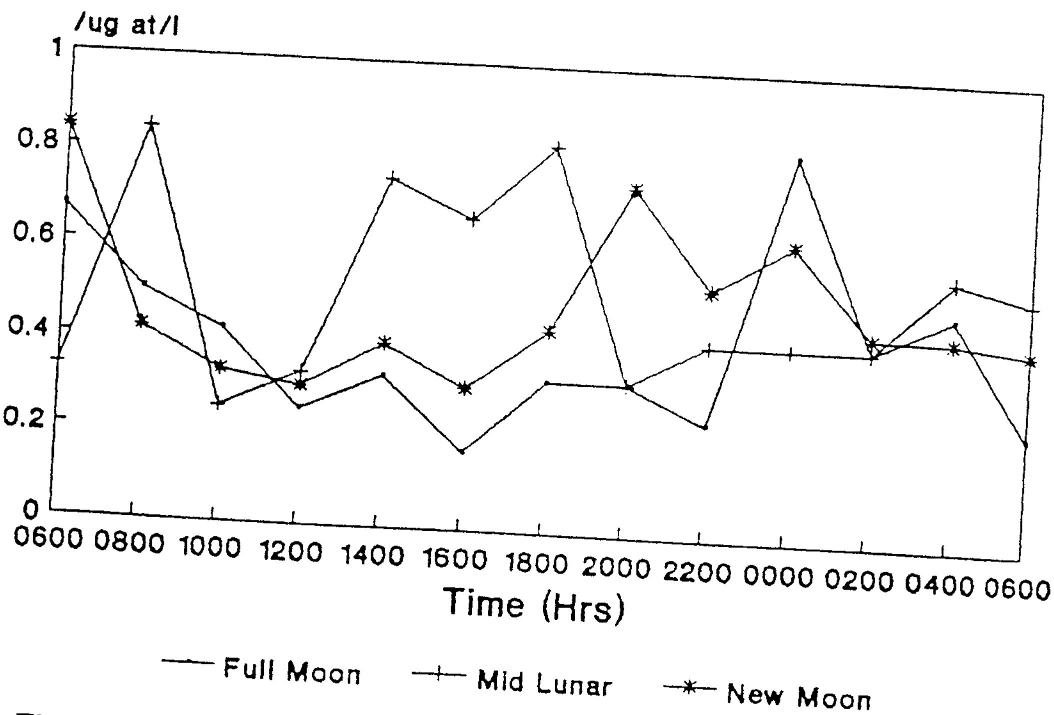


Fig. 45. Diurnal variation in a. Nitrate and b. Nitrite-Nitrogen

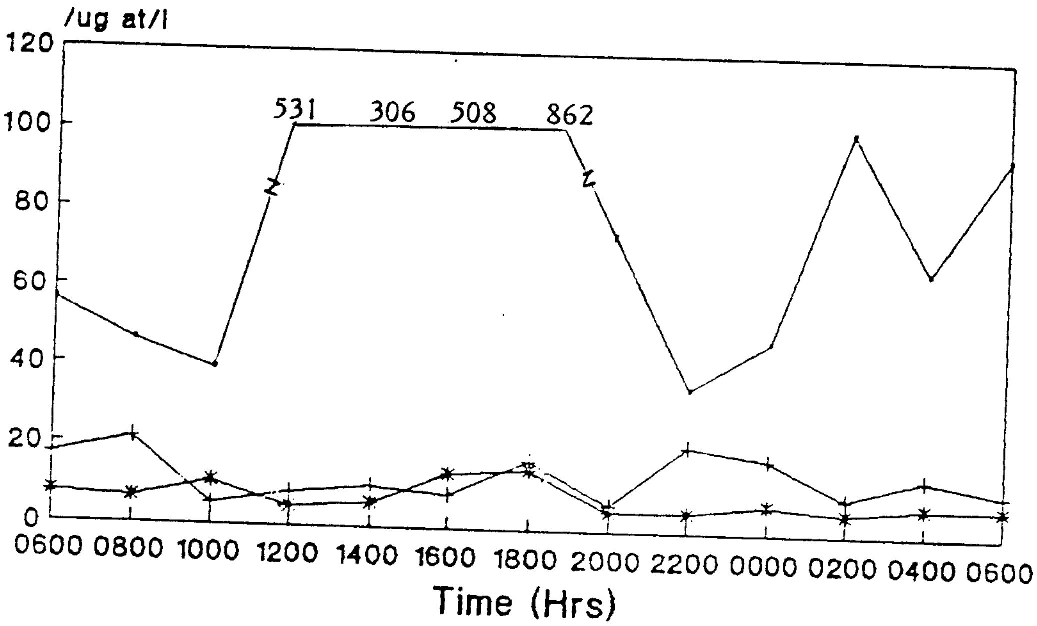
<u>Nitrite-Nitrogen:</u> Concentration of Nitrite-Nitrogen was very low compared to Nitrate-Nitrogen. The values were less than 1 µg at/l. The concentration ranged between 0.17-0.83, 0.25-0.84 and 0.30-0.84 µg at/l during full moon, mid lunar and new moon respectively. There was no trend in diurnal fluctuation (Fig. 45b).

<u>Ammonia-Nitrogen:</u> The level of Ammonia-Nitrogen concentration showed no wide fluctuation during mid lunar and new moon period of observation. In this period, the values ranged from 9.99-23.5 (mid lunar) and 8.13-18.21 µg at/l (new moon). Exceptionally high ammonia concentration (upto 862.49 µg at/l) was observed during full moon (Fig. 46a).

<u>Reactive phosphorus:</u> High phosphorus concentration was noticed in the early hours of the morning. The values ranged between 1.88-6.53, 2.9-6.05 µg at/l in full moon and mid lunar period, whereas in the new moon, concentration was between 1.88 and 4.12 µg at/l with a very high concentration of 17.8 µg at/l in 0600 hrs (Fig. 46b).

<u>Silicate-silicon:</u> Silicate values were generally high in new moon and mid lunar periods with no appreciable variation. In these periods, the concentration varied from 59 to 70 µg at/l in mid lunar and 53 to 78 µg at/l in new moon period. In full moon the concentration ranged between 31 and 102 µg at/l with the highest value during 0600 hrs (Fig. 47a).

a. AMMONIA-NITROGEN



b. REACTIVE PHOSPHORUS

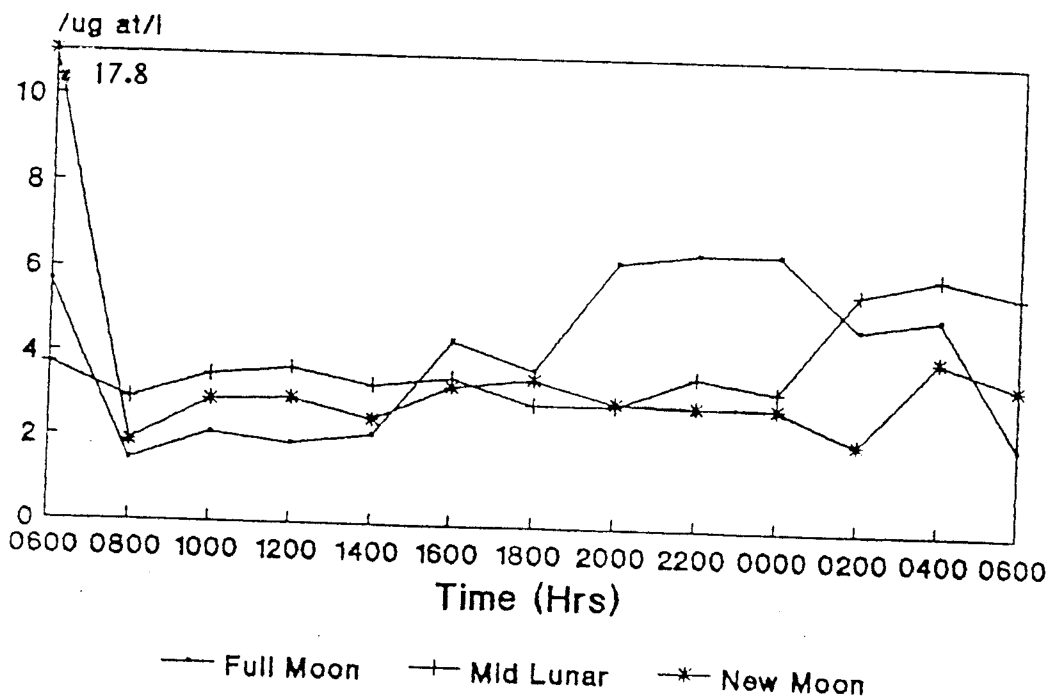
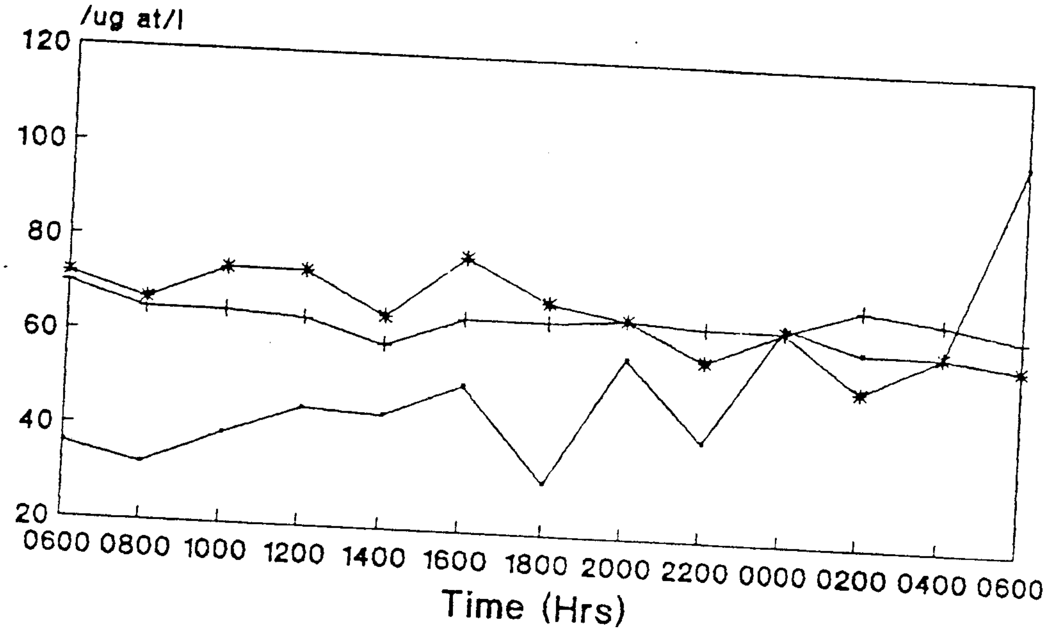


Fig. 46. Diurnal variations in a. Ammonia-Nitrogen and b. Reactive phosphorus

a. SILICATE-SILICON



b. ZOOPLANKTON NUMBER

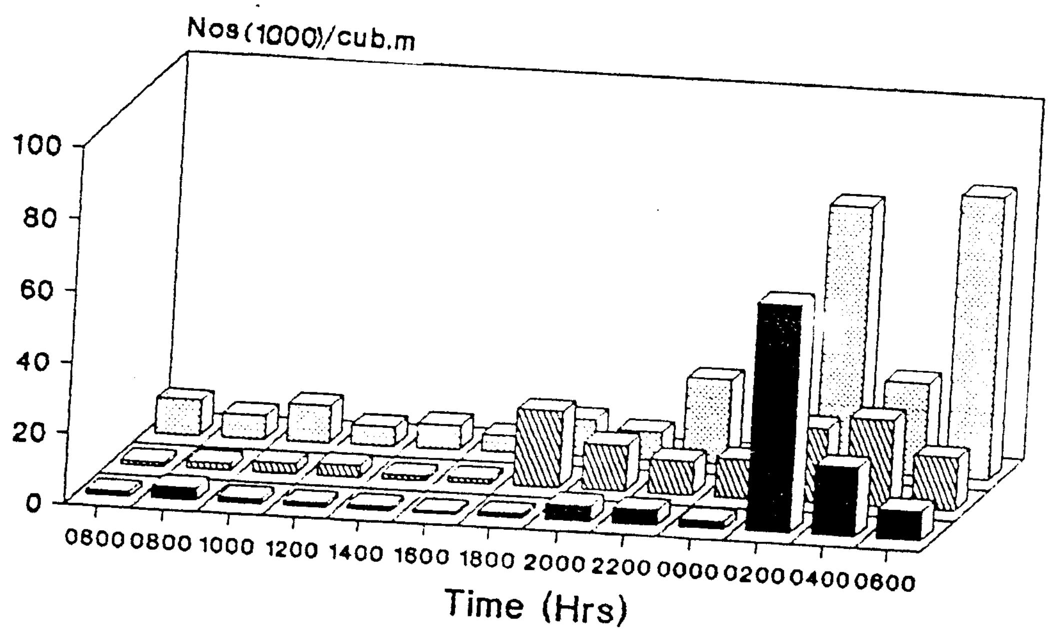


Fig. 47. Diurnal variations in a. Silicate-silicon and b. Zooplankton number.

