STUDIES ON SOME ASPECTS OF PHYTOPLANKTON

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IN
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BY
K. J. JOSEPH, M. Sc.

DIVISION OF MARINE BIOLOGY, MICROBIOLOGY AND BIOCHEMISTRY
SCHOOL OF MARINE SCIENCES
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
COCHIN - 682 016

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To

MY MOTHER, WIFE AND CHILDREN

CERTIFICATE

This is to certify that this thesis is an authentic record of the research work carried out by Mr. K.J. Joseph, M.Sc., in the Central Marine Fisheries Research Institute, Cochin and in the School of Marine Sciences, Cochin University of Science and Technology under my supervision, in partial fulfilment of the requirements for the degree of Doctor of Philosophy of the Cochin University of Science and Technology, and that no part thereof has been presented before for any other degree.

Dr. P.V. Ramachandran Nair
(Supervising Teacher)

DECLARATION

I hereby declare that the thesis entitled "STUDIES ON SOME ASPECTS OF PHYTOPLANKTON", is an authentic record of research carried out by me under the supervision and guidance of Dr. P.V. Ramachandran Nair in partial fulfilment of the requirements of the Ph.D. Degree in the Faculty of Marine Science of the Cochin University of Science and Technology and that no part of it has previously formed the basis for the award of any degree, diploma or associateship in any university.

K.J. JOSEPH

A C K N O W L E D G E M E N T S

I wish to express my deep sense of gratitude to my Supervising Teacher Dr. P.V. Ramachandran Nair (former Joint Director of Central Marine Fisheries Research Institute, Cochin) for suggesting the research problem, for inspiring guidance and constant encouragement throughout the course of this investigation.

I am much obliged to Dr. S.Z. Qasim and Dr. E.G. Silas (former Directors of Central Marine Fisheries Research Institute, Cochin) who were kind enough to provide me necessary facilities to carry out the productivity studies in the inshore waters. I record my gratitude to Dr. S.Z. Qasim who inspired me to take up the work on fractionate productivity and also the nutrient utilization by cultivated species of algae.

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CONTENTS

PREFACE

The candidate started his research work connected with phytoplankton in the Marine Biology Division of the Central Marine Fisheries Research Institute in 1964 and since then he has been engaged in the different facets of phytoplankton investigation. During the initial period he was actively engaged in the collection and enumeration of inshore phytoplankton as a part of the major programme of phytoplankton investigations of the inshore environment on the south east and southwest coasts of India. This enabled him to familiarise with the taxonomic aspects of all the major groups of phytoplankton namely diatoms, dinoflagellates, silicoflagellates, cocolithophores and other nanoplankters.

While undertaking a study of phytoplankton productivity of the above environments using the radioactive carbon technique, the problem of a suitable standardisation technique arose. Then existing technique was by extrapolation of samples under different thickness to zero thickness. But this method was found to be inadequate and there arose the necessity of developing a more convenient and accurate method of standardisation. The biological standardisation technique developed by Prof. Steemann Nielson in the Botany Department of Danish Pharmaceutical School provided the answer to this difficult problem. But this required the development of a suitable culture of a unicellular alga that could grow fast and photosynthesise in a lower pH than the medium in which it was growing. The candidate thus got engaged in the development of algal planktons in axenic cultures after isolating from estuarine and marine environments. Two strains of Chlorella, --- Chlorella vulgaris and Chlorella pyrenoidosa obtained from Danish school of Pharmacy were also continuously grown for the experimental work. The candidate was able to successfully

isolate Tetraselmis gracilis, a green flagellate belonging to Prasinophyceae, from inshore plankton. It was then felt that it would be worthwhile studying its growth pattern in order to have an understanding of the different phases and the suitable period for taking a viable harvest. Further studies on nutrient requirement and photosythetic behaviour were conducted with this culture. Subsequently a few more species were isolated when the candidate had to move over to Cochin University to take up a teaching cum research assignment. So the earlier part of the work was carried out in the Central Marine Fisheries Research Institute at Mandapam and Cochin. As an associate researcher in the project on plankton investigation at the University, the candidate had to teach the discipline of planktonology and the latter aspects of the work hence were carried out in the laboratory of the Department of Marine Sciences, University of Cochin.

The studies on estuarine and coastal algal planktons were also initiated at CMFRI and were continued in the University. The thesis thus embodies the results of research work carried out for a prolonged period.

The candidate carried out some investigation under Dr.S.Z. Qasim, presently Secretary of Department of Ocean Development, on the relative contribution of various size fractions of planktonic algae in the estuarine and coastal environments. This study reveals that a significant portion of the contribution of primary production is by nanoplankton. Hence the candidate undertook a detailed analysis of the floristic composition and their size groups along with their chlorophyll value and primary production measurements both in the estuarine and coastal environments. Such an aspect of study has never been attempted before in this region. The analysis of the data yielded some very

interesting observationswhich have been discussed in the main body of the thesis under a chapter 'Floristic size spectrum with special reference to nanoplankton and their contribution to productivity'. This aspect is of considerable significance in the larval recruitment of the major fisheries of this region as the larvae at the time of hatching and during its initial critical phase of growth require suitable size group of algal plankton in sufficient concentration for their survival. In a multi-specific fishery as in tropical waters with prolonged spawning periods the distribution of the size fraction is of considerable significance in fishery as it will enable the prediction of the larval survival and recruitment depending on the specific period of spawning along with the availability of the relative size group of algal plankton.

As this work formed the part of the teaching and research programme at the University I have taken the help and co-operation of a number of colleagues and students whose contribution I would like to acknowledge gratefully.

INTRODUCTION

The present study is concentrated on a composite group of algae of phytoplankton. The algae in the aquatic environment are the most important of all chlorophyll bearing life on earth on which considerable attention is being given on account of their supreme status in the aquatic food chain. Though the higher plants serve as the major primary producers in the terrestrial biocycle, the primary producers in the aquatic ecosystem especially in the marine environment assume unparalleled significance because of their contribution to the high magnitude of production generating the fishery resources.

The steady increase in world population and the consequent shortage of food on the land, demand the exploration of less exploited but potentially productive regions. Our attention is directed to the sea for more exploitation to meet our increasing food requirements. During the past thirty years with the advances in technology, man has chosen correctly algae as an alternate source of food to feed the millions from the biggest store house of nature - the sea.

Though the higher algae and certain flowering plants have dominant role in the production of organic matter in the shallow rocky regions, the minute algae are the major primary producers in the marine and estuarine environments. These microscopic plants found suspended in the aquatic environment without mobility or with very little mobility are the primary producers in the aquatic ecosystem and are called the phytoplankton. Their significance is revealed from the fact that the amount of photosynthesis going on in these algae is many times greater than the total production of all other types of vegetation in the aquatic ecosystem. By the term primary production in the marine environment we usually mean primary production due to algal plankton unless otherwise specified. These algal plankters are usually distributed within

the photosynthetic zone ie. down to a maximum depth of about 120m. Their rare occurrence below this zone is due to sinking when they no longer actively photosynthesise.

The algal plankers are of different size groups and are mainly classified on that basis into ultraplankton, nanoplankton and microplankton which come within the size range of less than 5 μ to about 0.5mm. There are still bigger forms of phytoplankton (0.5mm to 1mm) which are included in the group microplankton to which small zooplanktons are also included. The phytoplankton includes the following three major algal components. They are Bacillariophyceae, Pyrrophyceae and Cyanophyceae, besides a few other classes such as Chlorophyceae, Prasinophyceae, Chrysophyceae, Haptophyceae, Craspedophyceae, Cryptophyceae and Euglenophyceae are also included under phytoplankton (Raymont, 1980).

The thesis is mainly centered around the various aspects of the major components of algal plankters. The significance of the study of algal plankters (phytoplankton) and historical resume are given under the title Introduction. The physico-chemical parameters of the environments that influence the growth and distribution of these flora are described in Chapter I under the title Environmental features.

Chapter II, on material and methods contains the methodology of collection and experimental techniques. Chapter III, is on spectrum of the estuarine planktonic algae and deals with the inter- and intraspecific quantitative analysis of thirtyone species of planktonic algae belonging to the classes Bacillariophyceae, Cyanophyceae, Pyrrophyceae, Chlorophyceae and Prasinophyceae.

Chapter IV deals with the floristic composition of planktonic algae in the nearshore waters. The inter- and intraspecific quantitative analysis of 26 species of algal plankters belonging to the taxonomic classes Bacillariophyceae, Cyanophyceae, Pyrrophyceae and Prasinophyceae are described.

Chapter V describes the temporal and spatial variation of microplankters and chlorophyll in Cochin estuary and Chapter VI on primary production deals with seasonal and spatial variation of the productivity of the estuarine ecosystem extending from Alleppey to Azhikode.

Chapter VII, on productivity in polluted waters projects the impact of industrial effluents on productivity near the industrial belt at Alwaye in the Periyar river tributary and adjacent Cochin estuary.

Chapter VIII is on cultivation of planktonic algae and deals with the growth characteristics of Tetraselmis gracilis and its growth constant and generation time under varying concentration of nutrients. This chapter also discusses the growth constant and generation time of Thalassiosira subtilis and Synechocystis salina with special reference to the impact of trace elements on the latter species. Summary of the work forms the ninth chapter, followed by the list of references and also an appendix.

Thus this thesis embodies the results of investigations on various aspects of planktonic algae carried out for a prolonged period in an estuarine and near-shore environments.

Historical resume

In the Indian Ocean, prior to the International Indian Ocean Expedition (IIOE) (1962-65), DANA (1928-30), JOHN MURRAY (1933-34), DISCOVERY

(1934) and ALBATROSS (1947-48) Expeditions tried to evaluate the productivity from the nutrients and the standing crop of plankton. Gilson (1937) used the nitrate data of JOHN MURRAY Expedition to estimate the organic production in the Arabian Sea in wet weight of algae. During the GALATHEA Expedition, primary production was measured by 14_C technique in the western Indian Ocean along the coast of Africa, equatorial part of the Indian Ocean along the coast of Africa, equatorial part of the Indian Ocean in a section from Mombassa to Sri Lanka, Bay of Bengal and the Indo-Malayan waters (Steemann Nielson, 1952; 1954; Steemann Nielsen and Jensen, 1957). These studies revealed that, in general, the phytoplankton production in the shallow coastal regions of the tropics is high. It was also observed that in oligotrophic regions, where there was considerable addition of 'new water' with high nutrients in the photosynthetic zone, the daily production is very high.

During the last two decades there has been considerable progress in the study of primary production in the Indian Ocean and environmental phenomena that regulate it. In connection with the IIOE, between 1959 and 1965, a large number of ships belonging to several countries carried out investigations in the Indian Ocean. The Arabian Sea and under the Australian programme, the 110°E longitude section were well studied (Ryther et al. 1966; Jitts, 1969). After extensive measurements of primary production on board the ANTON BRUUN, Ryther et al. (1966) showed that the western Indian Ocean is one of the most productive regions in the world. Some of the highest values ever recorded in the marine environment, excepting those from coral reefs and seagrass beds, were observed in the northern Arabian Sea off the Arabian

peninsula. The observations in the western half of the Arabian Sea are summarised by Wooster et al. (1967).

A large number of phytoplankton productivity measurements were made on board R.V.VITYAZ which have been reported by Kabanova (1961, 1964, 1968), Zernova (1962), Sukhanova (1964) and Zernova and Ivanov (1964). In the eastern Indian Ocean, Wood (1966) found the horizontal distribution of phytoplankton related to land mass and upwelling. Besides, Burchall (1968) in the Agulhas Current region, Mitchell-Innes (1967) off South Africa, Jitts (1965) in the Australian waters and Humphrey (1966) from the eastern Indian Ocean have presented the results of their measurements. Krey (1973) has given an account of the distribution of chlorophyll and a potential assimilation in the Indian Ocean and Aruga (1973) has reviewed the relation of primary production in the Indian Ocean to chlorophyll and other environmental factors. As part of the U.S. Antarctic Programme, El-Syed and Jitts (1973) studied the primary production and standing stock of plankton in the southeastern Indian Ocean. Recently Trevor Platt (1986) studied the primary production of the ocean water column as a function of surface light intensity. Topliss and Platt (1986) studied the relationship between the passive fluorescence andphotosynthesis in the ocean.

Estimates of primary production in the different ecological zones of the Indian Ocean were presented by Moiseev (1969). Prasad et al. (1970) made a quantitative assessment of the primary production in relation to the potential fishery resources of the Indian Ocean and Cushing (1971) for the upwelling areas. Qasim (1976) reviewed the different aspects of the biological productivity of the Indian Ocean. In addition to such direct measurements of primary production, reports on phytoplankton pigments of the Indian Ocean by Ichimura

and Fukushima (1963), Laird et al. (1964), McGill and Lawson (1966), Humphrey and Kerr (1969) provide a sound basis for the estimation of productivity in the Indian Ocean. Krey and Babenerd (1976) compiled all the phytoplankton productivity information from the Indian Ocean in the form of an Atlas.

Several studies have been made in the coastal and offshore regions of the Indian Seas. Subrahmanyan (1959 a,b) measured the standing crop of phytoplankton by various methods and came to the conclusion that the production on the west coast of India is of a high order comparable to some of the most productive areas in the temperate regions. Prasad and Nair (1960, 1963) made a study of the seasonal variation and magnitude of production in the Gulf of Mannar on the south-east coast of India. The results of investigations carried out along the shelf regions of Indian seas and the Lakshadweep Sea were discussed in relation to the potential living resources by Nair et al. (1968) and Nair (1970, 1974). Radhakrishna (1969) made a study of the primary productivity in the shelf waters off Alleppey on the south west coast of India during the post monsoon period and Shah (1973) presented the seasonal variation of phytoplankton pigments in the Lakshadweep Sea off Cochin.

Further, Qasim et al. (1978) have discussed the biological productivity of the coastal waters of India upto 50m depth and stated that the larger phytoplankton organisms contributed greater spatial variation in primary production than the smaller forms (nanoplankton). Radhakrishna (1978) and Radhakrishna et al. (1978a) studied quantitatively some aspects of phytoplankton productivity from the coastal areas of east coast including some stations in the Bay of Bengal. Similarly Radhakrishna et al. (1978 b & c) studied primary productivity, chlorophyll a and related parameters from the shelf and oceanic regions

in the north-eastern Arabian Sea and northern Arabian Sea. Besides, the productivity of coral reefs (Nair and Pillai, 1972; Qasim et al. 1972), of sea-grass beds (Qasim and Bhattathiri, 1971) and liberation of particulate organic matter by coral reefs on an atoll (Qasim and Sankaranarayanan 1970) and the relation between nitrogenous nutrients and primary production in Lakshadweep waters (Wafar et al. 1986) have also been investigated.

Studies on the biology and ecology of the phytoplankton of the various estuarine systems of India have not received as much attention as those from the marine environment. The pioneering work on the ecology and seasonal succession of the diatom flora of the estuarine waters of India was that of Iyengar and Venkataraman (1951) for the Cooum estuary in Madras. Since then biological investigations were carried out by various authors on the planktonic algae of Chilka Lake (Roy, 1954; Devasundaram and Roy, 1954; Patnaik, 1973) and in the Hooghly estuary (Dutta et al. 1954; Roy 1949, 1955; Shetty et al. 1961; Gopalakrishnan, 1971). Seshadri (1957) studied the seasonal organic production in relation to environmental features in Zuari and Mandovi estuaries. Krishnamurty (1971) and Krishnamurty and Sundararaj (1973) studied the phytoplankton pigments in Porto Novo waters. Krishnamurty and Purushothaman (1971) studied the diurnal variations in phytoplankton pigments in the Vellar estuary. Krishnamurty and Santhanam (1974) and Santhanam et al. (1975) gave a descriptive account of the species distribution and quantitative ecology of phytoplankton of the same region. Mani et al. (1986) described the ecology of phytoplankton blooms in the Vellar estuary.

The Cochin Backwaters have been studied intensively for plant pigments (Qasim and Reddy, 1967), light penetration (Qasim et al. 1968), tidal amplitude

(Qasim and Gopinathan, 1969), organic production (Qasim et al. 1969), nutrient cycle (Sankaranarayanan and Qasim, 1969), salinity tolerance of phytoplankton (Qasim et al. 1972), seasonal abundance of phytoplankton (Gopinathan, 1972), spatial and temporal distribution of phytoplankton (Gopinathan et al. 1974) Joseph et al. 1975) contribution of nanoplankton (Qasim et al. 1974; Vijayaraghavan et al. 1974) plankton production (Pillai et al. 1975) and on primary productivity of the entire estuarine system (Nair et al. 1975). Recently Sankaranarayanan et al. (1986) studied the estuarine characteristics of the lower reaches of the River Periyar (Cochin estuary). The results of the investigations discussed in the following pages provide a complementary account to the existing knowledge on these ecosystems. For detailed discussion marine inshore regions, special ecosystem (Polluted waters) and cultivation of algal plankton have been dealt with in the same sequence.

CHAPTER I

ENVIRONMENTAL FEATURES

Knowledge of the hydrographic features prevailing in the region of study is essential for a clear understanding of the pattern and magnitude of primary producers. The major factors are temperature salinity, nutrients, dissolved oxygen and pH which are influenced to a great extent by seasonal changes. To understand these fluctuations, the extent of seasons must be known. In India seasons are determined by the monsoons and accordingly four seasons are recognised. They are (1) south west monsoon season extending from May/ June to September, (2) a post-monsoon season, which is the short transition period starting from end of September and including the whole October and is warm, steamy and dry (3) north east monsoon season, which is more prominent on the east coast, starting later in the southern parts, where it flourishes only in December and continues till March and (4) pre-monsoon season, which is a warm dry season prevailing during March-April. Weather is calm during this time; but by the month of May conditions again become unsettled heralding the onset of south west-monsoon. In this region under investigation as the effect of north east monsoon is negligible the hydrobiological parameters were classified and discussed on the basis of three seasons premonsoon, monsoon and post monsoon. The hydrographical parameters vary according to the seasons and the collective impact of all the parameters is much more important than that of individual ones.

Temperature (Fig. 2)

Temperature is an important factor determining the geographical distribution of certain algae. There seems to be significantly different temperature optima for different species of the same genus. Growth rate, cell

growth and various metabolic processes are affected by the drastic changes in temperature. However in the tropical estuaries, in general, the temperature being within the limits of tolerance throughout the year, its effect on phytoplankton and primary production is not significant and does not form a limiting factor. This has been the case of all the major estuaries along the Indian coast, especially the Cochin backwaters. The temperature values for the entire period of observation reflect to a certain extent the climatic variations.

Seasonal values of temperature for the 7 stations* are given below: (* Fig.1)

Temperature (^{o}C)

Station	Pre monsoon	Monsoon	Post monsoon
I	32.43	28.85	29.9
II	32.53	29.70	31.0
III	30.81	29.08	30.25
IV	31.85	29.98	30.10
V	29.82	28.15	28.60
VI	30.10	27.13	28.58
VII	29.88	27.50	27.93

During the monsoon period there was a decrease in both surface and bottom temperature in the entire area. The fluctuation in the surface temperature during this period is highly significant. Sankaranarayanan and Qasim (1969) stated that the influx of fresh water into the estuarine system is not the sole factor in bringing down the water temperature in the estuary but the influx of cold water from the sea may also be a significant factor.

Light

Solar radiation provides the energy necessary for photosynthesis - the process by which green plants convert light energy into chemical energy. Out of all the electromagnetic radiation falling on photosynthesizing plants only the visible light (wave length range 400 to 720 n m) is absorbed and used for photosynthesis. The amount of solar energy reaching the water surface is one of the most important factors affecting the distribution and production of algal plankters. This solar energy available to these flora depends on the altitude of the sun and changing weather conditions. Growth of algal plankters occurs only when photosynthesis exceeds respiration. The depth at which the two processes proceed at the same rate is called "compensation depth", which is a function of the incident radiation and transparency of the water. In the estuaries, transparency is variable. In Cochin backwaters light is not a limiting factor for floral distribution and production. The opaque nature of water due to high turbidity reduces light penetration. During monsoon, the under water illumination is reduced to 20% of the total incident radiation within 1m depth and to 1% at 3m depth. Likewise, during post-monsoon and pre-monsoon, the reduction in light is about 30% at 1m depth and 1% at a 4m depth (Qasim et al 1968).

Salinity (Fig. 2)

Salinity distribution in the estuary is a result of the combined action of water movements induced by the fresh water discharge, tidal variation and mixing processes. In the estuarine system salinity plays a dominant role in the succession of algal flora. In an estuary, salinity is perhaps the greatest limiting factor and it exerts profound influence on the algal composition as revealed by the present analysis. The salinity variations clearlyindicate a bimodal fluctuation in all the stations. The effect of monsoon can be easily seen from the decreasing

salinity gradients in the entire backwater area during June to August. During the months of February - April, the salinity distribution appears to be very stable, but in the other months especially during post-monsoon period (October to January) there is a lot of stability probably due to the mixing process continuing in the vertical profile. Invariably, the salinity pattern in the northern half was of a higher magnitude, may be due to the proximity to the sea and also the effect of two natural passages at Cochin and Azhikode. The fluctuation in salinity was of a higher magnitude at the southern-most station which is the farthest station from the passage to the sea, the salinity ranged from 0.2‰ during June - July to 19.7‰ and almost same magnitude in November. The average value of seasonal variations of salinity for the entire estuary is shown below:

Seasonal changes of salinity are shown below:

Salinity (‰)

Station	Pre-monsoon	Monsoon	Post-monsoon
I	13.73	1.65	13.25
II	19.68	1.33	13.40
III	21.40	0.83	10.83
IV	27.30	1.35	15.35
V	29.63	6.18	17.98
VI	30.10	0.73	15.35
VII	31.90	5.78	19.70

Dissolved Oxygen (Fig. 4)

Dissolved Oxygen showed a distinct pattern of seasonal fluctuations in the entire estuarine system. Comparatively high values were found during monsoon

season. Haridas et al. (1973) also observed the same type of phenomena in the same area during the monsoon season. According to Qasim et al. (1969) the higher oxygen concentration during this period can be due to the higher production occuring in the surface layers during monsoon season. The lowest value of 1.10 ml/l dissolved oxygen was recorded at station VI during April and the highest value of 5.9 ml/l at station I in June. In general, the higher values were recorded during monsoon period, the lowest during pre-monsoon season. The post-monsoon period appeared to be more stable with relatively lesser variations.

Dissolved Oxygen (ml/l)

Station	Pre-monsoon	Monsoon	Post-monsoon
I	3.23	4.88	3.13
II	2.38	4.28	2.93
III	2.78	4.45	2.93
IV	3.00	3.68	2.68
V	2.75	3.28	2.95
VI	1.90	2.95	2.43
VII	4.58	4.08	3.83

Inorganic Phosphate (Fig. 3)

Inorganic phosphate distribution showed a distinct bimodal fluctuation in almost all stations with one peak during June-July and the other during November-December. In station III even during monsoon period the values were only moderate. Very high value of 32 µg at/l was recorded in this station during the month of June. In the Cochin backwater, Sankaranarayanan and Qasim (1969) observed three peaks, one towards May and June when the first pre-monsoon

showers set in. Phosphate values decline sharply after the peak and another peak appears in August-September. A third peak appears in October which does not coincide with the preponderence of rainfall. However, a peculiar feature observed in the present investigation is the unusually large amount of PO_4-P as compared to earlier study. The maximum value observed by Sankaranarayanan and Qasim (1969) has been around 2 to 2.5 µg at/l while values exceeding 15 µg at/l have been observed very commonly during monsoon and pre-monsoon period. The highest value of even 32 µg at PO_4-P/l was recorded at station V during June indicating a level of eutrophication.

PO_4-P changes at various station in three seasons are given below:

PO_4-P µg at/l

Station	Pre-monsoon	Monsoon	Post-monsoon
I	0.31	1.63	4.03
II	0.48	6.33	3.54
III	0.31	0.56	4.56
IV	1.93	6.80	1.73
V	2.65	-	6.65
VI	2.60	6.56	7.03
VII	1.00	2.93	0.93

Nitrite - nitrogen (Fig. 3)

The Nitrite-nitrogen values are very low in most of the periods except at one or two stations in the pre-monsoon. The NO_2-N values do not seem to be affected by the fresh water discharge. Most of the values are within 1 µg at/l

except at a few stations during the pre-monsoon period. Sankaranarayanan and Qasim (1969) have observed a trimodal cycle with a peak occuring during a period when the system remains fresh water-dominated. They observed that NO_3-N occurs in very high concentrations during the monsoon period especially in the surface waters. According to them the NO_2-N may be formed as a result of decomposition of organic nitrogen and as it is a transistory stage in the nitrogen cycle and its progressive decrease from the surface to the bottom suggests its possible conversion into NO_3-N.

Variation in NO_2-N at various stations in three seasons are given below:

NO_2-N µg at/l

Station	Pre-monsoon	Monsoon	Post-monsoon
I	0.15	0.25	0.29
II	0.14	0.21	0.20
III	0.39	0.22	0.29
IV	0.48	0.70	0.61
V	0.46	0.72	0.43
VI	2.55	0.89	0.19
VII	0.41	0.23	0.13

Hydrogen ion concentration

Hydrogen ion concentration (pH) oscillated between acidic range of 5.65 to alkaline range of 8.1. Seasonal and spatial variation observed in pH values had profound influence in the distribution of algal plankton and primary production.

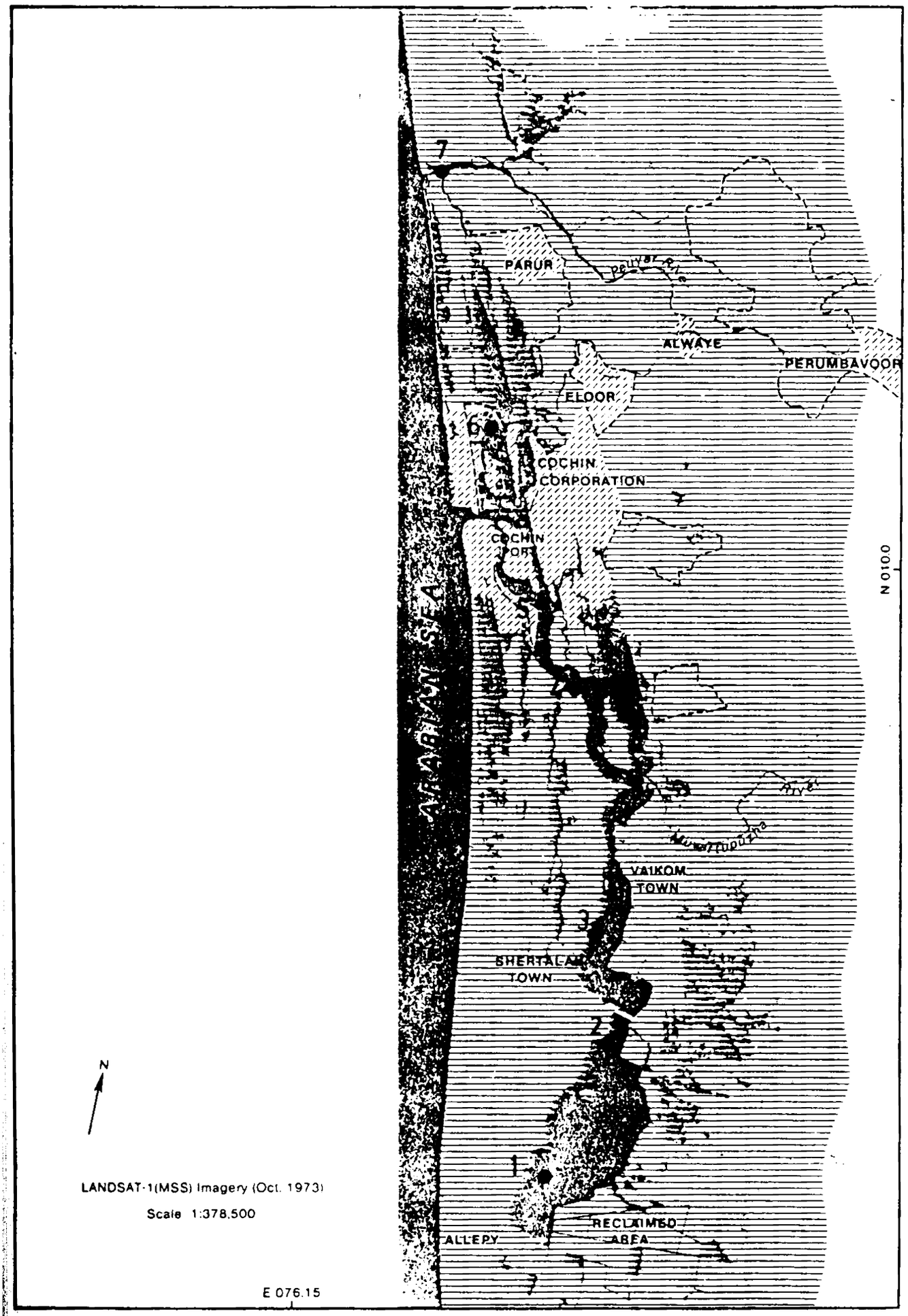

FIG.1. SITES OF INVESTIGATION

CHAPTER II

MATERIAL AND METHODS

1. Sampling of water analysis

For the study of algal plankton and primary organic production water samples were collected from both estuarine and marine environment using non-metallic water sampler. Surface samples were collected carefully without any large particulate organic matter and filamentous algae Water samples from various depths within the photic zone were collected using 'VAN DORN' (Schwoerbel's type) sampler of 1 litre capacity.

2. Algal plankton - Collection and numerical estimation

Larger algal plankters (60 μ of dimensions) were collected using net made of bolting nylon (No.25, mesh size 60 μ). These were counted using Sedgwick - Rafter cell. Total algal plankton of different size groups were collected by sedimentation technique. Here a unit volume (100 ml.) of sample settled after adding 1 ml. of Lugol's iodine in special settling chamber for a minimum period of 24 hours. One ml. of the settled sample was counted after identification of the organisms. The organisms were counted using Sedgwick-Rafter cell and haemocytometer.

3. Measurement of hydrographic parameters

Temperature

Temperature was measured immediately after collection of the water sample with an accuracy of $\pm$ 0.1^{o}C using precision mercury thermometer.

Transparency of estuarine and sea water was measured with a Secchi disc. Secchi disc transparency was then counted with extinction coefficient (Qasim et al. 1968) Total irradiance in marine environment was also measured using Tinsley Irradiance meter.

The light penetration and depth of the euphotic zone were studied using a Tinsley Irradiance Meter. It consists of a deck cell mounted on gimbals and a sea cell mounted in a bridle, a galvanometer and ratiometer which measures directly the ratio of the light intensities falling. And both the deck cell and sea cell are fitted with Megatron photocell and chance filters OB_2 blue/green which are red free. Opal flashed glass placed over the filters diffuse the light falling on the cells and as these are flush with the rim of the deck cell it can receive full 180^{O} of solid angle light.

The sea cell is lowered & the readings are taken at depths of every meter marked on the cable. The depth is then determined by the amount of Sea cell cable paid out both 'down readings' and 'up readings' are taken. Extinction coefficients are determined by plotting the logarithms of percentage transmission against the depth and also by using the formula:

$$P_5 = \frac{2.3\ (\log rO - \log r\ 10)}{10}$$

where P_5 is the extinction coefficient at 5 m depth, r0 is the transmission ratio at the surface i.e. the ratiometer readings, r 10 transmission ratio at 10 m and so on (Gall, 1949).

Water samples were analysed for hydrological properties. Determination of salinity, oxygen and nutrients such as nitrite, nitrate, phosphate and silicate were made according to Strickland and Parsons (1968) as follows:

Salinity

Salinity was estimated by Mohr-Knudsen method.

Nitrite (NO_2-N)

The determination of nitrite in sea water was by Bendschneider and Robinson (1952) method.

Nitrate

This method is based on the reduction of nitrate to nitrite and its subsequent photometric estimation (Morris and Riley, 1963; Grasshoff, 1964)

Reactive Phosphate (PO_4-P)

Reactive phosphate in water was measured photometrically according to the method of Murphy and Riley, 1962.

Reactive silicate (SiO_4-Si)

The method is based on the formation of silicomolybdate complex, when seawater is treated with ammonium molybdate in acid medium and its subsequent reaction to molybdenum blue using ascorbic acid as reductant (Koroleff)

Algal Pigment

Strickland and Parsons (1972) method was employed for the determination of pigments. According to this method the algal pigments present in an aliquot (500 ml) of sea water were separated by filtering through a Whatman GF/C glass fibre filter. This filter then was extracted with 10 ml of 90% acetone, and kept in a refrigerator for 24 hours. The absorbance of the clear acetonic extract was measured photometrically using 5 cm cells against 90% acetone as blank at different wavelengths (750, 665, 645, 630, and 450 n m). Concentration of various pigments (Chlorophyll and carotenoids) were then calculated using Strickland and Parsons equation.

Primary Productivity

Light and dark bottle oxygen technique (Gaarder and Gran 1927) has been employed for comparing the values with C^{14} values in culture experiments.

The difference in oxygen concentration between the light and dark bottles was converted into its carbon equivalents using a PQ of 1.25 for obtaining gross production values. The difference between the initial and dark bottle was taken as the respiration of the algal plankton and that between the light bottle and the initial was taken as the net production (Steemann Nielsen and Hansen, 1959).

In the estuarine, inshore and marine environment, primary productivity which is a measure of the uptake of carbondioxide by algal plankters was measured by C^{14} technique introduced by Steemann Nielsen (1952, 1954, 1964 1965) and as described by Strickland and Parsons (1972). A clean stoppered BOD bottle (60 ml reagent bottle for inshore and 300 ml for offshore water) was filled with the water sample and then innoculated with 1 ml of sodium bicarbonate solution in which the Carbon is labelled with C^{14} (5μ c). These samples were incubated under natural or artificial constant light (20 k lux) for 2 hrs. in experiments with laboratory cultures of algae and for a period of 6 hrs in experiments with estuarine and inshore and marine waters. Dark uptake also was determined simultaneously. (Corrections were applied for the efficiency of the counting system and for the slower uptake of $C^{14}O_2$ when compared with $C^{12}O_2$).

The samples were filtered through millipore membrane (0.45 μm) filter using a manifold filtering unit under suction. The filters were dried over silica gel and exposed to HCl fumes before counting. The activity of the filters were determined using a Geiger counting System. The production rate per unit volume was calculated by the corrected counts of the filtered samples as fraction of the added activity and multiplying with the total CO_2 content

of the water. In oceanic water it was assumed as 90 mg/l. For the inshore and estuarine environment it was calculated from the alkalinity and pH as described in Strickland and Parsons (1972) For determination of added activity the standardization procedure is given below.

Column production was calculated from in situ and simulated in situ experiments by integration of the different rates at various depths using the formula of Dyson et al (1965).

$$\text{Column production} = \frac{f}{1000}\,\frac{(a+b)}{(2)}\,(d1 - d0) + \frac{(b+c)}{2}\,(d2-d1) + \ldots.$$

where d0, d1, d2 are the depths samples: a, b, c are the respective production rates in $mgC/m^3/day$;

f, a factor (1 for in situ and simulated in situ experiment) In samples incubated under constant light the empirical formula given by Steemann Nielsen and Aabye Jensen (1957) was applied to get the column production. In shallow waters, the values for the best depth (where maximum values are recorded) were multiplied by the actual depth, if it is less than the depth of the euphotic zone and half the product if it is more (Steemann Nielsen and Aabye Jensen, loc. cit).

Standardization C^{14} Ampoules

In the measurements of primary production by C^{14} technique and the composition of values obtained by the different workers the C^{14} ampoules are to be standardized. The ampoules made at Babha Atomic Research Centre, Trombay were standardized by two different methods, (Prasad et al. 1964, Nair, 1966, and Nair and Joseph, 1975).

By the extrapolation of self absorption curves

Jitts and Scott (1961)

Planchets of $BaCO_3$ varying from 0.5 to 6.0 mg/cm^2 each containing the same amount of C^{14} activity were prepared in duplicate from the ampoules of each stock solutions. Each ampoule was diluted to 500 ml with a solution containing 1.36 g of Na_2CO_3 per litre of Carbon dioxide-free distilled water. 0.5 ml aliquots of the diluted C^{14} solution were pipetted into seven conical flasks treated with "Desikote" and containing, 0, 0.5, 1.5, 2.5, 3.5, 4.5 and 5.5 ml respectively of the same Na_2CO_3 solution used in diluting the ampoules To these flasks 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 ml of 6.26% $BaCl_2$ were then added.

The precipitate of $BaCO_3$ thus formed were allowed to stand for two hours with gentle swirling for every half hour. Planchets were prepared with each of these precipitates by their total transfer to Millipore H A filter mounted on manifold filtering unit. The effective filtering area was 2.5 cm^2. The planchets were dried over silica gel for 24 hours, weighed and counted. From the thickness of the filters (mg/cm^2) and the activity (cpm). The activity at zero thickness was extrapolated the value obtained from duplicate samples being 4.253 x 10^6 cpm and 4.376 x 10^6 cpm.

Biological method (Steemann Nielsen, 1965)

Cultures of Chlorella pyrenoidosa and Chlorella vulgaris obtained from the Botany Laboratory, Royal Danish School of Pharmacy, Copenhagen were grown in Osterlind's medium. In a series of experiments with different stock solution consistent results were obtained. By this method the first stock of ampoules gave an average activity of 6.32 x 10^6 cpm and the next stock gave an average activity of 7.27 x 10^6 cpm.

Liquid Scintillation counting method (Jitts and Scott, 1961)

The absolute activities (dpm) of the C^{14} stock solutions were determined by liquid scintillation counting.

Stock 1 gave 11.4×10^6 dpm

Stock 2 gave 11.2×10^6 dpm

The zero thickness counting efficiency of the gas flow counter was determined by counting thin films of C^{14} labelled plastic mounted on membrane filters. The absolute activities of these filters were determined in the liquid scintillation counting system. The activity of the stock solutions was obtained by multiplying the absolute activity with the counter efficiency, the values then obtained for two stock solution being 6.96×10^6 cpm for first stock and 6.90×10^6 cpm for the second stock.

A very close agreement is observed for the biological method and the liquid scintillation method and activity obtained by either the scintillation method or the biological method was followed for all the calculation.

Productivity of different size groups of algal plankton

The contribution of the nanoplankton to the productivity of total planktonic algae was studied for nine months in coastal waters of Cochin. Surface water samples were collected from a fixed station in the coastal waters near Manassery, a fish landing centre north of Cochin. Five litres of water were filtered through No.25 botting silk (openings of 60 μ) The water that passed through the net includes only nanoplankton. This fraction was taken for the measurement of productivity, chlorophyll a concentration and cell numbers. Besides the unfiltered water sample representing the total algae was also taken

for the study of the above parameters. Productivity was measured by C^{14} technique introduced by Steemann Nielsen (1952, 1954, 1964) and as described by Strickland and Parsons (1972). Chlorophyll a was estimated using the method of Strickland and Parsons (1972) and the enumeration of cells with Utermohl's inverted microscope (Utermohl 1958).

Productivity, chlorophyll a concentration and numerical estimation of four size groups of algal plankton were studied from the Cochin estuary. Surface water samples were collected at fortnightly intervals for a period of one year from a fixed station in the Cochin estuary. Five litres of water was filtered through bolting nylon nets having a pore size of 99 µm, 75 µm and 59 µm respectively. The organisms retained by each grade of bolting nylon were rinsed with millipore filtered estuarine water and collected in measuring glasses of 500 ml capacity, each sample was made upto 500 ml for the estimation of productivity, chlorophyll a and cell numbers. The water which had passed through 60 µm pore size bolting nylon was also used for the estimation of the above 3 parameters. Thus the productivity, chlorophyll a concentration and cell numbers of planktonic algae of all size groups, algae smaller than 60 µm (SG. 1) 60 to 75 µm (SG 2) 76 and 99 µm (SG.3) and larger than 99 µm (SG.4) were studied. Productivity . chlorophyll 'a' concentration and cell counts were studied by methods already described.

Numerical estimation of planktonic algae with Utermohl's inverted microscope (Utermohl 1958)

25 ml of the sample is poured into the sedimentation chamber. 10 drops Lugol solution were added and after a sedimentation time of 20 hours the enumeration of cells were carried out in two stages. First the large forms in the whole bottom area of the chamber were counted under low magnification.

The total number of cells was found by multiplying the number of individuals, counted in the transects with the ratio of the whole chamber area to the area of the observed transects.

SPECIES DIVERSITY

In some phyplankton populations (e.g. during a bloom) a very few diatom or dinoflagellate species may be overwhelmingly common, in other populations a large number of species may occur without clear dominance. These latter populations are said to have a high species diversity, in contrast to low diversity populations where there are a few dominant species. While a number of parameters might be used to express the diversity of a plankton community species composition is most usually considered. A simple method of expressing diversity is to determine the percentage composition of species in a sample. The total number of individuals, however, greatly influences the value determined. An improved index of diversity employed here is

$$d = \frac{S - 1}{\log 10^{N}}$$

where S = number of species in the population

N = number of individuals in the population

(Raymont, 1980)

Algal Culture

The following algal plankters isolated from both marine and estuarine environments are used for productivity and growth kinetic studies.

a. Marine:

1. Tetraselmis gracilis
2. Synechocystis salina

b. Estuarine:

1. Thalassiosira subtilis

The marine flora were collected from the inshore waters of Cochin; Tetraselmis gracilis from coastal water near Manassery (salinity 35.1‰) - a fish landing station southwest-coast of Cochin, Synechocystis salina from the bar-mouth at Cochin (Salinity 33.8‰ ` The estuarine form Thalassiosira subtilis was collected from very near CMFRI fish farm at Narakkal near Vypeen island (salinity 22.3‰ .

Collection and isolation of the flora

All the four flora were isolated from one litre each of water samples collected from a few centimeter below the surface from the various environments using Van Dorn samples. 250 ml. each of the sample was centrifuged and the plankters separated and centrifuged. All the samples were of composite mixture of different species of plankters. From these the plankters to be isolated were chosen based on classes and dominance. 10 litre each of the water were filtered, heated and kept ready for the preparation of media.

10 ml. each of water sample was added to 500 ml. of the respective filtered water taken in four clean sterilised one litre capacity conical flasks enriched with 0.3 ml of solution A and 0.25 ml of solution B. The flasks were plugged with sterilised cotton and exposed to natural light.

The marine forms showed sign of growth from fifth day onwards as indicated by the slight colour change. The sample was examined and the dominant flora was Tetraselmis gracilis. The aggregated green patches mainly of this particular flagellate was pipetted out and transferred to fresh culture media. After a week again examined under microscope, pipetted out the green patches and recultured. These green flagellates exhibited phototactic movements and hence they were aggregated towards the place of incidence of light. Since the sample contained only one phototactic species they could be isolated exploiting the phototactic property of these algae. Thus by repeating the process of pipetting and reculturing for six weeks unialgal cultures of Tetraselmis gracilis could be isolated.

The second flask in which the dominant flora was Synechocystis salina showed overall blue green colouration with brown patches at the bottom consisting of diatom such as Navicula. Carefully pipetted out 5 ml. of the blue green algae and recultured. Weekly observation, pipetting and subculturing were repeated for a month. Still the sample contained a few diatom cells. Finally the species was isolated by serial dilution method on the sixth week.

The estuarine form Thalassiosira subtilis was isolated in 5 weeks, by pipetting, subculturing and serial dilution methods.

Standard microbiological methods (Pringsheim 1949) were used for the isolation and maintenance of various species of algae. Tetraselmis gracilis was isolated both by the serial dilution of sample and by exploiting the phototactic property of the algae. All the other species were isolated by patching up the particular coloured patches and by serial dilution.

Culture media:

1. Miquel's medium modified by Ketchum and Redfield (1938)
2. Takano medium (1963)

Advantages of the medium:

As the aim of this part of investigation is to study the probable factors for the fluctuations of algal flora and productivity in the natural environment and to suggest the relevant methods by which the production can be enhanced in the aquatic culture fields. Hence special attention was given to a medium using natural water, estuarine or marine. For this purpose simple formulations based on Miquel's solution was found to be more effective for Tetraselmis gracilis and Synechocystis salina than the complex mixes of more recent times.

In solution A of the medium the active ingredient is the nitrate, solution B lowers the pH and results in the formation of a precipitate which seems to be essential for good growth, possibly due to the co-precipitation of toxic materials. Allen and Nelson (1910) were able to culture many species of Rhodophyceae, Myxophyceae and Chlorophyceae in Miquel's type medium. The probable deficiencies of this medium is that it forms precipitate giving inconsistent results and are generally restricted to the growth of bacterized cultures. To overcome this the precipitate is removed and only clear supernatant medium was used. Miquel's solution modified by Ketchum and Redfield (1938) was found to be well suited for the study where the species selected belonging to the classes Prasinophyceae and Myxophyceae were found to grow well.

Composition of the medium:

Solution A

KNO_3 - 20.2 g

H_2O - 100 g

Quantity of solution A added to 1 litre of sea or estuarine water - 0.55 ml.

Solution B

$MgSO_4$	- 4 g
Na_2HPO_4 $12H_2O$	- 4 g
$CaCl_2$ $6H_2O$	- 4 g
HCl (con.)	- 2 ml.
$FeCl_3$ (melted)	- 2 ml.
H_2O	- 100 ml.
Quantity of solution B added to 1 litre of sea or estuarine water	- 0.5 ml.