Chlorophyll: Diurnal variation of chlorophylls and carotenoids is shown in Table-26. During full moon the chlorophyll-a concentration ranged between 0 and 14.22 mg/m^3. Highest concentration was recorded during 2000 hrs and lowest in early morning hours (0600 hrs); whereas in mid lunar period, very high concentration was noticed and it ranged between 7.02 and 48.06 mg/m^3. Lowest value was noticed during 0600 hrs and the highest at 1600 hrs. In new moon its concentration varied from a minimum 0 to a maximum of 51.15 mg/m^3 with the highest value (51.15) recorded at 1400 hrs.

Chlorophyll-b concentration was low compared to that of chlorophyll-a. It varied from 0 to 6.52 mg/m^3. The diurnal chlorophyll-b concentration followed almost the same pattern as that of chlorophyll-a in full moon. In mid lunar phase, the concentration ranged from 2.36 to 10.38 mg/m^3. The highest concentration was recorded during 0600 hrs. In new moon period the range was from 0 to 11.95 mg/m^3 with the highest concentration at 1600 hrs.

Like chlorophyll-b, chlorophyll-c also showed its maximum concentration during 2000 hrs in full moon. But, its concentration was relatively less than that of chlorophyll-b and ranged from 0 to 2.0 mg/m^3. Lowest values were recorded during early morning hours, whereas during mid lunar period (2.24-28.78 mg/m^3), the concentration of chlorophyll-c was higher than that of chorophyll-b and highest concentration was at 1600 hrs. In new moon, the chlorophyll-c concentration showed the same trend as that of chlorophyll-b, i.e., concentration ranged between 0 and 11.95 mg/m^3.

Table-26. Diurnal variation of chlorophylls and carotenoids (mg/m^3)

Time	Lunar phase	Chlor-a	Chlor-b	Chlor-c	Carot
06 00	Full Moon	0.00	0.00	0.00	0.00
	Mid Lunar	15.43	4.74	14.40	14.94
	New Moon	2.37	1.09	0.33	4.56
08 00	Full Moon	2.37	1.08	0.33	3.42
	Mid Lunar	15.58	2.36	17.62	6.93
	New Moon	4.74	2.17	0.67	9.12
10 00	Full Moon	0.00	0.00	0.00	0.00
	Mid Lunar	21.18	7.36	2.24	15.69
	New Moon	15.41	7.06	2.17	11.94
12 00	Full Moon	3.56	1.63	0.50	0.76
	Mid Lunar	13.95	9.56	13.04	8.84
	New Moon	15.82	0.00	4.16	24.34
14 00	Full Moon	2.96	1.14	0.42	2.28
	Mid Lunar	22.45	4.40	5.30	13.71
	New Moon	51.15	0.00	2.78	33.86
16 00	Full Moon	0.00	0.00	0.00	0.00
	Mid Lunar	48.06	5.18	28.76	29.40
	New Moon	26.07	11.95	11.95	24.04
18 00	Full Moon	5.93	2.72	0.84	5.32
	Mid Lunar	17.13	2.64	16.52	17.19
	New Moon	18.95	8.42	0.00	19.99
20 00	Full Moon	14.22	6.52	2.00	15.96
	Mid Lunar	11.00	2.46	19.04	8.39
	New Moon	9.48	4.34	1.34	12.16
22 00	Full Moon	13.04	5.97	1.84	13.68
	Mid Lunar	16.94	5.04	18.22	11.45
	New Moon	2.83	0.00	2.60	24.04
00 00	Full Moon	1.19	0.54	0.17	3.04
	Mid Lunar	9.55	6.16	8.66	10.82
	New Moon	2.37	1.09	0.33	6.84
02 00	Full Moon	2.96	1.36	0.42	6.08
	Mid Lunar	22.43	3.60	12.64	17.06
	New Moon	2.37	1.09	0.33	10.49
04 00	Full Moon	1.78	0.81	0.25	2.28
	Mid Lunar	17.36	8.86	21.60	13.71
	New Moon	0.00	0.00	0.00	3.04
06 00	Full Moon	0.00	0.00	0.00	0.00
	Mid Lunar	7.02	10.38	17.28	8.23
	New Moon	0.00	0.00	0.00	0.76

Carotenoids followed more or less the same trend as that of chlorophyll-a. It varied from 0 to 15.96 mg/m^3 in full moon with maximum concentration at 2000 hrs, whereas in mid lunar period, slightly higher values were observed. The range was between 6.93 and 29.40 mg/m^3 at 0800 hrs and 1600 hrs respectively. In new moon, the maximum concentration (33.86) was noticed during 1400 hrs, whereas lowest concentration was found at 0600 hrs.

Zooplankton: Numerical abundance of zooplankton is shown in Fig. 47b. Plankton abundance showed an increasing trend from 2000 hrs onwards and reached a peak (63791 Nos/100 m^3) during 0200 hrs in full moon. In mid lunar period also the abundance showed the same trend as in full moon except for a decline in abundance at 2200 hrs. During this period, maximum abundance (24328/100m^3) was at 0400 hrs. In new moon the zoopankton abundance was generallly high with no appreciable change in the diurnal pattern of abundance. However, the maximum abundance was during 0600 hrs (78147 Nos/100 m^3).

Relation between tide level, pH and dissolved oxygen: Fig. 48 illustrates the relation between pH and dissolved oxygen with tide level.

In full moon, tide level fuctuated between 21 and 35 cm. When the water level started rising at 1400 hrs both pH and dissolved oxygen showed a decline and a sudden increase was noticed at 1600 hrs with maximum pH (8.2) and dissolved oxygen (5 mg/l). This water height remained

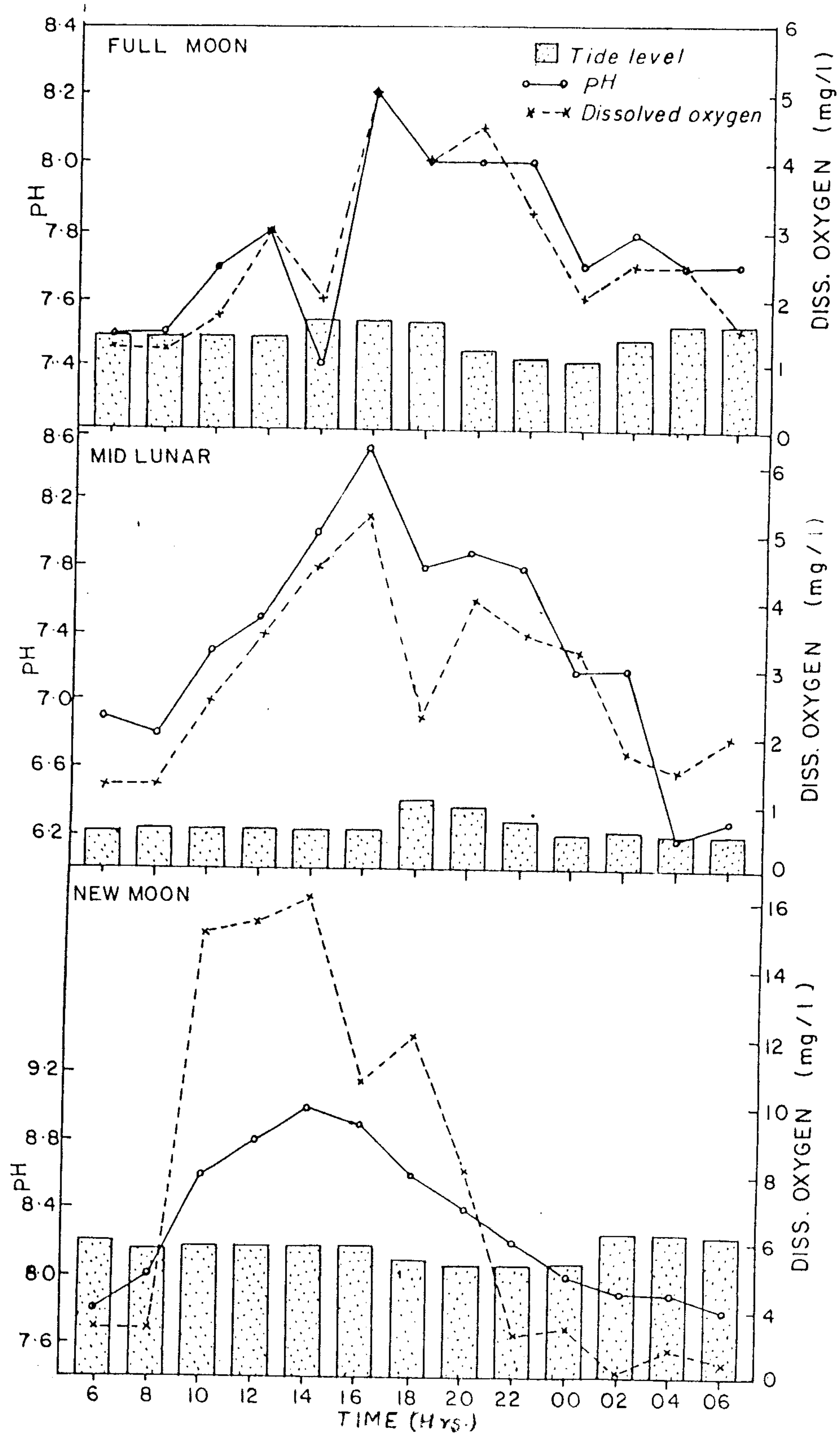


Fig. 48. Relationship between tide level, pH and Dissolved oxygen

till 1800 hrs and then declined gradually to 21 cm with slight increase in pH and dissolved oxygen. Fluctuations were not clear afterwards.

The tide level was lowest during mid lunar period and the range was between 10 and 20 cm. Water level was almost steady till 1600 hrs. In this lunar period also maximum pH (8.5) and dissolved oxygen content (5.28 mg/l) were recorded at 1600 hrs. An increase in tide level was noticed at 1800 hrs with a drop in pH and dissolved oxygen values. This was followed by a sudden increasing trend and then gradual increase irrespective of tide level.

Maximum tide level was observed during new moon. The water level was amost uniform (43 cm) except between 1800 and 0000 hrs (35 cm). The tide range was only 7 cm. Maximum values for pH (9.0) and dissolved oxygen (16.13 mg/l) were observed at 1400 hrs and the values did not show any fluctuation with tide level.

DISCUSSION

The Cochin backwater system is profoundly influenced by the monsoon and receives an average annual rainfall of 323 cm (As estimated by the India Meteorological Department). Consequently there is considerable influx of the nutrient rich freshwater, which when penetrated by tidal currents, makes it a highly dynamic brackishwater environment.

The culture fields and the canal system studied are directly connected to the estuarine and brackishwater system and are therefore subjected to wide variations in the environmental conditions. In these prawn culture systems, the monsoon brings out changes from nearly marine condition during premonsoon to freshwater condition during monsoon. Physico-chemical condition in the backwater and connected canals and the culture fields are controlled by tides to a great extent.