2. Takano medium (1963)

Thalassiosira subtilis was cultured in this medium

NaCl	- 24.0 g
$MgSO_4 \cdot 7H_2O$	- 8.0 g
$CaCl_2 \cdot 2H_2O$	- 0.37 g
KCl	- 0.7 g
$NaNO_3$	- 300 mg
K_2HPO_4	- 10 mg
$NaHCO_3$	- 200 mg
Na_2SiO_3	- 100 mg
EDTA	- 10 mg
B_{12}	- 0.015 µg
$FeSO_4 \cdot 7H_2O$	- 3 mg
Citric acid	- 3 mg
H_3BO_3	- 1.5 mg

$MnCl_2 \cdot 4H_2O$	- 1 mg
$ZnSO_4 \cdot 7H_2O$	- 22 µg
$CuSO_4 \cdot 5H_2O$	- 79 µg
$(NH_4)_6MO_7\ O_{24} \cdot 4H_2O$	- 15 µg
NH_4VO_3	- 23 µg
$CoCl_2 \cdot 6H_2O$	- 15 µg
EDTA	- 250 µg
Distilled H_2O	- 1 l

Fixing and preservation of samples

Algal plankton collected by net or concentrated by sedimentation are immediately fixed in Lugol's solution, kept in dark bottles. The composition of which is as follows:

Pure iodine	- 10 gm
Potassium Iodide	- 20 gm
Glacial aceticacid	- 20 gm
Distilled water	- 200 c.c.

This is added to the samples in the ratio 1 : 100

Estimation of growth by Numerical estimation:

Larger algal plankton was counted using Sedwick Rafter counting cell and the nano and ultra planktors were counted using a haemocytometer for the estimation of the total plankton 100 ml. of the water sample was centrifuged and the sediments counted using plankton counting cells under different magnifications.

Nutrient Utilization

Nutrient depleted filtered and sterilised sea water of known salinity and phosphate were taken in a series of clean conical flasks of 5 litre capacity.

Each flask was then enriched with nitrate-nitrogen so that the first set of 5 flasks had concentration of 0.5 µg, 1 µg, 5 µg and 10 µg at/litre respectively besides the initial concentration.

The second set of 7 flasks was enriched with phosphate-phosphorous having 0.5 µg, 1 µg, 2 µg, 3 µg, 5 µg, 6 µg and 10 µg - at/litre. In the third set of 5 flasks, both phosphate and nitrate were used in combination in 1:1 ratio. The concentrations of these two nutrients combined were 1 µg, 2 µg, 5 µg, 10 µg and 20 µg at/litre. One flask in each set was kept as unenriched and used as control. The unenriched and enriched media in all the three sets of flask were innoculated with equal and known concentration of Tetraselmis gracilis and the cultures exposed to 8 hour fluorescent illumination of 20 k lux during the day followed by darkness. A gentle stream of air bubbles was passed through all the flasks continuously to keep the organisms in suspension.

5 ml of the well mixed culture is pipetted out from each flask daily for cell counts. Aliquots of 50 ml. were drawn from each flask on every alternate day and their rates of photosynthesis were measured by C^{14} uptake.

Growth constant and generation time were calculated from the following equations:

$$\ln. nt = \ln. no + kt$$

$$\text{or } \ln pt = \ln. po + kt$$

$$tg = 0.7 k$$

$$\text{or } k = 0.7/tg$$

where nt or pt and no or po are the cell counts at times t and o respectively and k is the growth constant expressed in hr^{-1} and tg is the mean generation time expressed in hours.

Experiments with Thalassiosira subtilis and Synechocystis salina

Exponentially growing cells of Thalassiosira subtilis were used for inoculation. The algae were cultured in Takano medium (1963) at a light intensity of 20 klux and alternate light and dark periods at an ambient temperature of 27 ± 1°C under aeration. Aliquots of the culture were taken in different intervals to measure organic production and growth. Organic production was measured by C^{14} technique. The activity of the filters were determined on a Geiger Counting System. The growth of the algae was studied by counting the number of cells using a haemocytometer.

The alga Synechocystis salina was cultured in Miquel's medium having salinity of 32.0‰ (modified by Ketchum and Redfield) at a light intensity of 20 klux and alternate light and dark periods at the room temperature under aeration. Aliquots of the culture were taken in different intervals to measure organic production and growth.

S. Salina, cultured in Miquel's medium (modified by Ketchum and Redfield) and grown at a light intensity of 20 klux and alternate light and dark periods at the room temperature was used to study the effect the metal toxicity on growth constant and generation time. The metal solutions from a stock solution of 1000 ppm was added to the enriched media to get a final concentration of 0.05 and 0.1 ppm. The growth of the algae in different intervals was studied by counting the number of cells, using haemocytometer.

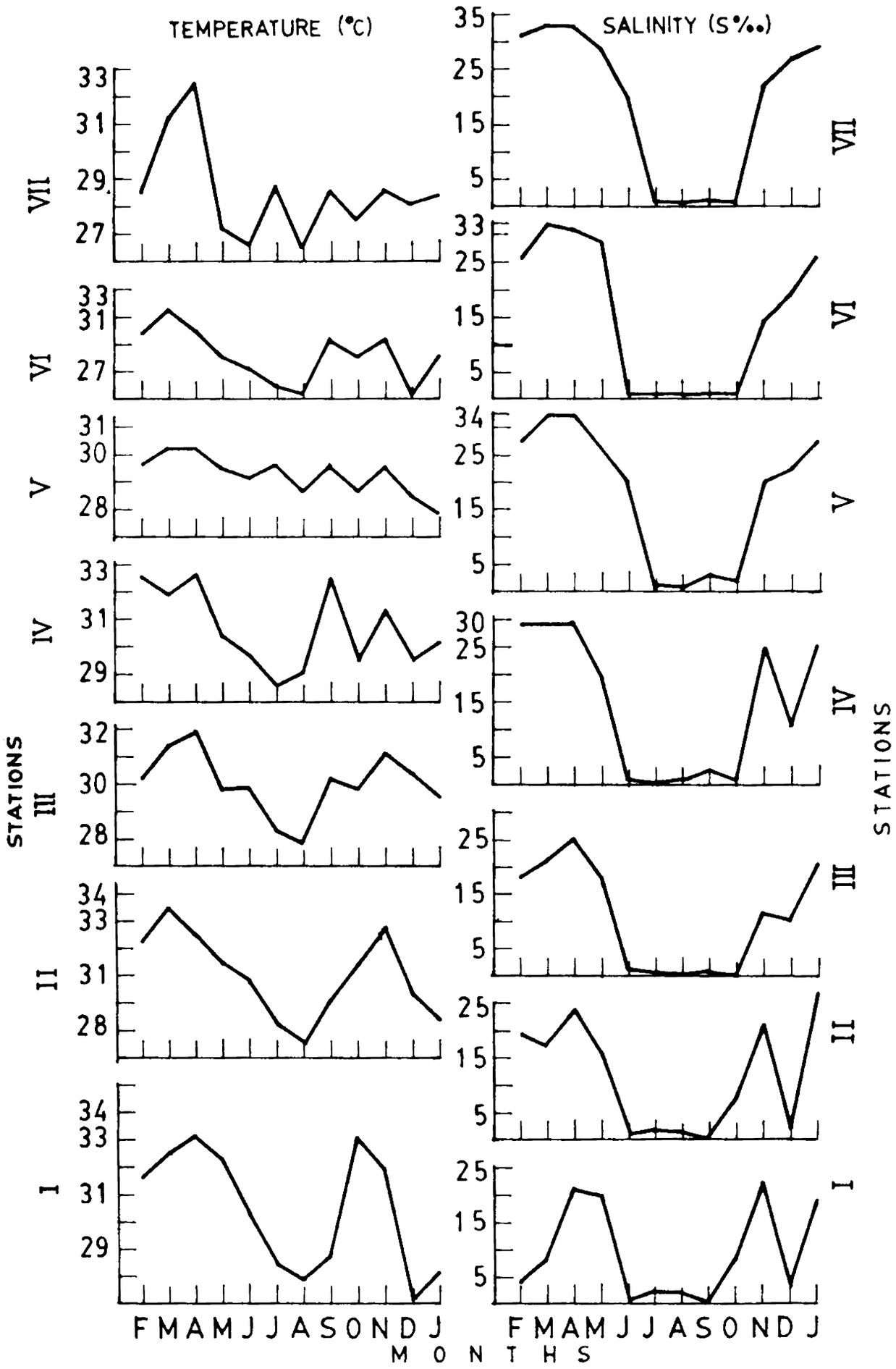

FIG.2. TEMPERATURE AND SALINITY

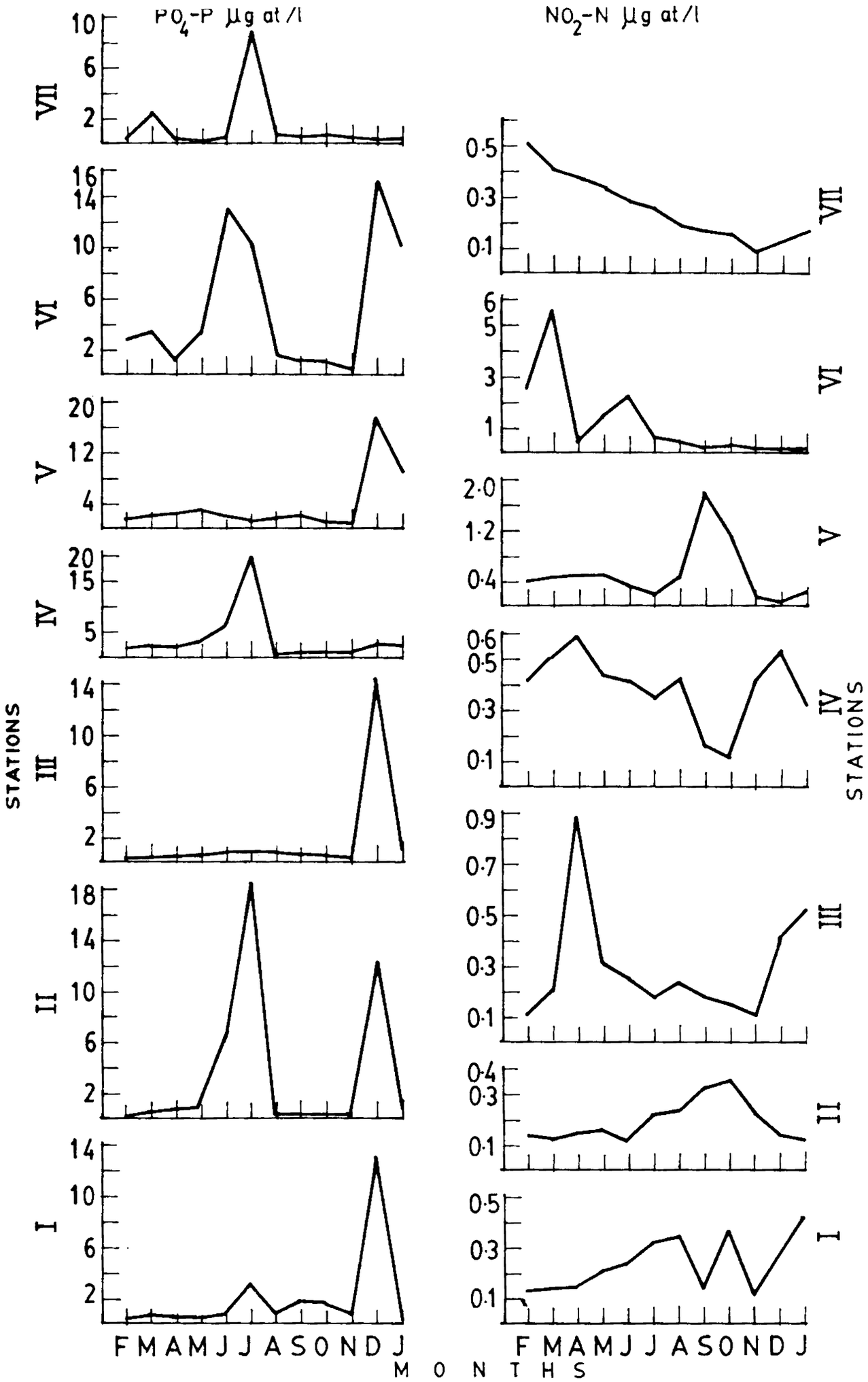

FIG.3. PHOSPHATE AND NITRITE

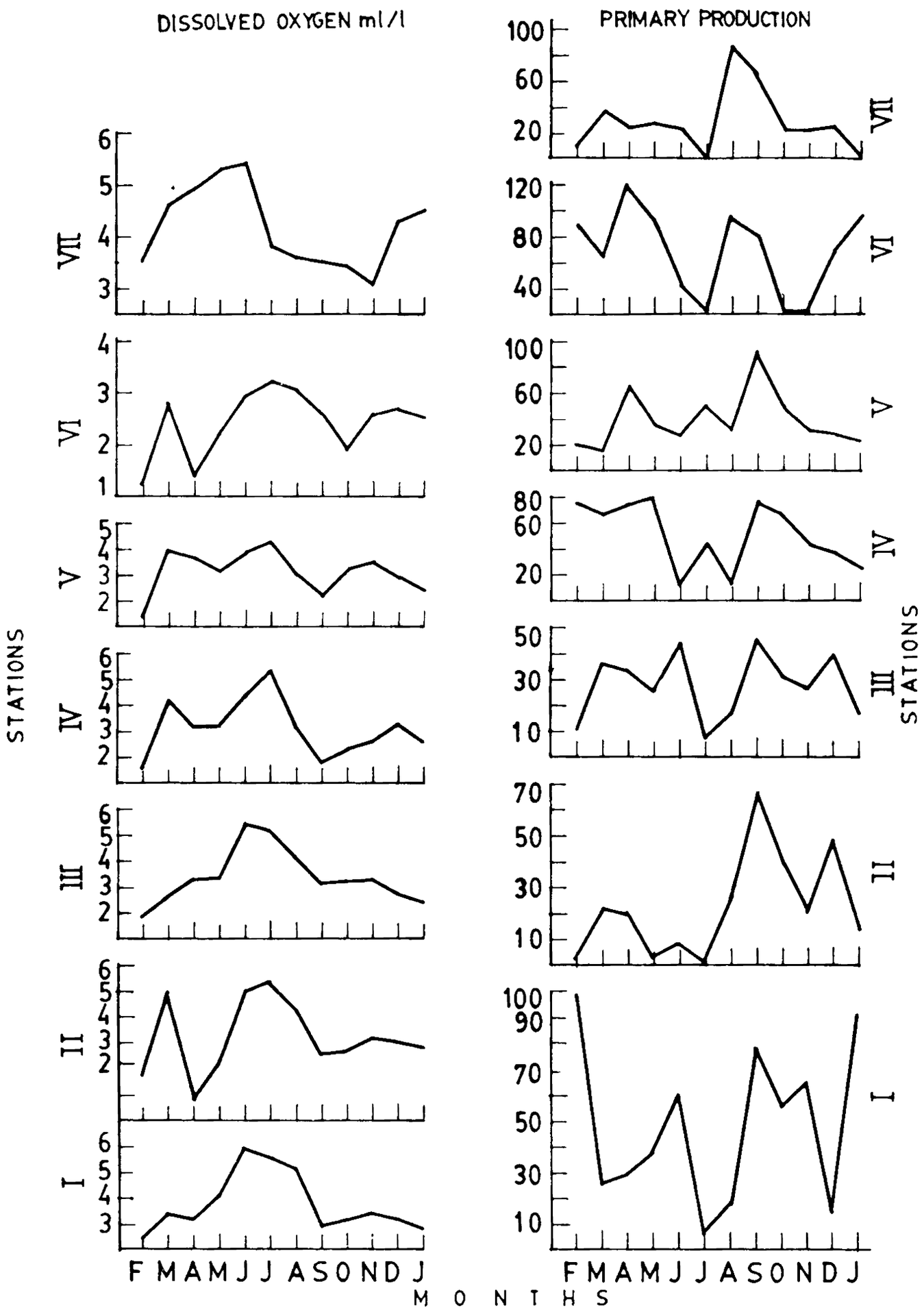

FIG.4. DISSOLVED OXYGEN AND PRIMARY PRODUCTION.

CHAPTER III

SIZE SPECTRUM OF THE ESTUARINE PLANKTONIC ALGAE

1. Size spectrum of cells

A critical evaluation of the various size fractions based on intraspecific quantitative analysis (ISQA) is discussed here.

In the latterpart of the work seasonal and spatial distribution of the microplanktom (larger algal plankton) and their role in the productivity in the estuary have been discussed. In fact the microplankton covers only a small percentage of the total algal plankton. The major contribution in the total primary production is that of smaller planktonic algae of size less than 60 μm which comprise nanoplankton, ultraplankton and picoplankton.

The nanoplankton is defined as that part of the algal plankton not retained by the finest plankton net of 60 μm mesh size. There can be however no precision in the catching power with a mesh dimension, age and method of manufacture of net, speed of towing and especially the diversity of size and density of the algal plankton all of which may modify the size of organism retained. By definition, nanoplankton cannot be sampled by net hauls, though many plankton organisms far smaller than 40 μm may be retained to a variable extent largely dependent on the degree of clogging. The investigation of total crop is now usually achieved by sampling known quantities usually several litres of sea water throughout the euphotic zone with large water samplers such as Van Dorn bottles. Part of the sample is subjected to cell count to assess the floristic composition; a sedimentation technique is often employed (Cf. Raymont, 1980). The presence of detritus poses a threat to the validity of the total floristic composition and concentration. A complete and reliable analysis is possible by isolation of the

T A B L E 1

OCCURRENCE OF VARIOUS SIZE FRACTIONS OF ALGAL PLANKTON IN COCHIN ESTUARY

Total species	SG.1	SG.2	SG.3	SG.4
BACILLARIOPHYCEAE				
Acbnanthes exilis	A *	A	A	P
Amphora ovalis	P **	A	A	A
Asterionella japonica	A	P	A	A
Biddulphia sinensis	P	A	A	A
Cerataulina bergonii	A	A	A	P
Chaetoceros lorenzianus	A	A	P	A
Fragilaria oceanica	P	P	P	A
Navicula hennedyii	P	P	P	P
Nitzschia closterium	P	A	A	P
Nitzschia seriata	P	A	P	A
Nitzschia forcipata	P	A	A	A
Pleurosigma aestuarii	P	A	A	A
Pleurosigma directum	P	P	A	P
Pleurosigma elongatum	P	A	A	A
Rhizosolenia alata	A	A	A	P
Skeletonema costatum	P	P	P	P
Surirella fluminensis	A	A	A	P
Thalassiosira subtilis	P	P	P	A
CHLOROPHYCEAE				
Chlamydomonas ohioensis	P	P	A	A
Chlorella sp.	P	A	A	A
Scenedesmus quadricauda	A	P	A	P
PYRROPHYCEAE				
Gymnodinium sp.	A	A	A	P
Peridinium depressum	P	P	P	P
Prorocentrum micans	A	P	A	A
CYANOPHYCEAE				
Merismopedia elegans	P	P	P	A
Oscillatoria prolifica	P	P	P	P
Synechocystis salina	P	P	P	A
Synechococus aeruginossus	P	P	P	A
PRASINOPHYCEAE				
Tetraselmis gracilis	P	P	A	A
Total species - 31	22	16	11	12

* absent

** present

constituents of the floristic spectrum. This is achieved by fractional filtration of the water samples through different nets having a mesh size of 60 μm, 75 μm and 99 μm. Besides the algal plankton retained by 99 μm, 75 μm and 60 μm mesh size nets, water that is filtered through 60 μm mesh size net is also analysed. Accordingly the planktonic algae are classified into four size groups (SG) i.e. <60 (SG.1) 60 -- 75 (SG.2), 75 -- 99 (SG.3) and >99 (SG.4). SG.1 forms the nanoplankton and the remaining three groups (SG.2, SG.3 & SG.4) together form microplankton.

The planktonic algae in the estuary includes the taxonomic classes Bacillariophyaae, Cyanophyceae, Pyrrophyceae, Chlorophyceae and Prasinophyceae. On analysis of the size spectrum of the planktonic algae it is observed that the major flora in the estuary are diatoms. Out of 31 species of planktonic algae recorded, 20 species belong to the class Bacillariophyceae, 4 species belong to Cyanophyceae, 3 species each belong to Pyrrophyceae and Chlorophyceae and one species belongs to the class Prasinophyceae (Table 1). All these taxonomic classes are represented in all the size groups of algal plankton i.e. SG.1, SG.2, SG.3 and SG.4 though at varying intensities. Table 2 shows the various size fractions of algal plankton and their total number expressed per litre for a period of one year. During November-February period only the total counts of different size groups have been given. But from February onwards a picture of the species composition of different size groups is available. (Tables 2 – 11).

In January the total cell concentration is 1.53×10^7 cells/l. SG.1 occupies the major portion in the autotrophic plankton with a cell concentration of 1.20×10^7 cells/l. The nanoplanktons are 79.0% of the total planktonic algae. The entire microplankton comprising three different size groups (SG.2, SG.3

TABLE 2

CELL CONCENTRATION OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Cell Numbers/l SG.1	%	Cell Numbers/l SG.2	%	Cell Numbers/l SG.3	%	Cell Numbers/l SG.4	%	Cell Numbers/l Total
January	12047500	79.0	793000	5.2	1342000	8.8	1067500	7.0	15250000
February	1367800	77.9	271300	15.5	45200	2.6	71400	4.0	1755700
March	2543400	62.1	427200	10.4	684400	16.7	443500	10.8	4098500
April	335700	63.4	85600	16.1	87300	16.5	21200	4.0	529800
May	128500	49.5	114300	44.1	7100	2.7	9600	3.7	259500
June	57200	29.7	14300	7.4	99800	51.8	21300	11.1	192600
July	11014200	96.5	171500	1.5	174200	1.5	48650	0.5	11408550
August	1439400	94.2	29000	1.9	50000	3.3	9500	0.6	1527900
September	424600	24.5	820000	47.3	478000	27.6	10000	0.6	1732600
October	10850000	38.9	7625000	27.4	8725000	31.3	675000	2.4	27875000
November	756000	36.0	357000	17.0	378000	18.0	609000	29.0	2100000
December	27186000	92.0	147750	0.5	1329750	4.5	886500	3.0	29550000

and SG.4) together contributes only 21.0% of the total cell contribution. SG.2 is only 5.2% with 7.93×10^5 cells/l, SG.3 is 8.8% with 1.34×10^6 cells/l and SG.4 is 70.0% its concentration being 1.07×10^6 cells/l.

In February the total cell concentration is 1.76×10^6 cells/l spread over 8 species. Four species belong to the class Bacillariophyceae, two species belong to the class Pyrrophyceae, one species each to the classes Cyanophyceae and Prasinophyceae. On analysing the size-wise contribution it is found that SG.1 is comprised of 1.37×10^6 cells/l. Out of the total species, 6 species are represented in the size fraction; 4 of which are diatoms one species each belong to the classes Cyanophyceae and Prasinophyceae. The diatoms are Nitzschia closterium, Skeletonema costatum, Thalassionema nitzschioides and Thalassiosira subtilis. All the 1.42×10^4 cells/l of Nitzschia closterium present in SG.1. The predominant species in this size group is the diatom Skeletonema costatum. Out of the total of 1.16×10^6 cells/l 96.8% distributed in this size group. Thalassionema nitzschioides and Thalassiosira subtilis are seen only in this size group making their intraspecific quantity (ISQ) 100%. The blue green alga present in Synechocystis salina the ISQ of which is 35.5% with the cell concentration of 1.14×10^5 cells/l. The Prasinophycean alga Tetraselmis gracilis with its total cell concentration of 8.50×10^4 cells are found only in this size fraction. SG.2 with 2.79×10^5 cells/l distributed among three species belong to three different classes Pyrrophyceae, Bacillariophyceae and Cyanophyceae. Pyrrophycean Prorocentrum micans with 7.14×10^4 cells/l, Bacillariophycean Skeletonema costatum with 3.57×10^4 cells/l and Cyanophycean Synechocystis salina with 1.64×10^5 cells/l make up their ISQ 100%, 3.1% and 51.2% respectively. SG.3 has three species in three different classes. They are Peridinium depressum of Pyrrophyceae (1200 cells/l) Skeletonema costatum

T A B L E 3

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
January		12047500	79.0	793000	5.2	1342000	8.8	1067500	7.0	15250000
February	BACILLARIOPHYCEAE									
	Nitzschia closterium	14200	100.0	-	-	-	-	-	-	14200
	Skeletonema costatum	1126000	96.8	35700	3.1	1200	0.1	-	-	1162900
	Thalassionema nitzschioides	14300	100.0	-	-	-	-	-	-	14300
	Thalassiosira subtilis	14300	100.0	-	-	-	-	-	-	14300
	PYRROPHYCEAE									
	Peridinium depressum	-	-	-	-	1200	1.7	71400	98.3	72600
	Prorocentrum micans	-	-	71400	100	-	-	-	-	71400
	CYANOPHYCEAE									
	Synechocystis salina	114000	35.5	164200	51.2	42800	13.3	-	-	321000
	PRASINOPHYCEAE									
	Tetraselmis gracilis	85000	100.0	-	-	-	-	-	-	85000
		1367800	77.9	271300	15.5	45200	2.6	71400	4.0	1755700
	Species diversity index	1.14		0.6		0.4		0.4	0	1.12

of Bacillariophyceae (1200 cells/l) and Synechocystis salina of Cyanophyceae ($4.28x10^4$ cells/l) with their ISQ of 1.7%, 0.1% and 13.3% respectively. SG.4 is represented by a single species Peridinium depressum with $7.14x10^4$ cells/l, the ISQ being 98.3%. The maximum standing crop is made up of the nanoplankton group recording $1.37x10^6$ cells/l. The minimum cell concentration of $4.52x10^4$ cells/l is recorded in SG.3. In SG.2 the cell concentration is $2.79x10^5$ cells/l and in SG.4 the cell concentration is $7.14x10^4$ cells/l. The percentages of composition of the size groups SG.1, SG.2, SG.3 and SG.4 are 77.9%, 15.5%, 2.6% and 4.0% respectively.

The percentage contribution of each taxonomic class of alga present in the total planktonic algae and nanoplankton (SG.1) is given below:

No.	Class	Total plankton %	Nanoplankton (SG.1) %
1.	Bacillariophyceae	68.7	85.5
2.	Cyanophyceae	18.3	8.3
3.	Pyrrophyceae	8.2	-
4.	Prasinophyceae	4.8	6.2

In March the standing crop of the entire planktonic algae is about $4.10x10^6$ cells/l. The species composition and the percentage composition of each size group is given in Table 4. There are 16 species, 11 of which are diatoms, 2 species each belong to the classes Pyrrophyceae and Cyanophyceae and one species belong to the class Prasinophyceae. Among the various size groups the maximum cell concentration of $2.54x10^6$ cells/l is recorded in SG.1, which amounts to 62.1% of the total standing crop. Among the 11 species

TABLE 4

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
March	BACILLARIOPHYCEAE									
	Asterionella japonica	-	-	228700	100	-	-	-	-	228700
	Chaetoceros lorenzianus	-	-	-	-	14300	100	-	-	14300
	Navicula hennedyii	14100	49.8	14200	50.2	-	-	-	-	28300
	Nitzschia closterium	14100	100	-	-	-	-	-	-	14100
	Nitzschia seriata	-	-	-	-	57000	100	-	-	57000
	Pleurosigma aestuarii	14100	100	-	-	-	-	-	-	14100
	Skeletonema costatum	1893400	64.8	127500	4.4	570500	19.5	328700	11.3	2920100
	Surirella fluminensis	-	-	-	-	-	-	14400	100	14400
	Thalassionema nitzschioides	14100	100	-	-	-	-	-	-	14100
	Thalassiosira coromandalina	28300	79.9	7100	20.1	-	-	-	-	35400
	Thalassiosira subtilis	98900	63.6	28300	18.2	28300	18.2	-	-	155500
	PYRROPHYCEAE									
	Gymnodinium	-	-	-	-	-	-	86100	100	86100
	Peridinium depressum	28300	100	-	-	-	-	-	-	28300
	CYANOPHYCEAE									
	Oscillatoria prolifica	84800	66.4	14300	11.2	14300	11.2	14300	11.2	127700
	Synechocystis salina	310900	100	-	-	-	-	-	-	310900
		2543400	62.1	427200	10.4	684400	16.7	443500	10.8	4098500
	Species diversity index	1.56		1.1		0.7			0.5	2.27

present in this size group 7 species belong to the class Bacillariophyceae, 2 species belong to the class Cyanophyceae and one species each to the class Pyrrophyceae and Prasinophyceae respectively. Predominant among the diatoms is Skeletonema costatum with a cell concentration of $1.89x10^6$ cells/l which is 64.8% of their total concentration ($2.92x10^6$ cells/l). The entire populations of Nitzschia closterium, Pleurosigma aestuarii and Thalassionema nitzschioides comprising $1.41x10^4$ cells come under nanoplankton. 49.8% of $2.83x10^4$ cells of Navicula hennedyii, 79.9% of $3.54x10^4$ cells/l of Thalassiosira coromandalina and 63.6% of Thalassiosira subtilis are the diatoms present in this size fraction. The blue green algae representing 66.4% of $1.28x10^5$ cells/l of Oscillatoria prolifica and the entire Synechocystis salina of $3.11x10^5$ cells/l also come under this group. All cells of Pyrrophycean Peridinium depressum with the cell concentration of $2.83x10^4$ cells/l are also observed only in this size fraction. 85.7% of $4.95x10^4$ cells of Prasinophycean Tetraselmis gracilis is present in SG.1. In SG.2 there are 5 species of diatoms, one species each of the classes Cyanophyceae and Prasinophyceae. The diatoms present are $2.29x10^5$ cells/l of Asterionella japonica, $1.42x10^4$ cells of Navicula hennedyii, $1.28x10^5$ cells/l of Skeletonema costatum, $7.10x10^3$ cells of Thalassionema coromandalina and $2.83x10^4$ cells/l of Thalassiosira subtilis. The ISQ of these species are 100%, 50.2%, 4.4%, 20.1% and 18.2% respectively. The blue green alga present is Oscillatoria prolifica with the cell concentration of $1.43x10^4$ cells/l and the Prasinophyceae is represented by Tetraselmis gracilis with a cell concentration of $4.24x10^4$ cells/l. The ISQ of Oscillatoria prolifica and Tetraselmis gracilis are 11.2% and 14.3% respectively. The cell concentrations of SG.2 is $4.27x10^5$ cells/l. SG.3 is comprised of 4 species of diatoms and one species of Cyanophyceae. The diatoms include $1.43x10^4$ cells of Chaetoceros lorenzianus and

TABLE 5

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
April	BACILLARIOPHYCEAE									
	Nitzschia closterium	35700	83.6	-	-	-	-	7000	16.4	42700
	Skeletonema costatum	221400	96.9	-	-	-	-	7000	3.1	228400
	Surirella fluminensii	-	-	-	-	-	-	7200	100	7200
	Thalassiosira subtilis	14300	33.3	28600	66.7	-	-	-	-	42900
	CYANOPHYCEAE									
	Oscillatoria prolifica	-	-	7200	100	-	-	-	-	7200
	Synechocystis salina	28600	17.3	49800	30.0	87300	52.7	-	-	165700
	PRASINOPHYCEAE									
	Tetraselmis gracilis	35700	100	-	-	-	-		-	35700
		335700	63.4	85600	16.1	87300	16.5	21200	4.0	529800
	Species diversity index	0.7		0.4		0		0.5		1.1

5.7×10^4 cells of Nitzschia seriata with ISQ of 100.0% each. The other two species of diatoms are Skeletonema costatum and Thalassiosira subtilis having the cell concentrations of 5.71×10^5 cells/l and 2.83×10^4 cells/l respectively. Their corresponding ISQ are 19.5% and 18.2%. The blue green alga Oscillatoria prolifica is 1.42×10^5 the ISQ of which is 11.2% in the size fraction. SG.3 is having a total cell concentration of 6.84×10^5 cells/l. SG.4 has four species of which 2 species belong to the class Bacillariophyceae and one species each belong to the classes Pyrrophyceae and Cyanophyceae. The diatoms species are Skeletonema costatum with a cell concentration of 3.29×10^5 cells/l and Surirella fluminensis with a cell concentration of 1.44×10^4 cells/l with their ISQ being 11.3% and 100% respectively. Gymnodinium species of Pyrrophyceae in the size group is 8.61×10^4 cells/l with ISQ of 100% while Oscillatoria prolifica is 1.43×10^4 cells/l with ISQ of only 11.2%. SG.4 has in all a cell concentration of 4.4×10^5 cells/l. The contribution of the various size fractions, SG.1, SG.2, SG.3 and SG.4 are 62.1%, 10.4, 16.7% and 10.8% respectively. The percentage contribution of various classes of algae in total plankton as well as in nanoplankton are shown below:

Sl. No.	Class	Total plankton %	Nano-plankton %
1.	Bacillariophyceae	85.3	81.6
2.	Cyanophyceae	10.7	15.6
3.	Pyrrophyceae	2.8	1.1
4.	Prasinophyceae	1.8	1.7

Table 5 shows the inter and intraspecific abundance of different size groups of planktonic algae during April. During the month the total cell concentration of 5.30×10^5 is spread over seven species. Out of these 4 species belong to the class

Bacillariophyceae, 2 to the class Cyanophyceae and one to the class Prasinophyceae. 63.4% of the total cell concentration is nanoplankton. This is comprised of five species of which three species belong to the class Bacillariophyceae. They include 3.57×10^4 cells/l of Nitzschia closterium and 2.21×10^5 cells/l of Thalassiosira subtilis. Their ISQ in the size fraction are 83.6%, 96.9% and 33.3% respectively. The cell concentration of the blue green alga Synechocystis salina is 2.86×10^4 cells/l with ISQ of 17.3%. Tetraselmis gracilis (Prasinophyceae) is present only in this size group recording a cell concentration of 3.57×10^4 cells/l, the ISQ being 100%. All the above species present in SG.1 contribute 3.36×10^5 cells/l out of the total cell concentration of 5.30×10^5 cells/l. SG.2 with a cell concentration of 8.56×10^4 cells/l is distributed among three species and form 16.1% of the total planktonic algae. Two species viz., Oscillatoria prolifica and Synechocystis salina are of the class Cyanophyceae and the third species, Thalassiosira subtilis is of the class Bacillariophyceae. While the entire cells of Oscillatoria prolifica (7200 cells/l) are confined to this size group with ISQ of 100%, only 30.1% of Synechocystis salina (4.98×10^4 cells/l) is present in this group. The cell concentration of Thalassiosira subtilis is 2.86×10^4 cells/l which is 66.6% of its concentration in this size fraction. The cell concentration of 8.73×10^4 cells/l i.e. 16.5% of the total standing crop is the contribution of a single species of blue green alga, Synechocystis salina, confined to the size fraction SG.3. 52.7% of the species is distributed in this size group. SG.4 contributes only 4.0% of to the total standing crop of 5.30×10^5 cells/l. The microplankton of the largest size group is comprised of three species of diatoms only. Out of these Surirella fluminensii is strictly confined to this size group, its concentration being 7200 cells/l. The other two species Nitzschia closterium and Skeletonema costatum have 7000 cells/l each, their ISQ being 16.4% and 3.1% respectively. The taxonomic classes and the floristic composition are as follows:

T A B L E 6

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
May	BACILLARIOPHYCEAE									
	Navicula hennedyii	-	-	-	-	7100	100	-	-	7100
	Nitzschia closterium	-	-	-	-	-	-	4800	100	4800
	Pleurosigma directum	-	-	-	-	-	-	4800	100	4800
	Skeletonema costatum	128500	64.3	71400	35.7	-	-	-	-	199900
	Thalassiosira subtilis	-	-	28600	100	-	-	-	-	28600
	CYANOPHYCEAE									
	Oscillatoria prolifica	-	-	14300	100	-	-	-	-	14300
		128500	49.5	114300	44.1	7100	2.7	9600	3.7	259500
	Species diversity index	0		0.4		0		0.3		0.95

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	59.3	80.9
2.	Cyanophyceae	32.6	8.5
3.	Prasinophyceae	6.1	10.6

In May the standing crop of planktonic algae of different size groups is 2.60×10^5 cells/l comprising six species (Table 6). Among these, all except Oscillatoria prolifica, the blue green, are diatoms. The dominant form among the flora is Skeletonema costatum. Nanoplankton with their concentration of 1.29×10^5 cells/l contributes 49.5% of the standing crop. Occurrence of a single species Skeletonema costatum in the group is rather unique, the ISQ of which is 64.3%. SG.2 has two species of Bacillariophyceae, (Skeletonema costatum and Thalassiosira subtilis) and a species of the class Cyanophyceae (Oscillatoria prolifica). Skeletonema costatum cells constitute 7.14×10^4 cells/l the ISQ of which is 35.7% while Thalassiosira subtilis has 2.86×10^4 cells/l with an ISQ of 100%. During this month, Oscillatoria prolifica cells are present only in this size group, their concentration being 1.43×10^4 cells/l. Thus this size group with a total of 1.14×10^5 cells/l contributes 44.1% of the total planktonic algae. SG.3 is the least in number comprising of a single species of diatom Navicula hennedyii. These cells with a concentration of 7100 cells/l are confined to this size fraction, which contributes only 2.7% of the total standing crop. SG.4 with a concentration of 9600 cells/l contributes only 3.7% of the total plankton. In this size group are present 4800 cells/l each of Nitzschia closterium and Pleurosigma directum of Bacillariophyceae. The dominance of diatoms in total plankton and among nanoplankters is evident from the following figures.

TABLE 7

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
June	BACILLARIOPHYCEAE									
	Navicula hennedyii	-	-	-	-	-	-	7100	100	7100
	Nitzschia closterium	-	-	-	-	-		7100	100	7100
	Nitzschia seriata	14300	100	-	-	-	-	-	-	14300
	Skeletonema costatum	-	-	14300	14.3	85500	85.7	-	-	99800
	Thalassiosira subtilis	28600	100	-	-	-	-	-	-	28600
	CYANOPHYCEAE									
	Oscillatoria prolifica	14300	40.1	-	-	14300	40.1	7100	19.8	35700
		57200	29.7	14300	7.4	99800	51.8	21300	11.1	192600
	Species diversity index	0.4		0		0.2		0.5		0.95

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	94.5	100
2.	Cyanophyceae	5.5	-

During June the standing crop of all the different size groups of planktonic algae of 1.93 x 10^5 cells/l is distributed among 5 diatoms and a blue green alga (Table 7) SG.1 includes two species of diatoms which are confined to this size group. They are the entire cells of Nitzschia seriata of 1.43 x 10^4 cells/l and Thalassiosira subtilis with concentration of 2.86 x 10^4 cells/l. The concentration of Oscillatoria prolifica in this size group is 1.43 x 10^4 cells/l with ISQ of 40.1%. The nanoplankton (SG.1) contributes only 29.7% of the total planktonic algae. SG.2 is 1.43 x 10^4 cells/l and forms 7.4% of the total standing crop. In this size group the only species present is Skeletonema costatum of Bacillariophyceae with ISQ of 14.3%. SG.3 contributes 51.8% of the standing crop of planktonic algae with a cell concentration of 9.98 x 10^4 cells/l. There are only 2 species in this group. They are Oscillatoria prolifica with a cell concentration of 1.43 x 10^4 cells/l and Skeletonema costatum with a cell concentration of 8.55 x 10^4 cells/l. Their ISQ are 40.1% and 85.7% respectively. In SG.4 there are only three species. They are Navicula hennedyii (7100 cells/l) and Nitzschia closterium (7100 cells/l) of Bacillariophyceae and Oscillatoria prolifica (7100 cells/l) of Cyanophyceae. While the two diatom species confined to this size group have the ISQ of 100% each, ISQ of Oscillatoria prolifica is 19.9% only. The contribution of this size group in the autotrophic plankton is 11.1% with a cell concentration of 2.13 x 10^4 cells/l. The contribution of different

T A B L E 8

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
July	BACILLARIOPHYCEAE									
	Cerataulina bergonii	-	-	-	-	-	-	17250	100.0	17250
	Navicula forcipata	114300	100.0	-	-	-	-	-	-	114300
	Nitzschia closterium	28600	100.0	-	-	-	-	-	-	28600
	Pleurosigma elongatum	14300	100.0	-	-	-	-	-	-	14300
	Rhizosolenia alata	-	-	-	-	-		14300	100.0	14300
	Skeletonema costatum	10484800	96.8	157200	1.5	171400	1.6	14300	0.1	10827700
	Thalassionema nitzschioides	257500	100.0	-	-	-	-	-	-	257500
	CYANOPHYCEAE									
	Oscillatoria prolifica	-	-	-	-	2800	50.0	2800	50.0	5600
	Synechococcus aeruginossus	71700	100.0	-	-	-	-	-	-	71700
	CHLOROPHYCEAE									
	Chlamydomonas ohioensis	43000	75.0	14300	25.0	-	-	-	-	57300
		11014200	96.5	171500	1.5	174200	1.5	48650	0.5	11408550
	Species diversity index	0.9		0.2		0.2		0.6		1.3

taxonomic classes in total standing crop and in nanoplankters , is shown below:

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	81.5	75.0
2.	Cyanophyceae	18.5	25.0

In July there is considerable increase in the standing crop recording a cell concentration of 1.14×10^7 cells/l. Ten species are present in these autotrophic plankton out of which 7 species belong to the class Bacillariophyceae, two to the Cyanphyceae and one to the Chlorophyceae (Table 8). On a sizewise analysis, it is observed that the largest contribution is from the smallest size group of plankton. These autotrophic plankters comprising the size group SG.1 contribute 96.5% of the photosynthetic plankton, their cell concentration being 1.10×10^7 cells/l. This size fraction consists of seven species belonging to the classes Chlorophyceae. Bacillariophyceae and Cyanophyceae. Chlorophyceae is represented by a single species of Chlamydomonas ohioensis with a cell concentration of 4.30×10^4 cells/l. Synechococus aeruginossus has a cell concentration of 7.17×10^4 cells/l and is confined to this size group. The predominant flora in this group is the diatom Skeletonema costatum forming a bloom with a high concentration of 1.05×10^7 cells/l. This forms 96.8% of the total Skeletonema costatum cells. The other diatoms present in this size group are Navicula forcipata (1.14×10^5 cells/l), Nitzschia closterium (2.86×10^4 cells/l), Pleurosigma elongatum (1.43×10^4 cells/l) and Thalassiosira nitzschioides (2.58×10^5 cells/l). These four diatoms are confined to this size group. The microplankters are numerically insignificant as their total contribution is only 3.5%. Among this the microplankters of SG.2 contributes only 1.5% of the total autotrophic plankters. SG.2 includes one species each of the class Chlorophyceae and

TABLE 9

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
August	BACILLARIOPHYCEAE									
	Biddulphia sinemsis	14100	100.0	-	-	-	-	-	-	14100
	Navicula hennedyii	14100	49.3	14500	50.7	-	-	-	-	28600
	Pleurosigma directum	14100	100.0	-	-	-	-	-	-	14100
	Skeletonema costatum	1071400	100.0	-	-	-	-	-	-	1071400
	Thalassiosira subtilis	42200	85.6	-	-	7100	14.4	-	-	49300
	CYANOPHYCEAE									
	Merismopedia elegans	227200	100.0	-	-	-	-	-	-	227200
	Oscillatoria prolifica	-	-	-	-	-	-	9500	100.0	9500
	Synechococcus aeruginossus	42200	42.4	14500	14.5	42900	43.1	-	-	99600
	CHLOROPHYCEAE									
	Chlamydomonas ohioensis	14100	100.0	-	-	-	-	-	-	14100
		1439400	94.2	29000	1.9	50000	3.3	9500	0.6	1527900
	Species diversity index	1.1		0.2		0.2		0		1.3

Bacillariophyceae. Chlorophyceae is represented by Chlamydomonas ohioensis with a cell concentration of 1.43 cells/l, the ISQ being 25%. The diatom Skeletonema costatum is 1.57 x 10^5 cells/l the ISQ of which is 1.5%. SG.3 too consists of two species one blue green alga and the other a diatom species. The blue green alga Oscillatoria prolifica is only 2800 cells/l and the diatom Skeletonema costatum is 1.43 x 10^4 cells/l. The ISQ of these two species in the size group are 50% and 1.6% respectively. SG.4 is the least in number (4.87 x 10^4 cells/l) contributing only 0.5% to the total standing crop. There are 4 species in the size group of which three are diatoms and the remaining one is a blue green alga. While there are the entire cells of diatoms Cerataulina bergonii (1.73 x 10^4 cells/l) and Rhizosolenia alata (1.43 x 10^4 cells/l), only 0.1% of 1.08 x 10^7 Skeletonema costatum cells (i.e. 1.43 x 10^4 cells/l) are present in it. The concentration of blue green alga Oscillatoria prolifica is only 2800 cells/l the ISQ of which is 50%. The class-wise contribution of algae in both total and nanoplankton given below projects the numerical predonderance of diatoms in the estuary during this period.