Out of an average rainfall of 323 cm more than 75% is recorded during southwest monsoon period (Silas and Pillai, 1975). The rainfall data obtained during 88-89 (2963 mm) and 89-90 (2371 mm) reveals that the maximum rainfall was recorded during southwest monsoon and postmonsoon months. Therefore the present study indicates that the total amount of rainfall shows a year round variation with maximum precipitation during monsoon.

Atmospheric temperature showed clear seasonal variations. High values were invariably recorded during premonsoon months. The variation in the air temperature was mainly because of the time of sampling. Very high temperature value (31.5°C) was recorded mostly during 1100-1300 hrs. This is evident from the diurnal studies that maximum temperature was recorded at 1200 hrs and minimum during early morning hours.

Water temperature influences the biochemical reaction and the microbial release of nutrients taking place in the pond ecosystem as well as the physiology of the fauna. The monthly variation in temperature in different culture fields were approximatey 10°C in the perennial and seasonal fields and the fluctuation was only 5°C in coconut groves. This wide fluctuation observed here may be due to the time lag between sampling (as evident from the diurnal studies) and the incursion of cold and highly saline water through the barmouth (Sankaranarayanan and Qasim, 1969). Since these fields are shallow the entire water column was warm throughout the study period. However, high temperature values were recorded during premonsoon. Earlier studies (Sankaranarayanan *et al.*, 1982; Prasad, 1982; Nair *et al.*, 1988, Devapiriyan, 1990; Joshi, 1990) also confirm this observation. Diurnal studies conducted in October showed that water temperature was above 30°C during the 24 hour period and the highest temperature was recorded at 1600 hrs. Vijayalakshmi and Venugopalan (1973) while studying the physicochemical properties of Vellar estuary stated that the diurnal variations in the surface temperature followed closely the air temperature and tidal rhythm. But the present study shows that the variation in temperature was not according to tide but it follows the time of the day. Ravindran (1983) also reported the same trend. The influence of tide on water temperature seems to be improbable as these culture fields are (1) situated far away from the bar mouth, (2) low tidal amplitude and above all (3) the tidal incursion is fully controlled by the sluice gates.

pH of the water is influenced by soil pH, concentration of carbon dioxide, carbonates and bicarbonates in water. Phytoplankton and other aquatic vegetation remove carbon dioxide from the water during photosynthesis and this results in the rise of pH. According to Roule (1930), the largest fish crops are usually produced in water just on the alkaline side of neutrality between pH 7 and 8.0. pH in the perennial fields showed alkaline values during premonsoon, whereas slightly acidic values were noticed during monsoon and postmonsoon. Similar observations were made by Subhash Chander (1986), Nair et al. (1988), Devapiriyan (1990) and Joshi (1990) from the prawn culture fields. Low pH may be due to the increased sedimentation and subsequent reduction of organic debris resulting in relatively more reducing condition near the bottom (Subhash Chander, 1986). Upadhyay (1988) explains it on the basis of the influence of freshwater influx and the decomposition of organic matter carried by flood water into the riverine system. In seasonal fields high values were recorded during both premonsoon and postmonsoon. The acidic values in Chittoor (December) was because of the spreading of Salvinia throughout the pond. Mollah et al. (1979)

opined that gradual decrease in pH of water and soil might be due to the occurrence of water hyacinth throughout the surface water which resulted in an increase of carbon dioxide through respiration and decomposition and decrease in the photosynthetic activity. In coconut groves high values were recorded during both premonsoon and monsoon. Prasad (1982), Srinivasan (1982), Sugunan (1983) and Singh (1987) while investigating the ecology of brackishwater culture system near Cochin, have reported high pH values for water and sediments during monsoon and postmonsoon. Ravindran (1983) and Chandran and Ramamurthy (1984a) reported that pH did not show any seasonal and tidal variation. This is further clear from the diurnal studies during which the maximum values were recorded between 1400 and 1600 hrs and did not show any variation with tide.

High salinity values were noticed during premonsoon. The precipitation and freshwater discharge into the ecosystem during monsoon reduced the salinity and the minimum values were recorded mostly during monsoon period. The recovery of salinity in the culture fields was either not felt or negligibly slow during the period of this investigation. This was because of the long distance of the culture fields from the barmouth and lesser tidal influence and mixing. Pattern of salinity distribution did not follow the tidal rhythm, maximum salinity being noticed much later than the attainment of high tide and low salinity much later than low tide. High salinity values were recorded during premonsoon followed by postmonsoon in all systems. The lowest salinity was recorded during monsoon. This observation agrees with that of Subhash Chander (1986), Prasad (1982), Gopalan <u>et al.</u>

(1982) and Gopinathan et al. (1982) from different prawn culture systems around Cochin. Although high salinity was recorded in February-March (25‰) there was a slight drop in salinity during April and May. This is due to the effects of premonsoon showers, common during this period, as reported by Sankaranarayanan et al. (1982). Diurnal study clearly indicates that the variation in salinity during different lunar phases ranged from 4 to 10‰ and it did not follow any tidal pattern. Ravindran (1983) also reported the fluctuation of salinity irrespective of tides from different prawn culture systems around Cochin.

In general the calcarious waters of fish farms with alkalinities of more than 50 ppm are reported to be most productive, waters with less than 10 ppm rarely produce large crops, and water intermedate between these groups may produce useful results (Banerjea,1967). High alkalinity values were usually recorded in all fields during premonsoon and monsoon months. Joshi (1990) reported high alkalinity values in seasonal fields and low values in coconut groves, during February and September respectively. But Datta et al. (1983) showed high values during postmonsoon from the brackishwater bheries. Sankaranarayanan and Qasim (1969) reported small changes in alkalinity during premonsoon and wide fluctuation in monsoon. Qasim (1973) and Silas and Pillai (1975) also observed the same trend. Diurnal studies indicate an irregular hourly trend and high values were noticed during early morning hours.

Among the chemical constituents of natural waters, oxygen is of primary importance both as a regulator of metabolic process of plant and animal community and as an indicator of water condition. Based on a study conducted at United States by Ellis (1937) it is found that dissolved oxygen concentration below 3 ppm can lead to asphyxia and to maintain a favourable condition for a varied fish fauna 5 ppm of dissolved oxygen is required. In the present observation the oxygen values ranged between 2.03 and 10.2 mg/l with major peak during monsoon in perennial fields. But in seasonal fields it varied from 1.4-6.66 mg/l and high values were recorded during premonsoon. In coconut groves the values were less than 6 mg/l with high values mostly in premonsoon. Seasonal fields, being shallow, recorded low oxygen when compared to perennial fields. This is due to the decomposition of organic matter present at the bottom by microbial activity. Qasim (1973), Pillai et al. (1975), Gopinathan et al. (1984), De Sousa and Sen Gupta (1986) have observed wide seasonal fluctuation in dissolved oxygen concentration with high values during monsoon in estuaries of Cochin and Goa. Diurnal studies showed that in all lunar phases the bihourly variation in the dissolved oxygen content was minimum. Low values were recorded during day break and maximum concentration between 1400 and 1600 hrs. Although the dissolved oxygen content was much low during the different lunar phases, the new moon period registered a concentration of 16.13 mg/l. This was because of the bloom of dinoflagellate (Peridinium). Banerjea (1967) also reported such high dissolved oxygen concentration (23.4 ppm) in a pond with thick algal bloom. Dissolved oxygen did not show any fluctuation with tide level. On the other hand Nair et al. (1988) observed that the dissolved oxygen content of prawn culture fields of Cochin widely fluctuated with tide and at varying rates of tidal flow.

The distribution of nutrients is largely dependent on the marine influence and the freshwater discharge. When the estuarine system remain predominantly marine, the nutrient concentration is low and homogenous throughout the water column, while during the period of freshwater discharge, high concentration of nutrients occur. As the culture systems are shallow, vertical mixing induced by tidal flow and wind will hasten the recycling process. One of the factors governing the distribution of nutrients may be the variation in the regenerative property of bottom mud rich in organic matter due to biological and chemical oxidation. In shallow systems the major recycling of nutrients is affected through sediments (Reddy and Sankara narayanan, 1972).

Nitrate-Nitrogen seems to play a significant role in the primary production which is evident from the seasonal pattern of nitrate profile. With the onset of monsoon the concentration suddenly increased along the whole estuary. This may be due to high land drainage and precipitation. The progressive decrease, however, during postmonsoon reaching a minimum can be attributed to biological utilisation (Upadhyay, 1988). In the present study, maximum concentration was recorded during southwest monsoon and postmonsoon in the perennial fields and coconut groves and the pattern was uneven in seasonal fields. The high values noted during monsoon was because of the freshwater discharge (Sankaranarayanan and Qasim, 1969) and due to the shallowness of the pond. Verlencar (1987) is of opinion that the seasonal changes in Nitrate-Nitrogen concentration was due to its quick utilization. Diel variation indicated that Nitrate-N followed no diurnal pattern and the variation was below 2.5 µg at/l in all lunar days. This is in agreement with the findings of Ravindran (1983).

Nitrite-Nitrogen may be formed as a result of the decomposition of organic nitrogen and it is a transitory stage in the nitrogen cycle (Sankara narayanan and Qasim, 1969). The present study shows no seasonal trend in the concentration of nitrite in the perennial fields. Subhash Chander (1986) also reported the same trend from the prawn culture fields. Whereas seasonal fields and coconut groves showed high values in postmonsoon and monsoon respectively. Findings of Sankaranarayanan and Qasim (1969), Manikoth and Salih (1973), Saraladevi et al. (1983) and Nair et al. (1988) substantiates the present observation. Exceptionally high values (11.1 µg at/l, Chittoor) could be attributed to the excretion by phytoplankton, oxidation of ammonia and the reduction of nitrate as reported from Vellar estuary (Venugopalan and Rajendran, 1975). The fluctuating values of nitrite seems to be related to its transitional nature in the nitrogen cycle. Diurnal variation did not show any trend in nitrite distribution in different lunar phases. Observation of Ravindran (1983) also supports this finding.

The main source of ammonia in the aquatic ecosystem is by the excretion of organisms and by the decomposition of organic nitrogenous material; whereas it is removed by phytoplanktonic, heterotrophic and chemotrophic organisms. Devapiriyan (1990) reported high concentration of ammonia during premonsoon, Subhash Chander (1986) and Reddy (1986) recorded maximum concentration in monsoon season. Venugopalan and Rajendran (1975) found that there is an increase in the levels of ammonia during monsoon and have suggested that the major factor responsible for the addition of ammonia might be non-biogenic. In the present study Ammonia-Nitrogen did not show any seasonal variation. Similar observations were made by Joshi (1990) also. Very high concentration (upto 164 μg at/l) was recorded from these fields irrespective of season. Sharma and Aswanikumar (1991) opined that this ammonia maximum is probably the indication of higher rates of nitrogen cycle both in water column and sediments associated with enhanced production, whereas the variation was much low in the diurnal studies (less than 21 μg at/l). However, exceptionally high values recorded (upto 862.49 μg at/l) could be due to the organic decomposition in the field at the time of observations.

The interchange of phosphate between sediments and the water is known to be one of the major factors governing the phosphate concentration of overlying waters. Sediments of estuaries are several times richer in phosphate compared to overlying water (Moore, 1930) and are reported to entrap phosphate in times of excessive run off (Jittis, 1959). Regenerative property of the sediment is also known to play a vital role in governing nutrient concentration. The inorganic phosphate distribution in the present study showed high values in premonsoon both in perennial and seasonal fields. Such high values have been reported by Gopinathan <u>et al.</u> (1984), Subhash Chander (1986) and Devapiriyan (1990) during premonsoon. Upadhyay

(1988) explained the low concentration of this nutrient during monsoon to massive land drainage. Phosphate is removed (adsorption) from an acidic environment (pH < 6) causing very low values in this period. Saraladevi et al. (1983) while studying the nutrients in the estuaries of Kerala reported that phosphate did not show any well defined seasonal pattern. Frequent oscillations in the phosphate content during the present study are indicative of regeneration of phosphate from the bottom sediment. Diurnal variations show that high concentration recorded during early morning hours would perhaps indicate addition from sources other than aquatic which could be by human activities.