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	98.8	98.9
2.	Cyanophyceae	0.7	0.7
3.	Chlorophyceae	0.5	0.4

In August nine species representing three classes of algae Bacilariophyceae, Cyanophyceae and Chlorophyceae have been recorded. All these nine species appearing in the four different size groups give a standing crop of

1.53×10^6 cells/l (Table 9). Among the various size groups, the dominant one is SG.1 with a cell concentration of 1.44×10^6 cells/l which is 94.2% of the total standing crop. Out of the eight species present in the size fraction five species are of Bacillariophyceae, two species are of Cyanophyceae and one species belongs to the class Chlorophyceae. The diatoms present are 1.41×10^4 cells/l each of Biddulphia sinensis, Navicula hennedyii and Pleurosigma directum, 1.07×10^6 cells/l of Skeletonema costatum and 4.22×10^4 cells of Thalassiosira subtilis. The intraspecific quantity (ISQ) of the above diatoms are 100%, 49.3%, 100%, 100% and 85.6% respectively. Cyanophyceae includes two species, Merismopedia elegans (2.27×10^5 cells/l) and Synechococus aeruginossus (4.2×10^4 cells/l). Their ISQ in this size group are 100% and 42.4% respectively. Chlorophyceae is represented entirely by Chlamydomonas ohioensis. Next size fraction SG.2 is having a cell concentration of 2.90×10^4 cells/l with a percentage contribution of only 1.9% of the total standing crop. Only two species are present in this size group. They are the diatom species Navicula hennedyii (1.45×10^4 cells/l with ISQ of 50.7%) and the blue green alga Synechococcus aeruginossus (1.45×10^4 cells/l with ISQ of 14.6%). SG.3 also includes two species only, one each of Cyanophyceae and Bacillariophyceae. The blue green alga is Synechococcus aeruginossus (4.29×10^4 cells/l with ISQ of 43.1%) and the diatom is Thalassiosira subtilis (7100 cells/l) with ISQ of 14.4%). The standing crop of SG.3 is 5.00×10^4 cells/l the percentage of contribution is 3.3%. The larger size fraction is comprised of only a single species Oscillatoria prolifica of the class Cyanophyceae. All the 9500 cells/l are present in this size fraction, SG.4. This size group is numerically insignificant registering only 0.6% of the total standing crop. The contribution of the taxonomic classes of the algae Bacillariophyceae, Cyanophyceae, and Chlorophyceae in the total plankton and nanoplankton is given below:

TABLE 10

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
September	BACILLARIOPHYCEAE									
	Achnanthes exilis	-	-	-	-	-	-	6000	100.0	6000
	Amphora ovalis	1600	100.0	-	-	-	-	-	-	1600
	Fragilaria oceanica	23000	33.8	35000	51.5	10000	14.7	-	-	68000
	Navicula hennedyii	15000	18.0	33000	39.8	35000	42.2	-	-	83000
	Nitzschia closterium	50000	33.3	55000	36.7	45000	30.0	-	-	150000
	Skeletonema costatum	185000	23.9	405000	52.2	185000	23.9	-	-	775000
	Thalassiosira subtilis	45000	42.9	40000	38.1	20000	19.0	-	-	105000
	CYANOPHYCEAE									
	Merismopedia elegans	40000	10.1	185000	46.9	170000	43.0	-	-	395000
	Synechococcus aeruginossus	-	-	30000	100.0	-	-	-	-	30000
	CHLOROPHYCEAE									
	Chlamydomonas ohioensis	-	-	25000	65.8	13000	34.2	-	-	38000
	Chlorella sp	65000	100.0	-	-	-	-	-	-	65000
	Scenedesmus quadricauda	-	-	6000	60.0	-	-	4000	40.0	10000
	PYRROPHYCEAE									
	Peridinium depressum	-	-	6000	100.0	-	-	-	-	6000
		424600	24.5	820000	47.3	478000	27.6	10000	0.6	1732600
	Species diversity index	1		1.2		1.3		0.2		1.5

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	71.9	80.3
2.	Cyanophyceae	22.0	18.7
3.	Chlorophyceae	0.9	1.0

The standing crop of the planktonic primary producers during the month of September is 1.73 x 10^6 cells/l. They are distributed in thirteen species belonging to four taxonomic classes, Bacillariophyceae, Cyanophyceae, Chlorophyceae and Pyrrophyceae (Table 10). Out of these, seven species belong to the class Bacillariophyceae, two species to Cyanophyceae, three species to Chlorophyceae and one species to Pyrrophyceae.

SG.1 includes eight species of which six species are diatoms, one species each belong to the class Chlorophyceae and Cyanophyceae. The diatoms are 1600 cells/l of Amphora ovalis (ISQ = 100%), 2.30 x 10^4 cells/l of Fragilaria oceanica (ISQ = 33.8%),1.50 x 10^4 cells of Navicula hennedyii (ISQ = 0.1%), 5.00 x 10^4 cells of Nitzschia closterium (ISQ 33.3%), 1.85 x 10^5 cells/l of Skeletonema costatum (ISQ = 23.9%) and 4.50 x 10^4 cells/l of Thalassiosira subtilis (ISQ 42.9%). The Chlorophycean Chlorella sp. is 6.5 x 10^4 cells/l with ISQ of 100% and the Cyanophycean Merismopedia elegans is 4.00 x 10^4 cells/l with ISQ of 10.1%. SG.1 records a cell concentration of 4.25 x 10^5 cells/l contributing 24.5% of the total standing crop. SG.2 has the highest cell concentration of 8.20 x 10^5 cells/l contributing 47.3% of the total standing crop. This size fraction has ten species of which five species are diatoms, two species each belong to blue green and algae and one species belongs to the Pyrrophyceae. The diatoms are Fragilaria oceanica (3.5 x 10^4 cells/l), Navicula hennedyii

(3.30 x 10^4 cells/l) Nitzschia closterium (5.50 x 10^4 cells/l), Skeletonema costatum (4.05 x 10^5 cells/l) and Thalassiosira subtilis (4.00 x 10^4 cells/l). Their ISQs are 51.5%, 39.8%, 36.7%, 52.3% and 42% respectively. Cyanophyceae in this group includes two species Merismopedia elegans and Synechococcus aeruginossus with a cell concentration of 1.85 x 10^5 cells/l and 3.00 x 10^4 cells/l with the corresponding ISQ of 46.8% and 100%. Chlamydomonas ohioensis and Scenedesmus quadricauda are the green algae present in this size group. Their concentrations are 2.5 x 10^4 cells/l, 6000 cells/l respectively with the corresponding ISQ of 65.8% and 60%. SG.3 has seven species of which five species belong to the class Bacillariophyceae and one species each belongs to the class Chlorophyceae and Cyanophyceae. The Bacillariophycean species are Fragilaria oceanica (1.00 x 10^4 cells/l), Navicula hennedyii (3.50 x 10^4 cells/l), Nitzschia closterium (4.50 x 10^4 cells/l), Skeletonema costatum (1.85 x 10^5 cells/l) and Thalassiosira subtilis (2.00 x 10^4 cells/l). Their ISQs are 14.7%, 42.2%, 30%, 23.9% and 19% respectively. The Chlorophyceae is represented by 1.30 x 10^4 cells/l of Chlamydomonas ohioensis with an ISQ of 34.2% and the Cyanophyceae is represented by 1.70 x 10^5 cells/l of Merismopedia elegans with an ISQ of 43.0%. All these species distributed in SG.3 with their population density of 4.70 x 10^5 cells/l constitute 27.6% of the total standing crop. The large algal plankters of the size group SG.4 has 10,000 cells coming under two species. They are Achnanthes exilis of the class Bacillariophyceae with an ISQ of 100% and Scenedesmus quardricauda of Chlorophyceae with a cell concentration of only 4000 cells/l (ISQ - 40%). These two species together contribute only 0.6% of the standing crop. The taxonomic classes and their contribution to the total standing crop and nanoplankton are shown below:

T A B L E 11

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COCHIN ESTUARY

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
October	BACILLARIOPHYCEAE									
	Fragilaria oceanica	875000	50.0	375000	21.4	500000	28.6	-	-	1750000
	Navicula hennedyii	1750000	26.9	2000000	30.8	2750000	42.3	-	-	6500000
	Nitzschia closterium	125000	41.7	50000	16.6	125000	41.7	-	-	300000
	Pleurosigma directum	-	-	5000	100.0	-	-	-	-	5000
	Rhizosolenia robusta	-	-	-	-	375000	100.0	-	-	375000
	Skeletonema costatum	4250000	55.4	620000	8.1	2375000	31.0	425000	5.5	7670000
	Synedra salina	-	-	1375000	73.3	500000	26.7	-	-	1875000
	Thalassionema nitzschioides	-	-	200000	40.0	50000	10.0	250000	50.0	500000
	Thalassiosira subtilis	1250000	50.0	500000	20.0	750000	30.0	-	-	2500000
	CYANOPHYCEAE									
	Merismopedia elegans	1750000	100.0	-	-	-	-	-	-	1750000
	Oscillatoria prolifica	750000	16.7	2500000	55.5	1250000	27.8	-	-	4500000
	CHLOROPHYCEAE									
	Scenedesmus quadricauda	100000	66.7	-	-	50000	33.3	-	-	150000
		10850000	38.9	7625000	27.4	8725000	31.3	675000	2.4	27875000
	Species diversity index	1		1.2		1.3		0.2		1.5
November	Total plansatonic algae	756000	36.0	357000	17.0	378000	18.0	609000	29.0	2100000
December	Total plansatonic algae	27186000	92.0	147750	0.5	1329750	4.5	886500	3.0	29550000

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	68.7	75.3
2.	Cyanophyceae	24.7	9.4
3.	Chlorophyceae	6.5	15.3
4.	Pyrrophyceae	0.3	-

Table 11 shows the inter and intraspecific concentration of different planktonic algae during October. The standing crop of autotrophic plankters is 2.96×10^7 cells/l spread over 12 species belonging to the classes Bacillariophyceae, Cyanophyceae, and Chlorophyceae. 31.5% of the standing crop is the contribution of nanoplankters. This size group of SG.1 is comprised of eight species of which five are diatoms, two species are of Cyanophyceae and one species is of Chlorophyceae. The diatoms include 8.75×10^5 cells/l of Fragilaria oceanica (ISQ= 50.0%), 1.75×10^6 cells/l of Navicula hennedyii (ISQ = 26.9) 1.25×10^5 cells/l of Nitzschia closterium (ISQ = 41.7%), 4.25×10^6 cells/l of Skeletonema costatum (ISOQ = 29.8%) and 1.25×10^6 cells/l of Thalassiosira subtilis (ISQ = 50%). The blue green alga include 1.75×10^6 cells/l of Merismopedia elegans (ISQ = 100%) and 7.50×10^5 cells/l of Oscillatoria prolifica (ISQ = 16.7%). The only species of green alga is Scenedesmus quadricauda with a population density of 10×10^4 cells/l (ISQ = 66.7%). SG.2 contributes 22.1% of the standing crop with a population density of 7.63×10^6 cells/l. There are nine species in the fraction which includes eight species of diatoms and one species of blue green algae. The diatoms are 3.75×10^5 cells/l of Fragilaria oceanica (ISQ = 21.4%), 2.0×10^6 cells/l of Navicula hennedyii (ISQ = 30.8%), 5.0×10^4 cells/l of Nitzschia closterium

(ISQ = 16.7%), 5000 cells/l of Pleurosigma directum (ISQ = 100%), 6.20 x 10^5 cells/l of Skeletonema costatum (ISQ = 4.4%), 1.38 x 10^6 cells/l of Synedra salina (ISQ = 73.3%), 2.00 x 10^5 cells/l of Thalassionema nitzschiodes (ISQ = 40%) and 5.00 x 10^5 cells/l of Thalassiosira subtilis (ISQ = 20%). The blue green alga Oscillatoria prolifica has 2.50 x 10^6 cells/l with an ISQ of 55.6%. SG.3 shows ten species of planktonic algae belonging to the classes, Bacillariophyceae Cyanophyceae and Chlorophyceae. Bacillariophyceae includes eight species which are Fragilaria oceanica 5.00 x 10^5 cells/l (ISQ = 28.6%) 2.75 x 10^6 cells of Navicula hennedyii (ISQ = 42.3%), 1.25 x 10^5 cells/l of Nitzschia closterium (ISQ = 41.7%), 3.75 x 10^5 cells/l of Rhizosolenia robusta (ISQ = 100%), 2.38 x 10^6 cells/l of Skeletonema costatum (ISQ = 16.7%), 5.00 x 10^5 cells/l of Synedra salina (ISQ = 26.7%) and 7.50 x 10^5 cells/l of Thalassiosira subtilis (ISQ = 30%) The Cyanophycean species of Oscillatoria prolifica records a population density of 1.25 x 10^6 cells/l and its ISQ is 27.8%. Chlorophyceae is represented by Scenedesmus quadricauda the population density of which is 5.00 x 10^4 cells/l and the ISQ is 33.3%. This size fraction contributes 25.3% of the standing crop with a population density of 8.73 x 10^6 cells/l. SG.4 contributes only 2.1% of the standing crop with a population density of 7.00 x 10^5 cells/l. The distribution pattern of various taxonomic classes of algae are shown below:

Sl. No.	Class	Total plankton %	Nanoplankton %
1.	Bacillariophyceae	81.5	76.1
2.	Cyanophyceae	18.1	23.0
3.	Chlorophyceae	0.4	0.9

In November as indicated earlier the species variations of different size groups have not been ascertained. However the contribution of various size

TABLE 12

CHLOROPHYLL a CONCENTRATION OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE IN COCHIN ESTUARY AND THEIR PERCENTAGE OF CONTRIBUTION TO TOTAL CHLOROPHYLL a

Month	Chlorophyll a mg/m^3 SG.1	%	Chlorophyll a mg/m^3 SG.2	%	Chlorophyll a mg/m^3 SG.3	%	Chlorophyll a mg/m^3 SG.4	%	Chlorophyll a mg/m^3 Total
January	23.76	67.5	2.46	7.0	6.79	19.3	2.18	6.2	35.2
February	60.88	62.0	14.73	15.0	16.69	17.0	5.89	6.0	98.2
March	55.43	62.0	18.24	20.4	8.58	9.6	7.15	8.0	89.4
April	64.45	69.8	15.89	17.2	7.39	8.0	4.62	5.0	92.4
May	75.03	82.0	2.75	3.0	11.34	12.0	2.35	3.0	91.5
June	5.18	69.0	1.58	21.0	0.42	5.6	0.33	4.4	7.5
July	5.12	55.0	2.05	22.0	0.47	5.0	1.67	18.0	9.3
August	10.35	65.5	3.71	23.5	0.95	6.0	0.79	5.0	15.8
September	15.81	62.0	2.01	7.9	4.11	16.4	3.57	13.7	25.5
October	24.86	74.0	4.64	13.8	1.75	5.2	2.35	7.0	33.6
November	32.69	67.4	7.08	14.6	6.79	14.0	1.94	4.0	48.5
December	42.46	82.6	3.29	6.4	2.67	5.2	2.98	5.8	51.4

groups can be understood from their counts. SG.1 comprising of nanoplankton is the major size group with the cell concentration of 7.56 x 10^5 cells/l which is 36.0% of the total population of 2.10 x 10^6 cells/l. SG.2 is 17% with a population density of 3.57 x 10^5 cells/l, SG.3 is 18% with 3.78 x 10^5 cells and SG.4 contributes 29.0% with a population density of 6.09 x 10^5 cells/l.

In December the nanoplanktons play a very significant role in the total autotrophic population as evident from its population density (Fig. 6). The total population is 2.96 x 10^7 cells/l. Nanoplankton (SG.1) records 2.71 x 10^7 cells/l which is 92.0% of the total. The size fraction SG.2 is 0.5% of the total with a population density of 1.48 x 10^5 cells/l. The minimum cell concentration is observed in this size group. SG.3 is 4.5% of the total with a cell concentration of 1.33 x 10^6 cells/l and SG.4 is 3.0% with a population density of 8.87 x 10^5 cells/l.

In conclusion it may be seen that the maximum standing crop of 3.45 x 10^7 cells/l is recorded during October and the minimum of 1.93 x 10^5 cells/l in June. The maximum recorded for SG.1 (2.72 x 10^7 cells/l) is in December and the minimum of 5.72 x 10^4 cells/l is in June. The percentage contribution varies from 96.5% in July to 29.7% in June. SG.2 registers the maximum cell concentration of 7.63 x 10^6 cells/l in October and the minimum of 1.43 x 10^4 cells/l in June. The percentage contribution varies from 0.5% in December to 47.3% in September. SG.3 records the maximum standing crop of 8.73 x 10^6 cells/l during October and the minimum of 7100 cells/l in May. Their percentage contribution varies from 1.5% in July to 51.8% in June. In the size fraction, SG.4, the maximum cell concentration of 1.07 x 10^6 cells/l is obtained in January and the minimum of 9500 cells/l in August. The percentage of contribution of this size fraction ranges from 0.5% in July to 29.0% in November.

2. Chlorophyll a

Chlorophyll a concentrations of the various size groups SG.1, SG.2, SG.3 and SG.4 (Table 12) have been analysed here with reference to their population density (Fig. 10 and Fig. 5).

In January the chlorophyll a concentration is 35.2mg/m^3 for a population density of 1.53 x 10^7 cells/l. Maximum chlorophyll a as well as population density is observed for the size group SG.1 (nanoplankton). SG.1 has a chlorophyll a concentration of 23.76 mg/m^3 which is 67.5% of the total. The corresponding cell concentration is 79.0%. SG.2 records a chlorophyll a concentration of 2.46 mg/m^3 which is 7.0% of the total. The corresponding population density of SG.2 is 5.2%. SG.3 records a chlorophyll a concentration of 6.79 mg/m^3 which is 19.3% of the total chlorophyll. The corresponding contribution in respect of population is 8.8%. SG.4 has a chlorophyll a concentration of 2.15 mg/m^3 which 6.2% and the corresponding percentage contribution of cell numbers is 7.0%.

During February the total chlorophyll a concentration is 98.2 mg/m^3. The maximum value of chlorophyll a among the various size fractions is 60.88 mg/m^3 which is recorded by SG.1. This is 62.0% of the total chlorophyll as against the corresponding population density of 77.9%. In SG.2 the chlorophyll a concentrationis14.73 mg/m^3 with a percentage contribution of 15.0%. Almost identical value of 15.5% is the contribution of the SG.2 as indicated by the density of population. SG.3 has chlorophyll a concentration of 16.69 mg/m^3 which is 17% of the total. But the low percentage contribution of 2.6% in respect of population density for the corresponding period is incongruous. This may be due to disparity in the magnitude of chlorophyll content of species occuring at the

particular period. This may be due to the disparity in the magnitude of chlorophyll content of unit number of cells of Synechocystis salina. The size fraction SG.4 with a population density of 4.0% gives chlorophyll a concentration of 6.0% (5.89 mg/m^3) of the total.

In March the total chlorophyll a concentration is 89.4 mg/m^3. SG.1 contributes the maximum with 55.43 mg/m^3, SG.2 has 18.24 mg/m^3, SG.3 has 8.58 mg/m^3 and SG.4 has 7.15 mg/m^3. In SG.1 the percentage contribution of chlorophyll a is 62.0% as against the corresponding value of 62.1% in respect of cell numbers. In SG.2 the percentage contribution of chlorophyll is 20.4% as against the corresponding value 10.4% in respect of cell concentration. In SG.3 the values are 9.6% for chlorophyll a and 16.7% for cell counts. In SG.4 the corresponding values are 8.0% for chlorophyll a and 10.8% for cell concentration.

In April 92.4 mg/m^3 is the total chlorophyll a concentration. Out of this 64.45 mg/m^3 is the contribution of nanoplankton, 15.89 mg/m^3 belongs to SG.2, 7.39 mg/m^3 belongs to SG.3 and 4.62 mg/m^3 belongs to SG.4. The percentage contribution of chlorophyll a of SG.1, SG.2, SG.3 and SG.4 are 69.8%, 17.2%, 8.0% and 5.0% respectively. These chlorophyll a values expressed in percentage are derived from different groups of algal plankters composed of 63.4% of SG.1, 16.1% of SG.2, 16.5% of SG.3 and 4.0% of SG.4.

In May the total chlorophyll a concentration is 91.50 mg/m^3. This is obtained from 2.60×10^5 cells/l. SG.1 records 75.03 mg/m^3 which is 82.0% of the total chlorophyll a. SG.2 gives 2.75 mg/m^3 of chlorophyll a with percentage contribution of 3.0%. The chlorophyll a concentration of SG.3 is 11.34 which is 12% of the total chlorophyll a. SG.4 gives 2.35 mg/m^3 of chlorophyll a the percentage contribution of which is 3.0%.

During June the chlorophyll a concentrations are of low magnitude because of the unfavourable ecophysiological conditions. SG.1 registers chlorophyll a concentration of 5.18 mg/m^3, SG.2 has 1.58 mg/m^3, SG.3 has 0.42 mg/m^3 and SG.4 has 0.33 mg/m^3; their values of percentage composition are 69.0%, 21.0%, 5.6% and 44.0% respectively. The corresponding values in respect of population density are 29.7%, 7.4%, 51.8% and 11.1% respectively. The anomaly could be accountable to the difference in chlorophyll concentration per unit number of cells of the constituent populations.

In July total chlorophyll a concentration is 9.3 mg/m^3. This is a comparatively low value considering the population density of 1.14 x 10^7 cells/l. Out of this 1.08 x 10^7 cells/l belong to a single species Skeletonema costatum. So during this period large number of planktonic algae is due to the bloom of Skeletonema costatum. But towards the later phases of blooming, the cells become physiologically inactive and the photosynthetic pigments get degraded. This may be the reason why chlorophyll a does not show corresponding increase in tune with the increase of cells. During this period the maximum chlorophyll a of 5.12 mg/m^3 is observed for SG.1. This is 55% of the chlorophyll as against 96.5% of the cell counts in this size group. SG.2 records a chlorophyll concentration of 2.05 mg/m^3. This forms 22.0% as against the corresponding value of 1.5% with regard to population density. SG.3 has chlorophyll a concentration of 0.47 mg/m^3. This forms 5.6% as against 1.5% of cell numbers of the same size group. SG.4 has chlorophyll a concentration 1.67 mg/m^3 which forms 18.0% of the total chlorophyll a. The corresponding percentage contribution of cell number is only 0.5%. This wide difference is probably due to the difference in the species composition in the various size groups.

During August the total chlorophyll a concentration is 15.8 mg/m^3 and the population density is 1.53 x 10^6 cells/l. Both chlorophyll a and the cell count shows maximum percentage contribution of SG.1. The difference is only in the magnitude. In SG.1 chlorophyll a concentration is 10.35 mg/m^3, which is 65.5% of the total. Corresponding percentage composition of cell counts is 94.2%. SG.2 records a chlorophyll concentration of 3.71 mg/m^3. This is 23.5% as against 1.9% which is the corresponding percentage contribution of cell counts. In SG.3 the chlorophyll a concentration is 0.95 mg/m^3 which is 6.0% of the total chlorophyll a. This is in contrast to 3.3% of cell number in the same size group. SG.4 records chlorophyll a concentration of 0.79 which is 5.0% of the total chlorophyll a. The corresponding value of cell numbers is only 0.6%.

In September the chlorophyll a concentration of 1.73 x 10^6 cells/l is found to be 25.5 mg/m^3. It may be noted that the contribution of chlorophyll in SG.1 is 62.0% as against 24.5% which is the corresponding value of cell counts. In SG.1 the chlorophyll concentration is 15.81 mg/m^3. SG.2 records chlorophyll a concentration of 2.01 mg/m^3 which is 7.9%. This is in contrast to 47.3% of the population density in this group. In SG.3 the photosynthetic pigment is 4.11 mg/m^3 with a percentage contribution of 16.4%. The corresponding numerical contribution of algal plankton in this size group is 27.6%. SG.4 records a chlorophyll concentration of 3.57 mg/m^3 which is 13.7% of the total chlorophyll a. The corresponding cell concentration is only 0.6%.

In October the total chlorophyll a concentration is 33.6 mg/m^3 and the population density is 3.45 x10^7 cells/l. Maximum chlorophyll a concentration of 24.86 mg/m^3 is recorded in SG.1. This forms 74.0% of the total chlorophyll a. The corresponding percentage of cell counts is 31.5%. Here also the disproportionate chlorophyll a values and cell counts may be due to the characteristics

of the syn-specific blooms comprised of several species such as Merismopodia elegans, Navicula hennedyii, Skeletonema costatum and Thalassiosira subtilis. Chlorophyll concentration varies with the phases of the bloom. The death phase, infact, shows inverse relationship between cell counts and chlorophyll. In SG.2 the chlorophyll a concentration is 4.64 mg/m^3 which is 13.8% of the total chlorophyll concentration. The corresponding value of the cell concentration is 22.1%. In SG.3 the chlorophyll a is 1.75 mg/m^3. The percentage contribution of chlorophyll a in SG.3 is 5.2% and the corresponding percentage contribution of population density is 25.3%. SG.4 records chlorophyll a concentration of 2.35 mg/m^3, the percentage contribution being 7.0%. The corresponding value in respect of cell counts is 2.1%.

In November the total chlorophyll a concentration is 48.5 mg/m^3 and the total cell counts 2.10 x 10^6 cells/l. Maximum chlorophyll a concentration of 32.69 mg/m^3 is recorded for the size group SG.1. This is 67.4% of the total chlorophyll a. The nanoplankton cell numbers are only 36.0% (Fig. 13). SG.2 of the microplankton registers a chlorophyll concentration of 7.08 mg/m^3 which is 14.6% of the total chlorophyll. The corresponding contribution of cell numbers is 17.0%. SG.3 has a chlorophyll concentration of 6.79 mg/m^3 which is 14.0% of the total. This value of chlorophyll a represents 18.0% of planktonic algae of the same size fraction. In SG.4 the chlorophyll a value of 1.94 mg/m^3 is 4.0% of the total chlorophyll (Fig. 7). The corresponding percentage contribution of the size group expressed in population density is 29.0%.

In December the total chlorophyll a concentration is 51.4 mg/m^3 and the population density is 2.96 x 10^7 cells/l. 82.6% of the total chlorophyll a is represented in the nanoplankton which constitute 92.0% of the planktonic

algae (Fig. 15). In SG.2 the chlorophyll a concentration 3.29 mg/m^3 is 6.4% of the total. The corresponding cell count is 0.5%. In SG.3 the primary photosynthetic pigment is 2.67 mg/m^3 which is 5.2% of the total pigments. In this size group 4.5% of the planktonic algae are present. In SG.4 the chlorophyll a concentration is 2.98 mg/m^3 the percentage contribution of which is 5.8%. This 5.8% of the chlorophyll a is the product of 3.0% of the total planktonic algae.

Thus it can be seen that the chlorophyll a concentration is not always directly proportional to the cell counts (Fig. 9 & 12). The chlorophyll concentration of population varies with the species and also with the phases of their growth. The species variation as well as the physiological state of the alga to a large extent determinesthe quantitative variation of chlorophyll a.

3. Productivity

The productivity of the various size groups are given in Table 13. In January the total primary organic production is 223.52 mg C/m^3/day This is the product of photosynthesis for 35.2 mg/m^3 of chlorophyll in 1.53 x 107 cells of plankton algae/l. Among the different size groups maximum production is observed in SG.1. The production estimated is 174.30 mg C/m^3/day, which is 78.0% of the total production. During this period both the cell counts and chlorophyll concentration are also found to be maximum in the size fraction. The nanoplankton cell counts are 79% and the chlorophyll a is 67.5%. In SG.2 the production is 15.65 mg C/m^3/day which is 7.0% of the total (Fig.11). The corresponding cell counts and chlorophyll a values are 5.2%, 7.0% respectively. In SG.3 the primary productivity is 29.1 mg/C/m^3/day which is 13.0% of the total production (Fig. 8). This is synthesised by 19.3% of the chlorophyll of 8.8% of the planktonic algae. SG.4 records a production of 4.47 mg C/m^3/day which

is only 2.0% of the total primary organic production. The corresponding value of cell counts is 7.0% and chlorophyll a is 6.2%. Thus during the period the major contribution is by the nanoplankton and the minimum is recorded by the microplankton of the size group SG.4.

In February the total productivity is 110.30 mg/C/m^3/day. This is the product of 1.76 x 10^6 cells/l of the planktonic algae, the chlorophyll concentration of which is 98.2 mg/m^3. During this period the maximum production is observed in the SG.1, which is 91% of the total. This considerably high production is supported by 77.9% of cells and 62.0% of chlorophyll a. The microplankton of SG.2 records a production rate of 3.97 mg C/m^3/day which is 3.6% of the total production. This is the contribution of 15.0%. The corresponding values for cell counts is 15.5% and that of chlorophyll a is 15.0%. The productivity of SG.3 is 3.75 mg C/m^3/day which is 3.4% of the total production. The corresponding value in respect of cell counts is 2.6% and that of chlorophyll a is 17.0%. In SG.4 the production recorded is 4.47 mg C/m^3/day which is 2.0% of the total production of 223.52 mg C/m^3/day. 7.0% of the planktonic algae of this size group having 6.0% of the total chlorophyll have contributed 2.0% of the total production.

In March 458.50 mg C/m^3/day is the total production for all the size groups. This is the contribution of 4.10 x 10^6 cells/l of algal plankton with their chlorophyll a concentration of 89.4 mg/m^3. Maximum production is recorded in the size group SG.1. Here the production is 394.31 mg C/m^3/day which is 86.0% of the total production. This high percentage of production is the contribution of 62.1% of the planktonic algae which are distributed in this size group. The corresponding value of chlorophyll a concentration is 62.0%.

In SG.2 the production recorded is 18.34 mg C/m^3/day which is 4.0% of the total production. The percentage contribution of population density is 10.4% and that of chlorophyll a concentration is 20.4%. In SG.3 the production of 20.63 mg C/m^3/day is observed which is 4.5% of the total production. Corresponding percentage contribution of cell numbers is 16.7% and that of chlorophyll a is 4.5%. The larger microplanktons of the size group SG.4 with their 10.8% of the planktonic algae and 8.0% of the chlorophyll a synthesised 25.22 mg C/m^3/day which is 5.5% of the total production.

In April the primary organic production of all the size groups of algae is 225.40 mg C/m^3/day. Corresponding cell concentration is 5.30 x 10^5 cells/l and chlorophyll a concentration is 92.4 mg/m^3. Maximum production of 130.73 mg C/m^3/day is obtained for the nanoplankton. This is 58.0% of the total production. Corresponding percentage contribution of population density is 63.4% and that of chlorophyll a is 69.8%. Microplankton of the size group SG.2, the percentage contribution of which is 16.1% with chlorophyll a concentration of 17.2% synthesised 13.52 mg C/m^3/day. This is 6.0% of the total production. Production of the size group SG.3 is 27.05 mg C/m^3/day which is 12.0% of the total production. The percentage contribution of the cell numbers of the size group is 16.5% and that of chlorophyll a is 8.0%. The microplankters of the size group SG.4 synthesized 54.10 mg C/m^3/day which is 24.0% of the total production. The percentage contribution of population-density and the primary photosynthetic pigment of this size fraction are 4.0% and 5.0% respectively.

In May the primary producers with their cell concentration of 2.60 x 10^5 cells/l having chlorophyll a concentration of 91.5 mg/m^3 produced 310.20 mg C/m^3. Among the various size fractions maximum production of 241.96 mg C/m^3/day is observed in SG.1. The percentage contribution of cell numbers of this

TABLE 13

PRIMARY PRODUCTIVITY OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE IN COCHIN ESTUARY AND THEIR PERCENTAGE OF CONTRIBUTION TO TOTAL PRODUCTION

Month	Production mg $C/m^3/d$ SG.1	%	Production mg $C/m^3/d$ SG.2	%	Production mg $C/m^3/d$ SG.3	%	Production mg $C/m^3/d$ SG.4	%	Total Production mg $C/m^3/d$
January	174.30	78.0	15.65	7.0	29.10	13.0	4.47	2.0	223.52
February	100.37	91.0	3.97	3.6	3.75	3.4	2.21	2.0	110.30
March	394.31	86.0	18.34	4.0	20.63	4.5	25.22	5.5	458.50
April	130.73	58.0	13.52	6.0	27.05	12.0	54.10	24.0	225.40
May	241.96	78.0	31.02	10.0	4.65	1.5	32.57	10.5	310.20
June	33.64	58.0	4.64	8.0	11.02	19.0	8.70	15.0	58.00
July	48.13	64.0	9.78	13.0	6.02	8.0	11.28	15.0	75.20
August	113.49	78.0	7.28	5.0	2.91	2.0	21.83	15.0	145.50
September	172.97	83.0	10.42	5.0	16.67	8.0	8.34	4.0	208.40
October	245.95	64.0	61.49	16.0	30.74	8.0	46.12	12.0	384.30
November	299.38	44.0	115.67	17.0	129.28	19.0	136.08	20.0	680.40
December	1138.87	84.0	94.91	7.0	67.79	5.0	54.23	4.0	1355.80

size fraction is 49.5% and that of chlorophyll a is 82.0%. The nanoplankton production of 241.96 mg C/m^3/day forms 78.0% of the total production. The next size group of SG.2 produces 31.02 mg C/m^3/day which is 10% of the total production. The percentage contribution of the cells of this size group is 44.1% and the corresponding value with regard to the chlorophyll a is 3.0%. The microplanktonic size group of SG.3 contributes only 1.5% of the total production which is 4.65 mg C/m^3/day. Population density of this size group is 2.7% and the chlorophyll a is 12.0%. SG.4 contributes 10.5% of the total production which is 32.57 mg C/m^3/day. Their cell numbers form 3.7% with chlorophyll a contribution of 3.0%.

The lowest production recorded is in June. This is probably due to the sudden ecophysical changes initiated by the onset of monsoon. During this period the total production drops to 58.00 mg C/m^3/day which is the photosynthetic product of 1.93 x 10^5 cells/l of planktonic algae of different size having chlorophyll concentration of 7.5 mg/m^3. Inspite of low magnitude in cell numbers, chlorophyll and production the nanoplankton stand out as the major producers. 58% of the total production (33.64 mg C/m^3/day) is the contribution of nanoplankters. Though nanoplankters form only 29.7% of the total algae plankters numerically they contribute 69% of the total chlorophyll a concentration. SG.2 contributes 4.64 mg C/m^3/day which is 8.0% of the total. The corresponding contributions of cell numbers and chlorophyll a in this group are 7.4% and 21.0% respectively. SG.3 contributes 19.0% (11.02 mg C/m^3/day) of the total production. This size group constitutes 51.8% of the total population density and 5.6% of the chlorophyll a. The contribution of the size group SG.4 is 8.70 mg C/m^3/day which amounts to 15.0% of the total production. The population density of this size group is 11.1% of the total planktonic algae which

gives a chlorophyll a contribution of 4.4%.

In July though there is an increase in the number of algal plankters, the magnitude of chlorophyll a concentration and production is almost same as that in June, which could perhaps be accounted to the lower radiation level due to cloud cover bringing down the rate of photosynthesis considerably at the surface and a proportionate reduction of photic zone. The total primary production during this period is 75.20 mg C/m^3/day. The total cell counts are 1.14 x 10^7 cells/l which is the contribution of a single species Skeletonema costatum. The absence of proportionate increase of chlorophyll a with the number of Skeletonema costatum cells indicate that the chlorophyll a present in the cells could be in the degraded state. Even in this highly dynamic situation caused by the bloom the nanoplankters are the major producers. Maximum production of 48.13 mg C/m^3/day (64.0%) is recorded in the size group SG.1. Corresponding cell concentration is 96.5% and chlorophyll is 55.0%. SG.2 contributes 13.0% (9.78 mg C/m^3/d) of the total production. The algal plankters of this size is 1.5% and the chlorophyll a concentration is 22.0% of the total. SG.3 contributes 8.0% (6.02 mg C/m^3/day) of the total primary organic production. The algal plankters constitute 1.50% and the chlorophyll a is 5.0%. SG.4 contributes 11.28 mg C/m^3/day of the total production. The percentage contribution of cell counts, chlorophyll a concentration and production are 0.5%, 18.0% and 15.0%. These figures are indicative of the high chlorophyll a concentration and production potential of the primary producers occuring under the size group SG.4.

During August the total primary organic production recorded is 145.50 mg C/m^3/day. The corresponding population density and chlorophyll a concentration are 1.53 x 10^7 cells/l and 15.8 mg/m^3 respectively. Nanoplankters are found to be the major primary producers as evident from the magnitude of cell counts, chlorophyll a concentration and production. Maximum production of

113.49 mg C/m^3/day is 78.0% of the total and their cell counts and chlorophyll a concentration are 94.2% and 65.5% respectively. The other size groups are apparently of lesser significance. In SG.2 the production is 7.28 mg C/m^3/day which is only 5.0% of the total primary production. The cell concentration of this size group is 1.9% of the total and the chlorophyll a concentration is 23.5%. The productivity of SG.3 is only 2.91 mg C/m^3/day which is 2.0% of the total. Cell concentrations of this size group is 3.3% and the chlorophyll a is 6.0%. SG.4 contributes 21.83 mg C/m^3/day which is 15.0% of the total primary production. The corresponding cell counts and chlorophyll a are 0.6% and 5.0% respectively.

The total primary organic production during September is 208.4 mg C/m^3/day. The total cell counts are 1.73×10^6 cells/l and the total chlorophyll a is 25.5 mg/m^3. SG.1 contributes 172.97 mg C/m^3/day which is 83.0% of the total production. Corresponding percentage contribution of cell counts is 24.5% and that of chlorophyll a is 62.0%. The productivity of the size group SG.2 is 10.42 mg C/m^3/day which is 5.0% of the total production. Cell counts of this size group gives a percentage contribution of 47.3%. This is the only instance where this size group gains dominance over SG.1 either in cell numbers or in chlorophyll or in production. In this size group chlorophyll a concentration is merely 7.9%. SG.3 contributes 16.67 mg C/m^3/day out of the total production of 208.4 mg C/m^3/day. The percentages of contribution of SG.3 in respect of cell counts, chlorophyll a and production are 27.6%, 16.4% and 8.0% respectively. 0.6% of the planktonic algae, 13.7% of the total chlorophyll a and 4.0% of the total primary production are confined to the group SG.4.

During October the total production for all the size groups is 384.30 mg C/m^3/day. The total cell counts of planktonic algae are 3.45×10^7 cells/l and that

of chlorophyll a is 33.6 mg/m^3. Among the various size groups the maximum production is recorded in the size group SG.1. Production of 245.95 mg C/m^3/ day form 64.0% of the total. The cell counts of the size group is 31.5% and the chlorophyll a value is 74.0%. SG.2 records a production of 61.49 mg/m^3/day which is 16.0% of the total production. The cell concentration of the SG.2 is 22.1% of the total and chlorophyll a concentration of the size group is 13.8% of the total. SG.3 contributes 25.3% of cell numbers, 5.2% of chlorophyll and 8.0% of the total production. SG.4 records 46.12 mg C/m^3/day which is 12.0% of the total primary production. The percentage contribution of cell counts and chlorophyll a concentration are 2.1% and 12.0% respectively during this period.

The total productivity in November is 680.40 mg C/m^3/day and the cell counts are 2.10 x 10^6 cells/l with their chlorophyll a concentration of 48.5 mg/m^3. Nanoplankters record the maximum of population density, chlorophyll a and productivity, their values being 36.0%, 67.4% and 44.0% respectively. SG.2 records 115.67 mg C/m^3/day which is 17.0% of the total production. The cell concentration of the size group SG.2 is 17.0% of the total while chlorophyll a is 14.6%. The percentage contribution of SG.3 with respect to cell numbers, chlorophyll a concentration and production are 18.0%, 14.0% and 19.0% respectively. SG.4 includes 29.0% of the population density, 4.0% of the chlorophyll a and 20% of the total production.

In December the primary organic production for all the groups is estimated to be 1355.80 mg C/m^3/day which is the maximum value recorded in the estuary during the year. The algal plankters are found to be about 2.96 x 10^7 cells/l. The chlorophyll a concentration is 51.4 mg/m^3. The dominant contribution of the nanoplankton in the estuarine productivity is evident from the numerical pre-

ponderance, higher magnitude of chlorophyll a concentration and productivity (Fig. 14 & 16). Nanoplankton productivity is 1138.87 mg C/m^2/day which is 84.0% of the total primary production. The nanoplankters constitute 92.0% of the total planktonic algae and the chlorophyll a concentration is 82.6%. The cell counts, chlorophyll a and productivity of SG.2 expressed in percentage of the total are 0.5%, 6.4% and 7.0% respectively. SG.3 has 4.5% of the total population, 5.2% of chlorophyll a and 5.0% of the total production. The higher size group of the microplankters SG.4 constitutes only 3.0% of the total algal plankters. Their chlorophyll a concentration is 5.8% and they contribute 4.0% of the primary organic production during this period in the estuary.

DISCUSSION

This is an attempt to understand the species composition of various size fractions of algal plankton and their contribution to the total organic production in Cochin estuary. This study, is advantageous in predicting the type of fishery resources. Though the estuary has been investigated for several parameters such as hydrography (Ramamritham and Jayaraman, 1963) plant pigments (Qasim and Reddy, 1967) penetration of the solar radiation (Qasim et al. 1968), Organic production (Qasim et al. 1969) and influence of salinity on the abundance of some phytoplankton (Qasim et al. 1972) etc. such a study on the size wise species composition and their contribution in the total density of planktonic algae,chlorophyll 'a' concentration and primary production has not been attempted. Qasim et al. (1974) studied the contribution of microplankton and nanoplankton in the estuary without indicating the species composition. Rut Kova (1981) studied the size distribution of phytoplankton in the Peru current region. He observed small forms predominate in the areas of most rapid water movement. An increase in population of larger forms is noted in divergence areas while smaller forms predominate in convergence zone. According to Malone (1971 a) it is clear that 80-100% of the total organic production in the sea is contributed by small forms or nanoplankton which pass through the net made of finest mesh as compared to microplankton, or net plankton, which are larger and normally retained by the apertures of the net, (Yentsch 1959, Andersen 1965). George (1958) gave a general account on the species composition, while Gopinathan (1972) has discussed seasonal abundance of phytoplankters in Cochin backwater. Krishnamurthy and Purushothaman (1971) recorded high and variable phytoplankton

crops (as plant pigment) in the Vellar estuary. Describing the flora of three stations in the estuary they found that the diatoms are the major flora. Peridinium, Pyrocystis and Ceratium were the abundant dinoflagellates in the estuary. Kannan and Krishnamurthy (1985) studied the biogeography of 86 spp. of neritic diatoms, recorded from coastal environmentofPorto Novo. Gopinathan (1972) studying the qualitative and quantitative distribution of the algal plankton in the Cochin backwater confirmed maximum abundance of the crop during the monsoon. Qasim et al. (1974) analysing the contribution of microplankton and nanoplankters in the estuary recorded that about 74.5% of the total production can be attributed to nanoplankton.

In the present study all the planktonic algae below 60 µm in size are considered as nanoplankton though several fractions of still smaller size called ultraplankton <5 µm) and picoplankton (1 µm) are also known. Since the original definition of nanoplankton referred to those organisms normally not retained by the 'finest' (No.25) silk net, of normal aperture size 60 µm, or, according to Harvey, 50x40 µm, the maximum diameter of nanoplankton cells would be of the order of 50 or 60 µm. Many of the algal species are 2-3 µm in diameter or even less. From these smaller forms, to forms of size 50 or 60 µm are included in nanoplankton. To day, nets of much smaller mesh dimensions (20-30 µm) are available, permitting further fractionation of the plankters. Some authorities suggest separating the very smallest cells (<5 µm) as "ultra plankters" and to limit the nanoplankton to algae not exceeding 30 µm. Dussart suggests nanoplankton organisms are in the range 2-20 µm, but limits cannot be precise (Raymont 1980). Larson and Hagstrom (1982) studied the distribution of phytoplankton primary production into four size fractions (10 µm, 10-3 µm, 3-0.2 µm and 0.2 µm) in a eutrophication gradient in the northern Baltic. A substantial fraction

of the primary production occurs in the size fraction 3 μm. The primary production encountered in the 3-0.2 μm was due to abundant picoplankton. The picoplankton was estimated to constitute upto 25% of the total phytoplankton biomass in the control area and upto 10% in the eutrophicated area.

The present work gives the species composition and size fractions of algal plankton and their contribution to the total density, chlorophyll 'a' concentration and productivity in the estuary. The study of species composition of the various size groups of planktonic algae is very significant, as many herbivores exhibit considerable selectivity in 'diet'. A suitable density of food organism of the right type at the appropriate time may be very important for the survival of a brood of zooplankton. Assuming that the timing of production of a new stock of fish larvae is more or less fixed, its measure of success as a year brood is largely dependent on a favourable food supply, usually particular zooplankton species (Raymont 1980). The appropriate type of zooplankton food for the fish larvae is developed from a suitable algal crop in a sufficient quantity by the critical time.

Altogether thirty one species are recorded from this particular area of observation of which the major contribution is that of Bacillariophyceae with twenty species. Dinophyceae is represented by three species, Cyanophyceae with four species, Chlorophyceae with three species and Prasinophyceae with one species. These diverse species of divergent classes serve as a good source of adequate food for the herbivores that exhibit selectivity in diet. Gopinathan (1972) recorded seventy four diatom species from the entire estuary. The present observation of thirty one species including twenty species of diatoms are from a single area of observation, spatial fluctuation not affecting the floristic composition.

Maximum species diversity is noted during March, index of diversity being 2.3 and 50.0% of the total number of species recorded is in this month. In March the algal flora consist of eleven species of Bacillariophyceae, two species of Dinophyceae and one species of Prasinophyceae. Minimum number of species recorded is six which is in May and June with diversity indices of 0.9 and 1.0 respectively. In both cases all are diatoms except the single species of blue green alga Oscillatoria prolifica. Hulburt (1963) described some algal flora, exhibiting marked differences in diversity. During spring and summer near Bermuda, he found that the poor nutrient conditions limited growth so that species, which at another season could be dominant, formed only a moderate proportion of the cells counted in samples. In coastal waters the maximum species diversity observed is 1.7 which is in April. Here a total of number of eleven species are recorded where all the species are diatoms except Oscillatoria prolifica of the class Cyanophyceae and Peridinium depressum of the class Dinophyceae. The lowest diversity index of 0.6 is obtained in January where all the four species present are diatoms. Thus in both estuary and coastal waters the species indices observed are low. The high species diversity values for oligotrophic regions, typically open tropical oceans, as contrasted with the low diversity of eutrophic areas leads to the question whether the differences in diversity are in part a reflection of nutrient limitation on species.

On analysing the size-wise composition of the floristic spectrum it is found that diatoms are frequently found distributed in various size groups because of the characteristic cell division in which the size of one generation is gradually getting reduced and the auxospore formation, in which the cell is regained to its original size, characteristic of each species. But in the present study it is observed that a few diatom species such as Chaetoceros lorenzianus, Surirella

fluminensis, Rhizosolenia alata, Cerataulina bergonii, Synedra salina, Achnanthes exilis and dinoflagellates such as Prorocentrum micans and Gymnodinium sp. found distributed among the various size groups of microplankton are not represented among nanoplankton. This may be either due to the fact that these species have not reached the minimum size, characteristic of the species by repeated cell division by which one of the generations is getting reduced in size or their minimum size is above 60 µm.

Among the various size groups of algal plankton the nanoplankters are found to be the major flora in the estuary. Their contribution to the total density of population, chlorophyll 'a' concentration and primary organic production are quite comparable and are found almost complimentary. They form average 70.7% of the total floristic composition with a maximum value of 95.7% in July. The average population density of nanoplankton is 5.68×10^6 cells/l with an average species diversity index of 0.9. In July, the month of highest nanoplankton concentration (1.1×10^7 cells/l) has species diversity index of 0.9. During this month the single species of Skeletonema costatum alone has the density of about 1.05×10^7 cells, and 96.8% of this species is seen in this size group. 1.5% of the species is represented in 60-75 µm size group, 1.6% in 76-99 µm size group and only 0.1% in the size group >99 µm. This is an instance where a single species is distributed among various size groups. The maximum diversity of species among nanoplankton is observed in the month of March, the index being 1.6 with a population density of 2.5×10^6 cells/l. The maximum diversity of species among the total planktonic algae also is during this month, the index being 2.3 which represent 16 species. Nanoplankters are always not the major flora among the planktonic algae as observed in the case of coastal region under observation.

Hence their contribution is only 14.9% of the total planktonic algae with an average density of 9.0 x 10^5 cells/l. The maximum nanoplanktonic population in the region is 37.3%, which is in the month of June, with species diversity index of 0.9. In coastal waters at this time the nanoplankton has an average index of 0.7 representing species diversity with an average population of 9.1 x 10^5 cells/l. The average index of species diversity for the total planktonic algae in the coastal region is 1.3 with an average total population of 6.1 x 10^6 cells/l. The maximum value of diversity index among this marine environment is 1 which is in September representing 1.5 x 10^6 cells/l found distributed among 12 species. During this month the maximum number of cells is contributed by the dinoflagellate Prorocentrum micans which actually forms only 15.7% of the total concentration of this species. 54.1% of the total number 9.3 x 10^6 cells/l is observed in 60-75 μm size group and the entire balance of 30.3% is seen in the next 76-99 μm size group. The maximum diversity index of the total planktonic algae of the coastal waters is 1.7 with a population density of 5.5 x 10^5 cells/l. Here there are only 11 species.

The estuarine nanoplankton contribute 69.5% of the total chlorophyll 'a' in the estuary. The average total chlorophyll 'a' concentration observed in the present study is 49.9 mg/m^3. This is a very high value compared to the earlier study covering the entire estuary extending from Alleppey in the south to Azhikode in the north. There the average value of chlorophyll 'a' varies from 3.3 mg/m^3 in the post-monsoon to 13.9 mg/m^3 in the monsoon, its value in the premonsoon being 9.1 mg/m^3. The maximum single value recorded there is 37.5 mg/m^3 at station 5 in August. The coastal water under observation also gives high value of chlorophyll 'a' 41.3 mg/m^3 which is 62.9% of the total chlorophyll 'a' in the environment. Narain (pers. comm.) observed chlorophyll 'a' concen-

tration of 6.4 mg/m^3 during October, 1.7 mg/m^3 in November and 1.4 mg/m^3 in December. Irrespective of the population density and chlorophyll 'a' concentration both the estuarine and marine areas under study, contribute very much to the organic production in the concerned ecosystem. In estuary 73.0% of the total organic production is claimed by nanoplankton whereas in the coastal region the nanoplankton production is 62.6% of the total. In this estuarine station the average production of nanoplankton is 257.8 mg C/m^3/day, the total production being 353.0 mg/C/m^3/day. The productivity in the estuary shows wide variation with space and time. Thus from the earlier observation it is found that the productivity varies from 0.24 mg C/m^3/hr to 242.5 mg C/m^3/hr. (Chapter 6). The average productivity of the entire estuary estimated from three years data is about 47.00 mg C/m^3/hr. (Chapter 6). The present study reveals that 73.0% of this total production is the contribution of nanoplankton.

The study on the coastal waters indicates that 62.6% of the total production of 50.3 mg C/m^3/day i.e. 31.5 mg C/m^3/day is synthesised by the autotrophic plankton of less than 60 μm in size.

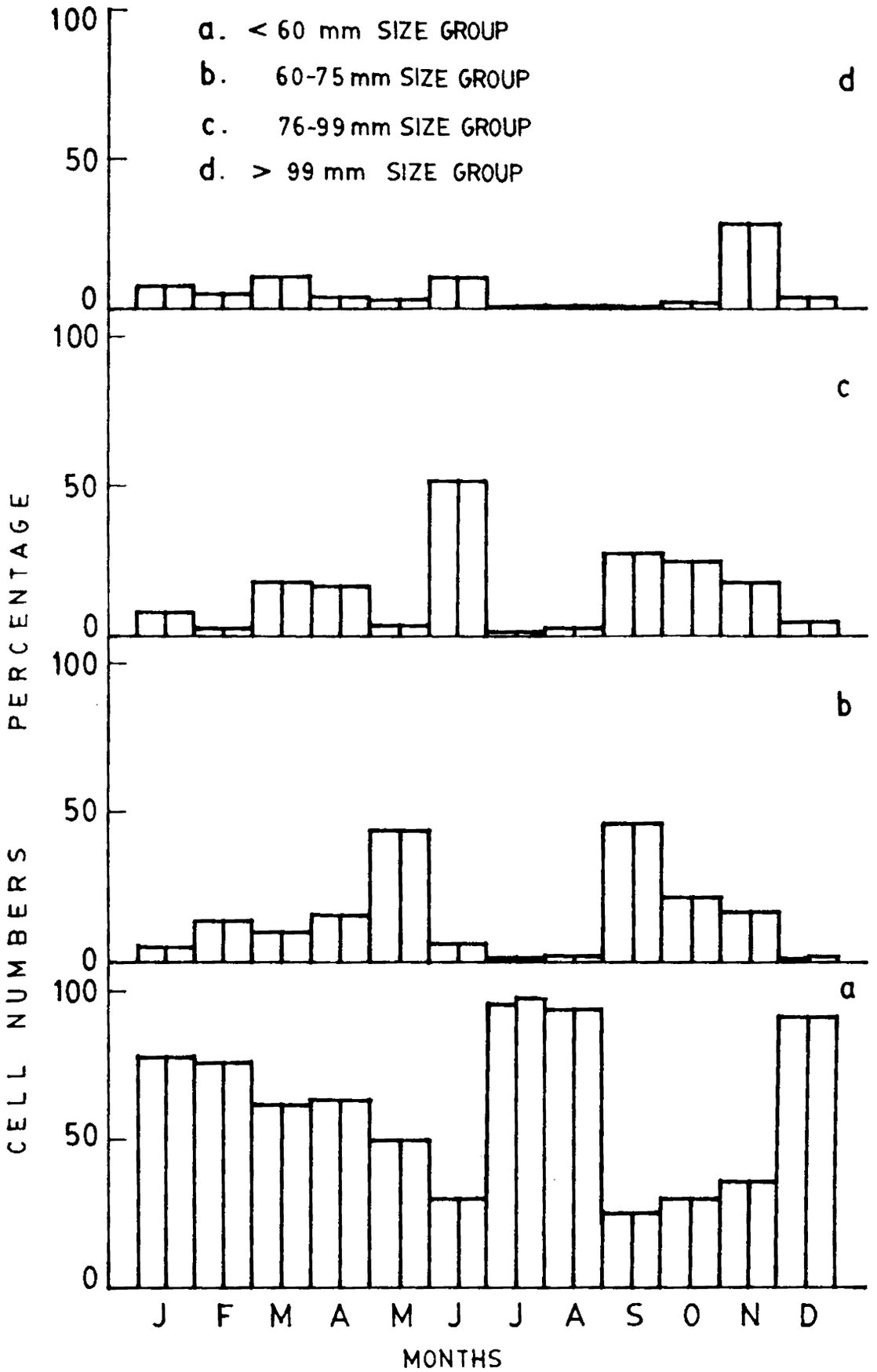

FIG. 5. PERCENTAGE COMPOSITION OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE IN COCHIN ESTUARY

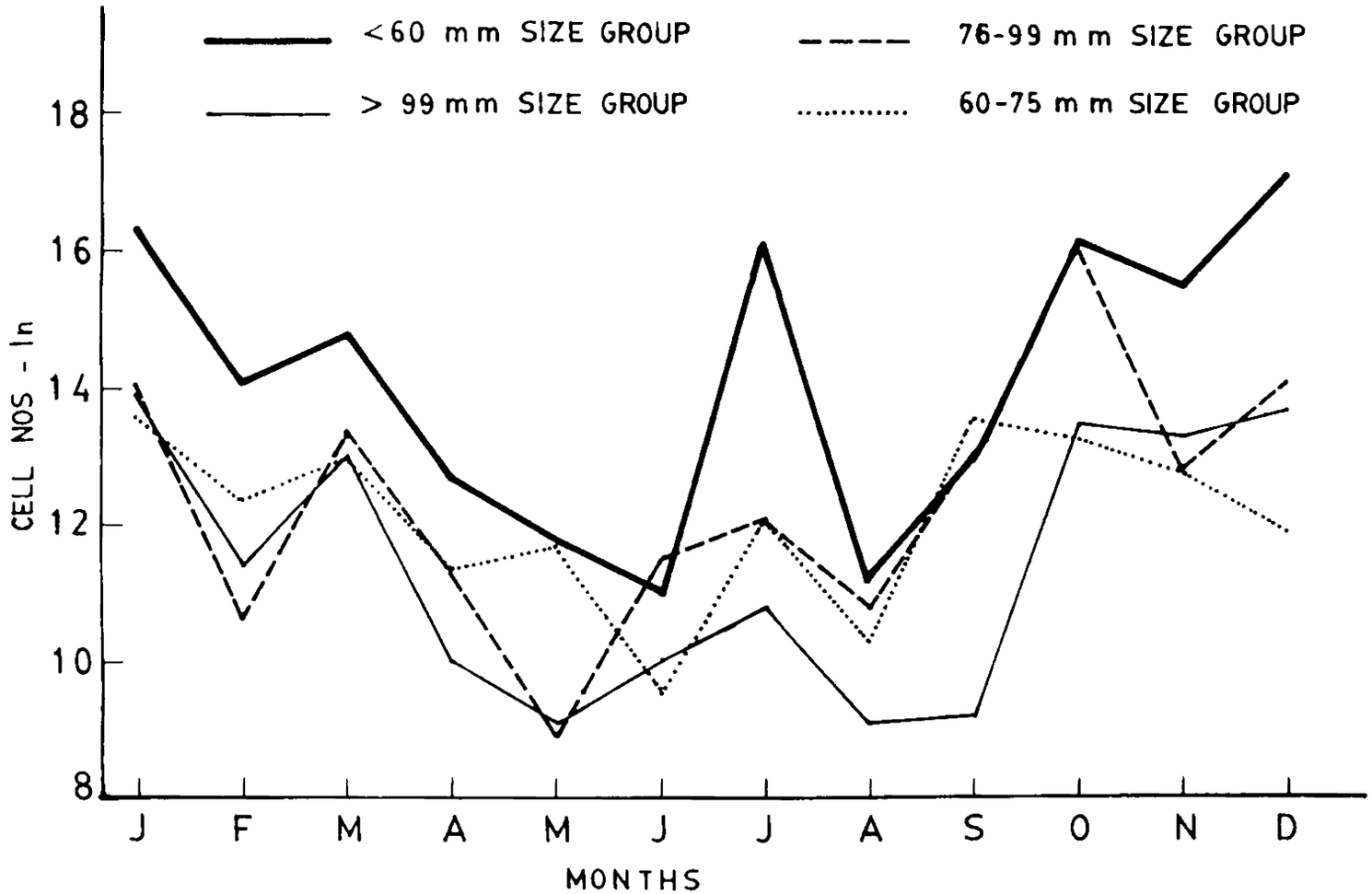

FIG.6. MONTHLY OCCURRENCE OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE

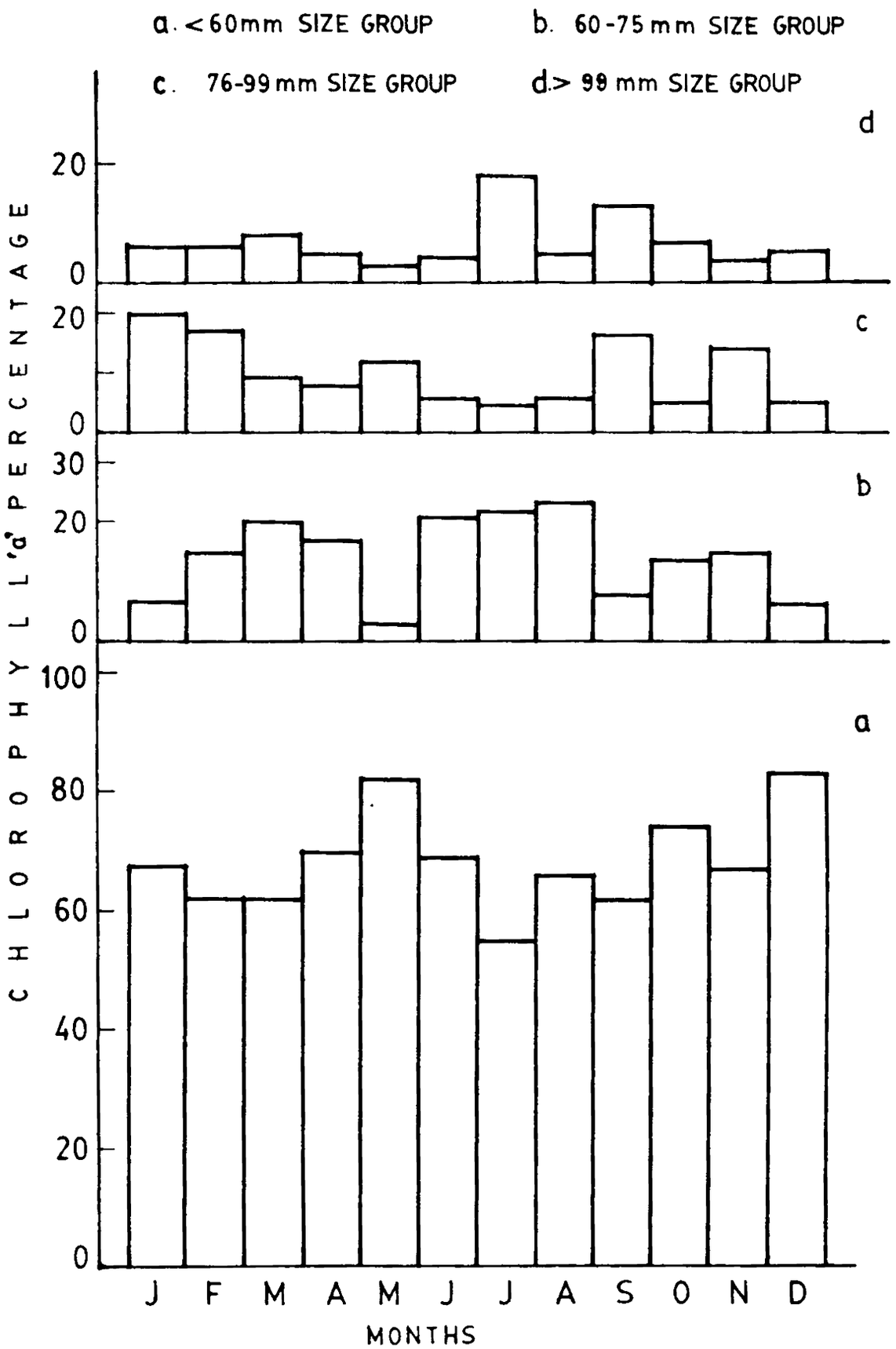

FIG.7. CHLOROPHYLL 'a' CONCENTRATION OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE

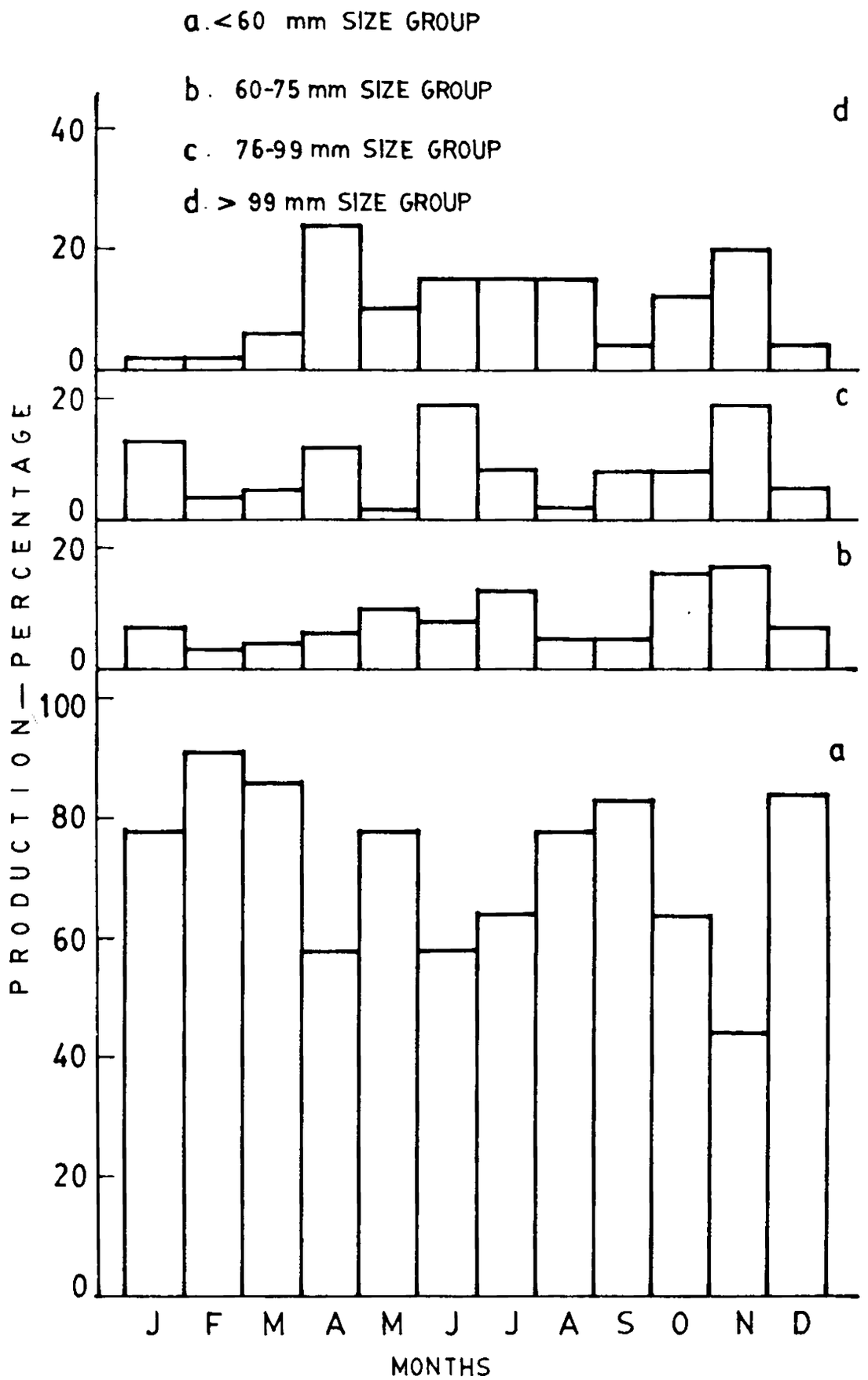

FIG. 8. PRODUCTIVITY OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE

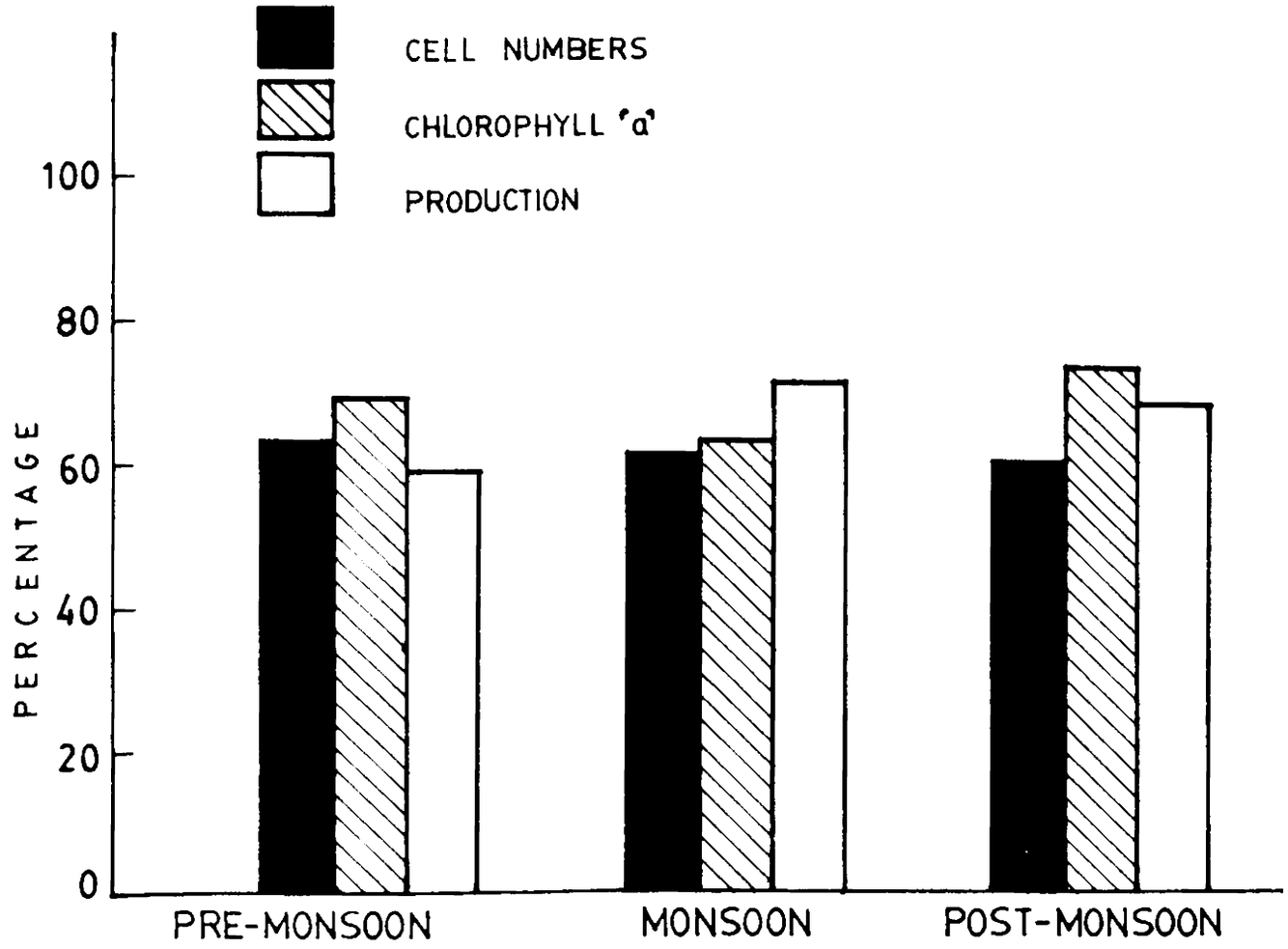

FIG. 9. SEASONAL VARIATION OF CELL NUMBERS, CHLOROPHYLL 'a' AND PRODUCTION

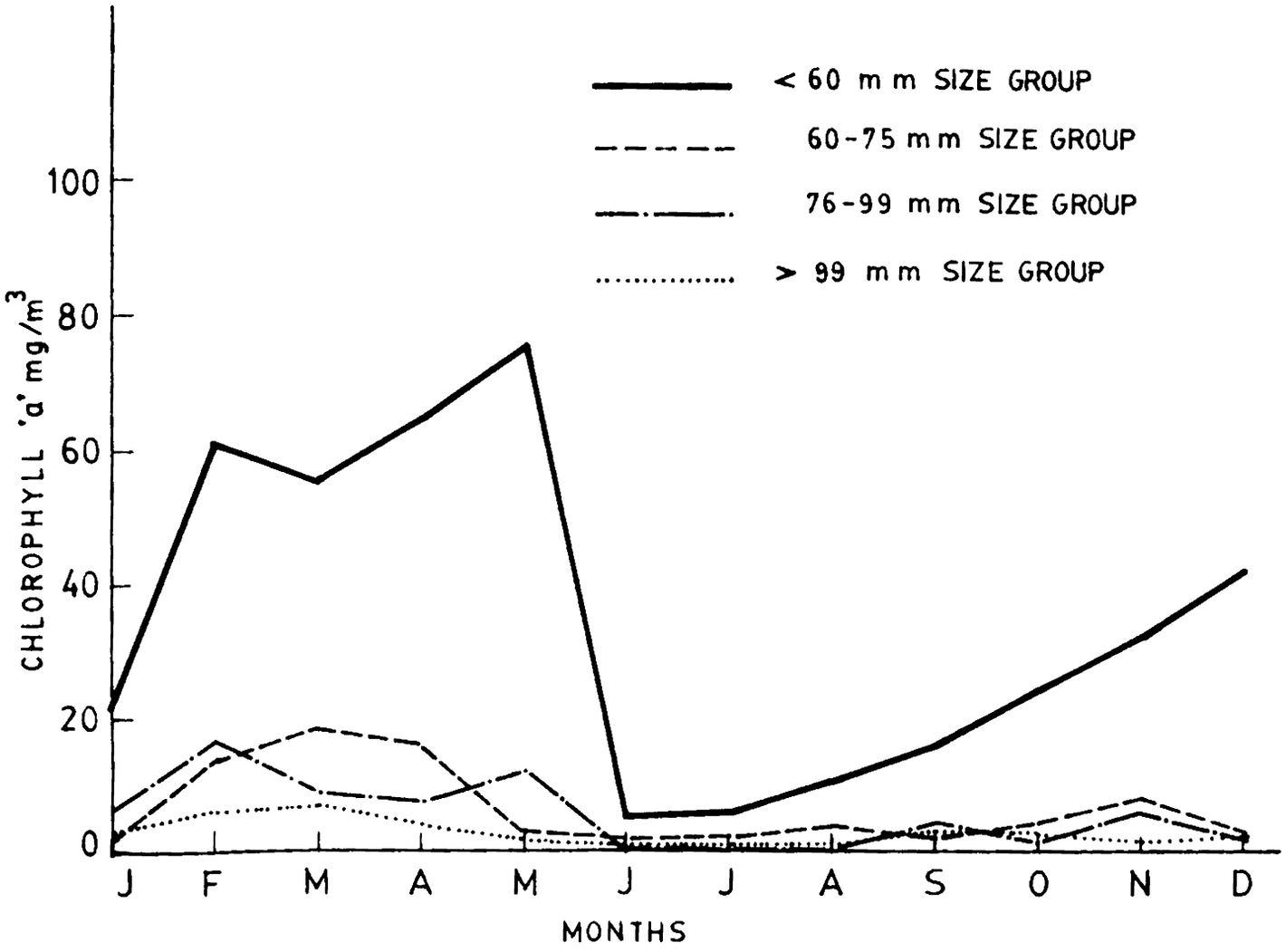

FIG.10. CHLOROPHYLL 'a' CONCENTRATION OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE

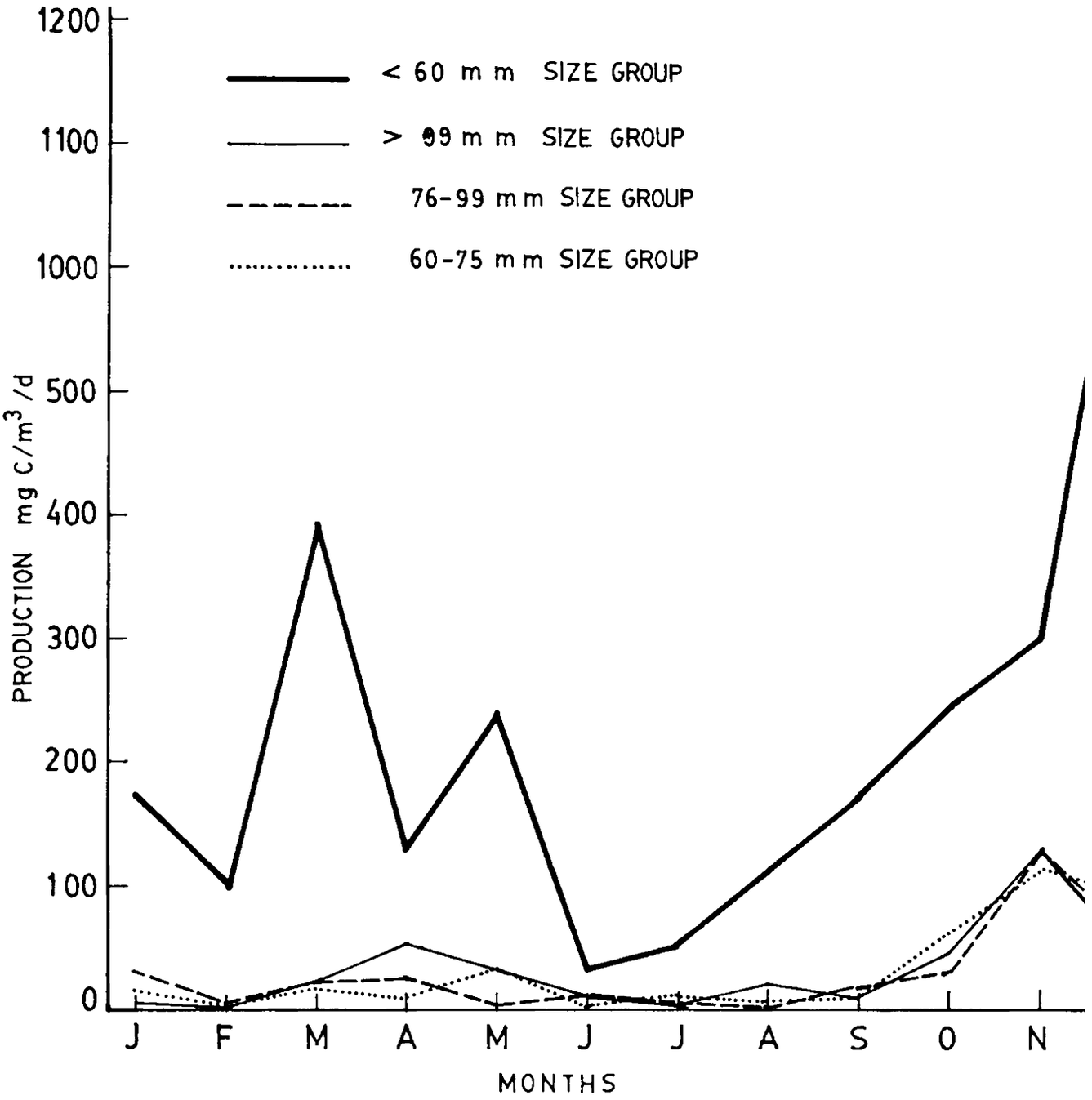

FIG.11. PRODUCTIVITY OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE

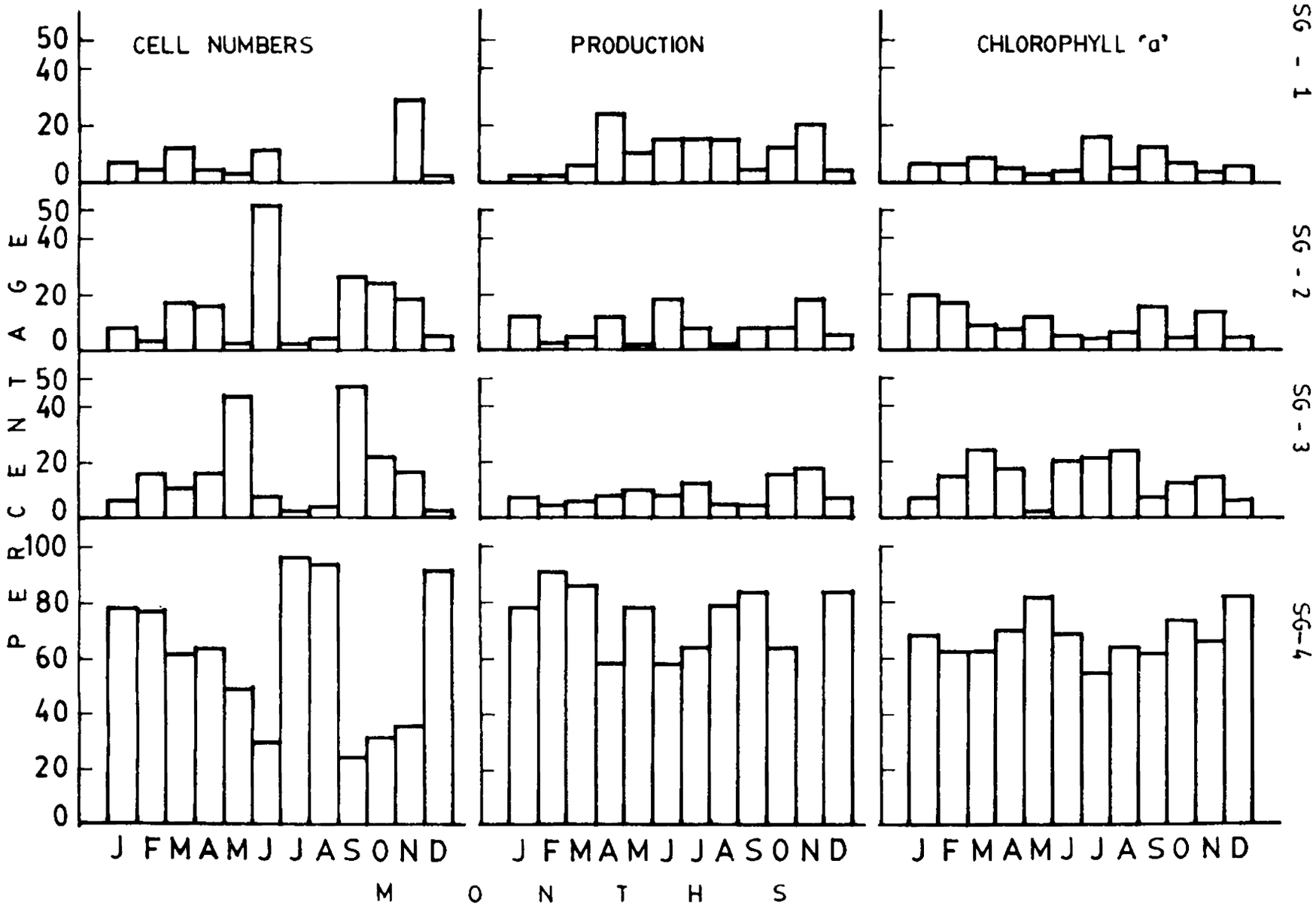

FIG.12. PERCENTAGE COMPOSITION OF CELL NUMBERS, PRODUCTION AND CHLOROPHYLL 'a' AMONG VARIOUS SIZE GROUPS OF ALGAL PLANKTON

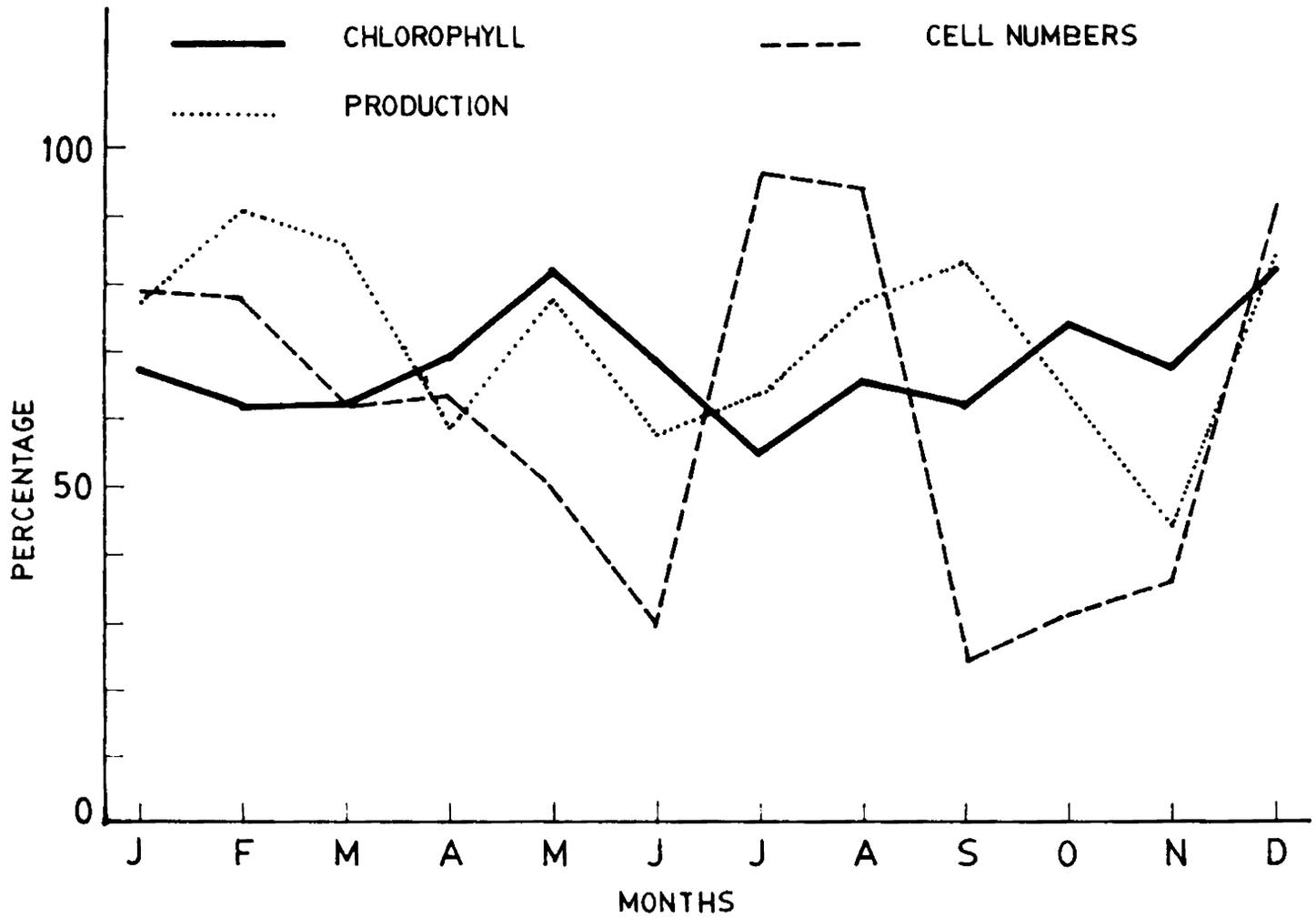

FIG.13. CONTRIBUTION OF ESTUARINE NANOPLANKTON (%)

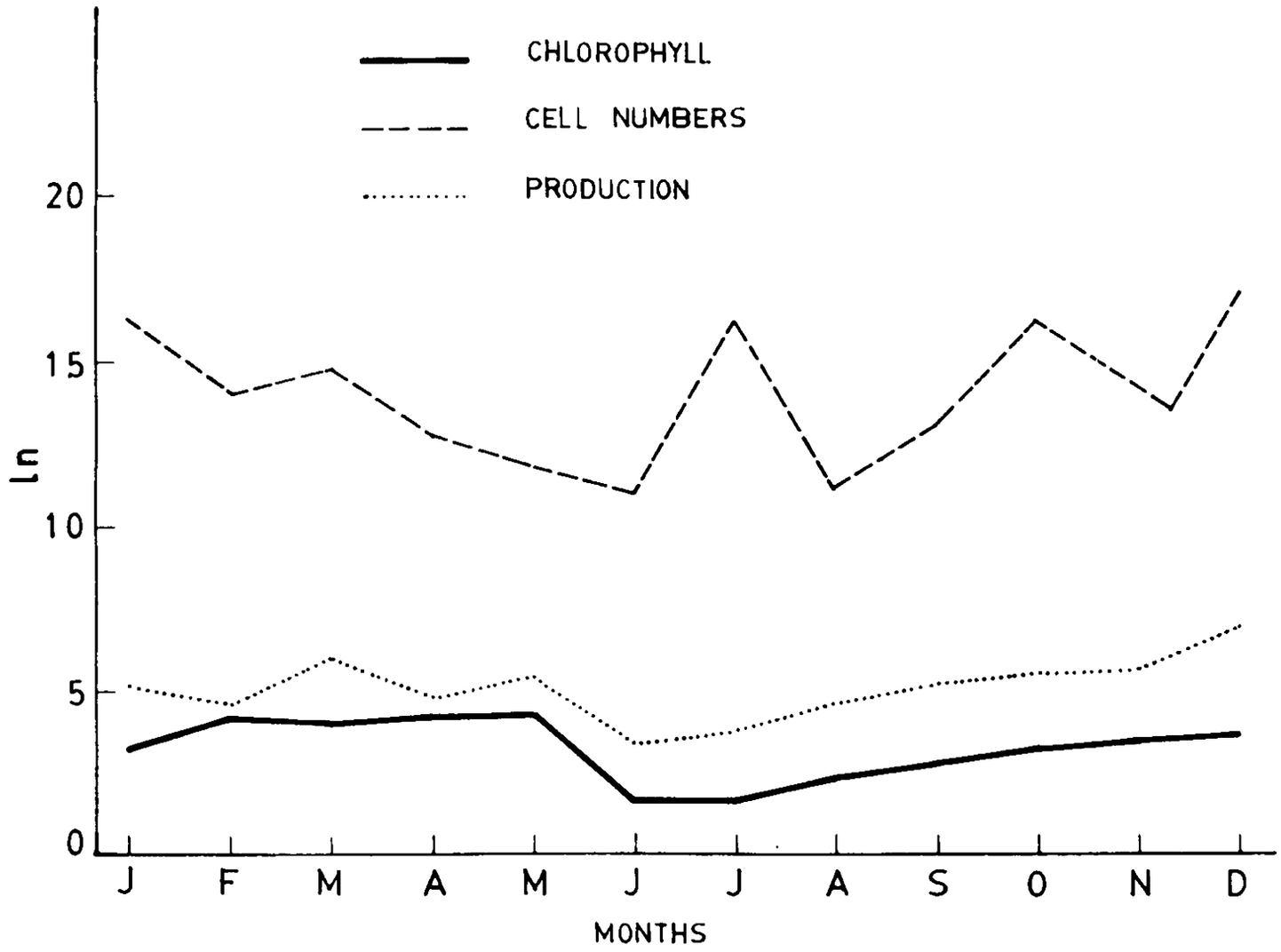

FIG. 14. CELL NUMBERS, CHLOROPHYLL 'a' AND PRODUCTIVITY OF NANOPLANKTON

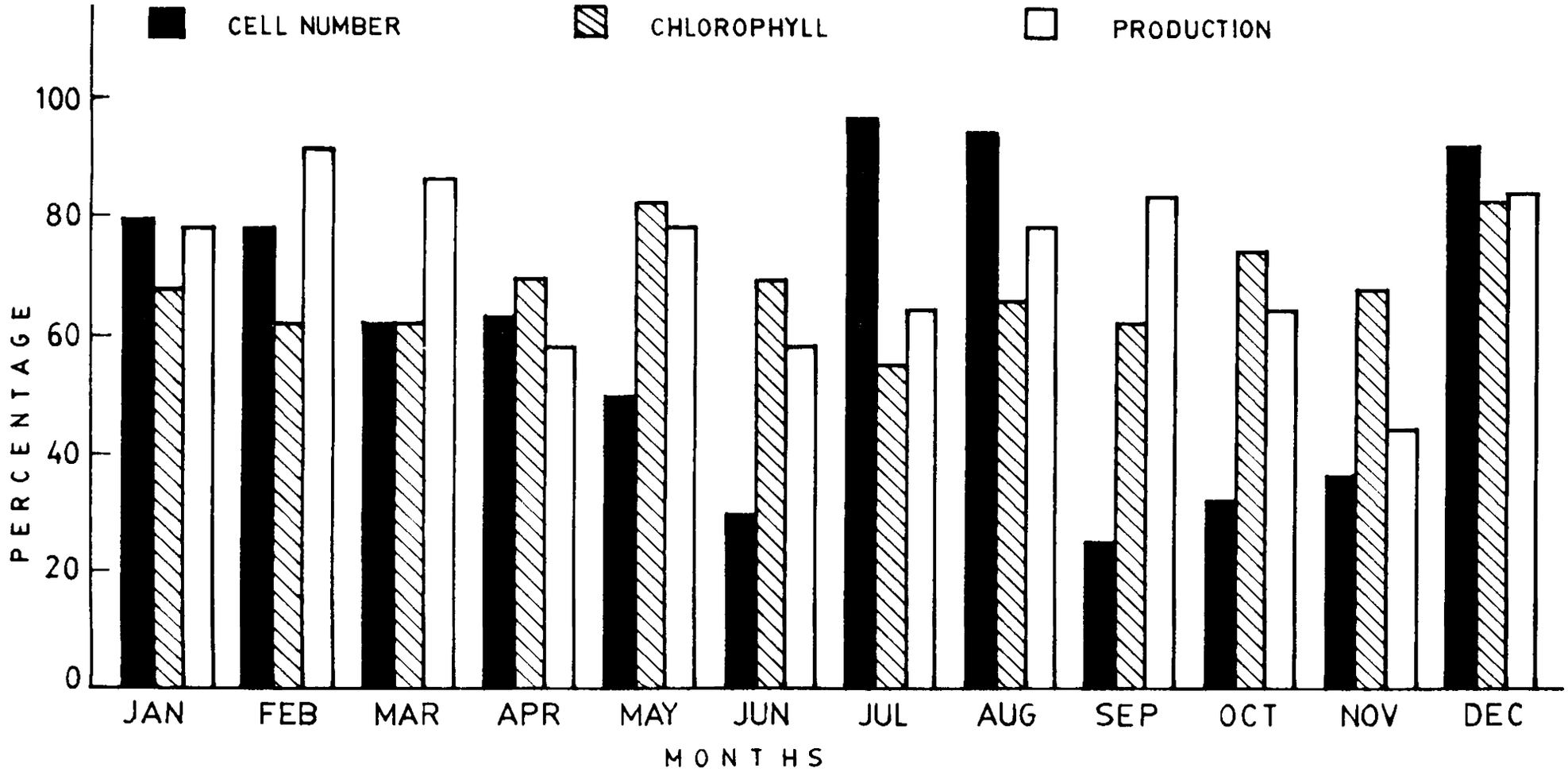

FIG. 15. CELL NUMBERS, CHLOROPHYLL 'a' AND PRODUCTIVITY OF NANOPLANKTON

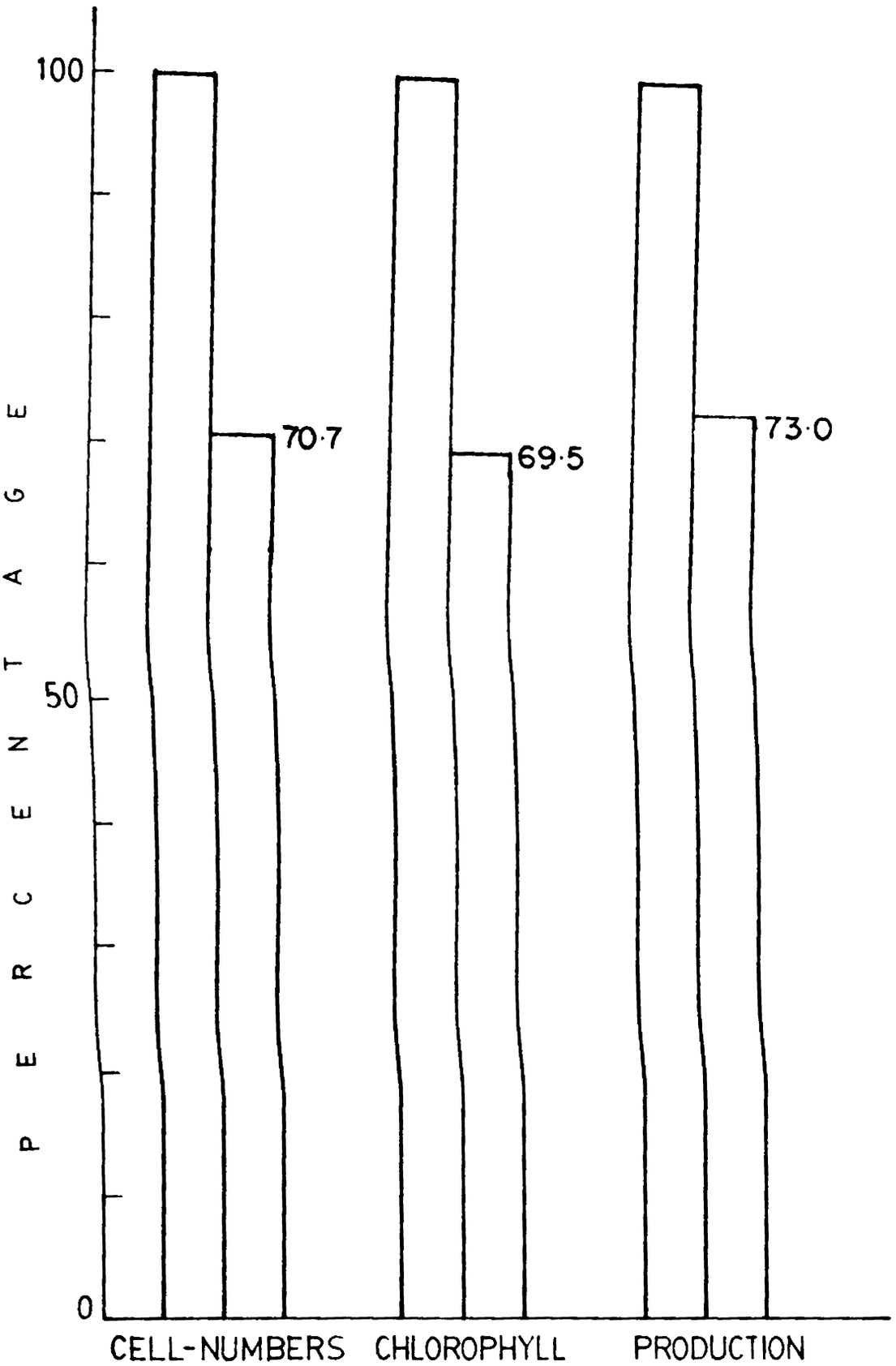

FIG. 16. ANNUAL CONTRIBUTION OF NANOPLANKTON

CHAPTER IV

FLORISTIC COMPOSITION OF PLANKTONIC ALGAE IN THE NEAR SHORE WATERS

1. Floristic size spectrum of the Planktonic Algae - Population density

The inter- and intraspecific analyses of the planktonic algae of the size groups (SG) 60 µm (SG.1), 60 — 75 µm (SG.2), 7€ - 99 µm (SG.3) and >99 µm (SG.4) have been carried out in coastal waters. While the species composition of the various size groups were analysed, special attention was given to assess the contribution of chlorophyll a and productivity of nanoplankton (Fig. 19). The floristic size spectrum of the planktonic algae has been analysed in order to estimate the contribution of the various size groups (Fig. 18). The coverage is only for months when the cruises of the vessel has been possible due to sea conditions. The major flora recorded in this part of the coastal waters are diatoms. They are distributed among different size groups in varying intensities. Altogether twenty six species of planktonic algae are recorded from this part of the coastal waters during the period. Out of these, twenty one species belong to the class Bacillariophyceae two species each belong to Cyanophyceae and Dinophyceae and one to Prasinophyceae. As the Table 14 shows SG.1 is constituted by sixteen species; SG.2 and SG.3 have eighteen species each and SG.4 has fourteen species.