Sankaranarayanan and Qasim (1969), Gopinathan et al. (1974; 1984), Datta et al. (1983) and Joshi (1990) observed high silicate values during monsoon season. From the present study it is found that though the silicate values were high its seasonal variation was irregular in different prawn culture systems. The high value recorded in monsoon may be due to the fact that the chief source of silicate is from the soil which in turn is brought down by land run off in monsoon; whereas De Sousa et al. (1981) found that large amounts of reactive silicate are removed from the water column during monsoon. De Sousa (1983) reported low silicate during this season and suggested biological utilization and abiological removal by adsorption into the suspended sediments as the probable mechanisms of removal. Apart from this Upadhyay (1988) suggested that dilution effect due to large river run off may have considerable influence on the lowering of silicate during monsoon. Probably the combined effects of all these factors might be responsible for the wide seasonal fluctuations of this nutrient in the culture systems. Diurnal studies did not show any wide fluctuation in the silicate concentration.

A series of reactions, either chemical or biochemical by microbial population inhabiting therein, continuously take place within the bottom soil result in the release of nutrient elements to the overlying water or adsorption or immobilization of nutrient elements from the water phase to the soil. The dynamics of these processes greatly influence the growth and population of micro and macro-food organisms for fish/prawn. The productivity of the cultured species is directly proportional to the organic carbon content in the soil. Tang and Chen (1967) emphasised the importance of soil organic matter in brackishwater aquaculture and demonstrated that the fish yield in such ponds increased with increase in organic carbon content of soil (by using manures). Thus organic carbon content form an index of the overall productivity of the environment.

The present observation on the organic carbon content of the sediment reveals that on the whole there was no cyclic change with season. Among different systems, seasonal fields showed more organic carbon content (1.45-3.92%) followed by coconut groves (0.16-3.38%) and perennial fields (0.12-3.64%). High organic carbon content in general is probably due to the stagnant nature of water and the presence of suspended vegetation. High organic carbon content in the pokkali fields might be due to the death and decay of benthic animals at the end of prawn culture season and the decay of paddy stumps after cultivation (Prasad, 1982). Similarly reduction in the organic carbon content may be attributed to higher rate of decomposition. Chattopadhyay and Mandal (1980) suggested organic manuring in ponds where the organic carbon content of soil is low for increasing the fish production.

Banerjea (1967) grouped the ponds into different catagories based on organic carbon content of soil. According to him organic carbon content of less than 0.5% was considered to be low for fish production, between 0.5 to 1.5% average, while 1.5 to 2.5% appeared to be optimal and above 2.5% high for fish production. In the present study organic carbon content of Mulavukad seasonal field ranged from 2.0 to 3.65%. This could account for very high prawn production from this field. Gopinathan et al. (1982) reported that the prawn culture fields located in between Cochin and Azhikode barmouth were relatively more productive. They explained this on the basis of (1) having two openings to the sea within a short distance, through which there is a regular incursion of saline water and (2) the periodical enrichment from the run off from Periyar river to this area. Gilbert and Pillai (1986) also found that the prawn culture fields located in the north and north central part of backwaters were more fertile than other regions. The reasons attributed for this were the predominance of fine grained fraction of sediment and the intense circulation of water by tidal action as well as by the large scale deposition of silt, clay and nutrients by the Periyar river in this region.

The fishery resource of any area is mainly dependent on the magnitude of primary and secondary production which in turn are influenced by various physical, chemical and biological factors. The account on the organic production of Cochin backwater by Qasim et al. (1969) have shown that the estuarine system is one of the most productive in the tropical environment. The subsequent studies indicated that the standing crop in terms of chlorophyll, biomass, total cell counts and primary production varied from place to place and from time to time as a result of water masses being constantly renewed by the inflow of freshwater from the river and seawater from the inshore areas of the Arabian sea.

In the present study the perennial fields did not show any seasonal trend in primary production, except for an unusually high value of 9186 $mgC/m^3/day$ recorded during May 1989. In seasonal fields the high production was invariably recorded during premonsoon, whereas in coconut groves high values were recorded mostly during monsoon and occasionally during premonsoon season. Peak production during premonsoon has been reported by Pillai et al. (1975) and explained the reason for high production as the optimum light intensity and effective utilisation of nutrients. Gopinathan et al. (1984) observed two peaks of production, primary peak in premonsoon and the secondary in postmonsoon. However, three peaks (April, July and October) in production was reported by Qasim et al. (1969). Qasim (1970) reported that primary production in the backwater is at a uniform level with little seasonal increase, throughout the year,· Bhattathiri et al. (1976), Verlencar (1984), Reddy (1986) and Joshi (1990) observed high primary production during monsoon months and the cause for high production was attributed to low salinity. This observation coincides with the present results obtained from coconut groves. From the present study thus it is clear that the fluctuation in primary production might not be consistant year after year, probably due to the prevailing environmental conditions. Among the three culture systems, both perennial and seasonal fields showed almost the same production trend, whereas the production was comparatively low in coconut grove. This low production may be due to the shading effect of coconut plantations, on either side of the system which inhibit the penetration of sunlight.

Phytoplankton constitute the primary producers synthesising the basic food in the estuarine and marine ecosystem .Diatoms, dinoflagellates, blue green algae and nannoplankton were the constituents of phytoplankton. Diatoms constitute the major part of phytoplankton and serve as the food directly or indirectly to almost every animal in the culture system. Throughout the study period diatoms were the dominant component (80-85%) of phytoplankton in all culture systems, whereas dinoflagellates were recorded only during monsoon and postmonsoon. Blue green algae and green algae were recorded only during monsoon. George (1958), Joseph and Pillai (1975), Gopinathan et al. (1984) and Preetha (1990) reported the same trend from Cochin backwaters and Gopalakrishnan et al. (1988) from the prawn culture fields of Cochin. Qasim et al. (1972) while studying the phytoplankton of Cochin backwater reported that many algal forms are adapted to changing conditions of salinity, light and nutrients. They found that photosynthesis in 12 species of algae were maximum in the salinity range of 10-20‰. This wide adaptability of phytoplankton to changes in salinity during monsoon supports the present observation that in the perennial fields and coconut groves, several species were recorded during monsoon, whereas in seasonal fields only few species were distributed in both pre and postmonsoon. Chandran (1985) in his observations on the seasonal and tidal variation of phytoplankton in the Vellar estuary is of opinion that salinity is found to play a major role in determining the species composition, succession and density of phytoplankton. He observed maximum phytoplankton population during high saline premonsoon season.

The pigment content of phytoplankton assumes great importance in productivity studies because of the use of these compounds for estimating the primary production and gross photosynthetic potential. Although there are several pigments involved in the photosynthetic process, the fundamental role is played by chlorophylls. Among the chlorophylls, chlorophyll-a is the major pigment in the phytoplankton which is able to transform light energy into chemically bound energy, whereas light energy absorbed by other pigments are also converted via chlorophyll-a (Rabinowitch, 1951).

The present study showed that the seasonal variation of chlorophyll-a in perennial fields and coconut groves are inconsistant, whereas in seasonal fields mostly high values were recorded in premonsoon. From the culture fields maximum concentration was noticed during premonsoon by Devapiriyan (1990) and Joshi (1990); whereas Gopinathan et al. (1984), Sankaranarayanan et al. (1982) and Nair et al. (1988) observed maximum concentration in monsoon substantiating the present observation. Chlorophyll-b showed high values in premonsoon in seasonal fields and coconut groves, the trend was irregular in perennial fields. Wright (1964) reported that chlorophyll-b is the prominant pigment in freshwater forms. But the present study showed the large concentration of this pigment during premonsoon when the culture ponds are saline. Chlorophyll-c concentration was more in premonsoon in all systems. Bhargava and Dwivedi (1976) attributed high concentration of chlorophyll-c to the suspended sediments, dead chlorophylls and degraded chlorophyll c bearing plant products. Verlencar (1984) observed sharp peaks in chlorophyll-c during the beginning and cessation of monsoon.

No regular pattern of distribution was noticed in the case of carotenoids in perennial fields as well as in coconut groves. On the other hand seasonal fields showed high concentration during premonsoon. Bhargava and Dwivedi (1976) observed carotenoid peak in premonsoon, when there was maximum chlorophyll-a and chlorophyll-c, from Goa waters.

The percentage composition of chlorophylls and carotenoids in the present study indicates that chlorophyll-a was the most dominant plant pigment followed by carotenoids in all systems. The percentage of other two pigments were more or less same. Diurnal study indicated that the maximum values of the various plant pigments were recorded in different hours. Jiyalal *et al.* (1984) observed maximum pigment concentration around mid day and mid night which coincided with high tide in Thal

(Maharashtra). Bhargava (1973) reported maximum concentration of chlorophyll-a during early morning hours and minimum at mid night. Qasim and Reddy (1967) and Gopinathan et al. (1984) stated that the pigment stocks were found to vary considerably from place to place and from time to time according to tidal rhythm. But the present study indicated that the diel variation in the plant pigments were not according to the prevailing tide. It could be due to the confined nature of the pond where water exchange is possible only at the time of opening and closing of the sluice gate coupled with the zooplankton grazing.

Estuaries are generally recognised as highly productive system both at primary and secondary levels. However, zooplankton biomass and counts are very poor during the low saline period. But during the postmonsoon and premonsoon season, zooplankton thrives and proliferates, standing stock (Displacement volume and count per volume) during this period often far exceeded those observed in the coastal waters and open sea. Zooplankton standing stock reached 1.91 ml and 18,000 Nos/m^3 in premonsoon in Cochin backwaters (Madupratap, 1987). This finding is further supported by the observation of Madhupratap from Cochin backwaters (1978), Selvakumar et al. (1980) from Mandovi and Zuari estuaries and Shanmugham et al. (1986) from Pitchavaram mangrove area. Desai et al. (1983) also reported low biomass values during June from the estuaries of Gujarat. In the present study also similar results, i.e., high biomass (in terms of number and volume) was invariably recorded during pre and post monsoon except in one perennial field (Panangad) during monsoon. Such high biomass values during monsoon has been reported by Murthy and Ganapathi (1975) from Vishakhapatnam, Verlencar (1987) and Rajagopal (1981) from Goa waters. Diurnal studies showed the maximum abundance of plankton around 0200 and 0400 hrs in all the lunar phases irrespective of tide. Pillai and Pillai (1974) reported that the variation in zooplankton biomass appeared to be partly influenced by diel rhythm of plankton and the incoming tides contribute to their increase during day time. Whereas Madhupratap and Rao (1979) while studying the tide and diurnal influence on estuarine zooplankton reported that tidal variations are not so much pronounced for most group and species of zooplankton and zooplankton seem to be able to maintain their position within the estuary during tidal exchanges. The present study also indicates the same trend in the culture systems regarding zooplankton population.

The pattern of ecological distribution of various groups and species are essentially controlled by the hydrographic changes. The seasonal cycle encountered in the hydrographic conditions were exhibited by zooplankton species also. Of the environmental factors, salinity acts as the major factor determining the diversity of the various species in the estuary and connected backwaters and fields. Except for a few low saline species, their relative abundance was high during premonsoon. The monsoon causes considerable changes in the environment as well as the population. During peak monsoon season water in the estuary becomes almost fresh and the total biomass of zooplankton reduced considerably. This recovery was gradual during postmonsoon and attained the maximum by late premonsoon (Rao _et al._ 1975).