In January (Table 16) the flora is constituted by only four species of diatoms Fragilaria oceanica, Thalassionema nitzschiodes, Thalassiosira subtilis and Navicula hennedyii. Fragilaria oceanica is distributed in the size groups SG.1, SG.2 and SG.3. The intraspecific analysis shows that 33.3% of the total of 2.9×10^4 cells/l is present in SG.1, SG.2 has 16.7% and SG.4 has 50.0% cells of the species. The concentration of 4.8×10^3 cells of Thalassionema nitzschioides is confined to the size of group SG.3. The entire number of 1.4×10^4 cells/l

T A B L E 14

INTRA SPECIFIC QUALITATIVE ANALYSIS OF VARIOUS SIZE FRACTIONS OF PLANKTONIC ALGAE IN COASTAL WATERS

Total species	SG.1	SG.2	SG.3	SG.4
BACILLARIOPHYCEAE				
Asterionella japonica	A *	A	P	P
Biddulphia mobiliensis	P **	P	A	A
Biddulphia sinensis	A	P	A	P
Cerataulina bergonii	A	P	A	A
Chactoceros lorenzianus	P	P	P	P
Coscinodiscus radiatus	A	A	P	P
Ditylum brightwelli	A	A	A	P
Fragilaria oceanica	P	P	P	P
Navicula hennedyii	P	P	P	A
Navicula forcipata	P	A	A	A
Nitzschia closterium	P	P	P	P
Nitzschia longissima	A	A	P	P
Nitzschia pungens	P	P	P	P
Pleurosigma directum	P	P	P	A
Pleurosigma elongatum	A	A	A	P
Rhizosolenia alata	P	P	A	A
Rhizosolenia stolterforthii	A	P	P	A
Skeletonema costatum	P	P	P	P
Surirella fluminensis	A	P	P	A
Thalassionema nitzschioides	P	P	P	P
Thalassiosira subtilis	P	P	P	A
CYANOPHYCEAE				
Oscillatoria prolifica	P	P	P	P
Synechocystis salina	P	A	A	P
DINOPHYCEAE				
Peridinium depressum	A	A	P	A
Prorocentrum micans	P	P	P	A
PRASINOPHYCEAE				
Tetraselmis gracilis	P	P	P	A
No. of species 26	16	18	18	14

* absent

** present

T A B L E 16

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
January	BACILLARIOPHYCEAE									
	Fragilaria oceanica	9600	33.3	4800	16.7	-	-	14400	50.0	28800
	Thalassionema nitzschiodes	-	-	-	-	4800	100.00	-	-	4800
	Thalassiosira subtilis	4800	12.4	29000	75.2	4800	12.4	-	-	38600
	Navicula hennedyii	-	-	14300	100.0	-	-	-	-	14300
		14400	16.6	48100	55.6	9600	11.2	14400	16.6	86500
	Species diversity index	0.2		0.4		0.3		0		0.6

TABLE 17

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
March	BACILLARIOPHYCEAE									
	Biddulphia mobiliensis	-	-	7200	100.0	-	-	-	-	7200
	Fragilaria oceanica	216000	38.7	-	-	171400	30.7	171000	30.6	558400
	Navicula forcipata	14400	100.0	-	-	-	-	-	-	14400
	Nitzschia closterium	-	-	7200	100.00	-	-	-	-	7200
	Nitzschia pungens	-	-	7200	100.00	-	-	-	-	7200
	Rhizosolenia stolterforthii	-	-	14300	100.00	-	-	-	-	14300
	Thalassiosira subtilis	-	-	7200	50.00	7200	50.00	-	-	14400
	CYANOPHYCEAE									
	Oscillatoria prolifica	7200	33.3	7200	33.3	7200	33.3	-	-	21600
		237600	36.9	50300	7.8	185800	28.8	171000	26.5	644700
	Species diversity index	0.4		1.1		0.2		0		1.2

TABLE 18

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
April	BACILLARIOPHYCEAE									
	Chaetoceros lorenzianus	-	-	-	-	21400	64.7	11700	35.3	33100
	Ditylum brightwelli	-	-	-	-	-	-	9500	100.0	9500
	Fragilaria oceanica	-	-	71300	75.3	11700	12.4	11600	12.3	94600
	Nitzschia pungens	7100	50.00	-	-	-	-	7100	50.00	14200
	Pleurosigma directum	14200	66.4	7200	33.6	-	-	-	-	21400
	Skeletonema costatum	103800	54.9	33100	17.5	-	-	52300	27.6	189200
	Surirella fluminensis	-	-	7100	100.0	-	-	-	-	7100
	Thalassionema nitzschioides	-	-	-	-	-	-	33100	100.0	33100
	Thalassiosira subtilis	42600	33.3	28500	22.2	57000	44.5	-	-	128100
	CYANOPHYCEAE									
	Oscillatoria prolifica	-	-		-	7100	74.7	2400	25.3	9500
	DINOPHYCEAE									
	Peridinium depressum	-	-	-	-	7000	100.00	-	-	7000
		167700	30.7	147200	26.9	104200	19.1	127700	23.3	546800
	Species diversity index	0.6		0.8		0.8		1.2		1.7

of Navicula bennedyii is represented in SG.2. During this month the total algal plankters are about 8.15 x 10^4 cells/l. The observed contribution of nanoplankton (SG.1) is only 16.6% distributed in two species. The next higher size group of SG.2 has the maximum cell concentration of 4.8 x 10^4 cells/l (55.6%) distributed among three species. SG.3 contributes 11.1% of the total plankton with two species and the size group SG.4 has 16.6% with a single species.

In March (Table 17) the planktonic flora consist of eight species of which seven species belong to the class Bacillariophyceae and one species belongs to the class Cyanophyceae. Included under nanoplankton are only three species, Fragilaria oceanica and Navicula forcipata of Bacillariophyceae and Oscillatoria prolifica of Cyanophyceae. The intraspecific quantitative analysis (ISQA) shows that 38.7% of about 5.6 x 10^5 cells/l of Fragilaria oceanica, the entire quantity of 1.4 x 10^4 cells/l of Navicula forcipata and 33.3% of 2.16 x 10^4 cells/l of Oscillatoria prolifica are present as nanoplankton (SG.1). The next size group (SG.2) comprised of six species, Biddulphia mobiliensis, Nitzschia closterium, Nitzschia pungens, Thalassiosira subtilis Oscillatoria prolifica and Rhizosolenia stolterforthii are present in the size group during this period. The first five species have 7.2 x 10^3 cells/l each and the last one is 1.4 x 10^4 cells/l. SG.3 consists of three species. ISQA shows that 30.7% of the total 5.5 x 10^5 cells/l, 33.3% of 2.16 x 10^4 cells/l and 50.0% of 1.44 x 10^4 cells/l are present in this group. The larger size fraction SG.4 is represented by 1.7 x 10^5 cells/l of Fragilaria oceanica alone. The total cell concentration for this month is 6.45 x 10^5 cells/l. These cells are distributed in the various size fractions, 36.9% in SG.1, 7.8% in SG.2, 28.8% in SG.3 and 26.5% in SG.4.

In April (Table 18) the planktonic algae consists of eleven species, nine species belong to the class Bacillariophyceae, one species each to Dinophyceae

TABLE 19

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
March	BACILLARIOPHYCEAE									
	Biddulphia mobiliensis	-	-	7200	100.00	-	-	-	-	7200
	Fragilaria oceanica	216000	38.7	-	-	171400	30.7	171000	30.6	558400
	Navicula forcipata	14400	100.0	-	-	-	-	-	-	14400
	Nitzschia closterium	-	-	7200	100.00	-	-	-	-	7200
	Nitzschia pungens	-	-	7200	100.00	-	-	-	-	7200
	Rhizosolenia stolterforthii	-	-	14300	100.00	-	-	-	-	14300
	Thalassiosira subtilis	-	-	7200	50.00	7200	50.00	-	-	14400
	CYANOPHYCEAE									
	Oscilla prolifica	7200	33.3	7200	33.3	7200	33.3	-	-	21600
		237600	36.9	50300	7.8	185800	28.8	171000	26.5	644700
	Species diversity index	0.4		1.1		0.2		0		1.2

and Cyanophyceae. The first size group consists of four species all of which are diatoms. They are Nitzschia pungens, Pleurosigma directum, Skeletonema costatum and Thalassiosira subtilis. ISQA shows that their contribution in the size group is 50.0%, 66.4%, 54.9% and 33.3% respectively. The predominant flora among this is Skeletonema costatum recording 1.0 x 10^5 cells/l out of the total 1.89 x 10^5 cells/l. SG.2 has five species of diatoms. They are Fragilaria oceanica, Pleurosigma directum, Skeletonema costatum, Surirella fluminensis and Thalassiosira subtilis. ISQA shows that the first species is 75.3% of the total of 9.16 x 10^4 cells/l, the second one is 33.6% of 2.13 x 10^4 cells/l the third is 17.5%, the fourth one is 100.0% and the fifth is 22.2%. The next size group SG.3 possesses five species of which three are diatoms, one is a blue green alga and the other is a dinoflagellate. The diatoms are Chaetoceros lorenzianus, Fragilaria oceanica and Thalassiosira subtilis. ISQA shows that they are 64.7%, 12.4% and 44.5% respectively. ISQA value of Oscillatoria prolifica and Peridinium depressum are 74.7% and 100.0% in this size group. SG.4 is constituted by seven species of which six are diatoms viz., Chaetoceros lorenzianus, Ditylum brightwelli, Fragilaria oceanica, Nitzschia pungens, Skeletonema costatum and Thalassionema nitzschioides. Their ISQA values are 35.3%, 100.0%, 12.3%, 50.0%, 27.6% and 100.0% respectively. The only other species present is a blue green alga Oscillatoria prolifica, the ISQA value of which is 25.3%. Thus during this month the total cell concentration of 5.46 x 10^5 cells are distributed in various size groups SG.1, SG.2, SG.3 and SG.4 their gross percentage composition being 30.7, 26.8, 19.1 and 23.4 respectively.

In May (Table 19) the plankton algae includes nine species of which eight species belong to the class Bacillariophyceae and the remaining one is a Cyanophycean species. In the first size fraction viz., nanoplankton all the four

TABLE 20

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
June	BACILLARIOPHYCEAE									
	Biddulphia sinensis	-	-	-	-	-	-	42600	100.0	42600
	Fragilaria oceanica	99600	17.5	187100	33.0	242800	42.7	38500	6.8	568000
	Nitzschia pungens	-	-	7100	50.0	-	-	7100	50.0	14200
	Pleurosigma directum	56800	56.7	43300	43.3	-	-	-	-	100100
	Skeletonema costatum	171100	63.3	-	-	-	-	99100	36.7	270200
	Thalassionema nitzschioides	-	-	115500	90.2	-	-	12600	9.8	128100
	Thalassiosira subtilis	99600	53.6	43300	23.3	42800	23.1	-	-	185700
	CYANOPHYCEAE									
	Oscillatoria prolifica	42700	74.9	-	-	14300	25.1	-	-	57000
	Synechocystis salina	40600	95.3	-	-	-	-	2000	4.7	42600
		510400	36.2	396300	28.2	299900	21.3	201900	14.3	1408500
	Species diversity index	0.9		0.7		0.4		0.9		1.3

species present are diatoms. They are Biddulphia mobiliensis, Fragilaria oceanica, Nitzschia pungens and Thalassiosira subtilis. Their ISQA values are 66.8%, 20.2%, 32.9% and 18.2% respectively. SG.2 is represented by six species five of which are diatoms. They are Biddulphia mobiliensis, Fragilaria oceanica, Navicula hennedyii, Thalassionema nitzschioides and Thalassiosira subtilis. The ISQ values of these species show their specific contribution in the size group. The first species viz., Biddulphia mobiliensis forms 33.2% of the total 2.14 x 10^4 cells/l. 59.6% of Fragilaria oceanica, the entire Navicula hennedyii and Thalassionema nitzschioides and 63.6% of Thalassiosira subtilis are present in this size group. Besides 16.5% of Oscillatoria prolifica is also present in this size fraction. SG.3 has five diatom species such as Fragilaria oceanica, Nitzschia pungens, Skeletonema costatum, Surirella fluminensis and Thalassiosira subtilis their ISQ being 20.2%, 67.1%, 85.7% and 18.2% respectively. SG.4 has only two species Oscillatoria prolifica of Cyanophyceae and the diatom species Skeletonema costatum, their ISQ being 83.5% and 14.3% respectively. The percentage composition of the size groups SG.1, SG.2, SG.3 & SG.4 are 13.2, 39.5, 34.3 and 13.0 respectively.

In June (Table 20) the various size fractions are represented by nine species of planktonic algae seven of which are diatoms and the remaining two belong to the class Cyanophyceae. Size fraction SG.1 is constituted by four species of diatoms and two species of Cyanophyceae. The diatoms include Fragilaria oceanica, Pleurosigma directum, Skeletonema costatum and Thalassiosira subtilis. 17.5% of the 5.68 x 10^5 cells/l of Fragilaria oceanica, 56.7% of 1.0 x 10^5 Pleurosigma directum cells, 63.3% of 2.7 x 10^5 cells/l Skeletonema costatum and 53.8% of 1.85 x 10^5 cells/l of

TABLE 21

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
September	BACILLARIOPHYCEAE									
	Asterionella japonica	-	-	-	-	5000	40.0	7500	60.0	12500
	Chaetoceros lorenzianus	27500	22.5	15000	12.2	65000	53.1	15000	12.2	122500
	Coscinodiscus radiatus	-	-	-	-	6500	100.0	-	-	2500
	Fragilaria oceanica	-	-	5000	25.0	-	-	15000	75.0	20000
	Navicula hennedyii	2500	8.3	15000	50.0	12500	41.7	-	-	30000
	Nitzschia closterium	10000	57.1	2500	14.3	5000	28.6	-	-	17500
	Pleurosigma elongatum	-	-	-	-	-	-	5000	100.0	5000
	Rhizosolenia alata	2500	33.3	5000	66.7	-	-	-	-	7500
	Rhizosolenia stoltenforthii	-	-	5000	28.6	12500	71.4	-	-	17500
	Thalassionema nitzschioides	7500	33.3	15000	66.7	-	-	-	-	22500
	DINOPHYCEAE									
	Thalassiosira subtilis	5000	28.6	5000	28.6	7500	42.8	-	-	17500
		1505000	15.8	5067500	53.2	2910000	30.5	43000	0.5	9525000
	Species diversity index	1.0		1.2		1.1		0.9		1.6

Thalassiosira subtilis are found in this size group. The blue green algae present are Oscillatoria prolifica with ISQ of 74.9% and Synechocystis salina having ISQ of 95.3%. SG.2 has five species of diatoms Fragilaria oceanica, Nitzschia pungens, Pleurosigma directum, Thalassionema nitzschioides and Thalassiosira subtilis, their ISQ being 33.0%, 50.0%, 43.3%, 90.2% and 23.4% respectively. SG.3 is represented by two species of diatoms, Fragilaria oceanica and Thalassiosira subtilis. 42.7% of 5.6 x 10^5 cells/l of the former and 23.1% of 1.85 x 10^5 cells/l of the latter are found in this size group. ISQ of Oscillatoria prolifica is 25.1% of 5.7 x 10^4 cells/l. SG.4 is constituted by six species, five diatoms and one blue green alga. The diatom species are Biddulphia sinensis, Fragilaria oceanica, Nitzschia pungens, Skeletonema costatum and Thalassionema nitzschioides, the ISQ of the above species are 100.0% (4.26 x 10^4 cells/l), 6.8% of 5.68 x 10^5 cells/l, 50.0% of 1.4 x 10^4 cells/l, 36.7% of 2.7 x 10^5 cells/l and 9.8% of 1.28 x 10^5 cells/l. The blue green alga present is Synechocystis salina the ISQ of which is 4.7% of 4.26 x 10^4 cells/l. The total standing crop of the month is 1.41 x 10^6 cells/l and the contribution of the various size groups of planktonic algae are 36.2%, 28 2% 21.3% and 14 3% respectively for the size groups SG.1, SG.2, SG.3 and SG.4 respectively.

In September (Table 21) out of the twelve species that occur eleven species are diatoms and the remaining one is a dinoflagellate. In SG.1 six species are diatoms and one Pyrrophycean Prorocentrum micans. The diatoms are Chaetoceros lorenzianus, Navicula hennedyii Nitzschia closterium, Rhizosolenia alata, Thalassionema nitzschioides, and Thalassiosira subtilis. Prorocentrum micans is the major component of the flora

of this size group recording about 1.5 x 10^6 cells/l, while the diatoms form only 5.5 x 10^4 cells/l. Chaetoceros lorenzianus shows an ISQ value of 22.4% out of the total of 1.23 x 10^5 cells/l. Navicula hennedyii has an ISQ value of 8.3% out of 3.0 x 10^4 cells/l. ISQ values of other diatoms Nitzschia closterium, Rhizosolenia alata, Thalassionema nitzschioides and Thalassiosira subtilis are 57.1%, 33.3%, 33.3% and 28.6% respectively. 15.7% of Prorocentrum micans is present in this size group. SG.2 has nine species of which eight are diatoms, the ISQ of which are given against each species. They are Chaetoceros lorenzianus (12.2%), Fragilaria oceanica (25.0%) Navicula hennedyii (50.0%) Nitzschia closterium (14.3%) Rhizosolenia alata (66.7%) Rhizosolenia stolterforthii (28.6%). Thalassionema nitzschioides (66.7%) and Thalassiosira subtilis (28.6%). The concentration of these diatoms varies from 2.5 x 10^3 cells/l as in Nitzschia closterium to 1.5 x 10^4 cells/l as in Chaetoceros lorenzianus, Navicula hennedyii and Thalassionema nitzschioides. The Pyrrophycean Prorocentrum micans is the major constituent of the flora recording 5.0 x 10^6 cells/l with an ISQ of 54.1% of this size fraction. SG.3 includes eight species of which seven species are diatoms and the remaining one is a Pyrrophycean flagellate Prorocentrum micans. The diatoms are Asterionella japonica, Chaetoceros lorenzianus, Coscinoidicus radiatus, Navicula hennedyii, Nitzschia closterium, Rhizosolenia stolterforthii and Thalassiosira subtilis. Their respective ISQ values are 40.0%, 53.1%, 100%, 41.7%, 28.6%, 71.4% and 42.9%. The concentration of these diatoms varies from 2.5 x 10^3 cells/l as in Coscinodiscus radiatus (ISQ = 100.0%) to 6.5 x 10^4 cells/l as in Chaetoceros lorenzianus. The Pyrrophycean flagellate Prorocentrum micans is the major species of the flora in the size fraction recording 2.8 x 10^6 cells/l. 30.3% of this species

TABLE 22

SIZE WISE COMPOSITION OF PLANKTONIC ALGAE IN COASTAL WATERS OF COCHIN

(Cell numbers/l)

Month	Algal flora	SG.1	%	SG.2	%	SG.3	%	SG.4	%	Total
October	BACILLARIOPHYCEAE									
	Asterionella japonica	-	-	-	-	20000	8.0	230000	92.0	250000
	Biddulphia sinensis	-	-	130000	100.0	-	-	-	-	130000
	Cerataulina bergonii	-	-	400000	100.0	-	-	-	-	400000
	Coscinodiscus radiatus	-	-	-	-	-	-	5000	100.0	5000
	Fragilaria oceanica	-	-	1750000	97.2	20000	1.1	30000	1.7	1800000
	Nitzschia closterium	250000	20.0	100000	8.0	50000	4.0	850000	68.0	1250000
	Nitzschia longissima	-	-	-	-	120000	96.0	5000	4.0	125000
	Pleurosigma directum	5000	1.0	250000	49.5	250000	49.5	-	-	505000
	Thalassionema nitzschioides	50000	3.8	750000	57.7	500000	38.5	-	-	1300000
	Thalassiosira subtilis	1000000	23.5	2250000	52.9	1000000	23.5	-	-	4250000
	CYANOPHYCEAE									
	Oscillatoria prolifica	2050000	12.5	7050000	42.8	7350000	44.7	-	-	16450000
	PRASINOPHYCEAE									
	Tetraselmis gracilis	500000	15.4	2250000	69.2	500000	15.4	-	-	3250000
		3855000	13.0	14930000	50.2	9810000	33.0	1120000	3.8	29715000
	Species diversity index	0.9		1.1		1.1		0.7		1.5

is present in the size group. SG.4 is represented by five species all of which are diatoms. Prorocentrum micans is conspicuous by its absence in this size fraction. The diatoms are Asterionella japonica, Chaetoceros lorenzianus, Fragilaria oceanica, Nitzschia closterium and Pleurosigma elongatum. Their concentration ranges from 500 cells as in Nitzschia closterium to 1.5 x 10^4 cells/l as in the case of Chaetoceros lorenzianus and Fragilaria oceanica. Their ISQ values are 60.0%, 12.2%, 75.0%, 2.9% and 100.0%. During the period the concentration of the various size groups of planktonic algae is 9.5 x 10^6 cells/l and 15.8% of this is present in SG.1, 53.2% in SG.2, 30.5% in SG.3 and only 0.5% in SG.4.

During October (Table 22) altogether 12 species are distributed in various size groups. All the species except the blue green alga Oscillatoria prolifica and Prasinophycean Tetraselmis gracilis are diatoms. In SG.1 six species are present. The dominant species among this size group is a blue green alga Oscillatoria prolifica, the concentration of which is about 2.05 x 10^6 cells/l. This is 12.5% of its total concentration among the different size groups. 15.4% of about 3.25 x 10^6 cells/l of Tetraselmis gracilis is present in the size group. The diatoms present are Nitzschia closterium, Pleurosigma directum, Thalassionema nitzschioides and Thalassiosira subtilis their ISQ being 20.0%, 1.0%, 3.8% and 23.5% respectively. The concentration of these diatoms varies from 5.0 x 10^3 cells/l to 1.0 x 10^6 cells/l. SG.2 is represented by nine species of which seven are diatoms. They are Biddulphia sinensis, Cerataulina bergonii, Fragilaria oceanica, Nitzschia closterium, Pleurosigma directum, Thalassionema nitzschioides and Thalassiosira subtilis. The first two species are present only in this size group making their ISQ values 100.0%. 97.2% of 1.8 x 10^6 cells/l of Fragilaria oceanica, 8.0% of 1.3 x 10^6 cells/l of Nitzschia

closterium, 49.5% of Pleurosigma directum 57.7% of Thalassionema nitzschiodes and 52.9% of Thalassiosira subtilis are distributed in this size group. Besides 42.8% of 1.65 x 10^7 cells/l of Oscillatoria prolifica and a Prasinophycean flagellate Tetraselmis gracilis are present. In SG.3 seven species are diatoms which are Asterionella japonica, Fragilaria oceanica, Nitzschia closterium, Nitzschia longissima, Pleurosigma directum, Thalassionema nitzschioides and Thalassiosira subtilis. Their ISQ are 8.0%, 1.0%, 4.0%, 96.0%, 49.5%, 38.5% and 23.5% respectively. The dominant flora of the size group is Oscillatoria prolifica recording a cell concentration of 7.35 x 10^6 cells/l which is 44.7% of their total concentration. 15.4% of 3.25 x 10^6 cells/l of Tetraselmis gracilis also is found in this size group. In SG.4 there are only five species all of which are diatoms. They are Asterionella japonica with ISQ of 92.0% of 2.5x10^5 cells/l, entire cells of Coscinoidiscus radiatus, 1.5% of 1.8 x 10^7 cells/l of Fragilaria oceanica, 68.0% of 1.25 x 10^6 cells/l of Nitzschia longissima. The total standing crop of algal flora is about 3.0 x 10^7 cells/l. Out of this 13.0% is the contribution of SG.1, 50.2% belongs to SG.2, 33.0% belongs to SG.3 and 3.8% belongs to the SG.4.

2. Inter and Intraspecific Qualitative Distribution of Planktonic Algae

In the coastal waters twenty six species of planktonic algae have been recorded from this particular area of observation (Table 14). These algae belong to the classes Bacillariophyceae, Cyanophyceae, Pyrrophyceae and Prasinophyceae. The majority of twenty one species are of Bacillariophyceae, two species each belongs to the classes Cyanophyceae and Pyrrophyceae and one species belongs to the class Prasinophyceae.

Qualitative analysis of the planktonic algae reveals that only few species occur only in a particular size group. Ditylum brightwelli and

T A B L E 15

CELL NUMBERS, CHLOROPHYLL a CONCENTRATION AND PRODUCTIVITY OF COASTAL WATERS

Month	Cell Numbers/l			Chlorophyll 'a'/mg/m^3			Production mg C/m^3/d		
	Nanoplankters	%	Total	Nanoplankters	%	Total	Nanoplankters	%	Total
January	14400	16.6	86500	38.3	90.1	42.5	28.0	43.6	64.2
March	237600	36.9	644700	39.5	43.4	91.0	4.2	64.6	6.5
April	167700	30.7	546700	20.1	70.5	28.5	102.5	60.9	168.4
May	50200	13.2	379100	50.0	49.3	101.5	19.5	65.4	29.8
June	510400	37.3	1368000	40.5	67.1	60.4	6.4	75.3	8.5
September	1505000	15.8	9525000	70.0	85.0	82.4	52.5	84.1	62.4
October	3855000	12.9	29915000	30.5	57.1	53.4	7.5	60.5	12.4

Pleurosigma elongatum are found only in the larger size group (SG.4). Though there are several known species of nanoplankton such as Tetraselmis gracilis, Synechocystis salina they are found distributed in larger size groups upto SG.4 due to formation of clumps. The only species confined to SG.1 is Navicula forcipata. So also Cerataulina bergonnii is found exclusively in SG.2. Peridinium depressum is confined to SG.3. Biddulphia mobiliensis and Rhizosolenia alata are found in both first and second size groups. They do not occur in the higher size fractions. There are forms which are found only in the higher size groups, which are Coscinodiscus radiatus, Asterionella japonica and Nitzschia longissima (SG.3 and SG.4). There are instances where a single species is found distributed in all the size groups. Chaetoceros lorenzianus, Fragilaria oceanica, Nitzschia closterium, Nitzschia pungens, Skeletonema costatum, Thalassionema nitzschioides of Bacillariophyceae and Oscillatoria prolifica of Cyanophyceae may be cited in this respect. Species such as Navicula hennedyii, Pleurosigma directum, Prorocentrum micans, Thalassiosira subtilis and Tetraselmis gracilis are found in the first three size groups. Among them, as already observed, Tetraselmis gracilis though a nanoplankton, appear in other higher size groups because of their nature of forming clumps.

3. Inter relationship of the productivity parameters with special reference to nanoplankton

In January the standing crop of planktonic algae as measured by cell numbers (Table 15) is 8.65 x 10^4 cells/l. The percentage composition of the size groups SG.1, SG.2, SG.3 and SG.4 are 16.6%, 55.6%, 11.1% and 16.6% respectively as observed by the cell counts. The total chlorophyll a concentration is 42.5 mg/m^3 and productivity is 64.2 mg C/m^3/day.

Analysis of the productivity parameters of the nanoplankters (Fig. 20) shows that the chlorophyll a value of 38.3 mg/m^3 is 90.1% of the total chlorophyll while the contribution is 43.6% for primary productivity expressed in terms of carbon (28.0 mg C/m^3). But the cell concentration of nanoplankton is only 16.6% and this value indeed is an under estimation as picoplankton does not come into the account. In almost all the cases such underestimation in the case of nanoplankton cells is observed. Consequently microplankton get an overestimation as far as cell numbers are concerned to the tune at which nanoplanktons are underestimated. This is not an isolated case. Such underestimation in the case of nanoplankton and consequent overestimations in respect of microplankton are a regular feature in the observations as far as the population density is concerned.

In March the total planktonic algae enumerated is 6.4 x 10^5 cells/l. The observed percentage composition of various groups of planktonic algae of SG.1, SG.2, SG.3 and SG.4 are 36.9%, 7.8%, 28.8% and 26.5% respectively. Here the maximum cell concentration is recorded for the nanoplankton which is itself an underestimation as evidenced by comparatively higher values of chlorophyll a concentration and productivity values.

The chlorophyll a concentration of the entire planktonic algae is 91.0 mg/m^3 and that of nanoplankton is 39.5 mg/m^3. The total production is 6.5 mg C/m^3/day and that of nanoplankton is 4.2 mg C/m^3/day. While the nanoplankton contributes 43.4% of the total chlorophyll a and 64.6% of the primary production, the cell numbers that could be counted is only 36.9%. The lowest productivity values of 6.5 mg C/m^3/day is observed during this month. This is probably due to the high intensity of light that inhibits the process of photosynthesis of the surface plankters by chlorophyll activated photoxidation decomposing the enzymes.

In April the standing crop of the entire planktonic algae is about 5.46 x 10^5 cells/l and that of the nanoplankton is about 1.7 x 10^5 cells/l. The cell concentration of the size groups SG.2, SG.3 and SG.4 are about 1.47 x 10^5 cells/l, 1.04 x 10^5 cells/l and 1.28 x 10^5 cells/l respectively. The total chlorophyll a value 28.5 mg/m^3 of which the contribution of nanoplankton is 20.1 mg/m^3 which is 70.5% of the total chlorophyll a. The total production is 168.4 mg C/m^3/day which is the maximum recorded during the period of observation. The nanoplankton production is 102.5 mg C/m^3/day which is 60.9% of the total. While 70.5% of the chlorophyll a and 60.9% of the productivity are accountable to the nanoplankton including picoplankton the low percentage contribution of cell numbers (30.7) is indeed glaringly an underestimation.

In May the total cell concentration is 3.79 x 10^5 cells/l of which the nanoplankton recorded is 5.02 x 10^4 cells/l. SG.2 is about 1.5 x 10^5 cells/l SG.3 is 1.3 x 10^5 cells/l and SG.4 is 4.9 x 10^4 cells/l. The percentage contribution of the various size groups SG.1, SG.2, SG.3 and SG.4 are 13.2%, 39.5%, 34.3% and 13.0% respectively. The chlorophyll a concentration of the entire planktonic algae is 101.5 mg/m^3, and 50 mg/m^3 of this is the contribution of nanoplankton alone. Corresponding primary production values are 29.8 mg C/m^3/day and 19.5 mg C/m^3/day respectively. Thus the contribution of nanoplankton is 49.3% in respect of chlorophyll a and 65.4% in respect of primary production. But the numerical estimation shows that they are only 13.2% of the total population. This discrepancy is also accountable to the non-inclusion of picoplankton. Takahashi and Hori (1984) detected a distinctive chlorophyll maximum around 60m depth in the Western North

Pacific Ocean and South China. More than 70.0% of the chlorophyll was the contribution of picoplankton.

In June about 1.4 x 10^6 cells/l is the cell concentration of the total planktonic algae and the nanoplankton concentration is 5.1 x 10^5 cells/l which is 37.3%. In SG.2 the cell concentration is about 4.0 x 10^5 cells/l (29.0%), SG.3 has a cell concentration of about 3.0 x 10^5 cells/l (2.2%) and SG.4 has the least concentration of 2.02 x 10^5 (1.5%). The total chlorophyll a concentration is 60.4 mg/m^3 of which the nanoplankters claim 67.1%, i.e. 40.5 mg/m^3. The total production is only 8.5 mg C/m^3/day. This low production may be indicative of adverse ecophysiological factors consequent on the environmental changes with the onset of the monsoon. Nanoplankton even in this unfavourable conditions claim 75.3% of the production.

In September algal plankters form 9.52 x 10^6 cells/l of which the nanoplankters alone are 1.5 x 10^6 cells/l. In SG.2 the cell concentration is 5.1 x 10^6 cells/l, in SG.3 is 2.9 x 10^6 cells/l and in SG.4 it is 4.3 x 10^4 cells/l. The percentage contribution of various size groups are 15.8, 53.2, 30.5, and 0.5 respectively for SG.1, SG.2, SG.3 and SG.4. The total chlorophyll a concentration is 82.4 mg/m^3 and nanoplankton concentration is 70 mg/m^3 which is 85.0%. The total production is 62.4 mg C/m^3/day of which the nanoplankton production alone is 52.5 mg C/m^3/day which is 84.1% of the total. The chlorophyll a concentration and productivity values are quite comparable. The very low percentage of cell concentrations observed (15.8%) is again due to the unaccounted picoplankton.

In October the total cell concentration of the planktonic algae is about 3.0 x 10^7 cells/l and the nanoplankton forms 3.86 x 10^6 cells/l, 1.5 x 10^7 cells/l is in SG.2, 9.8 x 10^6 cells/l is in SG.3 and 1.1 x 10^6 cells/l is

in SG.4. The observed contribution of the various size groups SG.1, SG.2, SG.3 and SG.4 are 12.9%, 49.9%, 32.8% and 3.7% respectively. The total chlorophyll a concentration is 53.4 mg/m^3 and the contribution of nanoplankton is 57.1% of it i.e. 30 5 mg/m^3. The total primary organic production is 12.4 mg C/m^3/day which is not proportional to the chlorophyll a concentration and cell numbers. The numerical preponderance of planktonic algae during this period is due to the blooming of blue green algae. The vagary in the relationship between cell numbers and production could be due to the physiological invertness of the majority of the cells that usually occur at the later stage of every bloom.

DISCUSSION

Though much work had been done on the primary productivity in the Indian ocean (Prasad and Nair, 1960., 1963., Nair, 1970., 1974., Nair et al. 1968., Qasim, 1977., Qasim et al., 1972 c., Radhakrishna, 1969,1978, Radhakrishna et al.,1978a,b,c) no work has been done on the specific nanoplankton productivity except by Qasim et al. 1974 and Vijayaraghavan et al. (1974).

It is now widely recognised that nanoplankton organisms make a substantial contribution to the total density of algal plankton, photosynthetic pigment and carbon assimilation. Very often their role is either generalised or overemphasized ignoring the characteristics of the particular ecosystem and wide geographical variations. A reliable assessment and correct interpretation of their role is very significant as the very pattern of food chain is influenced by them. Ryther (1969) has indicated that oceanic and coastal regions, probably with continental shelf areas differ in their overall pattern of food chains. In oceanic regions nanoplankton is generally far more abundant than the larger net plankton; the reverse is true for coastal waters. This difference in turn leads to a broad distinction in the food chain.

Oceanic

Nanoplankton -- Microzooplankton (eg. Protozoa) -- Macrozooplankton (eg. herbi crustaceae) — Megazooplankton (eg. euphasids) -- Planktivorous ocean fish (eg. myctophids) — Tuna etc.

Inshore

Net phytoplankton -- Macrozooplankton (eg. herbivorous copepods, etc.-- Planktivorous herring etc.

Some times in inshore areas and frequently in warmer seas the nanoplankton may predominate in biomass but there is great variability spatially and temporally in the ratio of nanoplankton to net phytoplankton (Sournia, 1968., Tundisi, 1971.,

Malone, 1971).

The study of the size spectrum -- typical of algal plankton poses problems for quantitative study. The proper enumeration of nanoplankton organisms is exceedingly difficult, centrifugation is not a reliable method for the collection of nanoplankters some of more delicate cells are destroyed or are not brought down even with prolonged centrifuging. Filteration employing hardened filter papers, glass fibre, membrane or sintered glass filters is frequently used and sometimes filters can be rendered translucent for subsequent cell counts. More usually chlorophyll extraction is carried out on the algal plankton filtered. To quantify the contribution of net and nanoplankton to the total phytoplankton Raymont (1980) has suggested fractional filtration. In tune with this suggestion this study is designed incorporating further elaborations such as productivity parameters and analysis of the size spectrum. They are classified according to the following size groups for convenience of study. While nanoplankters (SG.1) form the size group less than 60 µm, SG.2 forms net plankton or microplankton of the size 60-75 µm, SG.3 forms the size group 76-99 µm and finally SG.4 are net plankters larger than 99 µm. While the net planktonsare collected by filtering through nets of suitable mesh size, the filtered water is sedimented for the collection of nanoplankton. The probable error due to the detrital accumulation if any, or the possible extreme abundance of algal plankton especially due to blooms is overcome by proper dilution of the sedimented sample. The nanoplankters are counted using haemocytometer and the net plankton with Sedwick Rafter Cell.

For the coastal waters the total phytoplankton varies from 8.65×10^4 in January to about 3.0×10^7 cells/l in October. Hulburt, Ryther and Guillard (1960) observed the phytoplankton density from about 1000 to more than 200,000 cells/l

with the lowest population in summer in warm oceanic water of Bermuda. Thus a marked seasonal change is observed for total phytoplankton density in both inshore and oceanic waters. In the Cochin coastal waters the nanoplankters form 16.6% of the total algal plankters in January where the population is the minimum and 12.9% in October when the density is maximum. The nanoplankton density varies from 13.2% in May the total density being 5.0×10^4 cells/l, to 37.3% in June when the total algal plankton is about 1.4×10^6 cells/l. In March the nanoplankton concentration is 36.9% of the total 6.4×10^5 and in April it is 30.7% of about 5.5×10^5 cells/l. In September the nanoplankton density is only 15.8% of comparatively higher concentration of 9.5×10^6 cells/l. Only very few species are found distributed exclusively to a particular size group, while Ditylum brightwelli and Pleurosigma elongatum are confined to SG.4, Navicula forcipata to SG.1, Cerataulina bergonii to SG.2 and Peridinium depressum to SG.3. The common nanoplankton species are Fragilaria oceanica, Skeletonema costatum, Thalassiosira subtilis and Oscillatoria prolifica. The average contribution of nanoplankton is 23.3% of the total of the algal plankton.

On analysis of the various size groups of the net plankton it is found that the size group of 60-75 µm are apparently found to be the major flora in this coastal region. Their density varies from 7.8% in March to 55.6% in January. In January the dominant net planktons of the size group are Thalassiosira subtilis and Navicula hennedyii. In March the several species are represented in this group in less density the flora represented wholly in this size group being Biddulphia mobiliensis, Nitzschia closterium, Nitzschia pungens and Rhizosolenia stolterforthii. In April SG.2 form 26.9% of the total density of algal plankton the dominant flora being Fragilaria oceanica, Pleurosigma directum, Thalassionema nitzschioides and Thalassiosira subtilis. In September and October their contributions are 53.2%

and 49.9% both months exhibiting more number of species. In September the dominant flora is Prorocentrum micans of Pyrrophyceae with a density of 5.0×10^5 cells per litre. During October the dominant net plankton is the filamentous blue green alga Oscillatoria prolifica with a density of 7.0×10^6 cells per litre. The average contribution of the size group is 37.4%, more than that of nanoplankton. The average density of population of the size group SG.2 is 25.5% which is also more than that of nanoplankton and the contribution of the larger net plankton above 100 um size is comparatively little recording only 12.1% of the total algal plankton density. A very few species that are exclusively distributed in this large size group are Ditylum brightwelli and Pleurosigma elongatum. Thus in all the size groups the floral composition is conspicuously constant. Similarly in a tropical inshore area Smayola (1963, 1966) demonstrated that the phytoplankton was remarkably constant in composition over the Gulf of Panama and was dominated by the diatom. In the present study too the predominant flora are diatoms with 26 species exception being Oscillatoria prolifica and Synechocystis salina of Cyanophyceae and Prorocentrum micans and Peridinium depressum of Pyrrophyceae and Tetraselmis gracilis of Prasinophyceae. Steven (1966) describing the algal flora of Kingston Harbour, Jamaica, lists thirty two diatom species, seven dinoflagellates, six Cyanophyceae and four Chlorophyceae. Diatoms especially Rhizosolenia stolterforthii, Chaetoceros spp. Nitzschia seriata and Skeletonema costatum were usually dominant with bloom attaining concentrations of 2.5×10^6 cells/l; dinoflagellates mainly Ceratium tripos, Ceratium furca and Dinophysis diegenesis were usually in lower densities. A single bloom of Exuviella reaching a maximum density of 29.0×10^6 cells/l was also recorded. The present observation records the bloom of Prorocentrum micans with a density of about 9.3×10^{16} cells per litre found distributed in all the size groups except

in SG.4. In September 1.45 x 10^6 cells/l are found distributed in nanoplankton which is 15.7% of the total, 5.0 x 10^6 cells/l in SG.2, which is 54.1% and 2.8 x 10^6 cells/l in SG.3, (30.3%.) Another prominant bloom is that of the blue green alga Oscillatoria prolifica (October) with a total density of 1.65 x 10^7 cells, 12.5% in nanoplankton 42.8%in SG.2 and 44.7% in SG.3. Diatom bloom recorded is of lower magnitude the maximum being about 4.3 x 10^6 cells per litre with their contribution of 23.5% in SG.1, 52.9% in SG.2 and 23.5% in SG.3 (October).

Algal plankters are found to occur more either in monsoon or post monsoon months than in premonsoon period. This abundance of algal plankton is due to the monsoonal charges resulting in the regeneration of nutrients. Such marked seasonal variations in algal planktons are recorded by Subramanyan (1967) off Calicut, South West India. Standing crop estimated by fractional filtration followed by pigment measurement confirmed the very large size of crop especially during south west monsoon period. According to him nanoplankton constituted about 40.0% of the total algal plankton. The present study reveals that the nanoplankton constitutes only 15.0% of the total phytoplankton density. The present data demonstrate the view of Ryther (1969) that net plankters are the dominant flora in coastal waters.

Though in the environment nanoplankton organisms do not impart substantial contribution to the total density of phytoplankton, they remain as the major primary producers in the environment having 66.0% of the total photosynthetic pigment and contributing about an equal percentage (65.0%) of primary organic production. This may be due to the high rate of uptake and growth. An important feature of many nanoplankton species is that their optimal rate of multiplication is generally higher than that of the larger net phytoplankton following the very broad

generalisation that rate of uptake, growth and division is higher with reduced cell size. Studies by Savage (1969) in Southampton Water, using size fractionation techniques demonstrated the outstanding importance of nanoplankton. The great majority of the crop as chlorophyll (90.0%) was attributed to nanoplankton less than 55 um in size. Similarly 73.0% of the C^{14} assimilation was also found to be the contribution of nanoplankters. In this work average chlorophyll a concentration for the nanoplankton of less than 60 μm is 66.0%. The chlorophyll a values of nanoplankton varies from about 20.0 mg/m^3 to 70 mg/m^3 and the percentage of variation is from 43.4 to 90.0%. The C^{14} uptake projects the major contribution of the nanoplankton of less than 60 μm in size and the average contribution is estimated to be 64.9%. The minimum contribution 43.6% of the total primary organic production is recorded in January and the maximum contribution is 84.1% which is in September. The total production varies from 6.5 μg C/m^3/day in March to 168.4 mg C/m^3/day in April. The corresponding nanoplankton production values are 4.2 mg C/m^3/day in March and 102.5 mg C/m^3/day in April. Burkill (1978) confirmed, using size fractionation on samples taken in the same area, that 89.0% of the chlorophyll was the contribution of nanoplankton of less than 50 um in size. According to Malone (1971) nanoplankton has dominant role in the total phytoplankton concentration, though a greater proportions of net plankton appeared in neritic waters. In fact the high values of nanoplankton chlorophyll and primary organic production recorded by Savage (1969) Burkill (1978) etc. are not the contribution of the nanoplankters of coastal waters alone.

Thus, this study reveals that though the net plankton apparently exhibit numerical preponderance the nanoplankters are the major primary producers even in coastal waters contributing 66.0% of the total chlorophyll a and about 65.0% of the total production at the primary trophic level. In fact the contribution of nanoplankton on coastal water is numerically under estimated due to the limitation of the current method of enumeration.

Inspite of comparatively low numerical representation in the extreme coastal region the nanoplankters have proved themselves as very effective producers as evidenced by their high percentage of contributions to the total production. The average nanoplankton production is found to be 31.5 mg C/m^3/day out of the total 50.3 mg C/m^3/day i.e. 62.6%. The high chlorophyll _a_ concentration of nanoplankton 41.3 mg/m^3 out of the total 65.7 mg/m^3 and the high production raises the question whether the low density of nanoplankton is real or apparent. (Apparent in the sense whether the nanoplankton consists of extremely minute autotrophic forms that could not be counted). The low density may be even real as one would expect from their high surface/volume ratio; these small forms are more active per unit mass of cell material than the algae retained by a net (Fogg 1963). Though coccolithophorids are of great significance in some seas, minute diatoms may be extraordinarily abundant in the nanoplankton (Collier and Murphy, 1962; Thorrington - Smith, 1970b) Studies by Savage (1969) in Southampton Water, using size fractionation techniques demonstrated the outstanding importance of nanoplankton. 90% of the chlorophyll was attributed to the small phytoplankton (55 µm in size) much of it less than 10 um in diameter. Similarly the greater part of C^{14} assimilation (73.0%) was due to nanoplankton. Burkill (1978) confirmed using size fractionation on samples taken in the same area that 89.0% of the crop (as chlorophyll) was 50 µm in size . In the present observation nanoplankton contribution gives almost identical values in terms of chlorophyll _a_ (62.9%) and primary production (62.6%). Mc Allister, Parsons and Strickland (1960) found at Station P in the North Pacific that the great majority of the phytoplankton passed through the finest nets and was mainly less than 10 um. Further investigations by Parsons (1972) confirmed that

nanoplankton (size range 8-16 um) predominated in the sub-Artic Pacific. Pingree, Holligan, Mardell and Head (1976) confirmed the importance of the nanoplankton in the Celtic Sea (South-west of the British Isles). In terms of carbon fixed, nanoplankton contributed 70.0% before and after the spring outburst and although the relative contribution fell to less than 10.0% during the spring bloom, actual production of nanoplankton increased over that season.

The present observation on nanoplankton contribution in terms of population density of 14.9% is infact an underestimation. But this study elucidates the realistic estimate of their contribution which is expressed in terms of chlorophyll a contribution and carbon assimilation. More or less identical values are obtained from these studies, 66.0% in the case of chlorophyll a and 65.0% in respect of nanoplankton production. Thus about 63.0% is the contribution of nanoplankton in this region. The low percentage of nanoplankton population obtained from numerical estimation under the microscope is only apparent rather than real. As already pointed out in this study all the algal plankters <60 µm are considered as nanoplankton which may be divided into three size fractions 60 to 5 µm, 5 to 1 µm and 1 to 0.2 µm. The numerical representation of the so-called nanoplankton given here (15.0%) is indeed exclusive of the autotrophic forms 1 µm (Cynobacteria and eukaryotic algae) called picoplankton. But the nanoplankton contribution of 66.0% expressed in terms of chlorophyll a and carbon assimilation is inclusive of those of picoplankton. If it is assumed that there exists 1:1:1 ratio among population density, chlorophyll a concentration and primary organic production under average optimum conditions, in this case there is an under estimation by about 50.0% in the population density of all the autotrophic flora <60 µm.

Consequently the percentage of population density of the microplankters happens to be an overestimation by the same percentage. Hence the microplankters here form only 37.0% of the primary producers. In the estuary the nanoplankton production is 73.0% which is supported by 69.5% of the chlorophyll a and 70.7% of the density of population giving more or less 1:1:1 ratio among the three parameters, cell numbers, chlorophyll a concentration and primary production. Almost such a ratio is observed in the estuary indicating the absence of unaccounted flora of less than 1 µm (picoplankton) in considerable numbers compared to that in coastal waters. In this case if it is assumed that the carbon assimilation (73.0%) represent the realistic contribution of nanoplankton the picoplankton left unnoticed is only 2.3%. Slight decrease in chlorophyll percentage compared to that of carbon assimilation value is probably the reflection of particular ecophysiological conditions.

It is now well established that photosynthetic picoplankton is widely distributed in the world ocean and that the cyanobacteriaand small eukaryotic algae that make up the picoplankton can be responsible for a significant proportion of the primary production (Joint and Pomroy 1986) Cyanobacteria appears to be most abundant in tropical and subtropical obigotrophic waters (Waterbury et al., 1979; Murphy and Hangen,) where picoplankton has been reported to be responsible for more than 50.0% of the daily primary production (Li et al, 1983; Platt et al., 1983; Takahashi and Beinfang, 1983). In the coastal waters of Cochin the picoplankters that escaped microscopic observation is estimated to be about 50.0% which is quite comparable with the above referred observation. Joint et al., 1986 estimated that picoplankton fixed 23 g $Cm^{-2}yr^{-1}$ (22.4% of the total primary production) small nanoplankton (5 to 1 µm) fixed 42 g $Cm^{-2}yr^{-1}$ (40.7% of the total) and large

phytoplankton (75 µm) fixed 37.9 g $Cm^{-2}yr^{-1}$ (36.8% of the total) Joint et al., (1986) measured the photosynthetic characteristics of three size fractions (>5 µm, <5 to >1 µm and <1 to 0.2 µm) of phytoplankton populations at two oceanic stations and at one shelf station in the Celtic Sea. Phytoplankton was more abundant at the oceanic stations and chlorophyll a values were between 1.3 and 2.2 mg chlorophyll a m^{-3} compared with 0.3 to 0.6 mg chlorophyll a m^{-3} at the shelf station. The microplankton population 5.14 x 10^6 cells l^{-1} is about 85.0% of the total observed algal plankton. This contribution expressed in terms of percentage is an overestimation by 48.0% as already mentioned. In fact 5.14 x 10^6 cells l^{-1} is only 37% of the total of the contribution if uncounted picoplankton is also considered. The picoplankton along with the so called nanoplankton or the nanoplankton inclusive of picoplankton constitutes 63.0% of the total. Hence the estimated total of the algal plankton from the size fraction 1 µm to 100 µm is 13.88 x 10^6 cells^{l-1}. The total algal plankton <60 µm is 8.74 x 10^6 (63.0%) and those >60 µm is 5.14 x 10^6 cells^{l-1} (37%). The recalculated or estimated population density percentage of size fraction 60 µm to 75 µm is 21.4% instead of the observed value 49%. The algal plankton of the size fraction 75 to 99 µm has only 13.9% instead of the 32.0% observed. The microplankton >99 µm is 1.8% instead of the observed 4.0%.

The algal plankton of the size fraction 60 to 75 µm is 2.97 x 10^6 cells^{l-1} in the coastal waters. These flora which constitute 21.4% of the total algal flora are represented by eighteen species of which fifteen species are diatoms. The other species are the flagellate Tetraselmis gracilis the dinoflagellate Prorocentrum micans and the blue green alga Oscillatoria prolifica. Though many species are found distributed in various size fractions

some of these are found exclusively in the particular size groups at a time. In January Navicula hennedyii is wholly represented in this size fraction. In March Biddulphia mobiliensis, Nitzschia closterium Nitzschia pungens and Rhizosolenia stolterforthii are seen only in this microplankton size group. Here there are six species, five of which are diatoms and the other species being Oscillatoria prolifica of the class Cyanophyceae. The diversity index is 1.1 while the diversity index of the total observed algal plankton is only 1.2. In April no single species is wholly represented in this size group. Here the population density of this size group is 1.47×10^5 cells^{l-1} with a diversity index of 0.8. In January and March the cell concentrations are only 4.8×10^4 and 5.0×10^4 cells^{l-1} respectively. In May the population density is 1.49×10^5 with the diversity index of 1.0 representing six species five of which belong to Bacillariophyceae and one species belongs to the class Cyanophyceae. In June all the five species are diatoms and their concentration is 3.96×10^5 cells^{i-1}. In September high concentration of 5.06×10^6 cells^{l-1} is observed with species diversity index of 1.2 with twelve species of which eleven species are diatoms. The only exception is Prorocentrum micans of the class Dinophyceae, which recorded a population density of 5.0×10^6 out of the total cells of 5.06×10^6 cells^{l-1} in the month. This is 54.1% of their total number. In this month about 53.2% of the total observed algal plankton belong to this size fraction. In October two species Biddulphia sinensis and Cerataulina bergonii are entirely represented in this size fraction; and 97.2% of the species Fragilaria oceanica is also present in this size group of 60 to 75 μm. Maximum number of the size group of 1.49×10^7 cells^{l-1} is present in the month and the index of species diversity is 1.1 with nine species; seven species are diatoms, one is flagellate Tetraselmis gracilis and the other

filamentous blue green alga Oscillatoria prolifica. The average cell concentration of this size group is 2.97 x 10^6 cells^{l-1} which constitute 49.0% of the observed algal population and 21.4% of the entire autotrophic forms of 1 µm to >99 µm.

The size fraction 76 µm to 99 µm has a lesser population density of 1.92 x 10^6 cells^{l-1} which accounts for the 32.0% of the recorded forms. Out of the total autotrophic forms from 1 µm to >99 µm they constitute only 13.8%. This group of microplankton constitutes fifteen species; eleven species belong to the class Bacillariophyceae, two species belong to the class Dinophyceae viz. Prorocentrum micans and Peridinium depressum, and Tetraselmis gracilis of the class Prasinophyceae, and Oscillatoria prolifica of the class Cyanophyceae. In January they form only 11.1% of the total observed flora constituting 9.6 x 10^3 cells^{l-1} with a diversity index of 0.3. Thalassionema nitzschioides though present in few numbers are entirely represented in this size fraction during this month. The two species present are diatoms. In March their number is 1.86 x 10^5 cells^{l-1} with a diversity index of 0.2. Here of the three species present two are diatoms and they with the blue green algal species form 28.8% of the recorded cell concentration. In April this size fraction of 75 to 100 um form 19.1% of the total observed primary producers. During this month the cell concentration is 1.04 x 10^5 cells^{l-1}. The only dinoflagellate species Peridinium depressum is present entirely in this size fraction though only in low concentration of 7.0 x 10^3 cells^{l-1} Chaetoceros lorenzianus is the dominant flora of this size fraction during this month with a cell concentration of 2.14 x 10^4 cells^{l-1}. The index of species diversity here is 0.8 with five species of which one is a dinoflagellate Peridinium depressum, another a filamemtous blue green alga

Oscillatoria prolifica, the remaining are diatoms. In May this size fraction has a population density of about 1.3 x 10^5 cells^{l-1} with a diversity index of 0.8. The diatom Surirella fluminensii is exlusively present in this size fraction. In June the cell concentration of this size fraction is about 3.0 x 10^5 cells^{l-1} with three diatom species and the diversity index being 0.4. In September the microplankton of the size 76 µm to 99 µm are considerably high in number recording 2.9 x 10^6 cells^{l-1} and their index of diversity is 1.1. Of the eight species the diatom Coscinodiscus radiatus is found distributed in this size group. The only species other than diatoms is the dinoflagellate Prorocentrum micans which is found distributed in all the size fractions. Here they are 2.8 x 10^6 cells^{l-1} (30.3%) of the total density of 9.25 x 10^6 cells^{l-1}. In October the diversity index is 1.1 with nine species of which seven species are diatoms. The other two species are Oscillatoria prolifica of the class Cyanophyceae with a density of 7.35 x 10^6 cells^{l-1} (44.7%) and Tetraselmis gracilis of Pyrrophyceae with 15.4% of the total.

This larger size fraction of the microplankton of >.99 µm are the least in concentration. They are only 2.47 x 10^5 cells^{l-1} which contributes only 1.8% of the total autotrophic planktonic forms. The contribution data of 4.0% recorded is not realistic as the picoplankters are not included for the purpose of calculation. They are only few in numbers and in January and March this size fraction is represented by single species Fragilaria oceanica. In April this size group is well represented with seven out of the total eleven species, five of them belong to the class Bacillariophyceae, one is a filamentous blue green alga and the other Peridinium depressum of Dinophyceae. Their concentration is 1.28 x 10^5 cells^{l-1} with a diversity index of 1.2. Here two species are entirely represented in this size group Ditylum brightwelli

and Thalassionema nitzschioides. In May in this size fraction only two species are found Oscillatoria prolifica and Skeletonema costatum. The cell concentration is only 4.9 x 10^4 with a low diversity index of 0.2. In June the diversity index is 0.9 with six species and the species Biddulphia sinensis is wholly represented in this size fraction. The blue green alga present is a unicellular one called Synechocystis salina. The density of population of this size group of $>$ 99 µm is 2.02 x 10^5 cells^{l-1}. In September the cell concentration is 4.3 x 10^4 cells^{l-1} with a diversity index of 0.9. There are only five species all of them belonging to the class Bacillariophyceae. Among this Pleurosigma elongatum is exclusively in this size group. In October the cell concentration is 1.12 x 10^6 with the index of species diversity 0.6. Here all the species are diatom and the species Coscinodiscus radiatus found in this size group is not found in other size groups.

In this coastal water station altogether twentysix species are recorded; twenty one species belong to the class Bacillariophyceae, two to the class Cyanophyceae and three are dinoflagellates. It is very peculiar to observe the presence of nanoplankton in the net plankton which may be illustrated by the distribution of a flagellate Tetraselmis gracilis. This flagellate besides being present in the nanoplankton fraction is found in the various size fraction apparently rendering the numerical estimation erratic. But the phenomenon of the occurrence of nanoplankters in other size groups is not a common one. Usually this happens when there is a bloom especially the blooming of flagellates or unicellular blue green forms. In this case such an instance is observed in October when there is a bloom of Tetraselmis gracilis recording a density of 3.25 x 10^6 cells^{l-1}. At the time of blooming due to clump formation, they form, visible particulate structures in large numbers which are retained by the

nets having large mesh size. Same is the case with the blue green alga, Synechocystis salina, 4.06 x 10^4 cells^{l-1} are in the size group 60 um but 2.0 x 10^3 cells^{l-1} are present in the size group >99 µm. Several diatoms exhibit only limited size variation. For example in September the, diatom Asterionella japonica are distributed in microplankton, 60.0% in the size group >99 µm and 40.0% in the lower size group of 76 to 99 µm In October too they are restricted in distribution to these size groups only. This is because of the fact they have already reached the minimum possible size characteristic of these species and they cannot still be smaller. Almost similar cases are noted in the case of diatoms Coscinodiscus radiatus and Nitzschia longissima. A few algal flora are smaller than the 14 species present in this size group 100 µm.

Altogether thirtyone species of algal plankton are recorded from the estuarine station, twenty of which belong to the class Bacillariophyceae, four each to Chlorophyceae and Cyanophyceae and three species belong to the class Dinophyceae. Unlike in the coastal waters only a few species show their presence in all the size groups such as Navicula hennedyii and Skeletonema costatum. The anomalous occurrence of nanoplankton among microplankton is observed in the case of at least three species, all blue green flora, Synechocystis salina, Synechococcus aeruginossus and Merismopedia elegans. This is due to the clump formation as observed in the case of Synechocystis salina in the coastal waters. All these flora make their appearance upto the size fraction of 99 um; but not in the >99 µm size group. In February total population density of Synechocystis salina is 3.21 x 10^5 cells^{l-1}. Out of this, 1.14 x 10^5 cells^{l-1} (35.5% are present in the size groups <60 µm, but 1.64 x 10^5 cells are observed in the size group of 60 - 75 µm fraction and 4.28 x 10^4 cells^{l-1} in the size fraction of 76 to 99 µm. This need not always happen, in the absence of clump formation, they are found restricted

to their size group of <60 µm. In March all Synechocystis salina cells are seen in the size group <60 µm. But in the case of Tetraselmis gracilis, though 85.7% of the total of 4.95×10^4 cells are seen in the size group <60 µm, a few cells are found in the next size group 60 to 75 µm. In April when Synechocystis salina cells are distributed up to the size group 76 to 99 µm, Tetraselmis gracilis maintained their identity of nanoplankton confining themselves within the size group <60 um. In July several species such as Navicula forcipata, Pleurosigma elongatum, Synechococcus aeruginossus, Thalassionema nitzschioides are found exclusively in nanoplankton group. In August Biddulphia sinensis, Chlamydomonas ohioensis, Merismopedia elegans, Pleurosigma directum, and Skeletonema costatum are wholly represented in the nanoplankton. In September Amphora ovalis and Chlorella sp. and during October Merismopedia elegans are found within the size group of <60 µm. The species which occur only in the size group of >99 µm are Achnanthes exilis, Cerataulina bergonii, Gymnodinium sp., Rhizosolenia alata and Surrirella fluminensis. Although twelve species appear in the size group all except the above five species also occur in other size ranges. In the size group 60 to 75 µm though sixteen species are found the only species which is not found in other size groups is Asterionella japonica. The size group 76 to 99 µm has eleven species of which Chaetoceros lorenzianus identified itself fully to this size group.

All these various planktonic algal flora of different size fractions synthesise food at the primary trophic level contributing to the total organic production of the concerned ecosystem. The relevance of the contribution of various size fraction is more in the selectivity of diet of consumers. Since these various size fractions of the algal flora form the food of different varieties of consumers, many of them being selective feeders, this study of

the various size fractions of the primary producers and their proportionate contribution to the organic production at the primary trophic level is a useful tool for the estimation of not only the quantum but also the type of fishery resources, provided the selectivity of diet of the concerned consumers are known.

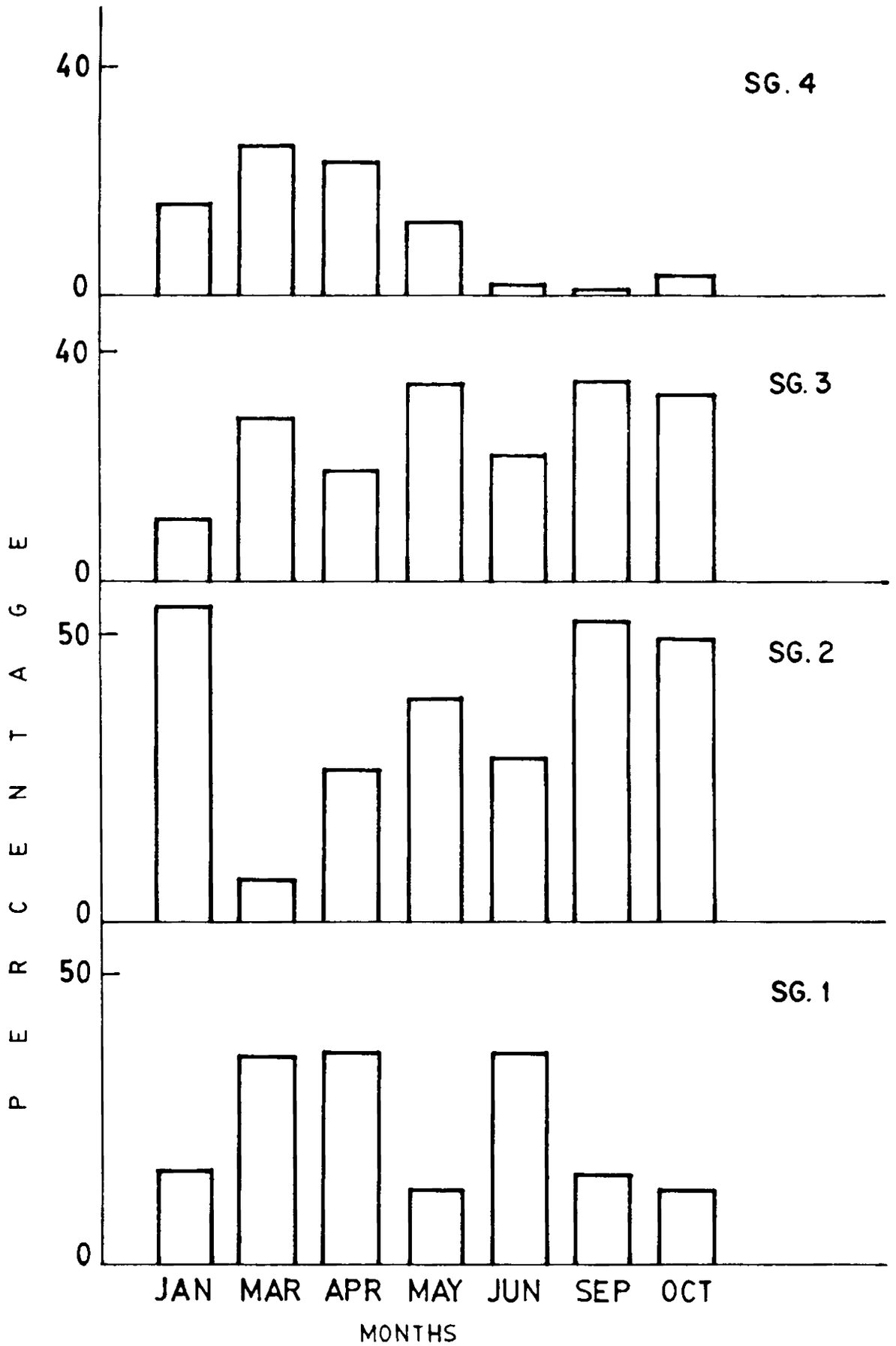

FIG. 17. SIZE GROUPS OF ALGAL PLANKTON IN COASTAL WATERS

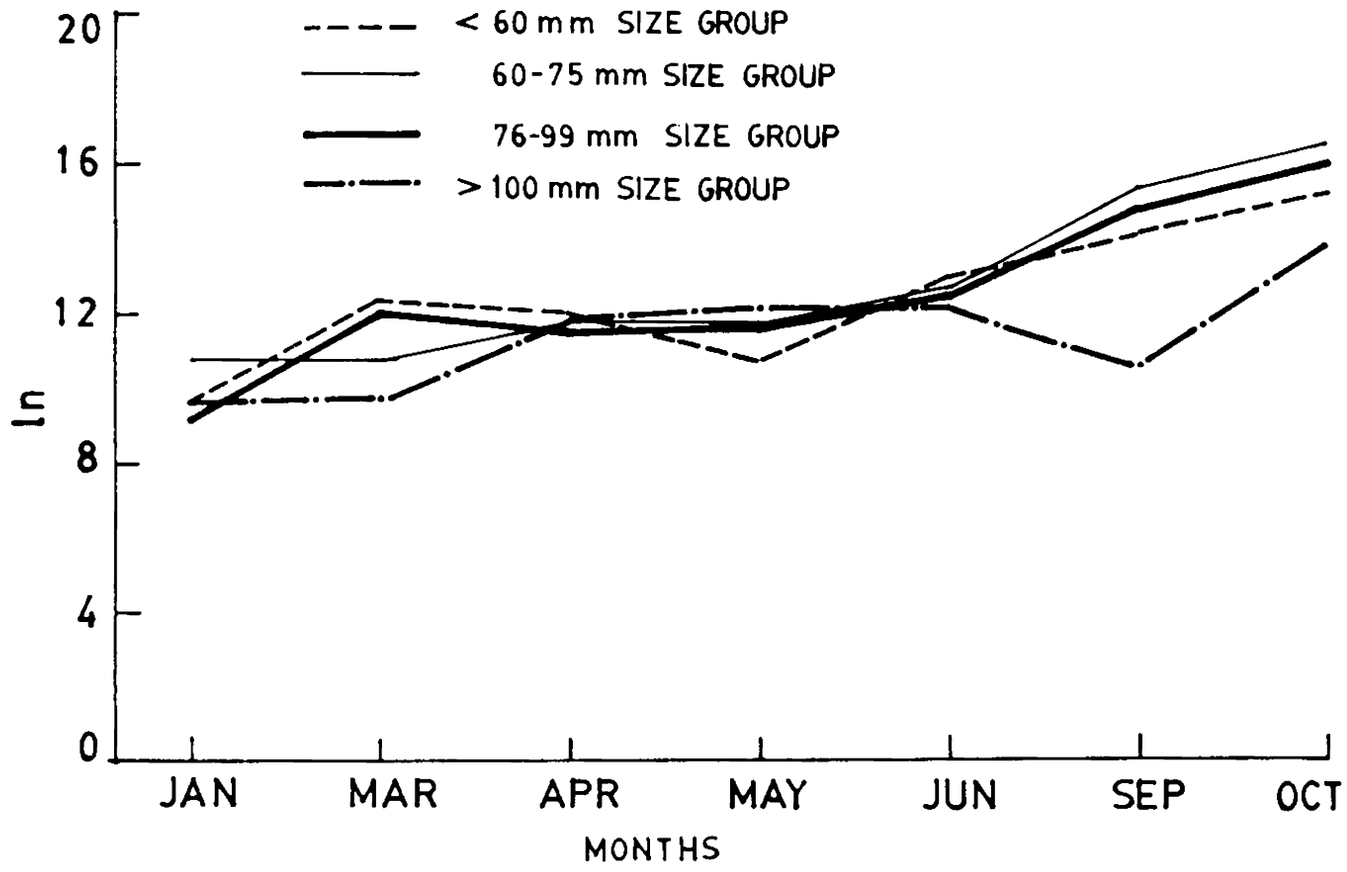

FIG. 18. OCCURRENCE OF VARIOUS SIZE GROUPS OF PLANKTONIC ALGAE IN COASTAL WATERS

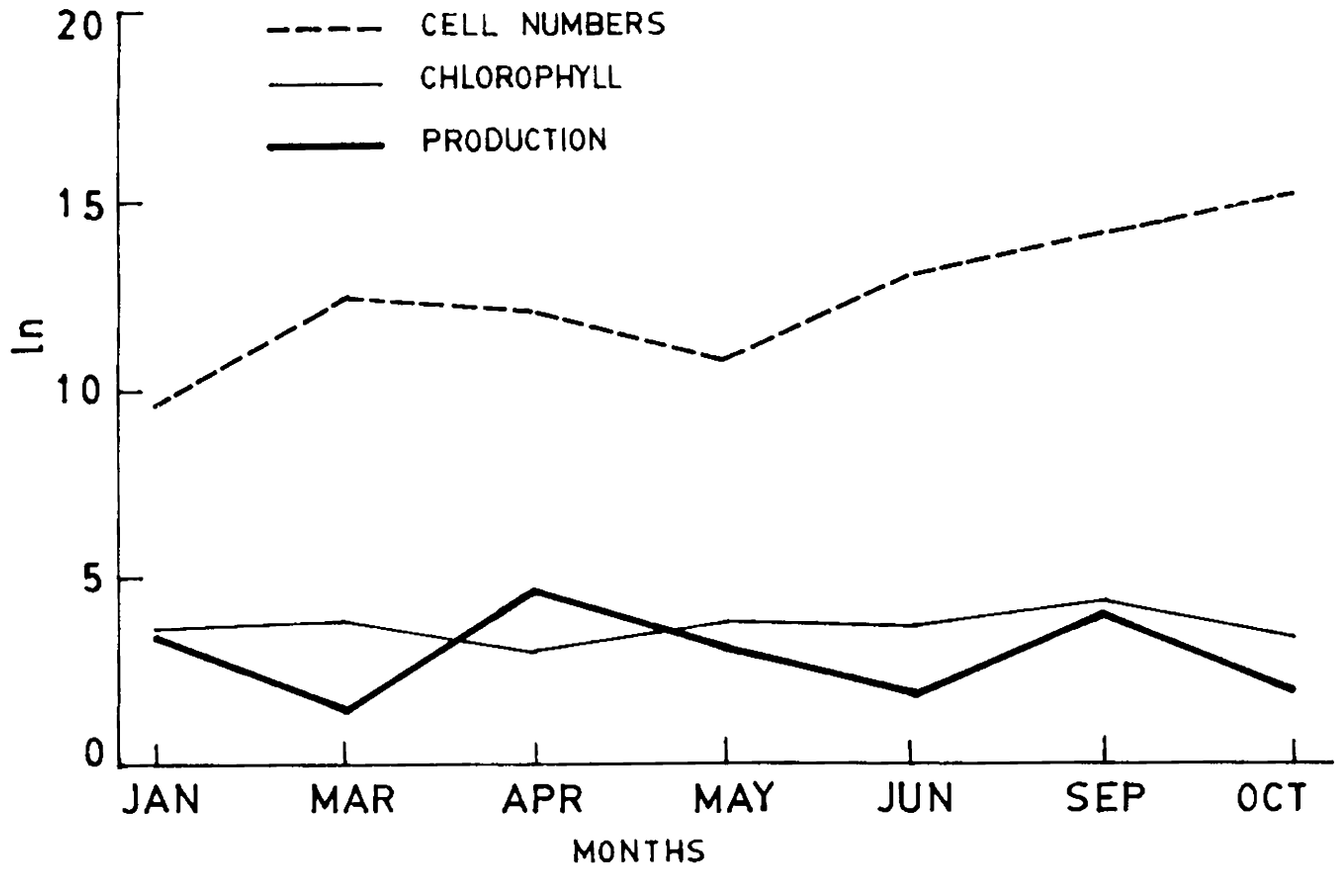

FIG. 19. CELL NUMBERS, CHLOROPHYLL 'a' AND PRODUCTIVITY OF NANOPLANKTERS

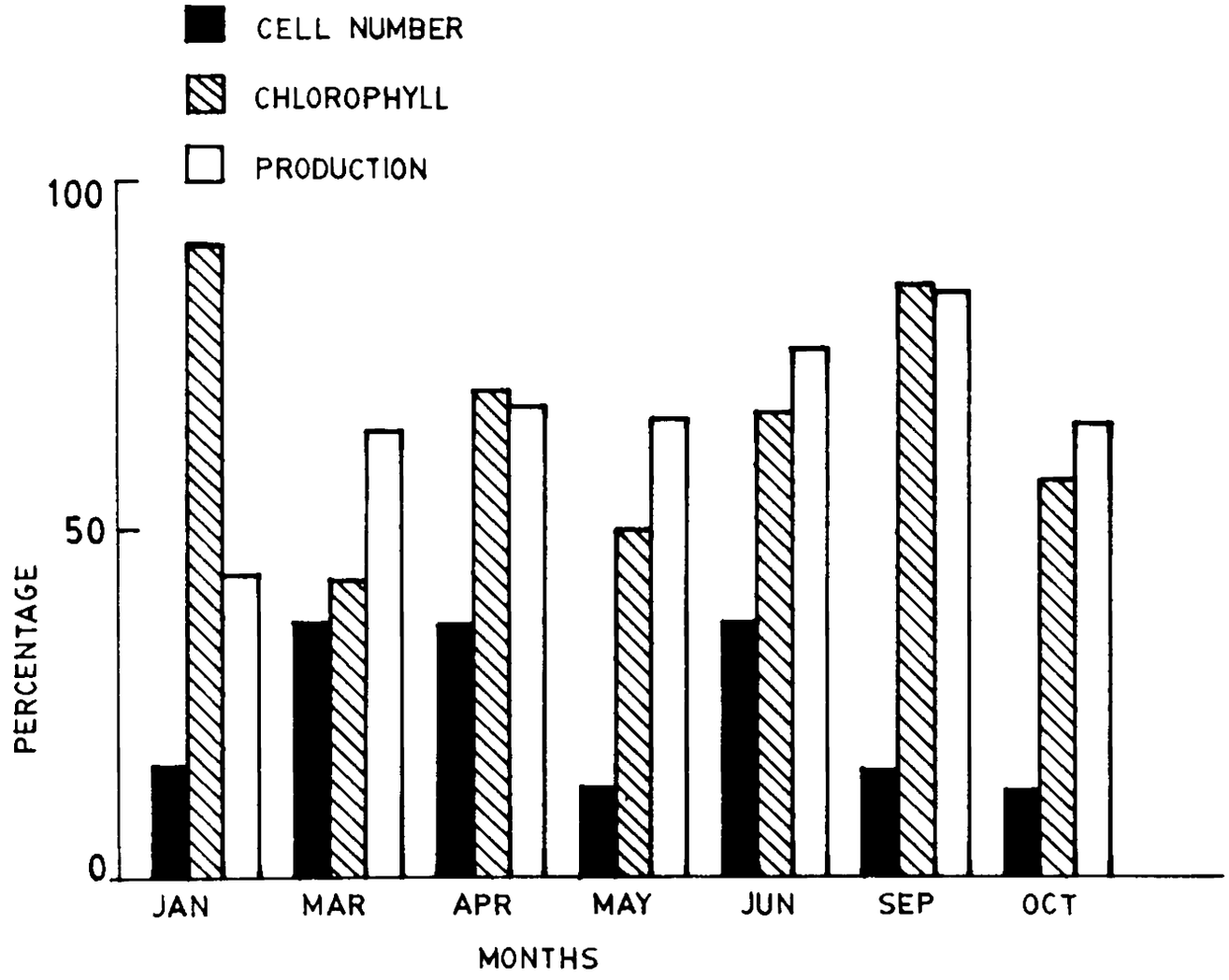

FIG. 20. CELL NUMBERS, CHLOROPHYLL 'a' AND PRODUCTIVITY OF NANOPLANKTON

CHAPTER V

TEMPORAL AND SPATIAL VARIATION OF MICROPLANKTERS AND CHLOROPHYLL IN COCHIN ESTUARY

Planktonic algae - distribution

This study projects the seasonal and spatial distribution of larger algal plankters (above 50 μ) in the estuary. These larger forms of planktonic algae can be grouped into microplankton and the autotrophic fractions of the mesoplankton. Since the planktonic algae above 500 μ are quite negligible in the estuary this is practically a study of microplankton.

A few nanoplankton species such as Synechococcus aeruginossus and Merismopedia elegans collected incidentally along with the larger plankters were also accounted. Qasim et al. (1974) found in Cochin backwater almost all nanoplankton species except some flagellates are represented in the net collection atleast in small numbers. Hence it can be considered that the study represents the entire flora except the picoplankton of the estuarine system.

The microflora having 10% or more of the total flora are analysed in relation to the salinity of the medium. In the southern-most station at Alleppey, where salinity ranges from 4.7% to 19.7% during pre-monsoon, the dominant flora are Chaetoceros sp., Nitzschia closterium, Gyrosigma balticum and Cerataulina bergonii of the class Bacillariophyceae, Synechococcus aeruginossus of the class Cyanophyceae and Gymnodinium sp. of the class Dinophyceae. During monsoon when the salinity is only 0.2 to 0.4% the major flora include Cerataulina bergonii, Nitzschia forcipata and Gyrosigma balticum

and Cerataulina bergonii of the class Bacillariophyceae, Synechococcus aeruginossus of the class Cyanophyceae and Gymnodinium sp. of the class Dinophyceae. During monsoon when the salinity is only 0.2 to 0.4‰ the major flora include Cerataulina bergonii, Nitzschia forcipata and Gyrosigma balticum of Bacillariophyceae and Merismopedia elegans of the class Cyanophyceae. During post-monsoon when the salinity range is from 0.2 to 16.7‰ the dominant microflora include Gyrosigma balticum, Cerataulina bergonii, Thalassiosira subtilis, Nitzschia closterium and Synedra sp. Thus the major flora during this period at this station are confined to the class Bacillariophyceae. The seasonal occurrence of the flora at this southernmost station is shown below:

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 4.7 - 19.7	S‰ 0.2 - 0.4	S‰ 0.2 - 16.7
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Chaetoceros lorenzianus	Nitzschia forcipata	Gyrosigma balticum
Nitzschia closterium	Cerataulina bergonii	Cerataulina bergonii
Cerataulina bergonii	Gyrosigma balticum	Thalassiosira subtilis
Gyrosigma balticum		
CYANOPHYCEAE	CYANOPHYCEAE	Nitzschia closterium
Synechococcus aeruginossus	Merismopedia elegans	Synedra sp.
DINOPHYCEAE		
Gymnodinium sp.		

During pre-monsoon the chlorophyll a concentration is 9.2 mg/m^3, in monsoon it is 5.5 mg/m^3 and in post-monsoon it is only 2.3 mg/m^3 (Fig. 22).

The high concentration of chlorophyll a is supported by the numerical preponderance of the species. In premonsoon there are six species of which four belong to the taxonomic class of Bacillariophyceae and one each belong to the class Cyanophyceae and Dinophyceae. During monsoon the number of species each having more than 10.0% of the standing crop is restricted to four, three of which belong to the class Bacillariophyceae and one belongs to the class Cyanophyceae. In postmonsoon all the four dominant species are restricted to the taxonomic class Bacilloriophyceae.

At the second station during the premonsoon the salinity range is between 19.3 and 23.6‰. The only dominant flora during this period is Chaetoceros sp., which forms monospecific blooms almost throughout the period. During monsoon when the salinity has considerably decreased i.e.,.when the salinity range is between 0.2 to 0.6‰, the dominant flora include Cerataulina bergonii Fragilaria oceanica, Nitzschia closterium and Surirella fluminensis of the class Bacillariophyceae and Merismopedia elegans of Cyanophyceae. During the postmonsoon when the salinity ranges from 0.6 to 17.4‰ the dominant flora include Surirella fluminensis, Nitzschia forcipata and Gyrosigma balticum of the class Bacillariophyceae. The seasonal distribution of the major micro-flora is shown below.

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 19.3 - 23.6	0.3 - 0.6	0.6 - 17.4
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Chaetoceros lorenzianus	Cerataulina bergonii	Surirella fluminensis
	Fragilaria oceanica	Nitzschia forcipata
	Nitzschia closterium	Gyrosigma balticum
	Surirella fluminensis	
	CYANOPHYCEAE	
	Merismopedia elegans	

Standing crop as measured by chlorophyll a concentration is 2.2 mg/m^3 in premonsoon, 15.9 mg/m^3 in monsoon and 2.3 mg/m^3 in post-monsoon. Though the chlorophyll a concentration recorded is the maximum during monsoon corresponding increase in the cell numbers is not observed during this period. This is probably due to the presence of nanoplankters such as Merismopedia elegans cells which could not be accounted fully.

In the third station during premonsoon the salinity ranges from 18.4 to 26.2‰ and the dominant flora are Cerataulina bergonii and Chaetoceros lorenzianus of the class Bacillariophyceae, Synechococcus aeruginossus of the class Cyanophyceae and Dinophysis sp. of Dinophyceae. During monsoon the salinity ranges from 0.2 to 0.4‰ and the dominant flora includes Cerataulina bergonii, Fragilaria oceanica and Nitzschia closterium. During post monsoon the salinity ranges from 9.2 to 17.9‰ and the dominant flora are Cerataulina bergonii and Synedra sp. The seasonal distribution of the microplankters at the third station is shown below:

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 18.4 - 26.2	S‰ 0.2 - 0.4	S‰ 9.2 - 17.9
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Chaetoceros sp.	Cerataulina bergonii	Cerataulina bergonii
Cerataulina bergonii	Fragilaria oceanica	Synedra sp.
CYANOPHYCEAE	Nitzschia closterium	
Synechococcus aeruginossus		
DINOPHYCEAE		
Dinophysis sp.		

Chlorophyll a concentration in pre-monsoon, monsoon and post-monsoon at this station are 9.6 mg/m^3, 23.2 and 2.8 mg/m^3 respectively. As the figure 21 shows the maximum microplankters are recorded during the pre-monsoon. Though there is disagreement in the values of phytoplankters and chlorophyll a concentration values during monsoon they agree very much during the post-monsoon. The lowest quantity phytoplankters and the lowest chlorophyll a concentration are observed during the post-monsoon. The comparatively high value of chlorophyll a which is disproportionate to the planktonic concentration is due to the presence of unaccounted nanoplankters, ultra-plankters and picoplankters.

At the fourth station there is an increase in salinity throughout the year. During the pre-monsoon when the salinity ranges from 29.2 to 29.4‰ the dominant flora are Coscinodiscus jonesianus, Cerataulina bergonii, Nitzschia closterium of the taxonomic class Bacillariophyceae and the dinoflagellate Dinophysis sp. The monsoon flora at the salinity range of 0.4 to 3.6‰ are Cerataulina bergonii, Coscinodiscus jonesianus and Fragilaria oceanica of the class Bacillariophyceae and Merismopedia elegans of the class Cyanophyceae. The post-monsoon flora consist of Synedra sp., Cerataulina bergonii, Fragilaria oceanica, Skeletonema costatum and Thalassionema nitzschioides of the class Bacillariophyceae and Synechococcus aeruginossus of the class Cyanophyceae. The salinity range during post-monsoon is 0.9 to 24.1‰. The dominant flora at the fourth station in relation to the salinity is shown below.

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 28.2 - 29.4	S‰ 0.4 - 3.6	S‰ 0.9 - 24.0
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Cosciodiscus jonesianus	Cerataulina bergonii	Synedra sp.
Cerataulina bergonii	Coscinodiscus jonesianus	Cerataulina bergonii
Nitzschia closterium	Fragilaria oceanica	Fragilaria oceanica
DINOPHYCEAE	CYANOPHYCEAE	Skeletonema costatum
Diophysis sp.	Merismopedia elegans	Thalasionema nitzschioides
		CYANOPHYCEAE
		Synechococcus aeruginossus

Cerataulina bergonii is the only diatom present throughout the season at this station. Dinoflagellates in considerable number are present only during the pre-monsoon. During the pre-monsoon the chlorophyll a concentration is 4.6 mg/m^3. The maximum chlorophyll a concentration of 21.8 mg/m^3 is recorded during monsoon. The maximum number of microplankton also is recorded during the monsoon (Fig. 21). The minimum chlorophyll a of 3.8 mg/m^3 is obtained during the post-monsoon.

In the fifth station during the pre-monsoon period the salinity range is from 27.8 to 33.2‰. The dominant flora are Coscinodiscus jonesianus, Planktoniella sol and Ditylum brightwelli of the class Bacillariophyceae, Ceratium tripos, Dinophysis sp. and Peridinium depressum of the class Dinophyceae. During monsoon the salinity decreases considerably and the range is from 0.3 to 19.0‰. Monospecific bloom of Cerataulina bergonii occured in June, July and August. In September the monospecific bloom is that of

Skeletonema costatum. The post-monsoon microflora within the salinity range of 1.9 to 25.0‰ are Cerataulina bergonii, Nitzschia closterium, Thalassionema nitzschioides, Thalassiothrix sp. Coscinodiscus radiatus and Chaetoceros decipiens of the class Bacillariophyceae and Synechococcus aeruginossus of the class Cyanophyceae. The floristic spectrum of the major microflora for the three seasons are indicated below.

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 27.8 - 33.2	S‰ 0.3 - 19	S‰ 0.9 - 25.0
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Coscinodiscus jonesianus	Cerataulina bergonii	Skeletonema costatum
Planktoniella sol	Skeletonema costatum	Cerataulina bergonii
Ditylum brightwelli		
DINOPHYCEAE		Nitzschia closterium
Ceratium tripos		Thalassionema nitzschioides
Dinophysis sp.		Thalassiothrix sp.
Peridinium depressum		Coscionodiscus radiatus
		Chaetoceros decepiens
		CYANOPHYCEAE
		Synechococcus aeruginossus

The chlorophyll a concentration shows clear seasonal variations. In pre-monsoon it is 10.1 mg/m^3, in monsoon it is the maximum with 20.1 mg/m^3 and in post-monsoon it is 3.0 mg/m^3 which is the minimum. While the maximum standing crop is recorded during post monsoon (Fig. 21) maximum chlorophyll a concentration is observed in monsoon when the entire season is

dominated with monospecific blooms of either Cerataulina bergonii or Skeletonema costatum.