Although estuarine zooplankton are volumetrically abundant their diversity in this habitat is limited to a few species. The zooplankton abundance is usually high during premonsoon and low during monsoon with relatively minor secondary peak during postmonsoon. Silas and Pillai (1975) observed that the adults of zooplankton taxa contribute to a major share of the premonsoon zooplankton biomass. The secondary peak of zooplankton during postmonsoon is largely constituted by the larval forms of benthic invertebrates, eggs and larvae of different species of fishes and holoplankters such as copepodes and cladoceran. The high diversity of the fauna which is noticeable during the premonsoon months seems to be derived partly induced by the restablishment of favourable hydrographic conditions prevailing in the estuary during this period. They concluded that a combination of hydrographic parameters and other biological features induce diversity of the fauna of the estuary. Salinity is found to be the key factor associated with the changes in the zooplankton abundance and the dominant planktonic components recorded during this period were hydromedusae, siphonophore, ctenophore, chaetognath, invertebrate eggs, larvae, fish eggs and larvae (Madhupratap, 1978). Nair et al. (1984) while studying the ecology of Kadinamkulam backwater reported that rotifers, copepods and their nauplii are the major components of zooplankton throughout the backwater. Copepods formed the dominant group near the barmouth and the middle portion of the barmouth. In Cochin backwater copepods constituted about 55-85% of the total zooplankton and larvae of prawns, brachyuran zoea, medusae, chaetognath, amphipod and lucifer are the other component items of zooplankton (Madhupratap, 1987). Studies by George (1958), Shanmugham et al. (1986) and Krishnakumari and Nair (1988) also showed the dominance of copepods in the plankton from different estuaries of India. The variation in the abundance of copepods has not clearly shown any relationship with the variation in salinity, their maximum and minimum having occurred during periods of both low and high salinities (George, 1958). The present study also confirms the dominance of copepods irrespective of season. Nauplii of copepods, zoea, rotifer, ostracods, and cladocerans were recorded only during monsoon and postmonsoon.

Data on the tertiary production (fish/prawn) shows that the total prawn production ranged from 270.87 to 1114.43 Kg/ha in the perennial field with a mean of 692.6 Kg/ha during 1988-90 period. Metapenaeus dobsoni was the dominant species followed by Penaeus indicus and Metapenaeus monoceros. Production showed variation between years. George (1974) reported a production range of 741-881 Kg/ha in the perennial fields (Edavanakkad) with fluctuation between years. Whereas Nair et al. (1988) reported a production of about 485 Kg./ha from perennial ponds near the northern part of Cochin barmouth. Nasser and Noble (1991) reported that the yield varied between 455 and 936 Kg/ha from two perennial fields at Edavanakkad.

The production potential and economics of the seasonal prawn culture fields are well studied compared to perennial fields. During the period of this study the production ranged from 1640.63 (89-90) to 2931.88 Kg/ha with an average of 2286.3 Kg/ha. Sathyadas et al. (1989) while studying the economic evaluation of paddy cum prawn culture fields in Kerala reported that the production from Pokkali fields in the Vypeen area decreased tremendously from 1000 Kg/ha in fifties to 700 Kg/ha in seventies. They recorded an average yield of about 620 Kg/ha in Vypeen island and much lower in other areas. Nair et al. (1988) recorded a production of about 764 g/ha from the seasonal fields near the northern end of Cochin harbour. A recent study by Nasser and Noble (1991) reported a production of about 739 Kg/ha from Edavanakkad. All these studies showed the dominance of *M. dobsoni* in the catch followed by *P. indicus* and *M. monoceros.*

George (1974) is of opinion that the higher yield in the seasonal fields is due to the higher primary productivity of these fields and due to the fluctuations in the recruitment of juvenile prawns into the fields. But from the present study no such high productivity was noticed in the seasonal field in primary level (250-2465 mgC/m^3/day) compared to perennial field (375-5500 mgC/m^3/day). Nair et al. (1988) opined that the fluctuation in the prawn production was not because of the variation in the production in the lower trophic levels or due to the scarcity of food but related to fluctuation in salinity. From the present study it can be concluded that high prawn production in the Mulavukad field could be due to high organic carbon content (2.0 to 3.65%) of the soil. Moreover, earlier reports of Gopinathan et al. (1982) and Gilbert and Pillai (1986) indicated that this region is the most productive area in the Cochin estuarine system. Apart from this high production during 88-89 in both perennial and seasonal fields may be due to the proper management measures (application of cowdung and groundnut oil cake) taken by the prawn culturists, as these fields were given on lease for 6 months (seasonal fields) and one year (perennial field) during 88-89. Whereas in 89-90, farm owners themselves did the culture without much additional inputs such as manuring etc. which resulted in low production.

A comparison of primary, secondary and tertiary production showed that only a very few percent (less than 14%) of the primary production is utilized by zooplankton in these culture fields. Qasim (1970) reported that primary production was inefficiently utilized in the Cochin estuary. The main factor responsible was the lack of zooplankton herbivores which inturn may be due to the changing environmental features of the estuary. This apparent wastefulness of the primary production however, may not remain so well marked, if we consider that the unconsumed material may perhaps be used more efficiently by the other members of the estuarine ecosystem. This raises the possibility of several "alternate pathways" in the food chain. One such pathway may be directly linked with the herbivorous fishes (mullets) which are always present in the estuary in appreciable numbers. Another direct link from basic food may be with the omnivorous prawns and shrimp population through detritus, as backwater is well known for its crustacean fishery. Finally a substantial portion of the basic food which keeps sinking to the bottom may be utilized directly by the sedentary animal communities. Gopinathan *et al.* (1982) also reported high quantities of suspended detritus in the northern part of the estuarine system and connected prawn culture systems. Whereas a good percent of the primary production (33.61-61.27%) is efficiently utilized in the tertiary level in the seasonal field and the percentage was less than 9 in perennial field. This high percentage of utilization in the seasonal field may be due to the presence of large quantity (upto 1528 kg) of herbivorous fishes. In general, tertiary producers get a minor contribution from the secondary producers and the rest could be from the detritus and benthic organisms.

The results of the present study points to the fact that all hydrobiological parameters, except temperature, salinity phytoplankton and chlorophyll-c, did not follow any steady seasonal trends in the three different prawn culture systems. The major factor determining the tertiary production was found to be the organic carbon content of the soil. Apart from this, proper management measures such as fertilization and manuring of the field also resulted in better production.

S U M M A R Y

1. The present investigation on the ecological characteristics of prawn culture fields in the Cochin area was carried out for a period of two years from December 1988 to November 1990 in perennial fields, seasonal fields and canals of coconut plantation.

2. The study area received a total rainfall of 2963 mm and 2371 mm during 1988-89 and 89-90 respectively.

3. Atmospheric temperature ranged between 24° to 31.5°C in these culture systems. Water temperature closely followed the air temperature and the range was from 26.8° to 36°C in perennial fields, 26.5° to 36°C in seasonal fields and 27° to 31.5°C in coconut groves. All systems showed high temperature values in premonsoon.

4. pH fluctuated from 6 to 9.2 in perennial fields, 6.75 to 8.25 in seasonal fields and 6.1 to 8.35 in coconut groves. No seasonal trend was observed.

5. High salinity values were recorded in premonsoon followed by postmonsoon and the lowest in monsoon. The variation was from 0.28 to 27.23‰ (perennial fields), 4.9 to 28.5‰ (seasonal fields) and 0.96 to 25.25‰ (coconut groves).

6. Total alkalinity values were generally high with wide fluctuation in different systems. It ranged from 10-130 mg/l in perennial fields, 22.5-111 mg/l in seasonal fields and 24-185 mg/l in coconut groves. High values were generally recorded during premonsoon and monsoon.

7. Dissolved oxygen concentration never exceeded 10.29 mg/l. In perennial fields peak concentration was noticed during monsoon, whereas in seasonal fields and coconut groves it was during pre-monsoon. Dissolved oxygen concentration ranged from 2.03-10.29 mg/l in perennial fields, 1.4-6.66 mg/l in seaonal fields and 1.65-5.59 mg/l in coconut groves.

8. High Nitrate-Nitrogen concentration was noticed in monsoon and postmonsoon in perennial fields and coconut groves; but no such seasonal trend was discernible in seasonal fields. Its concentration varied from 0.15-27.8 μg at/l (perennial fields), 0.15.22.5 μg at/l (seasonal fields) and 0.94-12.6 μg at/l (coconut groves).

9. No seasonal trend was observed in Nitrite-Nitrogen concentration in the perennial fields. But in seasonal fields and coconut groves high values were recorded during premonsoon and monsoon respectively. Nitrite concentration varied between 0.003-3.38 μg at/l (perennial fields), 0.02-11.1 μg at/l (seaonal fields and 0.003-2.03 μg at/l (coconut groves).

10. Ammonia-Nitrogen concentration ranged from 1.88 to 164.93 μg at/l in perennial fields, 1.96 to 91.04 μg at/l in seasonal fields and from 1.01 to 93.5 μg at/l in coconut groves and seasonal fluctuation was irregular.

11. Reactive phosporus concentration was high during premonsoon in perennial and seasonal fields with values ranging from 0 to 15.5 μg at/l and 0.13 to 22.88 μg at/l respectively. Whereas in coconut groves high concentration was recorded during monsoon and post-monsoon and the range was from 0 to 11.23 μg at/l.

12. Silicate-silicon concentration fluctuated from 3 to 160 μg at/l (perennial fields), 4 to 196 μg at/l (seasonal fields) and 12.5 to 112.5 μg at/l (coconut groves). Seasonal fluctuation was inconsistant in these culture systems.

13. Organic carbon content of the sediment did not show any seasonal trend. Among the three culture systems studied, seasonal fields showed high organic carbon content (1.45-3.93%) followed by coconut groves (0.16-3.38%) and perennial fields (0.12-3.64%).

14. In perennial fields no seasonal trend was noticed in primary production; whereas the production was high during premonsoon in seasonal fields and in monsoon and occasionally during premonsoon in coconut groves. The production ranged from 156-9186 mgC/m^3/day (perennial fields), 250-6378 mgC/m^3/day (seasonal fields) and 100-3338 mgC/m^3/day (coconut groves).

15. Diatoms were the dominant component of phytoplankton, forming about 80-85% of the total phytoplankton in all seasons, followed by dinoflagellates (monsoon) and (postmonsoon), blue green algae (monsoon) and green algae (monsoon).

16. There were no seasonal variations of chlorophyll-a values in perennial fields and coconut groves, whereas high values were recorded during premonsoon in seasonal fields. Both seasonal fields and coconut groves showed high chlorophyll-b concentration during premonsoon, but the seasonal trend was irregular in the perennial fields. Chlorophyll-c concentration was more during premonsoon in all systems. No definite pattern in the distribution of carotenoids was observed in perennial fields and coconut groves. On the other hand high carotenoids concentration was recorded during premonsoon in seasonal fields. Percentage composition of different plant pigments indicated that chlorophyll-a was the dominant plant pigment followed by carotenoids. Chlorophyll b and c were the least abundant and occurred in more or less uniform percentages.

17. High zooplankton biomass was noticed during pre-and postmonsoon in these culture systems. Species composition of zooplankton showed that copepods were the dominant component of the plankton in all fields and throughout the seasons. Copepod nauplii, brachyuran zoea, rotifers, ostracods and cladocerans were recorded during monsoon and postmonsoon months.

18. In the total tertiary production of the perennial fields, prawns accounted for 95.04 to 73.96% and fishes 4.96 to 26.04% . Prawn production fluctuated from 270.87 to 1114.43 kg/ha, with an average of 692.6 kg/ha. Fish species recorded were Liza parsia, Etroplus suratensis, E. maculatus, Tachysurus maculatus and Ambassis sp. In seasonal field about 25% of the tertiary production was contributed by fish, comprising of species such as Tilapia mossambica, Etroplus suratensis, E. maculatus, Liza parsia and Ambassis sp. The prawn production fluctuated from 1640.63 to 2931.88 kg/ha (average 2286.3 kg/ha).

In both perennial and seasonal fields, M. dobsoni (56%) was the dominant species of prawn followed by P. indicus (29%) and M. monoceros(15%)

19. Comparison of primary, secondary and tertiary production revealed that only less than 14% of the primary production was utilized in the secondary level in these culture systems. A high percentage of primary production (33.67 to 61.27%) was utilized in the tertiary level in seasonal field, but in the perennial field it was less than 9%.

20. Diurnal study conducted at the Edavanakkad perennial field showed that fluctuation in none of the environmental parameters followed tidal rhythm and the tidal incursion was fully controlled by the sluice gate.

R E F E R E N C E S

AJITHKUMAR, V. 1990. An analysis of factor-product relationship in prawn farming - A production function approach. M. Sc. Dissertation, Cochin Univ. Sci. & Technol., 67 p.