At the sixth station during pre-monsoon period when the salinity ranges from 27.7 to 33.4‰ the dominant flora are Chaetoceros lorenzianus, Coscinodiscus centralis and monospecific bloom of Skeletonema costatum. The monsoon flora at the salinity range of 0.2 to 1.4‰ are Cerataulina bergonii, Coscinodiscus centralis and Campylodiscus sp. The post-monsoon microflora at this station are Cerataulina bergonii, Nitzschia closterium, Coscinodiscus centralis and monospecific bloom of Skeletonema costatum. The salinity ranges between 1.1 and 16‰ . The seasonal floristic spectrum of the dominant microplankters is indicated below:

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 27.7 - 33.4	S‰ 0.2 - 1.4	S‰ 1.1 - 16.0
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Coscinodiscus centralis	Cerataulina bergonii	Cerataulina bergonii
Chaetoceros lorenzianus	Coscinodiscus centralis	Nitzschia closterium
Skeletonema costatum	Campylodiscus sp.	Coscinodiscus centralis
		Skeletonema costatum

At this area under observation Skeletonema costatum forms bloom twice, once in March and another in November.

The chlorophyll a concentration shows clear seasonal fluctuation. The chlorophyll a value during pre-monsoon is 23.1 mg/m^3 which is the maximum. The minimum value of chlorophyll a of 3.8 mg/m^3 is recorded in

post-monsoon and in monsoon the chlorophyll a value is 6.1 mg/m^3. The cell counts also is found to be the maximum during pre-monsoon. But no direct relationship is observed between chlorophyll a concentration and cell counts. This may be either due to the presence of picoplankton or due to unfavourable ecophysiological conditions.

In the northernmost station when the salinity ranges from 32.8 to 35.1‰ the microflora consist of Coscinodiscus centralis, Fragilaria oceanica, Pleurosigma directum and Cyclotella nana. During monsoon the salinity varies from 0.2 to 2.5‰. The microflora consist of monospecific bloom of Cerataulina bergonii, Ceratium tripos and Oscillatoria prolifica. In the post-monsoon the salinity varies from 0.7 to 25‰. The larger algal plankters at the station include the monospecific blooms of Cerataulina bergonii, Stephanopyxis sp. and Coscinodiscus centralis. The dominant microplankters distributed in pre-monsoon, monsoon and post-monsoon are shown below:

PRE-MONSOON	MONSOON	POST-MONSOON
S‰ 32.8 - 35.1	S‰ 0.2 - 2.5	S‰ 0.7 - 25.0
BACILLARIOPHYCEAE	BACILLARIOPHYCEAE	BACILLARIOPHYCEAE
Coscinodiscus centralis	Cerataulina bergonii	Cerataulina bergonii
Fragilaria oceanica	DINOPHYCEAE	Stephanopyxis sp.
Pleurosigma directum	Ceratium tripos	Cosinodiscus centralis
Cyclotella nana	CYANOPHYCEAE	
	Oscillatoria prolifica	

In December the flora consist entirely of the diatom Coscinodiscus centralis. In this northernmost station there is practically no seasonal fluctuation in

the chlorophyll a concentration the values being 5.1 mg/m^3, 4.8 mg/m^3 and 5.4 mg/m^3 in pre-monsoon, monsoon and post-monsoon respectively. The other parameters such as cell counts and productivity too do not show any remarkable fluctuation.

DISCUSSION

Seasonal and spatial fluctuations of the microplankters in the estuary are found to be influenced mainly by the variation in salinity. There is remarkable variation in the salinity range at the various sites of observation. This is very clear by considering the maximum salinity at each station. When the maximum salinity is 19.7‰ at station 1, it is 23.6‰ at station 2, 26.2‰ at station 3, 29.4‰ at station 4, 33.2‰ at station 5, 33.4‰ at station 6 and 35.1‰ at station 7.

During pre-monsoon at the first site of observation where the salinity range is 4.7 - 19.7‰ the dominant microplankters are Nitzschia closterium, Chaetoceros lorenzianus, Cerataulina bergonii and Gyrosigma balticum of the class Bacillariophyceae. At the next station at a higher salinity range of 19.3 - 23.6‰ the dominant flora is Chaetoceros lorenzianus which forms monospecific blooms during this period. At station three where the salinity range is 18.4 - 26.2‰ Dinophysis sp. make their appearance. Besides Chaetoceros lorenzianus present in the previous station Cerataulina bergonii and Synechococcus aeruginossus which are found to occur in wide variations of salinity are also present at this station. At the fourth station at a higher salinity range of 28.2 - 29.4‰ diatom such as Coscinodiscus jonesianus and dinoflagellate such as Dinophysis sp. which are adapted to more salinity appear. At the higher salinity range of 27.8 - 33.2‰ diatoms such as Planktoniella sol, Ditylum brightwelli and dinoflagellate such as Ceratium tripos and Peridinium depressum make their appearance besides Coscinodiscus jonesianus and Dinophysis sp. Still towards north at a salinity range of 27.7 - 33.4‰ the dominant microplankters are Chaetoceros lorenzianus and Skeletonema costatum. The northern most station has got the highest salinity range of 32.8 - 35.1‰ during pre-monsoon. The planktonic algae present are

diatoms such as Coscinodiscus centralis, Fragilaria oceanica Pleurosigma directum and Cyclotella nana. Thus it is seen that there is conspicuous spatial variation, in the distribution of planktonic algae mainly influenced by the salinity variation. Thus based on the distribution, the planktonic algae can be grouped into three categories: those which are distributed at low saline medium, forms which are found at high salinity and forms which are adapted to wide range of salinity so that they are found distributed at varying salinities. Thus during pre-monsoon, when in the first three stations, Chaetoceros species is the main planktonic alga in the remaining four stations, where the salinity ranges are higher various species of Coscinodiscus become dominant. It is the salinity which plays the important role in the spatial distribution as an ecological master factor.

During monsoon, at all the stations the salinity is very low and hence there is not much variation in the floristic composition. The important plankters present during monsoon are Cerataulina bergonii, and Synechococcus aeruginossus. In the post-monsoon at all stations there are salinity variations which are reflected in the distribution of autotrophic plankters. Thus during post-monsoon at lower salinities species such as Cerataulina bergonii, Gyrosigma balticum, Synedra sp. and Skeletonema costatum are found. These species are distributed throughout the estuary. But species such as Coscinodiscus centralis are found only from fourth station onwards. Among the first three stations Coscinodiscus spp. are found to be totally absent.

The phytoplankton population in a tropical estuary as the one which is discussed here includes estuarine, marine and fresh water species. Estuarine diatoms have the widest adaptability to any change in salinity of the external medium (Williams, 1964). While the growth rates of estuarine clones are not

affected in media of wide salinity ranges, clones isolated from sea do not survive in lower salinities (Desikachary, 1972). The above fact illustrates pattern of distribution and the probable prominant factor responsible for it. The present study reveals that phytoplankton in the estuary can broadly be divided into (1) flora which are well adapted to the fluctuating estuarine conditions and (2) those which are not adapted or little adapted. While the former comprise of typical estuarine forms which may be permanent residents, the latter represent either fresh water or marine forms migrated to the estuary and seen only for short periods. The different species show different degrees of salinity tolerance. Species such as Cerataulina bergonii tolerates a wide range of salinity but blooms appear only at low salinity. At station I, there is bloom of this species at 0.4‰. When the salinity range is 5-17‰ the population is reduced to an average of 20.0‰ . At salinity 20‰ they almost disappear. Two peaks of abundance each followed by a fall in salinity are shown by such species. Cerataulina bergonii is largely distributed in the monsoon months. Iyengar and Venkataraman (1951) observed that Cyclotella meneghiana showed two peak periods, each followed by the south-west and the north-east monsoon showers resulting in a fall in salinity. With further increase in salinity the diatoms disappeared. Chaetoceros and Coscinodiscus spp., adapted to comparatively high salinity are the dominant flora during the premonsoon.

Salinity changes affect the distribution of dinoflagellates also. Species of Peridinium, Ceratium, Gymnodinium and Dinophysis are seen in the premonsoon when the salinity is high. In addition to this, temperature also may have a critical role in the distribution of dinoflagellates. They can survive at lower nutrient concentrations than diatoms.

The standing crop as measured by chlorophyll a shows distinct spatial variation. The southern station and the northern extremity show low standing crops, whereas the two stations adjacent to the Cochin barmouth has comparatively high chlorophyll concentration. At the southern station the chlorophyll a concentration is almost directly proportional to the cell concentration. This is a site of comparatively low salinity where there is only little chance of marine forms being recruited to this area and rendered physiologically inactive. During monsoon fresh water forms are recruited to the area where they thrive well. A few of these forms are found even in post and pre-monsoon. At the northern station too, there is general agreement between chlorophyll a concentration and cell numbers. Here the salinity is comparatively high and the autotrophic plankters are adapted to high salinity. During monsoon the dominant flora present are Cerataulina bergonii which are adapted to wide fluctuations of salinity especially low salinity. Lack of any definite relationship between cell counts and chlorophyll a concentration is probably due to the ecophysiological imbalance triggered by the tidal effect and consequent abrupt change of the ambient water and the flora.

The annual average concentration of chlorophyll a of the seven selected stations extending from Alleppey to Azhikode are 5.7, 6.8, 11.9, 10.1, 11.1, 11.0 and 5.1 mg/m^3 respectively. While at the first station the salinity is less in most of the months, at the last station salinity is very high. The areas of intermediate salinity record comparatively high chlorophyll a concentration, maximum chlorophyll a concentration of 13.9 mg/m^3 is recorded during monsoon and the minimum of 3.3 mg/m^3 is recorded in post-monsoon and pre-monsoon it is 9.1 mg/m^3.

Though salinity has apparently no influence on primary production in the estuary it is one of the important factors which controls the species

composition and succession of planktonic algae. It is true that the quantum of production is not affected even by the drastic fluctuation in salinity. This is not because the physiological activity of these autotrophs is unaffected but due to the replacement of suitable flora along with the displacing of ambient water and the salinity tolerance of certain existing species. The balance of the total quantity of the organic material is not upset as the process of photosynthesis *in toto* is not retarded.

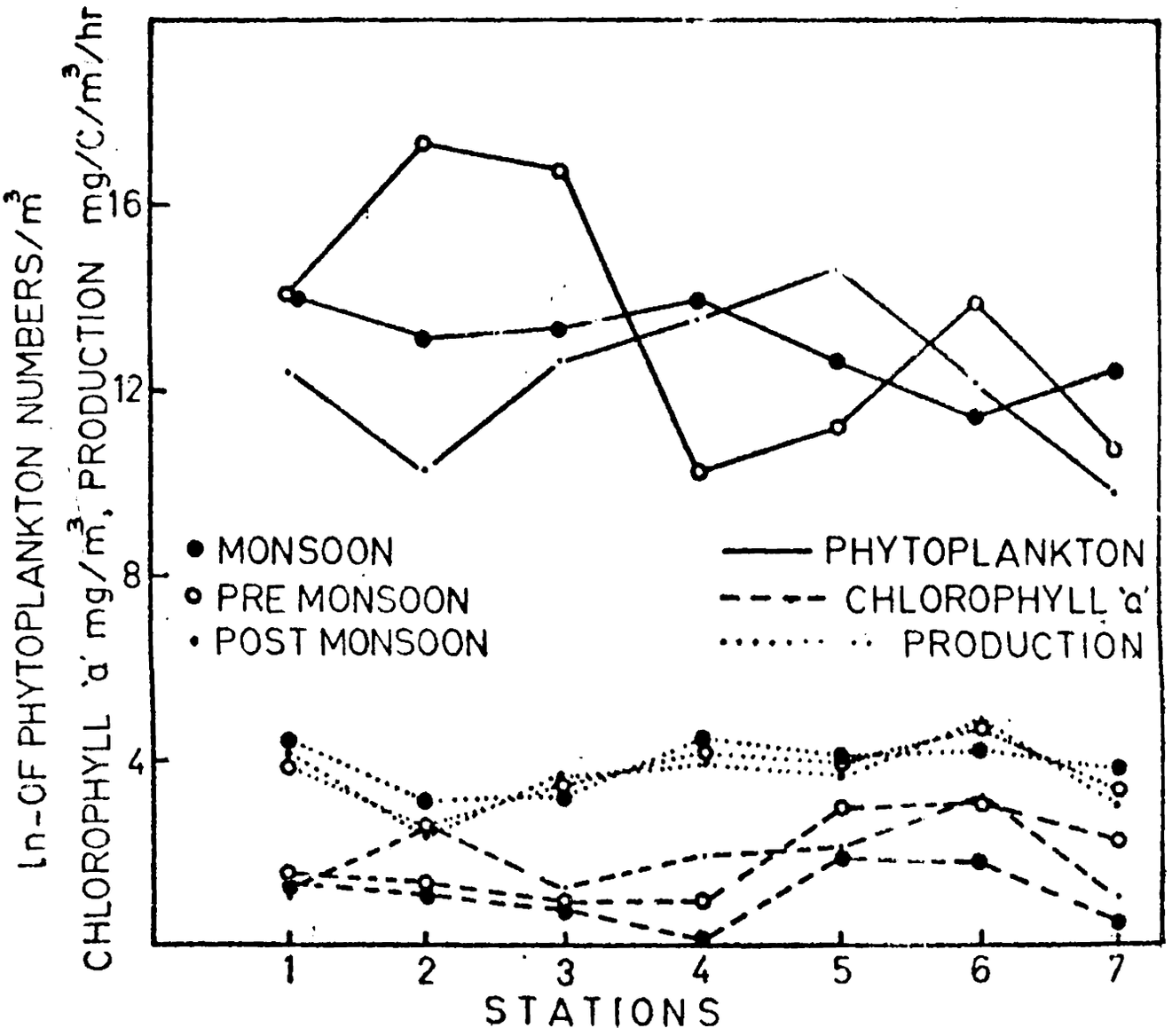

Fig. 21. Season-wise (Pre-monsoon, Monsoon and Post-monsoon) distribution of Phytoplankton, Chlorophyll and Primary production in Cochin backwaters.

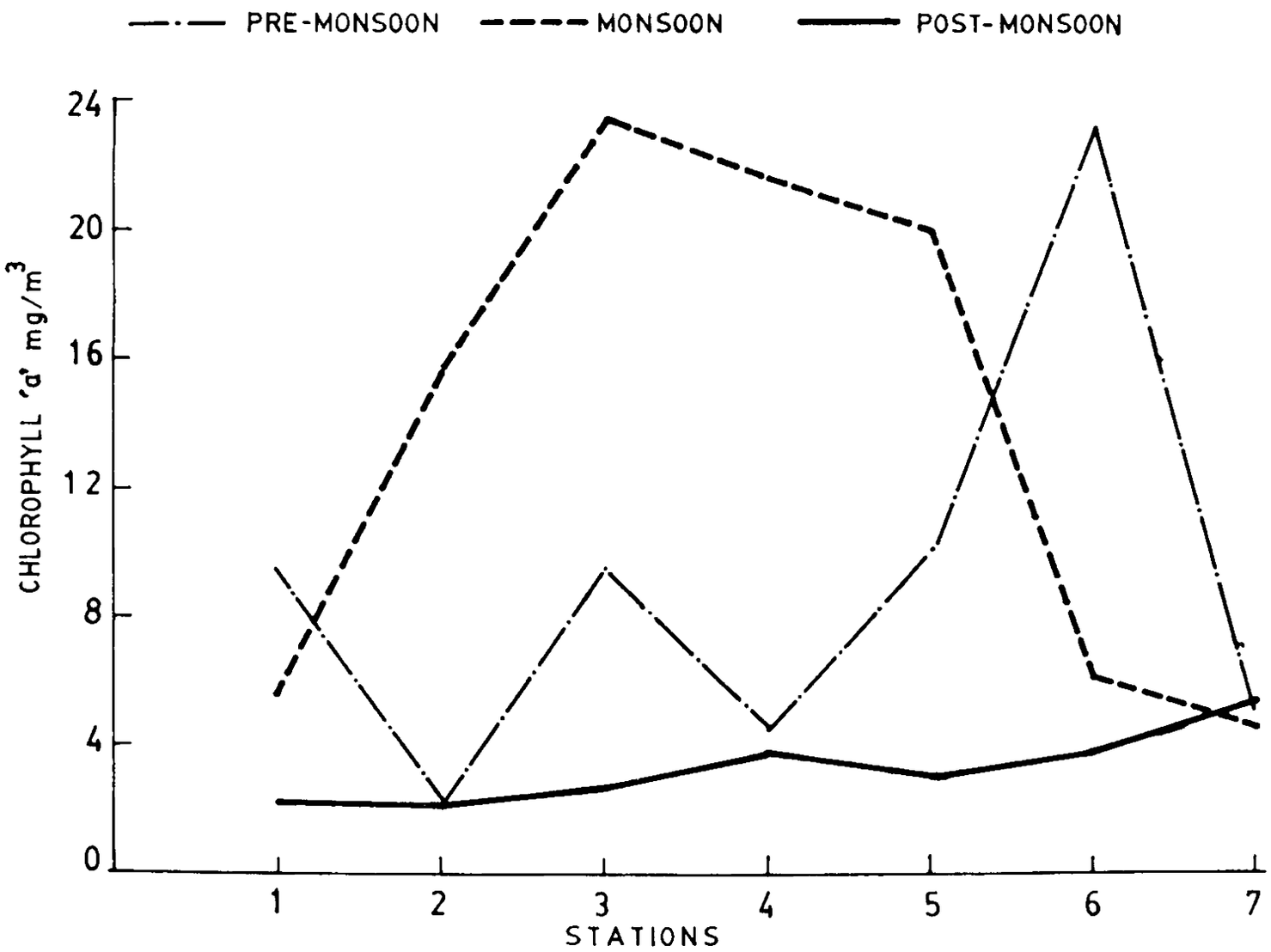

FIG. 22. SEASONAL AND SPATIAL FLUCTUATION OF CHLOROPHYLL 'a'

CHAPTER VI

PRIMARY PRODUCTION IN THE ESTUARY

1. Temporal and seasonal variation of productivity

Organic production at the primary trophic level as measured by C^{14} shows wide fluctuation from station to station when analysed monthwise. In the southernmost station (Station I) during pre-monsoon the production rate ranged from 29.7 to 98.2 mg C/m^3/hr with an average value of 47.7mg C/m^3/hr. In the monsoon when the ambient water is practically fresh water, the production rate is almost double (82.8 mg C/m^3/hr) compared to the pre-monsoon months (Fig. 30). The production rate ranged from 6.7 to 185.4 mg C/m^3/hr. In the post-monsoon, the average primary production rate is 56.7 mg C/m^3/hr. When considered monthwise the range is from 14.4 to 90.9 mg C/m^3/hr. There are two peaks of production, the major peak in August (185 mg C/m^3/hr) and the minor peak in January (90.9 mg C/m^3/hr) (Fig. 23).

In the second station, average production rate during the pre-monsoon is only 11.7 mg C/m^3/hr. The minimum production is 2.2 mg C/m^3/hr which is in February and the maximum is 21.2 mg/C/m^3/hr which is in March. During the monsoon the lowest value recorded is 0.24 mg C/m^3/hr, which is the lowest production rate ever recorded from this estuary during the present investigation and the production rate had gone up to 67.8 mg C/m^3/hr during the same season, with an average production rate of 25 5 mg C/m^2/hr In the post-monsoon the average rate of production is 31.2 mg C/m^3/hr., the range being 13.6 mg C/m^3/hr in January to 48.71 mg C/m^3/hr in December. There are two peaks of production, one in September (67.8 mg C/m^3/hr) and another in December (48.7 mg C/m^3/hr) (Fig. 24).

Station 3, in the southern half, does not exhibit considerable fluctuation in the seasonwise production rate, the values being 27.8, 28.9 and 29.0 mg $C/m^3/hr$ in pre-monsoon, monsoon and post-monsoon respectively. In the pre-monsoon the values ranged from 11.1 to 34.6 mg $C/m^3/hr$, in the monsoon the range is between 8.9 and 45.2 mg $C/m^3/hr$ and in the post-monsoon it is between 18.0 and 39.9 mg $C/m^3/hr$. Two depressions in productivity one in January - February and another in June-July are observed (Fig. 25).

The fourth station records comparatively high production of 80.8 mg $C/m^3/hr$ during monsoon, 74.2 mg $C/m^3/hr$ during pre-monsoon and 44.2 mg $C/m^3/hr$ in the post-monsoon. In the monsoon the highest value recorded from the station is 182.5 mg $C/m^3/hr$ in the month of August and the lowest value being 19.4 mg $C/m^3/hr$ recorded during the month of June. During pre-monsoon the production ranges from 68.0 mg $C/m^3/hr$ in March to 80.2 mg $C/m^3/hr$ in May. Monsoon production ranges from 19.4 mg $C/m^3/hr$ in June to 182.5 mg $C/m^3/hr$ in August. The peak production is recorded in August (Fig. 26).

In the next station, the production rate is 35.1 mg $C/m^3/hr$ during the pre-monsoon with a monthly variation of 19.4 to 66.0 mg $C/m^3/hr$. In the monsoon the average production rate is 52.2 mg $C/m^3/hr$ with a monthly fluctuation of production rate from 30.4 to 88.4 mg $C/m^3/hr$. In the post-monsoon the average production rate is 35.8 mg $C/m^3/hr$ with a fluctuation of monthly value ranging from 26.9 to 47.8 mg $C/m^3/hr$. Three peaks of production are observed at this site. The major peak is in September (88.4 mg $C/m^3/hr$) the second peak in April with 66.2 mg $C/m^3/hr$ and the third peak with 52.0 mg $C/m^3/hr$ in July (Fig. 27).

At station 6 the highest production rate of 242.5 mg $C/m^3/hr$ is recorded in the month of November. In this station, unlike other stations, very high production is recorded in post-monsoon. The post-monsoon production rate of 108.7 mg/$C/m^3/hr$ is the highest average value of any season ever recorded during this investigation. The individual values vary from 23.8 to 242.5 mg $C/m^3/hr$. During pre-monsoon the monthly values vary from 65.2 to 120 mg $C/m^3/hr$ with an average production rate of 65.4 mg $c/m^3/hr$. The production varies from 23.8 mg $C/m^3/hr$ in October to 242.5 mg $C/m^3/hr$ in November (Fig. 28).

In the northernmost station (Station VII) the average production rate during the pre-monsoon, monsoon and post-monsoon are 26.1, 43.5 and 21.1 mg $C/m^3/hr$ respectively (Fig. 30). In pre-monsoon the production rate varies from 13.4 to 39.5 mg $C/m^3/hr$, in the monsoon it varies from 0.50 to 86.6 mg $C/m^3/hr$ and in the post-monsoon the production rate lies between a narrow range of 11.1 and 26.9 (Fig. 29).

Thus the mean value for pre-monsoon is 45.1 mg $C/m^3/hr$ for the entire Cochin estuarine region. In monsoon the mean production rate is 54.2 mg $C/m^3/hr$ and for post-monsoon it is 48.6 mg $C/m^3/hr$.

The annual mean for the entire estuary comprising an area of 300 sq.km is computed at 48.6 mg $C/m^3/hr$ and the estimated annual production for the estuary is about 53,000 tonnes of carbon for the surface waters in the upper one metre depth. This is about a little more than half the value computed for the entire euphotic zone of the estuarine region. The depth of the euphotic zone varies from about 1.5 to 3 metres depending on the season and annual carbon production is 100,000 tonnes.

DISCUSSION

The productivity in the estuary exhibit temporal and spatial variations. The average productivity of the estuary extending from Alleppey to Azhikode is 48.5 mg $C/m^3/hr$. In that part of the estuary from Alleppey to Cochin, the productivity is 44.24 mg $C/m^3/hr$ and in the northern half the productivity is 59.0 mg $C/m^3/hr$. The observation on the pigments (Qasim and Reddy, 1967) also indicates that it varies considerably from place to place and from time to time or with the state of tide. Primary production was significantly higher at the flood tide than at the ebb tide (Qasim and Gopinathan, 1969). The present observations on phytoplankton and primary production extending throughout the entire Vembanad lake system further confirm the seasonal and spatial variability. During the pre-monsoon the phytoplankters were mostly marine in the lower reaches of the lake as the salinity was comparatively high reaching upto about 34‰ . The flora was constituted by diatoms such as species of Chaetoceros, Coscinodiscus, Skeletonema, Pleurosigma and Nitzschia and dinoflagellates such as species of Peridinium, Gymnodinium and Ceratium. The highest rate of production of 98.8 mg $C/m^3/hr$ was observed near station 6 in the northern part of the backwaters. The maximum chlorophyll a concentration (206 mg/m^3) was also recorded in the same area. The cell counts were compatible. Thus more or less a direct relationship of the three parameters is found here. This may be attributed to the optimum nutrient concentration, salinity and temperature which render the organisms physiologically very active. The higher O_2 values in the area is a clear evidence of the considerably higher photosynthetic efficiency of the phytoplankters. The lowest organic production during this period (10.5 mg $C/m^3/hr$) was recorded near

station 2 where the largest number of phytoplankters of all the three seasons was observed. Such anomaly may be due to the retardation in the physiological conditions of phytoplankters caused by high temperature, low salinity and nutrient concentration.

The advent of monsoon tilts the whole picture of the flora, it inactivates the marine species present and goes upto the extent of replacing marine species by fresh water species in certain areas. During this season the southern most region turns out to be a typically fresh water environment recording the highest production of the season (84 mg $C/m^3/hr$). A switch over from salinity of 11‰ in the pre-monsoon to less than 0.5‰ results in the disappearance of marine species. The optimum temperature with sufficiently high amount of nutrients enhance the photosynthetic efficiency of the fresh water species. At station 2 the picture is quite different. The production (23 mg $C/m^3/hr$) is the lowest recorded in the season with low chlorophyll contents but with considerably large number of phytoplankters. A slight increase in the salinity renders the fresh water species physiologically inactive resulting in very low production. On reaching the outlet of Ithypuzha river (station 3) no environmental factors seem to limit the photosynthetic rate and hence the production is comparatively high. Here the flora comprise mostly of the fresh water species. Thereafter the production values show an increasing trend almost upto to the sixth station. This increasing trend of production coupled with increasing salinity is due to gradual replacement of fresh water species with marine ones. The decline in the production values in the last station may be due to the reduction in the salinity and nutrient concentration.

The post-monsoon season is characterised by an increase in salinity. The average salinity varies from about 8‰ near station 3 to about 24‰ in

the north at station 6. During the process of gradual transition from fresh water habitat, fresh water species to some extent succeed in acclimatising themselves in low salinity conditions. The presence of fresh water species in the area of low salinity (stations 1 and 3) is an indication to their low salinity tolerance. But, these species completely disappear with the further increase in salinity as evidenced by their total absence in the pre-monsoon. Of the main ecological factors which determine the rate of primary production in the estuary, the influence of nutrients has already been pointed out. During the monsoon and post-monsoon period although tidal influences bring in large volume of the sea water into the estuary, fresh water influx far surpasses that of the saline water and therefore surface salinity continues to be low whereas the sea water remains as a distinct bottom layer with sharp gradients. The bottom water of the estuary is considered as the same as the upwelled water of the Arabian Sea which has spread over the continental shelf (Ramamritham and Jayaraman 1963). This nutrient - rich water when moves upto the euphotic zone triggers high rate of primary production in the inshore environment. But in the estuary, since there is considerable resistance to the mixing of the bottom waters with those of the surface almost till the end of October, effective utilization of the nutrients does not take place till that time This accounts for the lower rate of primary production during the monsoon and progressive increase during the subsequent period.

With an annual average rate of gross production ranging from 150 to 650 g C/m^2 at different regions and the total annual gross production of 100,000 tonnes of carbon for the entire Vembanad Lake it can be considered as a very highly productive area almost comparable to the inshore area of the seas around India where there is constant replenishment of nutrients.

However, certain problems in the food chain relationship have been raised by the earlier workers (Qasim et al, 1969 and Qasim, 1970). Of the gross production, 20 to 45% can be considered to be used for respiration and from the net production available to the next trophic level only a very small portion is supposed to be used up by zooplankton (30 g C/m^2/year) leaving a large surplus of basic food (Qasim et al, 1970). Hence it has been suggested that there may alternate pathways in the trophic chain and it is difficult to determine quantitatively how much from the surplus production would be utilized by these consumers. Qasim (1970) has suggested that one such pathway may be linked with herbivorous fishes which are found in the lake in appreciable numbers and another direct link from the basic food through detritus with prawn population which are omnivorous. As the euphotic zone is considerably less in the lake, a good part of the phytoplankton production while sinking below the euphotic zone, could form food of the benthic animal communities. Thus the magnitude of primary production of the Vembanad Lake could sustain a very rich biota of organisms feeding at different trophic levels.

TABLE 23

HYDROGRAPHIC PARAMETERS IN THE SOUTHERN REGION OF THE ESTUARY

(AVERAGE VALUES FOR TWO YEARS)

Sl. No.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
TEMPERATURE (^{o}C)												
1.	32.0	31.8	32.4	31.6	29.1	29.0	28.0	31.2	33.4	33.1	27.3	27.2
2.	32.5	32.6	32.6	31.9	30.9	29.8	26.3	31.6	32.9	33.1	29.8	28.4
3.	30.1	30.6	32.8	30.0	31.0	29.8	28.6	31.2	31.8	33.1	28.9	27.5
4.	33.3	31.2	33.2	32.2	29.7	30.0	29.7	31.9	33.0	30.9	30.7	30.8
5.	30.4	31.0	32.0	32.8	30.9	30.3	32.1	32.0	32.3	31.0	30.0	29.9
SALINITY ($S‰$)												
1.	4.7	9.6	18.4	10.2	0.6	0.5	0.9	0.8	1.5	24.2	1.7	15.7
2.	19.5	14.6	23.2	19.6	0.3	0.5	0.7	0.9	1.5	22.6	4.3	25.1
3.	20.1	22.4	24.8	22.2	0.4	0.4	0.4	0.6	6.6	14.7	6.4	17.2
4.	29.8	29.8	29.8	30.3	0.4	0.6	2.2	3.2	8.3	31.7	9.8	18.7
5.	30.1	32.0	24.5	32.8	19.5	0.8	2.6	4.7	12.5	33.0	19.8	23.2
DISSOLVED OXYGEN (ml/l)												
1.	2.8	3.5	3.8	3.8	5.5	4.3	4.5	3.4	3.1	3.4	3.5	3.4
2.	2.6	4.3	1.6	3.6	4.4	5.3	3.3	2.6	2.7	3.4	2.8	2.8
3.	2.2	2.9	3.2	2.8	4.4	5.4	3.5	2.9	3.2	3.4	3.2	2.4
4.	1.9	4.0	3.2	4.1	4.8	4.9	2.9	2.2	3.2	4.0	3.0	2.8
5.	2.0	3.8	2.8	3.2	4.0	4.0	3.3	2.4	3.4	3.5	3.5	3.0
INORGANIC PHOSPHATE (ug at PO_4-P/l)												
1.	0.50	0.53	0.71	3.8	1.3	3.9	0.43	2.1	1.8	0.25	13.1	1.31
2.	0.35	0.40	0.36	3.6	1.8	14.3	0.45	0.50	0.55	0.28	10.9	1.28
3.	0.50	0.25	0.28	2.8	0.50	9.0	0.60	0.57	0.6	0.40	8.2	3.6
4.	0.30	1.2	1.4	4.1	8.2	13.6	0.55	0.45	0.45	0.80	3.1	3.4
5.	2.10	2.2	4.1	3.2	20.4	2.2	2.15	1.32	0.5	0.12	8.1	6.7
NITRITE (ug at NO_2-N/l)												
1.	0.10	0.14	0.32	0.21	0.34	0.27	0.19	0.16	0.16	0.08	0.06	0.45
2.	0.09	0.13	0.41	0.28	0.12	0.18	0.13	0.12	0.11	0.10	0.07	0.10
3.	0.10	0.10	1.12	0.20	0.20	0.35	0.27	0.27	0.13	0.12	3.06	0.45
4.	0.10	0.72	0.70	0.30	0.46	0.27	0.28	0.09	0.35	0.70	0.52	0.30
5.	0.47	0.40	0.60	0.20	0.10	0.40	0.25	1.60	0.30	0.42	0.50	0.45
PRODUCTION (mg C/m^3/hr)												
1.	51.8	18.2	61.0	74.62	12.74	55.4	114.31	146.1	23.8	50.8	46.3	77.42
2.	43.2	46.3	48.5	56.42	37.80	26.63	65.55	52.23	23.55	26.6	107.43	83.38
3.	38.2	15.0	45.0	49.14	24.57	7.8	64.55	42.20	85.7	29.4	52.90	14.40
4.	32.5	77.0	4.2	54.6	76.44	26.15	97.40	153.65	1.4	-	21.20	12.50
5.	20.0	27.3	14.0	98.28	10.92	6.3	116.50	55.5	26.4	-	1.50	11.95

2. A critical evaluation of productivity in a selected region in the estuary

In the previous studies, the estuary was investigated incorporating five selected stations in the southern region and two stations from the northern region. To have a clear understanding on the regional variation of productivity, intensive studies have been carried out for a further period of two years at the same five stations in the southern part which had been investigated earlier. There are no considerable variation in the hydrographic parameters. Hence two years' data have been pooled for the purpose of brevity. These pooled data are shown in Table 23.

In the southernmost site (Station 1) during pre-monsoon, the primary production varies from 18.2 mg $C/m^3/hr$ in March to 74.62 mg $C/m^3/hr$ in May with an average value of 51.41 mg $C/m^3/hr$. The mean value of temperature, salinity, dissolved oxygen, inorganic phosphate and nitrite recorded at this site during pre-monsoon are 31.95^{oC}, 10.73‰, 3.48 ml/l, 1.30^{o} ug at PO_4-P/l and 0.19 ug at NO_2-N/l respectively. During monsoon the mean primary production is 82.14 mg $C/m^3/hr$, the production ranging between 12.74 mg $C/m^3/hr$ in June and 146.1 mg $C/m^3/hr$ in September. The average temperature during monsoon is 29.33^{oC}, the salinity is only 0.7‰, dissolved oxygen is 4.43 ml/l, inorganic phosphate is 1.93 ug at PO_4-P/l and nitrite is 0.24 ug at NO_2-N/l. In post-monsoon the primary organic production varies from 23.8 mg $C/m^3/hr$ in October to 77.42 mg $C/m^3/hr$ in January with a mean value of 49.58 mg $C/m^3/hr$. The average temperature of 30.23^{oC} is higher than that in monsoon. The salinity showed considerable increase from 0.7 to 10.78‰ which is almost equal to that in pre-monsoon. The dissolved oxygen concentration of 3.35 ml/l is slightly lower than that of the monsoon.

The inorganic phosphate concentration recorded is much higher (4.12 µg at PO_4-P/l) than that of the monsoon. The nitrite concentration is almost the same with that in monsoon, its concentration being 0.26 µg at NO_2-N/l.

At the second station during pre-monsoon the average primary organic production recorded is 48.61 mg C/m^3/hr. The production varies from 43.2 mg C/m^3/hr in February to 56.42 mg C/m^3/hr in May. The temperature during this period is 32.4^{o}C, salinity is 19.23‰ , dissolved oxygen is 3.03 ml/l, inorganic phosphate is 1.18 ug at PO_4-P/l and the nitrite is 0.23 µg at NO_2-N/l. During monsoon the average value of primary organic production is 45.55 mg C/m^3/hr. Productivity varies from 26.63 mg C/m^3/hr in July to 65.55 mg C/m^3/hr in August. There is not much variation in productivity values of pre-monsoon and monsoon. In monsoon the temperature has decreased from 32.40^{o}C of pre-monsoon level to 29.90^{o}C. The salinity is reduced very much from 19.23‰ in pre-monsoon to 0.6‰ in monsoon. The dissolved oxygen level is 3.90 ml/l which is more or less similar to that of pre-monsoon. The inorganic phosphate value has increased from 1.18 ug at PO_4-P/l to 4.26 ug at PO_4-P/l in monsoon. The nitrite concentration is 0.17 ug at NO_2-N/l which is more or less similar to that of pre-monsoon. In post-monsoon the average productivity is 60.24 mg C/m^3/hr. The lowest production during post-monsoon is recorded in October (23.55 mg C/m^3/hr) and the highest production recorded is in December (107.43 mg C/m^3/hr). The temperature has increased from 29.90^{o}C in monsoon to 31.05^{o}C and the salinity from 0.60‰ in monsoon to 13.38‰ in post-monsoon.

The dissolved oxygen is 2.93 ml/l which does not exhibit much variation from that in monsoon. When inorganic phosphate has decreased from 4.26 µg at PO_4-P/l in monsoon to 3.25 µg at PO_4-P/l in post-monsoon, the nitrite

concentration remains at 0.19 ug at NO_2-N/l which is the same with that for the monsoon.

At the third station during pre-monsoon the average production at the primary trophic level is 36.84 mg C/m^3/hr. The productivity during this period ranges from 15.0 mg C/m^3/hr in March to 49.14 mg C/m^3/hr in May. The average temperature, salinity, dissolved oxygen, inorganic phosphate, nitrite are 30.88^{oC}, 22.38‰ , 2.78 ml/l, 0.96 µg at PO_4-P/l and 0.38 µg at NO_2-N/l respectively. During monsoon the productivity is 34.78 mg C/m^3/hr which is more or less same as that for pre-monsoon. The minimum production recorded during the monsoon is 7.8 mg C/m^3/hr which is in July and the maximum recorded is 64.55 mg C/m^3/hr which is in August. The average temperature during monsoon is 30.15^{oC}. Salinity is reduced to 0.55‰ , from 22.38‰ in the pre-monsoon. The dissolved oxygen concentration is remarkably increased to 4.05 ml/l from 2.78 ml/l in pre-monsoon. Inorganic phosphate shows considerable increase from 0.96 µg at PO_4-P/l in pre-monsoon to 2.65 µg at PO_4-P at/l during monsoon. Nitrite concentration is 0.27 µg at NO_2-N/l which is almost similar to that of pre-monsoon. In post-monsoon the average production is 45.6 mg C/m^3/hr which is indeed higher than the productivity values in pre-monsoon and post-monsoon. The minimum productivity observed is 26.6 mg C/m^3/hr which is during November and the maximum is 107.43 mg C/m^3/hr which is in December. The average temperature recorded during the season is 30.38^{oC}, salinity has increased from 0.55‰ in monsoon to 10.98‰ in post-monsoon. The dissolved oxygen concentration is 2.93 ml/l which does not show any considerable fluctuation from those of other seasons. The inorganic phosphate concentration increases from 2.65 µg at PO_4-P in the monsoon to 3.20 µg at PO_4-P/l in post-monsoon. The nitrite concentration does not exhibit any seasonal fluctuation here.

Station 4 exhibits conspicuous seasonal fluctuation in productivity. The average primary organic production in pre-monsoon is 42.1 mg $C/m^3/hr$. The minimum productivity recorded is 4.2 mg $C/m^3/hr$ which is in April and the maximum recorded is 77.0 mg $C/m^3/hr$ which is in March. The average temperature, salinity, dissolved oxygen, inorganic phosphate and nitrite during this season are 32.48^{o}C, 29.93‰ , 3.30 ml/l, 1.75 µg at PO_4-P/l, and 0.46 µg at NO_2-N/l respectively. During monsoon the average productivity at the primary trophic level is 88.41 mg $C/m^3/hr$. During the period the minimum value of production registered is 26.15 mg $C/m^3/hr$ (July) and the maximum is 153.65 mg $C/m^3/hr$ (September). The temperature during monsoon decreased to 30.33^{o}C from 32.48^{o}C in pre-monsoon. Average salinity has decreased from 29.93‰ in pre-monsoon to 1.60‰ in monsoon. Dissolved oxygen concentration of 3.70 ml/l does not deviate from the values for other seasons. Inorganic phosphate shows considerable increase in its concentration recording 5.70 µg at PO_4-P/l as against 1.75 µg at PO_4-P/l in pre-monsoon. The concentration of nitrite has varied from 0.46 µg at NO_2-N/l in pre-monsoon to 0.59 µg at NO_2-N/l. In post-monsoon the primary organic production ranges from 1.4 mg $C/m^3/hr$ in October to 21.20 mg $C/m^3/hr$ in December recording an average value of only 11.70 mg $C/m^3/hr$. The average temperature has increased from 30.33^{o}C in monsoon to 31.35^{o}C during this period. The salinity has increased from 1.60‰ in the monsoon to 17.13‰ in the post-monsoon. The concentration of dissolved oxygen varies from 3.70 ml/l in the monsoon to 3.25 ml/l in the post-monsoon. The concentration of inorganic phosphate is decreased from 5.70 µg at PO_4-P/l to 1.94 µg at PO_4-P/l. The variation of nitrite is from 0.59 µg at NO_2-N/l in monsoon to 0.47 µg at NO_2-N/l.

The fifth station at Edacochin records an average primary organic production of 38.15 mg $C/m^3/hr$ during pre-monsoon. The minimum production of 14.0 mg $C/m^3/hr$ is obtained in April and the maximum production rate of 98.28 mg $C/m^3/hr$ is recorded in May. The average temperature, salinity, dissolved oxygen, inorganic phosphate and nitrite recorded during pre-monsoon at this site of investigation are 31.55°C, 29.85‰ , 2.95 ml/l, 2.90 µg at PO_4/l and .42 µg at NO_2-N/l respectively. During monsoon the average production is 47.35 mg $C/m^3/hr$. During this period the production varies from 6.3 mg $C/m^3/hr$ in July to 116.5 mg $C/m^3/hr$ in August. The average value of hydrographic parameters such as salinity, dissolved oxygen and inorganic phosphate show considerable fluctuation. Temperature remains without much change. It is 31.33°C as against 31.55°C in pre-monsoon. Salinity recorded is 6.9‰ as against 29.85‰ in the pre-monsoon. Dissolved oxygen value is 3.43 ml/l as against 2.95 ml/l in the pre-monsoon. The concentration of inorganic phosphate is increased from 2.90 µg at PO_4-P/l in the previous season. The concentration of nitrite is 0.59 µg at NO_2-N/l as against 0.42 µg at NO_2-N/l. The post-monsoon the average production has decreased very much from the pre-monsoon and monsoon periods. It is only 13.28 mg $C/m^3/hr$ in the post-monsoon as against 38.15 mg $C/m^3/hr$ in the pre-monsoon and 47.31 mg $C/m^3/hr$ in the monsoon. The production during post-monsoon varies from 1.5 mg $C/m^3/hr$ in December to 26.4 mg $C/m^3/hr$ in October. The average value of temperature is 30.80°C as against 31.33°C in monsoon. Average salinity has increased to 22.05‰ from 6.9‰ in monsoon. Dissolved oxygen concentration is 3.35 ml/l as against 3.43 ml/l in monsoon. The concentration of inorganic phosphate has reduced to 3.86 µg at PO_4-P/l in post-monsoon from 6.52 µg at PO_4-P/l in monsoon. This is the highest concentration of inorganic phosphate ever recorded from the southern region of the

estuary during this investigation. The average concentration of nitrite during the period is 0.42 µg at NO_2-N/l as against 0.42 and 0.59 µg at NO_2-N/l in pre-monsoon and monsoon respectively. Thus out of the five stations in the southern part of the estuary under investigation, the southernmost site (Station 1) is found to be the most productive area as indicated by the annual average productivity of 61.04 mg C/m^3/hr. The fifth station at Edacochin is found to be the least productive with the annual productivity of 32.91 mg C/m^3/hr. At the second station the annual productivity is 51.47 mg C/m^3/hr at third station it is 39.1 mg C/m^3/hr, and at the fourth station the annual average productivity is 47.4 mg C/m^3/hr.

DISCUSSION

The average productivity of the entire estuary as per the earlier investigation is 48.5 mg $C/m^3/hr$. During this investigation it is observed that the region from Alleppey to Cochin recorded an average productivity of 44.24 mg $C/m^3/hr$. In the northern half the average productivity recorded is 59.0 mg $C/m^3/hr$.

In the subsequent investigation carried out in the region extending from Alleppey to Cochin five stations studied earlier were selected for extensive studies on productivity for a further period of two years. During this period, since the hydrographic parameters and primary productivity of the first year showed much resemblances with those of the next year, these values were pooled so as to have a consolidated picture characteristics of each station.

In the southernmost site (station 1) the annual average productivity is 61.04 mg $C/m^3/hr$ as against 62.4 mg $C/m^3/hr$ in the earlier studies for one year. In the present investigation at the first station it is found that the productivity in pre-monsoon, monsoon and post-monsoon are 51.41 mg $C/m^3/hr$, 82.14 mg $C/m^3/hr$ and 49.58 mg $C/m^3/hr$ respectively. The corresponding values of the earlier studies were 47.7 mg $C/m^3/hr$, 82.8 mg $C/m^3/hr$ and 56.7 mg $C/m^3/hr$. The maximum productivity in both cases is about 82.0 mg $C/m^3/hr$, that too these identical values are recorded in the same season i.e in post-monsoon.

In the next site of investigation the average productivity recorded is 51.47 mg $C/m^3/hr$ as against 22.8 mg $C/m^2/hr$. Though there is difference in the magnitude of productivity, the seasonal distribution of productivity is

quite comparable. When the present studies records the maximum production of 60.24 mg C/m^3/hr during post-monsoon, the earlier studies too records the maximum production of 29.0 mg C/m^3/hr in the post-monsoon. The rate of production recorded in the present investigation during pre-monsoon, monsoon and post-monsoon are 48.61, 45.55 and 60.24 mg C/m^3/hr respectively. The corresponding productivity values recorded in the early studies are 11.7, 25.5 and 31.2 mg C/m^3/hr respectively.