ANIRUDHAN,T.S. and P.N.K.NAMBISAN. 1990. Distribution of salinity and silicon in Cochin estuary. Indian J. mar. Sci., 19: 137-139.

ANON. 1975. Manual of methods in aquatic environment research, FAO. Fish. Tech. Paper, 137: 1-238.

ANON. 1978. Proposals for the development of fresh and brackishwater capture and culture fisheries including mariculture in Kerala during the Sixth Plan Period 1978-'83. Report to the Task Force on Inland and Estuarine Fisheries including culture programme, 44 p.

ANON. 1991. Fish farming international, 18(2): 1 pp.

ANON. 1991. Annual Report 1990-91, Cent. Mar. Fish. Res. Inst, 111 p.

BALACHANDRAN,T., C.B.LALITHAMBIKA DEVI, T.C.GOPALAKRISHNAN and M.KRISHNAN KUTTY. 1982. On the availability of food for prawns in some tidal ponds of Cochin backwater at Ramanthuruth (Abstract). In: Proc. Symp. Coastal Aquaculture, 1: 422 pp.

BALACHANDRAN,T. and K.J.PETER. 1987. The role of plankton research in fisheries development. Cent. Mar. Fish. Res. Inst. Spl. Pbl. 40 pp 24. (Abstract).

BALASUBRAHMANYAN, K. 1961. Studies on the ecology of Vellar estuary. 2-Phosphates in the bottom sediments. J. Ecol. Soci. India, 13: 166-169.

BANERJEA,S.M. 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian J. Fish., 14: 115-144.

BANERJEA,S.M. and A.N.GHOSH. 1963. Soil nutrients and plankton production in fish ponds. A. available soil phosphorus Indian J. Fish., 10(2)A: 627-633.

BANERJEE,R.K. and P.B.PAKRASI. 1986. Physico-chemical nature and biomass production of newly constructed brackishwater impoundments (Nona gheri) in the lower Sunderbans. Proc. Symp. Coastal. Aquaculture, 4: 1103-1106.

BANERJEE,S.C. and R.K.BANERJEE. 1975. Soil-water behaviour in ponds in brackishwater zone. J. Inland Fish. Soc., 24(1): 84-85.

BHARGAVA,R.M.S. 1973. Diurnal variation in phytoplankton pigments of Mandovi estuary, Goa. Indian J. mar. Sci., 2: 27-31.

BHARGAVA,R.M.S. and S.N.DWIVEDI. 1976. Seasonal distribution of phytoplankton pigments in the estuarine systems of Goa. Indian J. mar. Sci., 5(1): 87-90.

BHATTATHIRI,P.M.A., V.P.DEVASSY and R.M.S.BHARGAVA. 1976. Production of different trophic levels in the estuarine systems of Goa. Indian J. mar. Sci., 5: 83-86.

BHATTATHIRI,P.M.A. and V.P.DEVASSY. 1978. Diurnal variation in phytoplankton pigments and primary production. Indian. J. mar. sci., 7: 191-193.

BHUNIA,A.B. and A.CHOUDHARY. 1981. Studies on the seasonal abundance and biomass of crustacean zooplankton and chaetognaths in relation to ecological parameters of a tidal creek (Mooriganga) of Sagar island (North) Sunderban, West Bengal. Proc. Symp. Ecol. Animal. Popul. Zoopl. Surv., 1: 175-183.

CHANDRAN,R. 1985. Seasonal and tidal variations of phytoplankton in the gradient zone of Vellar estuary. Mahasagar, Bull. Natn. Inst. Oceanogr., 18(1): 37-48.

CHANDRAN,R. and K.RAMAMURTHY. 1984a. Hydrobiological studies in the gradient zone of the Vellar estuary. 1. Physicochemical parameters. Mahasagar, Bull. Natn. Inst. Oceanogr., 17(2): 69-77.

CHATTOPADHYAY,G.N. and R.K.CHAKRABORTI. 1986. A comparative study on the nature and properties of some brackishwater and nearby freshwater fish pond soils. Proc. Symp. Coastal Aquaculture., 4: 1110-1114.

CHATTOPADHYAY,G.N. and L.N.MANDAL. 1980. Distribution of different inorganic forms of phosphorus in some brackishwater fish pond soil of West Bengal. J. Inland. Fish. Soc. India, 12(1): 25-29.

CHERIAN,P.V. 1967. Hydrological studies in and around Cochin harbour. Bull. Dept. mar. biol. Oceanogr., Univ. Kerala, 9-17.

DATTA,N.C., S.CHAUDHURI,M. DAS and B.GHOSH. 1983. Ecological characteristics of brackishwater bheri of the Sunderbans, West Bengal. Env. Ecol., 1(4): 235-239.

DEHADRAI,P.V. and R.M.S.BHARGAVA. 1972. Distribution of chlorophylls, carotenoids and phytoplankton in relation to certain environmental factors along the central west coast of India. Marine. biol. 17: 30-37.

DEHADRAI,P.V. and R.M.S.BHARGAVA. 1972. Seasonal organic production in relation to environmental features in Mandovi and Zuari estuaries, Goa. Indian. J. mar. Sci., 1(1): 52-56.

DESAI,B.N., S.N.GAJBHIYE, M.JIYALAL RAM and V.R.NAIR. 1983. Comparative account of zooplankton in polluted and unpolluted estuaries of Gujarat. Mahasagar, Bull. Natn. Inst. Oceanogr., 16: 281-291.

DESOUSA,S.N. 1983. Studies on the behaviour of nutrients in Mandovi estuary during premonsoon. Estuarine. Coastal and Shelf Sci., 16: 299-308.

DESOUSA,S.N., R.SEN GUPTA, S.SANZGIRI and M.D.RAJAGOPAL. 1981. Studies on the nutrients of Mandovi and Zuari river systems. Indian J. mar. Sci., 10: 314-326.

DESOUSA,S.N. and R.SEN GUPTA. 1986. Variations of dissolved oxygen in Mandovi and Zuari estuaries. Indian J. mar. Sci., 15(2): 67-71.

DEVAPIRIYAN,R. 1990. Studies on the ecology and production of algae in prawn culture systems. Ph.D. Thesis, Cochin Univ. Sci & Tech. 81 p.

DEVASSY,V.P. and P.M.A. BHATTATHIRI. 1974. Phytoplankton ecology of the Cochin backwater. Indian J. mar. Sci., 3: 46-50.

DJAJADIREDJA,R. and A.POERNOMO. 1972. Requirements for successful fertilization to increase milkfish production. In: Coastal Aquaculture in Indo-Pacific region (ed.) T.V.R. Pillay, Fishing News (Books) Ltd., London, 308-409.

*ELLIS,M.M. 1937. Detection and measurement of stream pollution. Bull. zz. U.S. Bur. fish 58: 365-437.

GAARDER,T. and H.H.GRAN. 1927. Investigations of the production of plankton in the OS&O Fjord. Rapp. Proc. Verb. Cons. Int. Explor. Mar. 42: 1-48.

GEORGE,K.V. 1974. Some aspects of prawn culture in seasonal and perennial fields of Vypeen island. Indian J. Fish., 21: 1-19.

GEORGE,K.V. 1978. Economics of traditional prawn culture practices in Kerala with a note on the advantages of intensive prawn culture. Proc. First National Symposium on Shrimp farming, 131-137.

GEORGE,M.J. 1958. Observations on the plankton of Cochin backwater. Indian J. Fish., 5: 375-401.

GEORGE,M.J. 1975. Observations on the growth in certain penaeid prawns studied in prawn culture experiments in paddy field. Bull. Dept. mar. Sci., Univ. Cochin, 7(1): 41-55.

GEORGE,M.J. and C.SUSEELAN. 1983. Culture fishery of prawns - Existing practices and future prospects. Proc. Summer. Inst. Hatch. Prod. of prawn seeds and culture of marine prawn. 18th April - 17th May 1983, CMFRI, Cochin.

GEORGE,M.J., K.H.MOHAMED and N.N.PILLAI. 1968. Observations on the paddy field prawn filtration of Kerala, India. FAO. Fish Rep., 57(2): 427-442.

GILBERT, JOSEPH,P.G. and V.K.PILLAI. 1986. Physico-chemial characteristics of soils in the aquaculture systems of the Cochin estuarine area. J. aqua. Trop. 1(2): 161-170.

GOMATHI,S. 1990. Studies on the hydrology and the abundance of phytoplankton of fish culture ponds. M. Sc. Dissertation, Cochin Univ. Sci. & Technol, 96 p.

GOPALAKRISHNAN,T.C., C.B.LALITHAMBIKA DEVI, P.N.ARAVINDASHAN, K.K.C.NAIR, T.BALASUBRAMANIAN and M.KRISHNANKUTTY. 1988. Phytoplankton and zooplankton of some of the paddy-cum prawn culture fields in and around Cochin. Mahasagar, Bull. Natn. Inst. Oceanogr., 21(2): 85-94.

GOPALAN,U.K. and K.S.PURUSHAN. 1981. Present status of backwater shrimp culture in India. Seafood Export, J. 8(1): 9-14 and 3: 11-19.

GOPALAN,U.K., K.S.PURUSHAN, V.SANTHAKUMARI and P.P.MEENAKSHI KUNJAMMA. 1982. Experimental studies on high density, short term farming of shrimp, P. indicus in a Pokkali field in Vypeen island, Kerala. Proc. Symp. Coastal Aquaculture, 1982, I: 151-159.

GOPALAN,U.K., K.S.PURUSHAN and T.S.S.RAO. 1978. Case studies on the economics of an improved method of paddy field shrimp culture in Vypeen island, Kerala. Proc. first National Symposium on shrimp farming, 175-186.

GOPINATHAN,C.P. 1972. Seasonal abundance of phytoplankton in the Cochin backwater. J. Mar. biol. Ass. India., 14(2): 568-577.

GOPINATHAN,C.P. 1975. Studies on the estuarine diatoms of India Bull. Dept. mar. Sci. Univ. Cochin, 7(4): 995-1004.

GOPINATHAN,C.P., P.V.R. NAIR and A.K.K.NAIR, 1974. Studies on the phytoplankton of the Cochin backwater, a tropical estuary. Indian J. Fish, 21(2): 501-513.

GOPINATHAN,C.P., P.V.R.NAIR, V.K.PILLAI, P.P.PILLAI, M.VIJAYA KUMARAN and V.K.BALACHANDRAN. 1982. Environmental characteristics of the seasonal and perennial prawn culture fields in the estuarine systems of Cochin. Proc. Symp. Coastal Aquaculture, 1: 368-382.

GOPINATHAN,C.P., P.V.R.NAIR and A.K.K.NAIR. 1984. Quantitative ecology of phytoplankton in the Cochin backwaters. Indian J. Fish., 31(3): 325-346.

GOSWAMI,S.C. 1985. Zooplankton standing stock and composition in coastal waters of Goa, West Coast of India. Indian J. mar. Sci., 14(4): 177-180.

GOSWAMI,S.C., R.A.SELVAKUMAR and S.N.DWIVEDI. 1977. Zooplankton production along central west coast of India. Proc. Symp. Warm-water Zoopl, Spl. Publ. N10, Dona Paula, Goa, India, 337-353.

HARIDAS,P., P.GOPALAMENON and M.MADHUPRATAP 1980. Annual variations in zooplankton from a polluted coastal environment. Mahasagar, Bull. Natn. Inst. Oceanogr., 13(3): 239-248.

HARIDAS,P., M.MADHUPRATAP and T.S.S.RAO, 1973. Salinity, temperature oxygen and zooplankton biomass of the backwaters from Cochin to Alleppey, Indian J. mar. Sci., 2(2): 94-102.

*HARVEY,H.W. 1955. The chemistry and fertility of seawaters. Cambridge University Press, London, 240 p

HOBBIE,J.E. 1976. Nutrients in estuaries. Oceanus, 19: 41-47.

IVERSON,E.S. 1976. Utilizing productive areas. In: Farming the edge of the sea. Fishing News (Books) Ltd., London. 53-84.

JAGTAP,T. 1987. Seasonal distribution of organic matter in mangrove environment of Goa. Indian J. mar. Sci., 16(2): 103-106.

JAYALAKSHMY,K.V., S.KUMARAN and M.VIJAYAN. 1985. Phytoplankton distribution in Cochin backwater, a seasonal study. Mahasagar, Bull. Natn. Inst. Oceanogr., 19(1): 29-37.

* JITTIS,H.R. 1959. The adsorption of phosphates by estuarine bottom deposits. Australian. J. mar Freshwat. Res., 10: 7-21.

JIYALAL RAM,M., B.N.DESAI and S.A.H.ABIDI. 1984. diurnal variation of phytoplankton pigments and population in the nearshore waters off thal (Maharashtra). Mahasagar, Bull. Natn. Inst. Oceanogr., 17(1): 41-48.

JOSANTO,V. 1971. Bottom salinity characteristics and the factors that influence the salt penetration in the Vembanad lake. Bull. Dept. mar. Sci., Univ. Cochin, 5: 1-16.

JOSANTO,V. 1971. On the grain size distribution of the Cochin backwater sediments. Bull. Dept. mar. biol. Oceanogr., Univ. Cochin, 5: 109-122.

JOSANTO,V. 1975. Bottom salinity characteristics of the Cochin backwaters. Proc. Symp. Estuarine. Biol., Annamalai Univ, 223-230.

JOSEPH,P.S. 1974. Nutrient distribution in Cochin harbour and its vicinity. Indian J. mar. Sci., 3: 28-32.

JOSEPH K.J. and V.K.PILLAI. 1975. Seasonal and spatial distribution of phytoplankters in Cochin backwater. Bull. Dept. mar. Sci. Univ. Cochin, 7(1): 171-180.

JOSHI,K.K. 1990. Nature and ecological significance of nutrient regeneration in different prawn culture fields. Ph. D. Thesis, Cochin Univ. Sci. & Tech. 192.

KANNAN,L. and K.KRISHNAMURTHY. 1985. Nutrients and their impact on phytoplankton. In: Marine plants. Papers presented at All India Symposium on Marine Plants, their biology, chemistry and utilization, 73-78.

KRISHNAKUMARI,L. and V.R.NAIR. 1988. Biomass, organic carbon and calorific content of zooplankton from the Arabian sea off Central West Coast of India. Indian J. mar. Sci., 17(1): 78-80.

KUMARAN,S. and T.S.S.RAO. 1975. Phytoplankton distribution and abundance in the Cochin backwaters during 1971-72. Bull. Dept. mar. sci., Univ. Cochin, 7(4): 791-799.

LAKSHMANAN,P.T., C.S.SHYNAMMA, A.N.BALCHAND, P.G.KURUP and P.N.K.NAMBISAN. 1982. Distribution and seasonal variation of temperature and salinity in Cochin backwaters. Indian J. mar. Sci., 11(2): 170-172.

LAKSHMANAN,P.T., C.S.SHYNAMMA,A.N. BALCHAND and P.N.K.NAMBISAN 1987. Distribution and variability of nutrients in Cochin backwater, Southwest coast of India. Indian J. mar. Sci., 16(2): 99-102.

LEGENDRE,M., M.PAGANO and L. SAINT JEAN. 1987. Zooplankton populations and biomass on brackishwater aquaculture ponds (Layo, Ivory coast), Recolonisation after liming and tilling. Aquaculture, 67 (3): 321-341.

* LIN,S.V. 1970. Fish pond fertilization and the principle of water conditioning China Fisheries Monthly, 209 p.

MADHUPRATAP,M. 1978. Studies on the ecology of zooplankton of Cochin backwaters. Mahasagar, Bull. Natn. Inst. Oceanogr., 11: 45-56.

MADHUPRATAP,M. 1987. Status and strategy of zooplankton of tropical Indian estuaries: A review. Bull. Plank. Soc. Japan, 34(1): 65-81

MADHUPRATAP,M. and P.HARIDAS. 1975. Composition and variation in the abundance of zooplankton of backwater from Cochin to Alleppey. Indian J. mar. Sci, 4: 77-85.

MADHUPRATAP.M., T.S.S.RAO and H.KRISHNA IYER. 1977. A model for the production of zooplankton abundance in an estuary. Indian J. mar. Sci., 6(2): 183-184.

MADHUPRATAP,M. and T.S.S.RAO 1979. Tide and diurnal influence on estuarine zooplankton. Indian J. mar. Sci., 8: 9-11.

MALLIK, T.K. and G.K.SUCHINDAN. 1984. Some sedimentological aspects of vembanad Lake, Kerala, West Coast of India. Indian J. mar. Sci., 13: 159-163.

MANIKOTH, SREEDHARAN and K.Y.M.SALIH. 1974. Distribution characteristics of nutrients in the estuarine complex of Cochin. Indian J. mar. Sci., 3: 125-130.

MAYA ANTONY,T. 1991. A study on fluctuation of zooplankton in the etuarine waters of Cochin during May-September 1991. M. Sc. Dissertation, Cochin. Univ. Sci. and Technol., 95 p.

MC QUEEN,D.J., J.R.POST and E.L.MILLS. 1986. Trophic relationships in freshwater pelagic ecosystems. Can. J. Fish. Aquat. Sci., 43: 1571-1581.

MENON,M.K. 1954. On the paddy field prawn fishery of Travancore-Cochin and an experiment on prawn culture. Proc. Indo. Pacific. Fish. Coun. 5th Sess. 2: 1-5.

MENON,N.R., P.VENUGOPAL and S.C.GOSWAMI, 1971. Total biomass and faunistic composition of the zooplankton in Cochin backwater. J. mar. biol. Ass. India, 13:220-225.

*MULLIN,J.B. and J.P.RILEY. 1955. The colorimetric determination of silicate with special reference to sea and natural waters Anal. Chim. Acta., 27: 162-175.

MOLLAH,M.F.A., A.K.M.AMINUL HAQUE, M.HAQUE, M.IDRIS and M.Y.CHAUDHURY. 1979. Interaction between pond bottom soil and water qualities. Indian J. Fish., 26(1&2): 101-114.

*MOORE,H.B. 1930. The muds of the Clyde sea area I. Phosphate and nitrogen content. J. mar. Biol Ass. 16: 595-607.

MURTHY,K.V.R. and P.N.GANAPATI. 1975. Ecological aspects of zooplankton production of Visakhapatnam (Bay of Bengal). Proc. Indian acad. Sci., 81B: 207-222.

MURTHY,P.S.N. and M.VEERAYYA. 1972. Studies on the sediments of Vembanad lake, Kerala State. Part 1. Distribution of organic matter. Indian J. mar. Sci., 1(1): 45-51.

MUTHU,M.S. 1978. A general review of penaeid prawn culture, Cent. Mar. fish. Res. Inst., Spl. Publ. 3: 25-33.

NAGARAJAIAH,C.S. and T.R.C.GUPTA. 1985. Seasonal fluctuations of plankton in brackishwater ponds of Nethravathi estuary, Mangalore. 1. Phytoplankton. Mysore J. agri. Sci., 19: 115-120.

NAIR,K.K. and D.J.TRANTER. 1971. Zooplankton distribution along the salinity gradient of Cochin backwater before and after monsoon. J. mar. biol. Ass. India. 13: 203-210.

NAIR,K.K.C., V.N.SANKARANARAYANAN, T.C.GOPALAKRISHNAN, T.BALASUBRAMANIAN, C.B.LALITHAMBIKA DEVI, P.N. ARAVINDAKSHAN and M.KRISHNANKUTTY. 1988. Environmental conditions of some paddy cum prawn culture fields of Cochin backwater, Southwest coast of India. Indian. J. mar. Sci., 17(1): 24-30.

NAIR,P.V.R., K.J.JOSEPH, V.K.BALACHANDRAN and V.K.PILLAI. 1975. A study on the primary production in Vembanad lake. Bull. Dept. mar. sci., Univ. Cochin., 7(1): 161-170.

NAIR,N.B., K. KRISHNAKUMAR, M. ARUNACHALAM, P.K.ABDUL AZIZ and K. DHARMARAJ. 1984. Ecology of Indian estuaries : Studies on the zooplankton ecology of Kadinamkulam backwater. Proc. Indian. Acad. Sci., (Anim. Sci), 93(6): 573-584.

NAIR,V.R. 1980. Production and assimilation of zooplankton in the estuarine and nearshore waters of Goa. Indian J. mar. Sci., 9(2): 116-119.

NAIR,V.R., V.P.DEVASSY and S.Z.QASIM. 1980. Zooplankton and Trichodesmium phenomenon. Indian J. mar. Sci., 9(1): 1-6.

NAIR,V.R., S.N.GAJBHIYE, M.JIYALRAM and B.N.DESAI. 1981. Biomass and composition of zooplankton in Auranga, Ambika, Purne and Mindola estuaries of South Gujarat. Indian J. mar. Sci., 10(2): 116-122.

NASSER,A.K.V. 1986. A comparative study of sediment nutrients in seasonal and perennial prawn culture pond, during the southwest and immediate post-monsoon months M.Sc. Dissertation, Cochin Univ. Sci. & Technol., 83 p.

NASSER,A.K.V. and A.NOBLE. 1991. Economics of prawn culture in Vypeen, Kerala. Abs. Natn. Workshop. on Aquaculture Economics. 20-22 Nov., 1991. Bhubaneswar, India Abs. No. 28.

NITTALA S. SARMA and I.NAGESWARA RAO, 1989. Distribution of chlorophyll-a, organic carbon and carbohydrate of particulate matter of Visakhapatnam harbour water, east coast of India. Indian J. mar. Sci., 18: 24-29.

PANT,A., B.G.P.MATONDKAR and S.C.GOSWAMI. 1984. Biomass relationship between phytoplankton and zooplankton in Goa waters. Indian J. mar. Sci., 13: 116-118.

PARSONS,T.R., Y.MAITA and C.M.LALLI. 1984. A manual of Chemical and Biological methods for seawater analysis. 177p. Pergamon press.

PAULINOSE,V.T., T.BALASUBRAMANIAN, P.N.ARAVINDAKSHAN, P.GOPALA MENON and M.KRISHNANKUTTY. 1981. Some aspects of prawn ecology of Cochin backwaters. Mahasagar, Bull. Natn. Inst. Oceanogr., 14(2): 123-133.

PILLAI,P.P. and M.A. PILLAI. 1974. Tidal influence on the diel variation of zooplankton with special reference to copepods in Cochin back-water. J. mar. biol. Ass., India, 15(1): 411-417.

PILLAI,V.N., THOMAS CHERIAN, M.D.GEORGE and A.F.ANTO. 1973. The effect of tidal currents on the hydrography of the backwaters around Cochin barmouth during post and premonsoon season. Proc. Indian Geophysics Union, 10: 231-239.

PILLAI,V.K., K.J.JOSEPH and A.K.K.NAIR. 1975. The plankton production in the Vembanad lake and adjacent waters in relation to environ-mental parameters. Bull. Dept. mar. Sci., Univ. Cochin, 7(1): 137-150.

PRADEEP,H.S. and T.R.C.GUPTA. 1986. Organic carbon in the sediments of brackishwater ponds at Mulki, South Kannada. Environ. Ecol., 4(1): 154-155.

PRASAD,P.E. 1982. Studies on the soils of some brackishwater prawn culture fields around Cochin. M.Sc. Dissertation, Cochin Univ Sci. & Tech., Cochin 80 p.

PREETHA PAUL. 1990. A study on the phytoplankton pigments and primary productivity in the Cochin backwater during southwest monsoon. M.Sc. Dissertation, Cochin Univ. Sci. & Tech. 83 p.

QASIM,S.Z. 1970. Some problems related to the food chain in a tropical estuary. In: Marine food chains (ed) J.H. Steele, Oliver and Boyd, Edinburgh, 45-51.

QASIM,S.Z. 1973. Productivity of backwaters and estuarines. In: Biology of Indian Ocean, B. Zeitzschel, (ed) Springer-Verlag, Berlin-Heidelberg-New York, 143-154.

QASIM,S.Z. 1973. Productivity of specialised environments. Mahasagar, Bull. Natn. Inst. Oceanogr., 6: 95-100.

QASIM,S.Z. 1977. Contribution of zooplankton in the food chains of some warm water environments. In: Proc. Symp. Warm Water Zoopl. Spl. Publn. NIO, Dona Paula, Goa, 700-708.

QASIM,S.Z. 1979. Primary production in some tropical environments. In: Marine production mechanism (ed) J. Dunbar (Cambridge University Press) IBP 20: 31-69.

QASIM,S.Z. 1980. Adaptations in phytoplankton to changing conditions in tropical estuaries. Mahasagar, Bull. Natn. Inst. Oceanogr., 13(2): 117-124.

QASIM,S.Z., P.M.A.BHATTATHIRI and V.P.DEVASSY. 1972. The influence of salinity on the rate of photosynthesis and abundance of some tropical phytoplankton Mar. biol., 12: 200-206.

QASIM,S.Z. and C.K.GOPINATHAN. 1969. Tide cycle and the environmental features of Cochin backwater (a tropical estuary). Proc. Indian Acad. Sci., 69B: 336-348.

QASIM,S.Z. and M.MADHUPRATAP, 1981. Changing ecology of Cochin backwaters. In: Contribution to Marine Sciences, dedicated to Dr. C.V.Kurian, 137-142.

QASIM,S.Z. and C.V.G.REDDY. 1967. The estimation of plant pigments of Cochin backwater during the monsoon months. Bull. mar. Sci., 17(1): 95-110.

QASIM,S.Z., S.WELLERSHAUS, P.M.A.BHATTATHIRI and S.A.H.ABIDI. 1969. Organic production in a tropical estuary. Proc. Indian Acad. Sci., 69B: 51-94.

*RABINOWITCH,E.J. 1951. Photosynthesis and related processes II, I. New York.

RAJAGOPAL,M.D. 1981. Plankton studies in the estuarine and near shore region of Mandovi and Zuari. Indian J. mar. Sci., 10(2): 112-115.

RAMAMIRTHAM,C.P. and R.JAYARAMAN. 1963. Some aspects of hydrographical conditions of the backwaters around Willingdon island (Cochin). J. mar. biol. Ass. India., 5: 170-177.

RAMARAJU,V.S., P.UDAYAVARMA and ABRAHAM PYLEE. 1979. Hydrographic characteristics and tidal prism at the Cochin harbour mouth. Indian J. mar. Sci., 8(2): 78-84.

RAO,T.S.S., M.DADHUPRATAP and P.HARIDAS. 1975. Distribution of zooplankton in space and time in a tropical estuary. Bull. Dept. mar. sci. Univ. Cochin, 7(4): 695-704.

RAO,P.V. 1980. Seed requirements for intensive culture of penaeid prawns in coastal waters, particularly in Kerala. Natn. Symp. Shrimp Farming, Bombay, 16-18 August 1978: 73-82.

RAVINDRAN,N. 1983. Studies on the diurnal variation of certain environmental parameters in culture pond. M.Sc. Dissertation, Cochin Univ. Sci. & Tech., 84 p.

REDDY,C.V.G. and V.N.SANKARANARAYANAN. 1972. Phosphate regenerative activity in the muds of a tropical estuary. Indian J. mar. Sci., 1: 57-60.

REDDY,K.M.S. 1986. Photosynthesis in relation to some selected environmental parameters in prawn culture fields. M.Sc. Dissertation, Cochin Univ. Sci. & Technol., 76 pp.

REGUNATHA REDDY. 1984. Studies on the phosphorus cycle and its influence on the standing crop of plankton in the estuarine and nearshore waters of mangalore. Mysore J. Agri. Sci. 18(1): 340 p. (Abstract).

REMANI,K.N., P.VENOGOPAL, K.SARALA DEVI and R.V.UNNITHAN. 1981. Sediments of a retting yard. Indian J. mar. Sci., 10(1): 41-44.

* ROULE,L. 1930. L'essai du pH dans l' evaluation de la productive des etangs a carpes (pH determination in the evaluation of carp ponds). C.R. Acad. Agri. France, 16: 1056-1060.

SANKARANARAYANAN,V.N. and S.Z.QASIM. 1969. Nutrients of Cochin backwater in relation to environmental characteristics. Mar. Biol. 2: 236-247.

SANKARANARAYANAN,V.N. and S.U.PANAMPUNNAYIL. 1979. Studies on Organic carbon, Nitrogen and Phosphorus in sediments of the Cochin backwater. Indian J. mar. Sci., 8: 27-30.

SANKARANARAYANAN,V.N., S.KUMARAN, T.BALASUBRAMANIAN, ROSAMMA STEPHEN and S.U.PANAMPUNNAYIL. 1982. Studies on the environmental conditions of tidal ponds in Ramanthuruthu island. Proc. Symp. Coastal Aquaculture 1: 362-368.

SANKARANARAYANAN,V.N., T.JOSEPH, K.V.JAYALAKSHMI and K.K.BALA CHANDRAN. 1984. Atypical behaviour of dissolved silicate in the Cochin backwater and river Periyar. Indian J. mar. Sci., 13: 60-63.

SANKARANARAYANAN,V.N., P.UDAYA VARMA, K.K.BALACHANDRAN, A. PYLEE and T.JOSEPH. 1986. Estuarine characteristics of the lower reaches of the river Periyar (Cochin backwater). Indian J. mar. Sci., 15(3): 166-170.

SARALADEVI, K., P. VENUGOPALAN, K.N. REMANI, S. LALITHA and R.V.UNNITHAN. 1979. Hydrographic features and water quality of Cochin backwaters in relation to industrial pollution. Indian J. mar. Sci., 8(3): 141-145.

SARALADEVI,K., P.VENUGOPALAN, K.N. REMANI, DOMINIC ZACHARIAS and R.V.UNNITHAN. 1983. Nutrients in some estuaries in Kerala. Mahasagar, Bull. Natn Inst. Oceanogr., 16: 161-173.

SATHYADAS,R., K.K.P.PANIKKAR, U.K.SATYAVAN and T.JACOB. 1989. Economic evaluation of paddy - prawn integrated farming in Kerala. Seafood Export J., 21(11): 9-12.

SELVAKUMAR,R.A., V.R.NAIR and M.MADHUPRATAP. 1980. Seasonal variation in secondary production of the Mandovi-Zuari estuarine systems of Goa. Indian J. mar. Sci., 9(1): 7-9.

SHANMUGHAM,A., R.KASINATHAN and S.MARITHAMUTHU. 1986. Biomass composition of zooplankton from Pitchavaram Mangroves, Southeast coast of India. Indian J. mar. Sci., 15(2): 111-113.

SHARMA,M.P. 1987. Ecological affinity of the zooplankton population in their natural environment. Curr. Sci. 17: 328-329.

SARMA,V.V. and V.ASWANIKUMAR. 1991. Subsurface chlorophyll maxima in the northwestern Bay of Bengal. Plank. Res. 13(2): 339-352.

SHYNAMMA,C.S. and K.P.BALAKRISHNAN. 1973. Diurnal variation of some physico-chemical factors in Cochin backwater during southwest monsoon. J. mar. biol. Ass. India., 15(1): 391-398.

SILAS,E.G. and P.P.PILLAI. 1975. Dynamics of zooplankton in a tropical estuary (Cochin backwater) with a review on the plankton fauna of the environment. Bull. Dept. mar. Sci., Univ. Cochin, 7(1): 329-356.

SILAS,E.G., M.J.GEORGE and T.JACOB. 1983. Prawn culture and its importance in national development. Proc. Summer. Inst. Hatchery production of seeds of marine prawns. 18th April. 17th May 1983. CMFRI, Cochin.

SINGH, DALJEET. 1987. Comparative studies on the ecology of bottom macrofauna in seasonal and perennial fish ponds and in the adjacent backwaters. M.Sc. Dissertation, Cochin Univ. Sci. & Tech. 108 p.

*SOLARZANO, L. 1969. Determination of Ammonia in natural waters by the phenol-hypochlorite method. Limnol. Oceanogr., 14: 799-801.

SRINIVASAN,A., R.SANTHANAM and G.JAGATHEESAN, 1988. Biomass and seasonal distribution of planktonic tintinids of Pullavazhi estuary Indian J. mar. Sci., 17(2): 131-133.

SRINIVASAN,R. 1982. Studies on the distribution of benthos and hydrological parameters in prawn culture systems. M.Sc. Dissertation, Cochin Univ. Sci. & Technol., 96 p.

STRICKLAND J.D.H. and T.D.PARSONS. 1968. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada, 167: 311 p.

SUBHASH CHANDER. 1986. Studies on ecophysiology of Penaeus indicus H. Milne Edwards in the grow out system. Ph.D. Thesis, Cochin Univ. Sci. & Technol., 325 p.

SUBHARAJU,R.C. and K.KRISHNAMURTHY. 1972. Biological aspects of plankton production, Mar. Biol, 14: 25-31.

SUBRAMANIAM,B.R. and U.K.VENUGOPALAN. 1978. Diurnal variation and nanoplankton primary production and chlorophyll-a in the Vellar estuary. Indian J. mar. Sci., 7(3): 191-193.

SUGUNAN,V. 1983. Ecology of meiobenthos in selected culture fields around Cochin. M.Sc. Dissertation, Cochin Univ. Sci. & Tech 88 p.

SUNDARARAJ,V. and K.KRISHNAMURTHY. 1975. Nutrients and plankton: Backwater and Mangrove environment. In: Recent Researches in Estuarine Biology (ed. N. Natarajan), 273-290.

SUSEELA JOSE, P.M.MATHEW M.M. JOSE and P.S.MRITHUNJAYAN. 1987. Studies on the zooplankton and macrobenthos in a brackish-water fish farm in the southwest coast of India. In: The first Indian Fisheries Forum, December 4th, Mangalore, Karnataka pp. 135. (Abstract).

*TANG,Y.A. and S.M.CHEN. 1967. FAO. Fish Rep. 3(44): 108-209.

UDAYAVARMA,P., ABRAHAM PYLEE and V.S.RAMARAJU. 1981. Tidal influence on the seasonal variation in current and salinity around Willingdon island. Mahasagar, Bull. Natn. Inst. Oceanogr., 14(4): 225-237.

UPADHAYAY,S. 1988. Physico-chemical characteristics of the Mahanadi estuarine ecosystem,East coast of India. Indian J. mar. Sci.,17(1):19-23

VENUGOPALAN,V.K. and K.RAJENDRAN. 1975. Dissolved and particulate nitrogen in Vellar Estuary. Bull. Dept. mar. Sci., Univ., Cochin, 7(4): 885-897.

VERLENCAR,X.N. 1984. Dissolved organic nutrients and phytoplankton production in the Mandovi estuary and coastal waters of Goa. Mahasagar, Bull. Natn. Inst. Oceanogr., 17(3): 141-149.

VERLENCAR,X.N. 1987. Distribution of nutrients in the coastal and estuarine waters of Goa. Mahasagar, Bull. Natn. Inst. Oceanogr., 20(4): 205-215.

VIJAYALAKSHMI,G.S. 1986. Primary production and phytoplankton pigments in an estuarine environment. Proc. Symp. Coastal. Aquaculture, 4: 1074-1083.

VIJAYALAKSHMI,G.S. and V.K.VENUGOPALAN. 1973. Diurnal variation in the physico-chemical and biological properties in Vellar estuary. Indian J. mar. Sci., 2: 19-22.

VIJAYALAKSHMI,K.V. 1984. Empirical relationship between phytoplankton and zooplankton biomass in Indian Ocean. Indian. J. mar. Sci., 13: 19-23.

*WALKELY,A. and T.A.BLACK. 1934. Determination of organic carbon. Soil Sci., 37: 29.

WELLERSHAUS,S. 1971. On the hydrography of Cochin backwater, a South Indian estuary. J. mar. biol. Ass. India, 14(2): 487-495.

WELLERSHAUS,S., 1974. Seasonal changes in the zooplankton population in the Cochin backwater (A South Indian Estuary). Hydrobiol., Bull. 8: 213-223.

WRIGHT,R.T. 1964. Dynamics of phytoplankton community in an ice covered lake. Limnol. Oceanogr., 10: 163-178.

---

* Not referred in original.