In station 3, when the average annual production recorded is 39.1 mg C/m^3/hr, it is 28.57 mg C/m^3/hr in the earlier observation. Here also the more or less same pattern of distribution of seasonal productivity in both cases are quite comparable. When the present investigation records 36.84 mg C/m^3/hr in pre-monsoon, 34.78 mg C/m^3/hr in monsoon and 45.60 mg C/m^3/hr in the post monsoon the corresponding values in the earlier observations are 27.8, 28.9 and 29.0 mg C/m^3/hr respectively in the corresponding seasons.

In the fourth station the annual primary organic production recorded is 47.4 mg C/m^3/hr as against 66.40 mg C/m^3/hr recorded earlier. At this station the maximum production values recorded are 88.41 mg C/m^3/hr in the present observation as against 80.8 mg C/m^3/hr in the earlier studies. Both these maximum values are recorded during monsoon. In both the occasions the minimum values are recorded during post-monsoon. In the present observation the seasonal productivity recorded are 42.10, 88.41 and 11.70 mg C/m^3/hr respectively in pre-monsoon, monsoon and post-monsoon respectively. The corresponding values in the earlier studies are 74.2, 80.8 and 44.2 mg C/m^3/hr respectively.

At station 5 the present investigation registers an annual organic production of 32.9 mg $C/m^3/hr$ as against 35.8 mg $C/m^3/hr$ recorded in the earlier observation. When the present investigation for the duration of two years records 38.15 mg $C/m^3/hr$ in pre-monsoon, 47.35 mg $C/m^3/hr$ in monsoon and 13.2 mg $C/m^3/hr$ in post monsoon the corresponding values in the earlier observation are 35.1, 52.2 and 35.8 mg $C/m^3/hr$ respectively.

Thus it is found that there is general uniformity in the magnitude of production and a definite pattern of temporal and spatial variation in productivity is reflected from year to year.

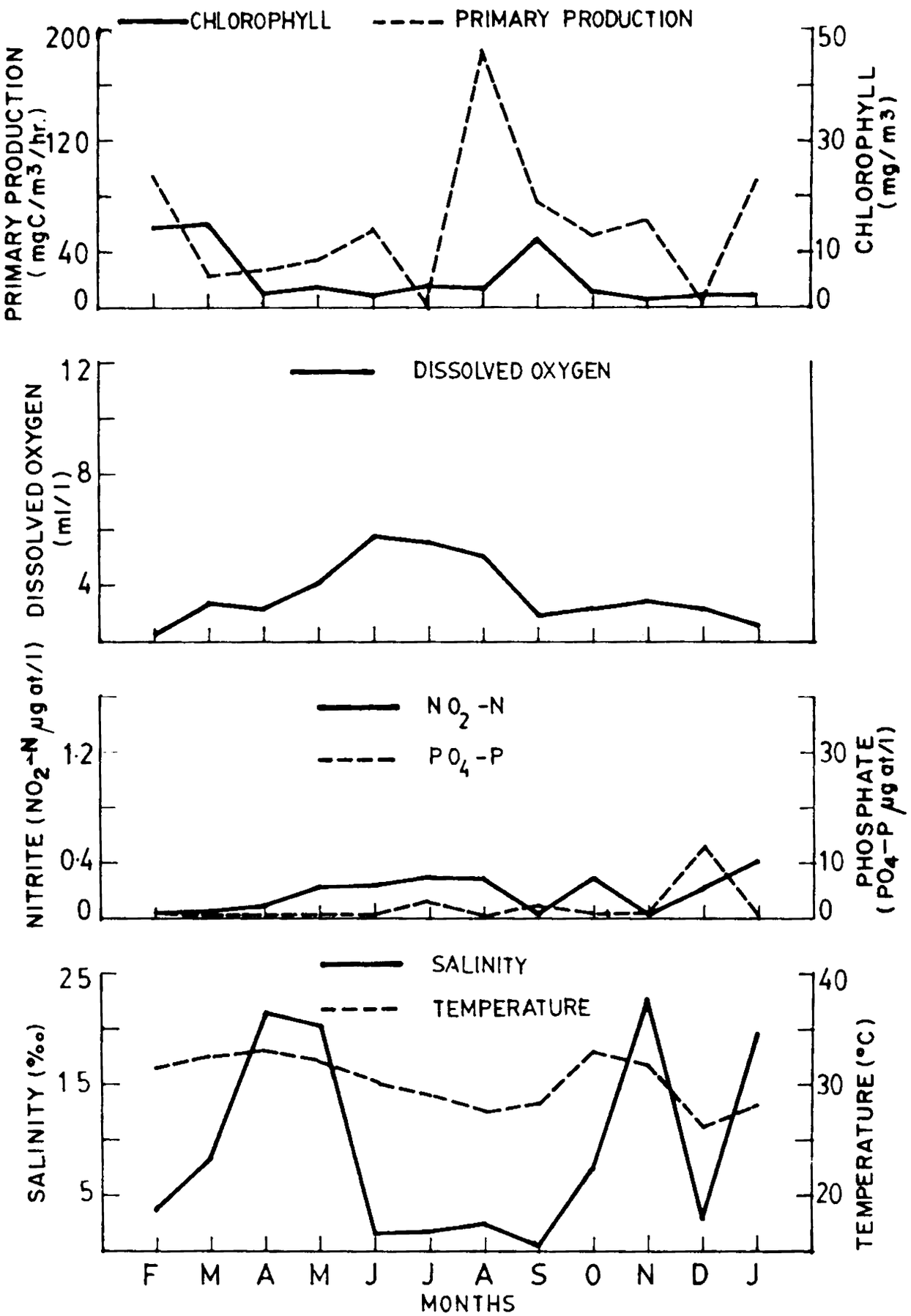

FIG. 23. STATION I

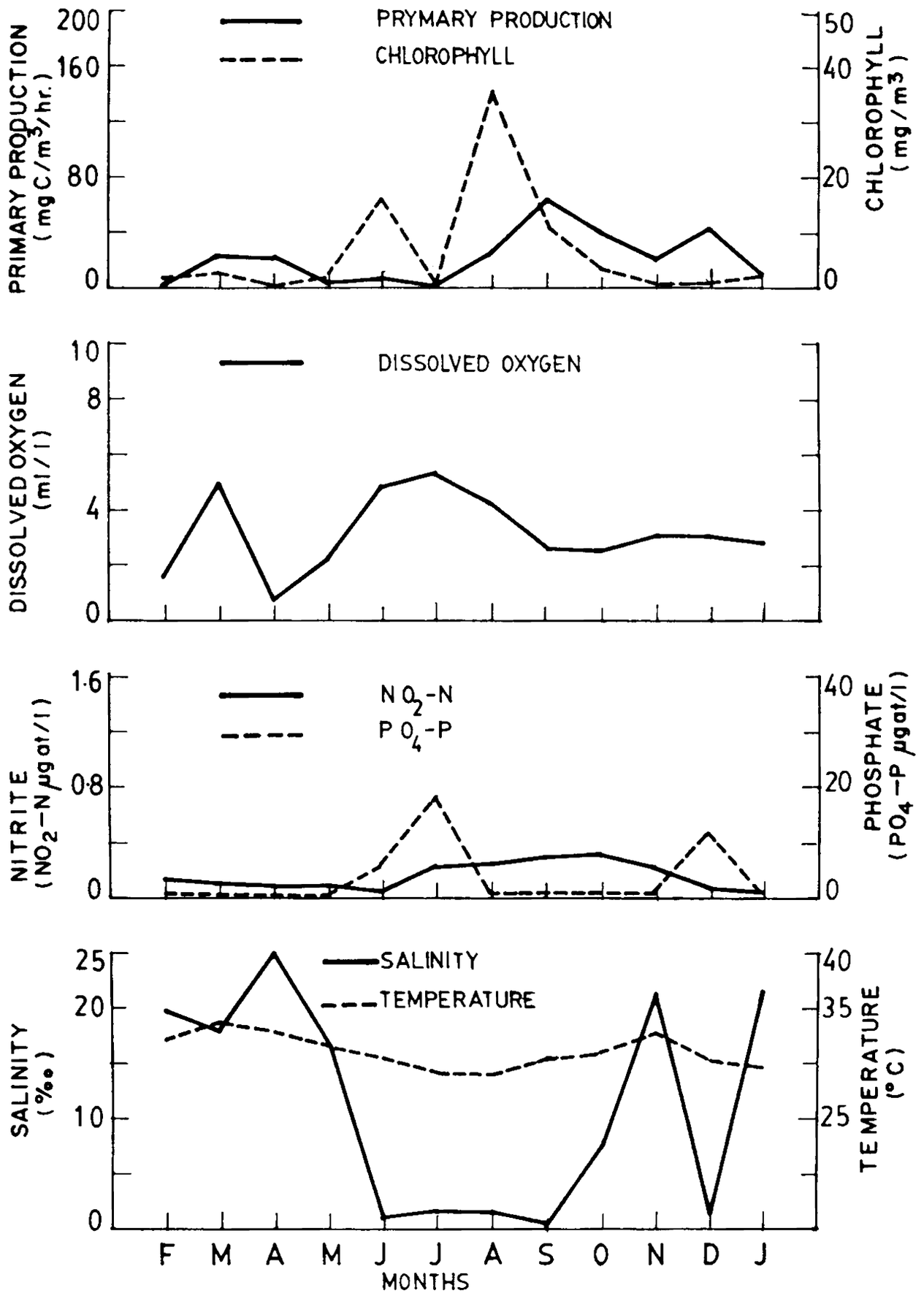

FIG. 24. STATION II

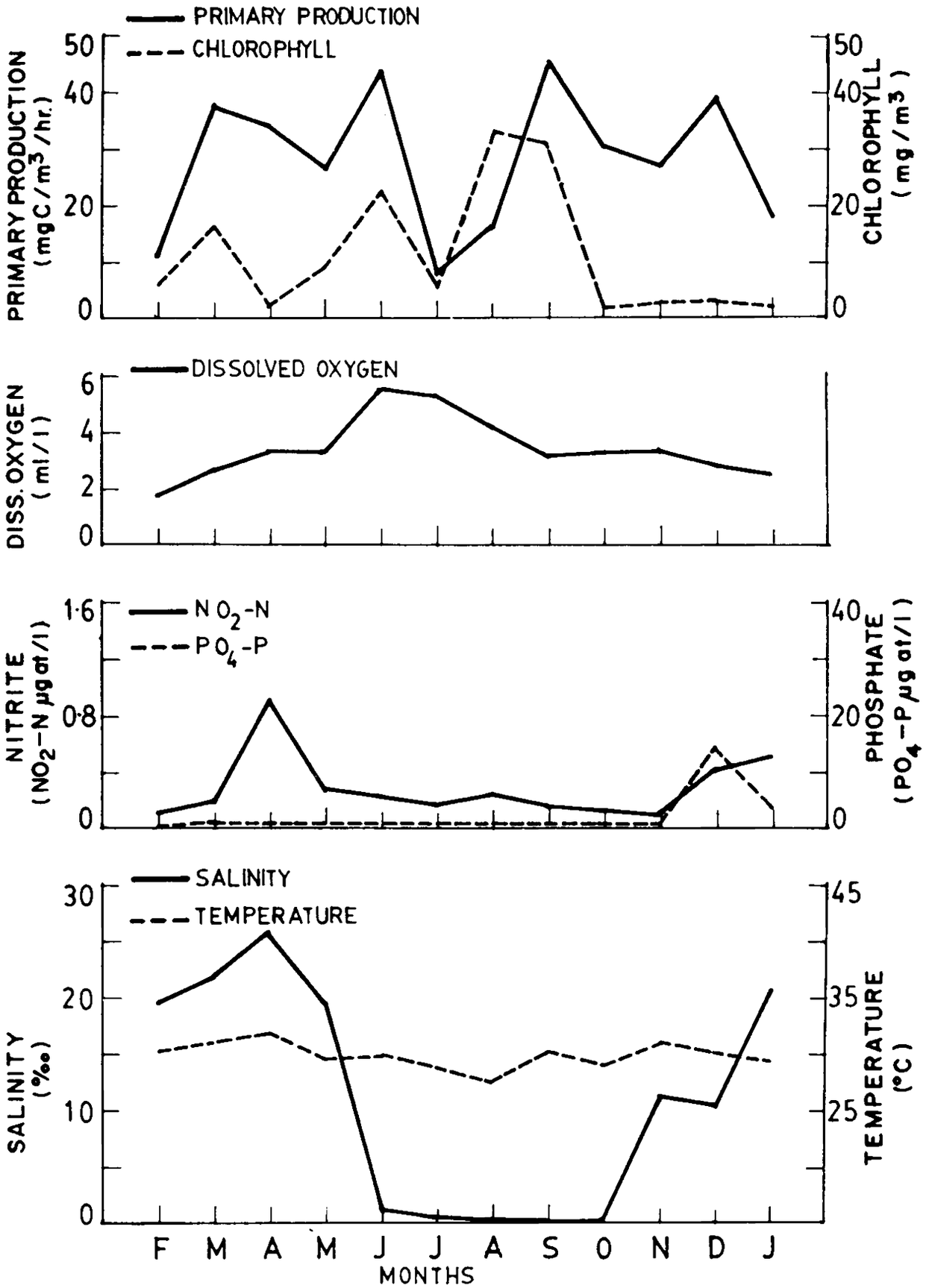

FIG. 25. STATION III

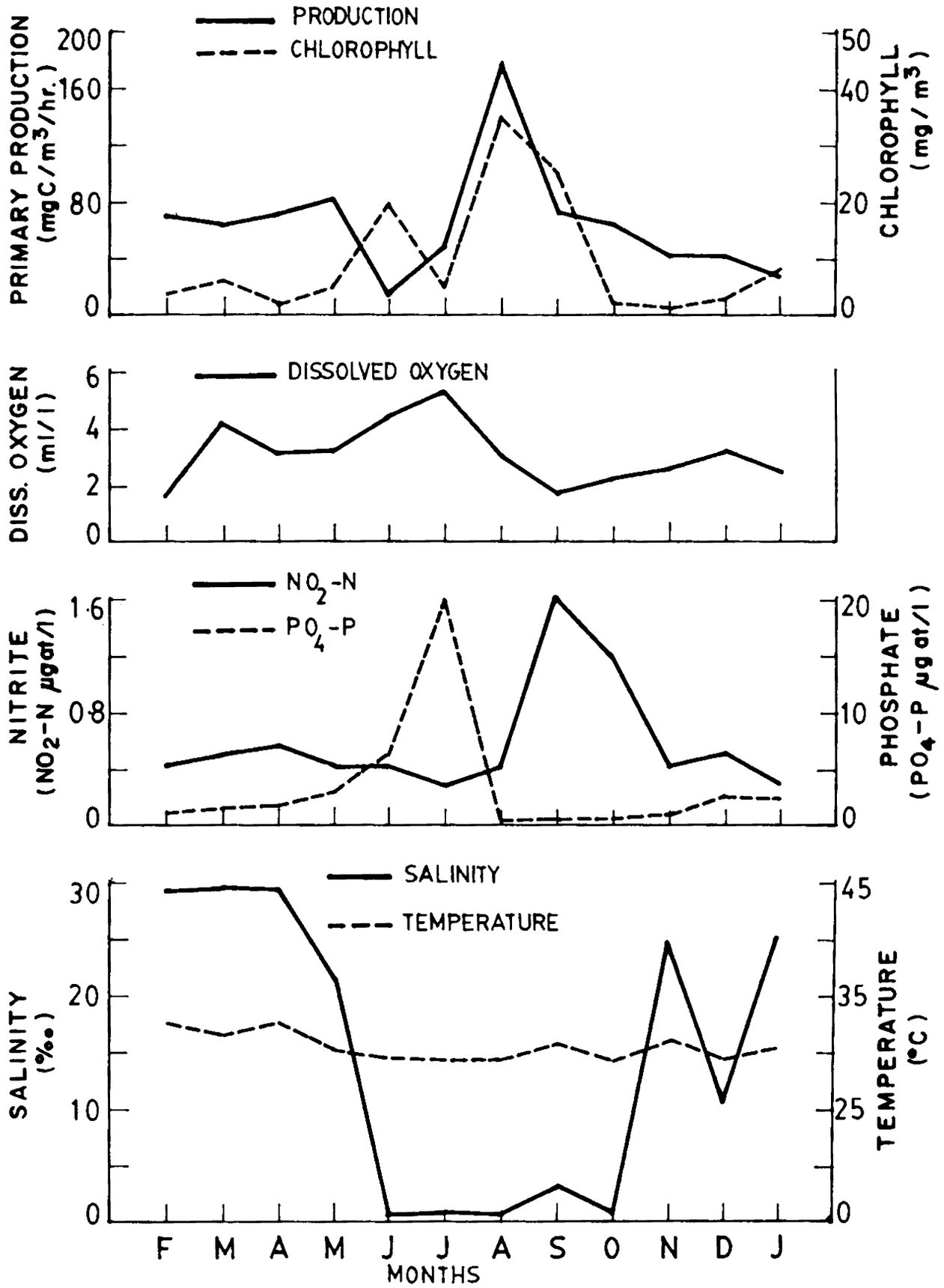

FIG. 26. STATION IV

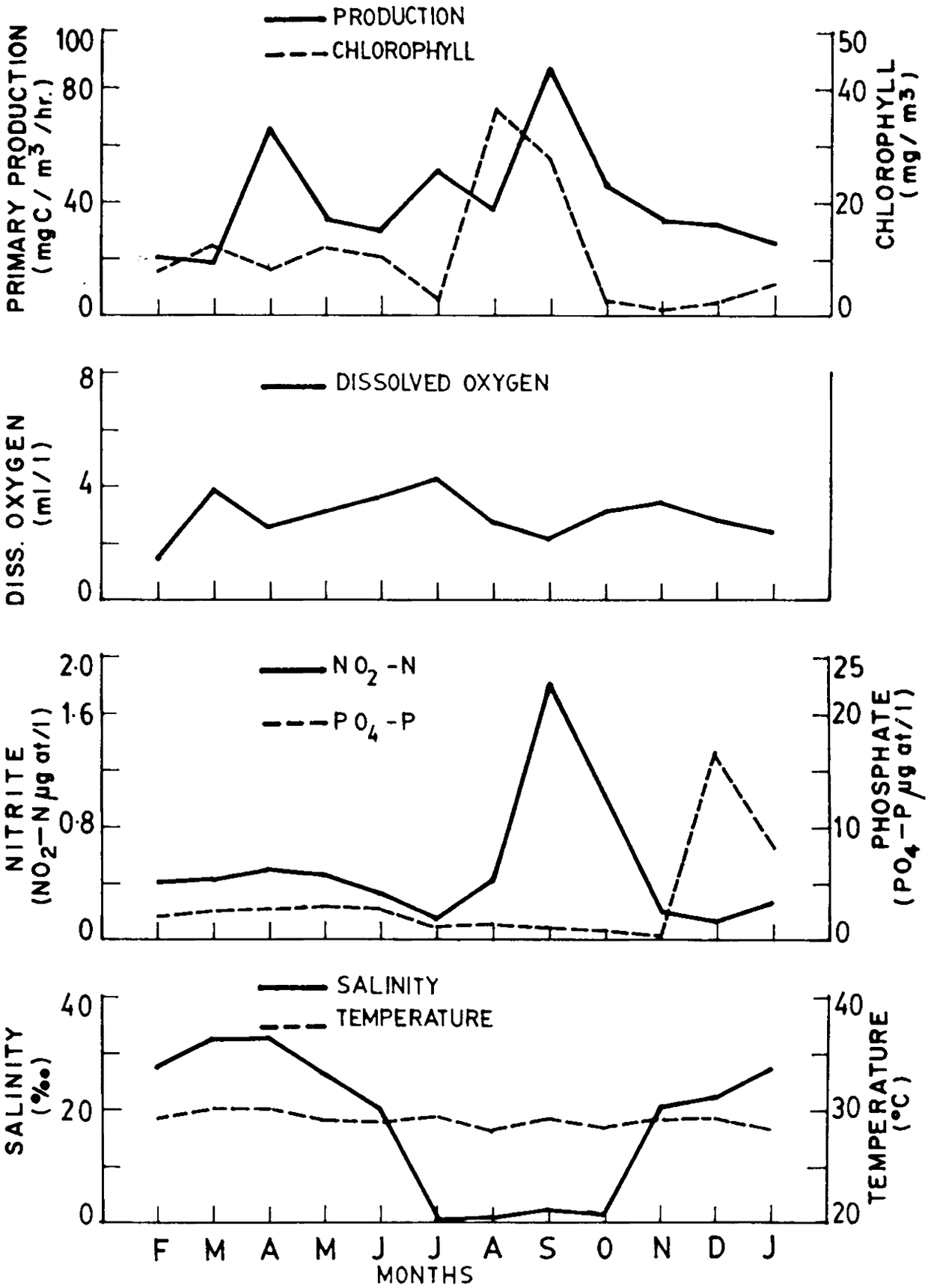

FIG. 27. STATION V

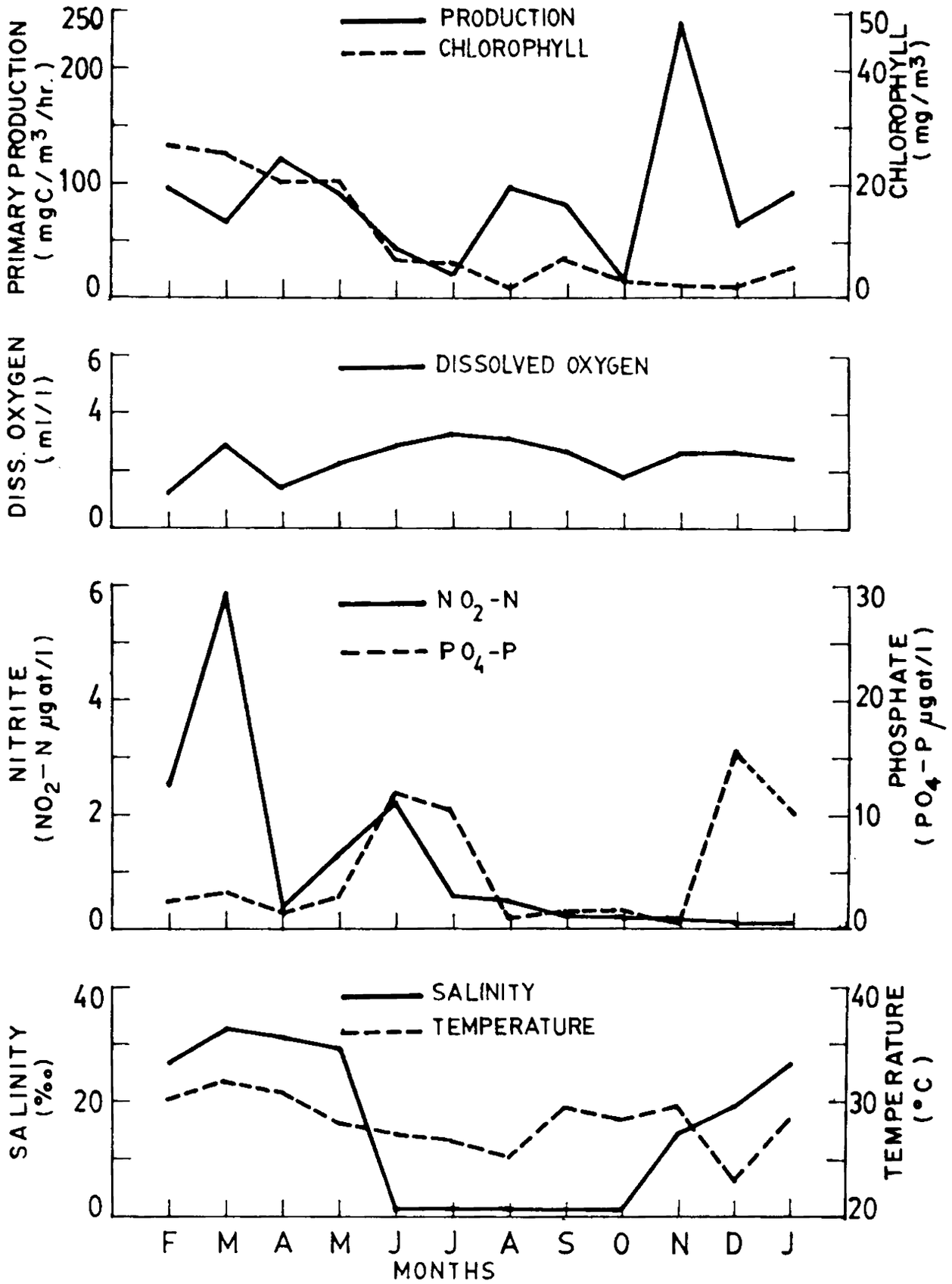

FIG. 28. STATION VI

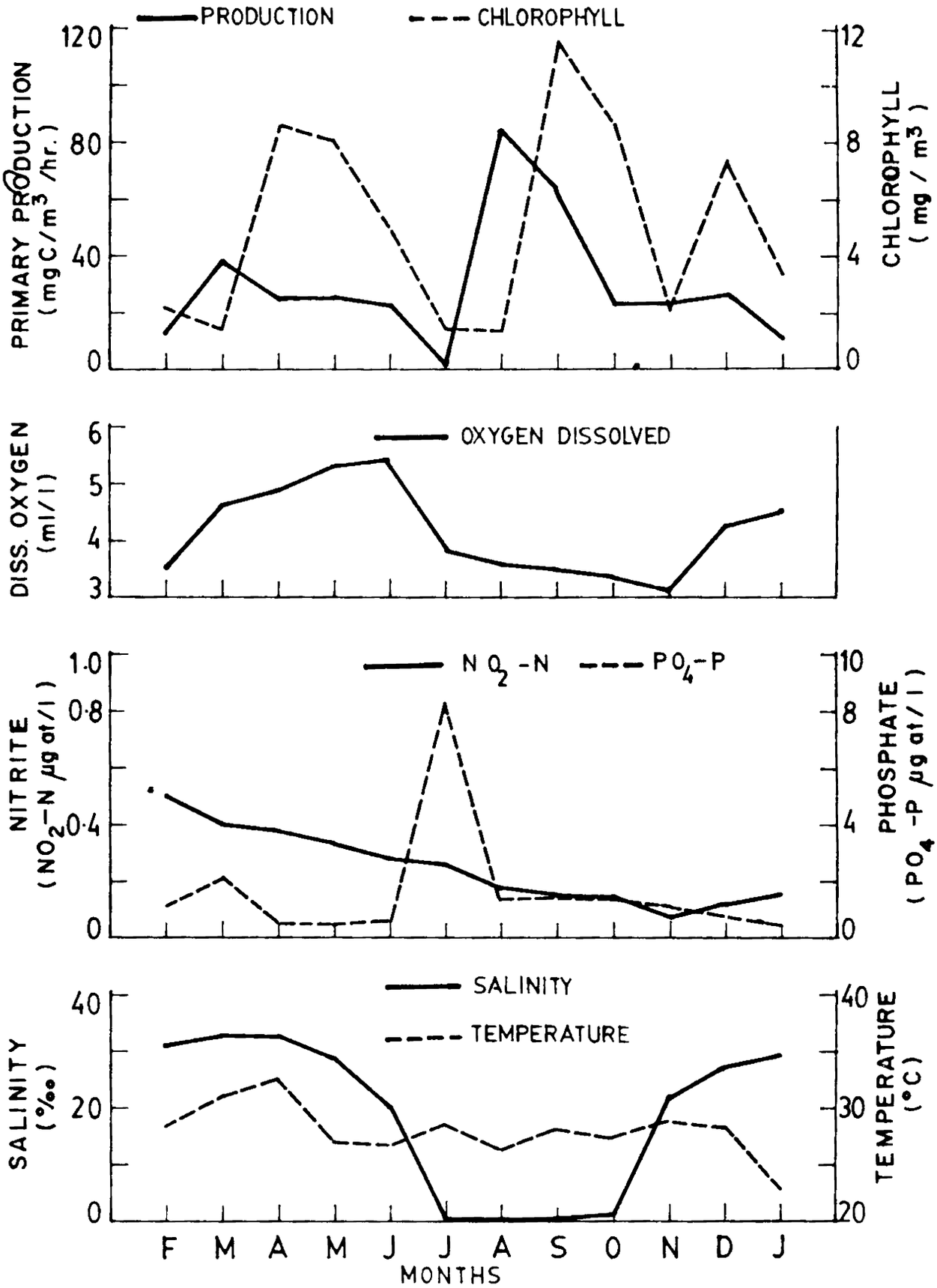

FIG. 29. STATION VII

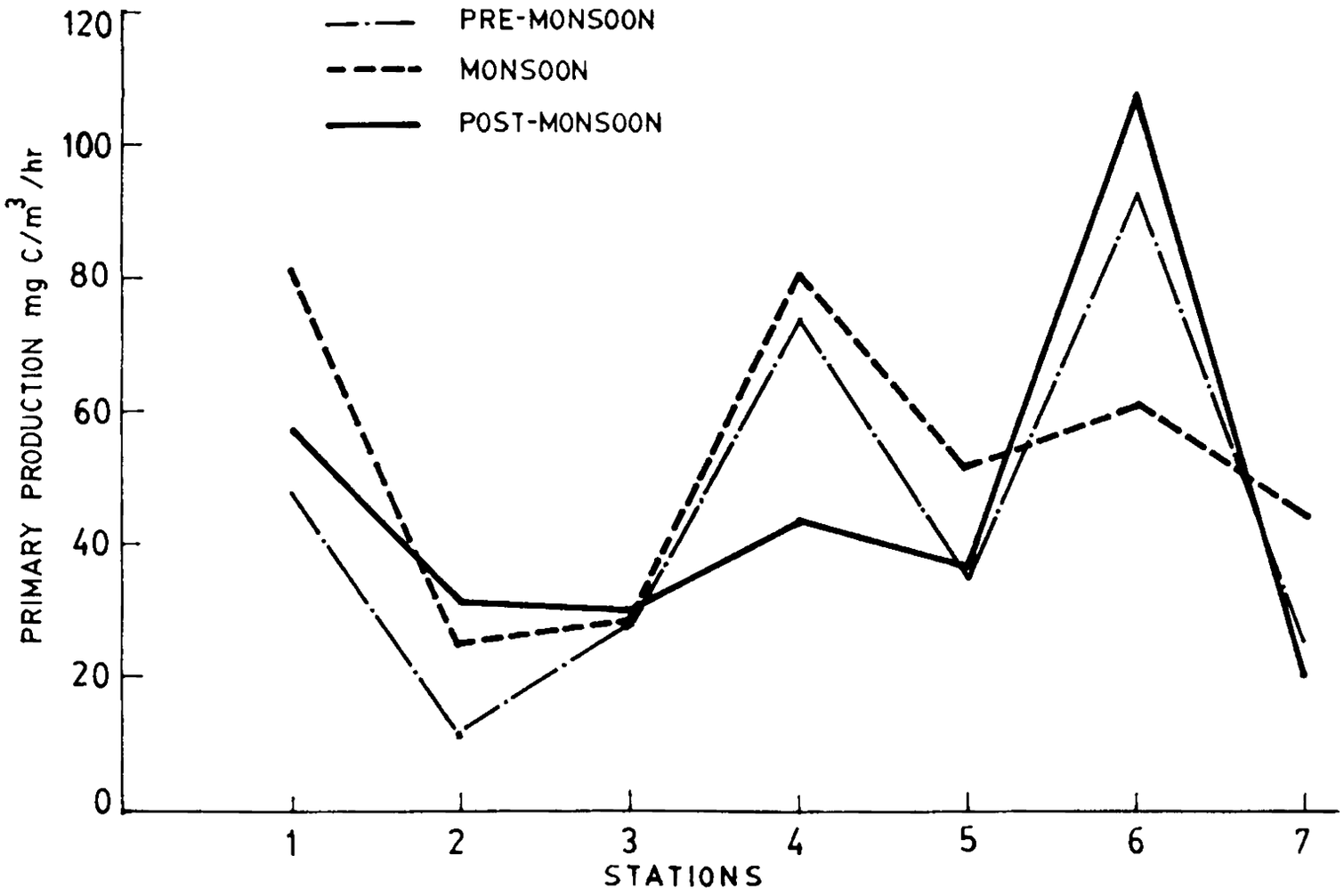

FIG. 30. SEASONAL AND SPATIAL FLUCTUATION OF PRIMARY PRODUCTION

CHAPTER VII

PRODUCTIVITY IN POLLUTED WATERS

1. Environment

The study projects the impact of industrial effluents on productivity near the industrial belt at Alwaye in the Periyar River tributary and adjacent Cochin estuary. The observations at six selected sites clearly indicate the effect of pollution on productivity of the region. Among the six sites one is estuarine (Station 1) which has recovered completely from any pollution effect due to massive dilution with the backwater consequent on tidal influx. The productivity of all the other stations are influenced rather affected by the effluents at varying intensities. Among the three down stream sites (stations 2, 3 and 4) Station 2 is at the mouth of Periyar River where it joins the estuary. Among the remaining down stream sites (stations 3 and 4) station 4 is nearer to the impact site which is station 5. The only upstream site is station 6 which also has some deleterious effect of pollution as effluents are carried further up during high tides. Hydrographic parameters investigated are temperature, salinity dissolved oxygen, nitrite, inorganic phosphate, hydrogen ion concentration and productivity.

2. Hydrographic Parameters

Temperature (Fig. 31-36)

Maximum surface temperature of 35.0^{o}C recorded is at the impact station (station 5) and the upstream station (station 6) during March. The minimum surface temperature of 24^{o}C is observed at stations 1, 3 and 4 all in April. Monthly temperature variations of the surface for all the stations are given in figures (Fig. 31-36). Seasonal variation of surface and bottom temperature for all the six stations are given below:

TEMPERATURE ^{o}C

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	31.18	26.50	28.97
	B	30.75	26.67	29.07
Station 2	S	31.30	27.10	29.60
	B	30.50	26.40	28.87
Station 3	S	31.62	26.77	30.32
	B	31.45	26.32	29.92
Station 4	S	32.00	26.85	30.17
	B	31.90	26.30	30.27
Station 5	S	33.00	26.40	30.00
	B	31.67	26.77	29.85
Station 6	S	32.62	26.90	29.97
	B	31.87	26.82	29.87

The average surface and bottom temperature recorded for the entire region of study for the various seasons are shown below:

TEMPERATURE ^{o}C

	Pre-monsoon	Monsoon	Post-monsoon
Surface	31.95	26.75	29.82
Bottom	31.36	26.55	29.64

Salinity (Fig. 31-36)

Salinity which plays a dominant role in the floral distribution and bio-productivity in the region at the primary trophic level exhibit wide variation from place to place and season to season. The highest value of salinity recorded at the surface is 22.33‰ which is at the typical estuarine site (station 1) and is during March. The bottom salinity is also the same. The highest bottom salinity recorded is 23.01‰ also at the first station during December. In June the entire area becomes fresh water. The salinity fluctuations at various stations during pre-monsoon, monsoon and post-monsoon are shown below:

SALINITY ‰

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	14.19	1.60	11.06
	B	13.92	0.84	9.59
Station 2	S	8.14	0.64	5.91
	B	8.41	0.42	4.79
Station 3	S	7.00	0.91	2.24
	B	7.28	0.36	1.08
Station 4	S	4.08	0.81	0.80
	B	4.03	0.70	1.02
Station 5	S	2.30	0.45	0.31
	B	0.87	0.64	0.30
Station 6	S	2.10	0.33	0.28
	B	1.95	0.44	0.30

The consolidated average value of salinity of this region during the various seasons are given below:

SALINITY ‰

	Pre-monsoon	Monsoon	Post monsoon
Surface	6.3	0.79	3.43
Bottom	6.1	0.57	2.85

Dissolved Oxygen (Fig. 31-36)

Dissolved oxygen recorded a maximum concentration of 5.85 ml/l at both surface and bottom at station 3 during May. The lowest value of dissolved oxygen in the surface recorded is 1.47 ml/l which is at the impact station (station 5) in June. The lowest bottom value of dissolved oxygen is 1.98 ml/l which is at station 4 which is downstream and adjacent to the impact station. Seasonal variation of both surface and bottom value of dissolved oxygen at the various stations are shown below:

DISSOLVED OXYGEN (ml/l)

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	4.04	3.80	4.18
	B	3.25	3.59	3.48
Station 2	S	4.22	4.05	3.82
	B	3.61	4.31	3.17
Station 3	S	4.07	3.61	3.61
	B	4.20	3.91	3.64
Station 4	S	4.39	4.02	2.98
	B	3.59	3.86	3.89
Station 5	S	3.61	3.54	3.71
	B	3.90	3.88	3.74
Station 6	S	3.99	4.67	3.73
	B	4.13	4.50	4.01

Consolidated seasonal values of dissolved oxygen for the entire area is given below:

DISSOLVED OXYGEN (ml/l)

	Pre-monsoon	Monsoon	Post-monsoon
Surface	3.95	3.95	3.67
Bottom	4.00	4.01	3.66

Inorganic Phosphate (Fig. 31-36)

The phosphate values are generally of low magnitude compared to the other estuarine areas already investigated though isolated high values exceeding 15 µg at PO_4-P/l are recorded at areas adjacent to the fertiliser factory (station 4 and 5). The maximum surface value of 27.28 µg at PO_4-P/l is recorded at station 5 during the same month. Many of the stations investigated registered values >5 µg at PO_4-P/l and the lowest value being 0.15 µg PO_4-P/l recorded at the first station during November. The seasonal and temporal variations of PO_4-P/l of both surface and bottom are given below:

INORGANIC PHOSPHATE (PO_4-P/l)

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	5.94	2.65	2.61
	B	5.84	1.79	3.35
Station 2	S	9.28	3.24	2.93
	B	7.09	3.45	3.33
Station 3	S	8.09	2.16	3.06
	B	6.76	2.47	4.40
Station 4	S	10.42	3.45	3.05
	B	10.24	2.24	3.21
Station 5	S	9.73	2.49	3.00
	B	6.44	1.61	3.30
Station 6	S	4.38	2.07	2.57
	B	4.99	1.98	3.12

The seasonal variations of PO_4-P/l at the surface and bottom waters under investigation are indicated below:

INORGANIC PHOSPHATE (PO_4-P µg at/l)

	Pre-monsoon	Monsoon	Post-monsoon
Surface	7.97	2.68	2.87
Bottom	6.89	2.26	3.45

Nitrite Nitrogen (Fig. 31-36)

The nitrite nitrogen values show wide monthly fluctuation. High values are recorded only during March and low values during February and July at almost all stations. The highest surface value of 27.0 µg at NO_2-N/l is recorded at Station 2, the other high values are 24.4 µg at/l at station 1, 24.08 µg at/l at station 3, 23.24 µg at/l at station 4, 23.8 µg at/l at station 5, and low value being 3.12 µg at NO_2-N/l which is at station 6.

The minimum value of 0.01 µg at/l is recorded during February, both surface and bottom in station 1 and at the bottom sample in station 4. The following values indicate the seasonal and spatial fluctuation of nitrite nitrogen at both surface and bottom.

NITRITE NITROGEN (NO_2-N µg at/l)

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	7.29	1.90	4.61
	B	7.37	1.97	2.84
Station 2	S	7.91	2.08	3.53
	B	6.61	1.29	3.12
Station 3	S	6.49	1.29	3.24
	B	6.18	1.08	4.07
Station 4	S	6.35	1.66	2.54
	B	7.20	1.50	3.38
Station 5	S	6.31	0.62	2.50
	B	6.38	0.54	3.58
Station 6	S	2.44	1.06	3.45
	B	0.38	0.68	3.52

The values given below show the general trend of seasonal fluctuation of nitrite nitrogen.

NITRITE NITROGEN µg at/l

	Pre-monsoon	Monsoon	Post-monsoon
Surface	6.13	1.44	3.31
Bottom	5.69	1.18	3.42

Hydrogen ion concentration (Fig. 31-36)

The highest pH value of 8.4 is recorded in station 5 at the surface waters during May. The corresponding pH value at the bottom is only 7.45.

The minimum hydrogen ion concentration of 5.65 is also recorded from the impact station at the surface during February. Lower pH value indicate the probability of having acid pollutants being discharged upstream. The temporal and spatial fluctuations of hydrogen ion concentrations are shown below:

HYDROGEN ION CONCENTRATION

		Pre-monsoon	Monsoon	Post-monsoon
Station 1	S	7.33	7.13	7.45
	B	7.38	7.40	7.52
Station 2	S	7.16	6.91	7.00
	B	7.18	6.88	7.00
Station 3	S	7.13	7.10	7.10
	B	7.23	6.90	7.15
Station 4	S	7.07	7.08	7.12
	B	6.98	7.15	7.32
Station 5	S	7.00	6.91	7.85
	B	7.15	6.85	7.87
Station 6	S	7.01	7.05	7.75
	B	6.97	6.95	7.3

The variations of pH of the area during the three seasons are given below:

HYDROGEN ION CONCENTRATION

	Pre-monsoon	Monsoon	Post-monsoon
Surface	7.12	7.03	7.38
Bottom	7.15	7.02	7.36

3. Primary Production (Fig. 31-36)

The analysis of the bioproductivity at the first trophic level clearly indicates its spatial variation influenced by the concentration of the pollutants. The typical estuarine station apparently least affected by the pollutant is more productive than the other stations. During pre-monsoon the productivity varies from 89.9 mg $C/m^3/hr$ in March to 204.0 mg $C/m^3/hr$ in February. The average productivity during pre-monsoon is 137.9 µg $C/m^3/hr$. During monsoon the productivity exhibit wide fluctuation i.e. from 2.7 µg $C/m^3/hr$ in August to 409.8 mg $C/m^3/hr$ in September. The average productivity during this period is 124.4 µg $C/m^3/hr$. During post monsoon the fluctuation of productivity is from 185.0 mg $C/m^3/hr$ in November to 390.0 µg $C/m^3/hr$ in October with an average value of 266.0 mg $C/m^3/hr$. The average productivity for the three seasons is 176.1 mg $C//m^3/hr$ which is the highest value among the six stations studied.

In the station at the mouth of the tributary (Station 2) during pre-monsoon the productivity varies from 71.9 mg $C/m^3/hr$ in May to 312.4 mg $C/m^3/hr$ in February. The average production during this period is 165.7 mg $C/m^3/hr$. The monsoon productivity is of low magnitude ranging from 3.2 mg $C/m^3/hr$ in August to 80.9 mg $C/m^3/hr$ in September. The average productivity in monsoon is only 26.0 $mg/m^3/hr$. The post monsoon period showed marked increase in production. The minimum recorded is 113.7 mg $C/m^3/hr$ which is in November and the maximum is 340.4mg $C/m^3/hr$ which is in October. The average productivity during post-monsoon period is 197.6 mg $C/m^3/hr$.

At the third station during pre-monsoon the production varies from 16.1 mg $C/m^3/hr$ in February. The average value of productivity during this

season is 67.2 mg C/m^3/hr. During monsoon the production is of low magnitude. The productivity varies from 2.8 mg C/m^3/hr in August to 25.2 mg C/m^3/hr in July. The average monsoon productivity at this station is only 12.0 mg C/m^3/hr. During post-monsoon the minimum production of 31.5 mg C/m^3/hr is in December and the maximum value of 77.3 mg C/m^3/hr is recorded in January. 57.5 mg C/m^3/hr is the average productivity for this season.

The fourth station which is nearer to the impact station showed comparatively less production than the three stations discussed above. During pre-monsoon the production ranges from 3.4 mg C/m^3/hr in April to 157.9 mg C/m^3/hr in March. The average production during this season is 70.0 mg C/m^3/hr. In the monsoon period the production varies from 7.0 mg C/m^3/hr in July to 18.2 mg C/m^3/hr in September. The average production is only 9.1 mg C/m^3/hr. In the post-monsoon the productivity varies from about 1 mg C/m^3/hr in October to 61.5 mg C/m^3/hr in December with an average value of 27.25 mg C/m^3/hr.

The productivity values at the impact station are invariably of low magnitude in all the seasons. In pre-monsoon the production varies from 4.7 mg/C/m^3/hr in February to 40.7 mg C/m^3/hr in March. The average productivity during this season is 19.3 mg C/m^3/hr. In monsoon the production varies from 2.4 mg C/m^3/hr in July to 24.8 in September with an average productivity of 8.7 mg C/m^3/hr. The post-monsoon values vary from about 0.3 mg C/m^3/hr in October to 37.2 in November, the average value being 18.1

The upstream station (station 6) showed an increase in production compared to that of the impact station. In the upstream station during

pre-monsoon the rate of uptake of carbon varies from 14.1 mg $C/m^3/hr$ in May to 69.6 mg $C/m^3/hr$ in February. The average productivity during this period is 46.3 mg $C/m^3/hr$. In monsoon the productivity range is from 1.6 mg $C/m^3/hr$ in July to 102.1 mg $C/m^3/hr$ in September. The average production during monsoon is 34.9 mg $C/m^3/hr$. In post-monsoon the productivity variation is from 2.0 mg $C/m^3/hr$ in November to 69.6 mg $C/m^3/hr$ in January and the average productivity during this period is 27.8mg $C/m^3/hr$. The seasonal and spatial variations of productivity are shown below:

PRIMARY PRODUCTION mg $C/m^3/hr$

Station	Pre-monsoon	Monsoon	Post-monsoon	Average
1	137.9	124.4	266.0	176.1
2	165.7	26.0	197.0	129.8
3	67.2	12.0	57.5	45.6
4	70.0	9.1	27.3	35.5
5	19.3	8.7	26.3	18.1
6	46.3	34.9	27.8	36.3

DISCUSSION

The physico-chemical conditionsin the tributary of Periyar river which is connected to the Cochin estuary, serve as an indication of the ecological imbalance caused by the industrial effluents. Many industrial wastewaters contain high concentration of toxicants. Often several toxicants are present in lethal concentrations in these effluents. If this effluent is discharged untreated, virtually all aquatic organisms may be killed in the vicinity of the outfall. Besides these toxicants are bioaccumulated by fish or shell fish until the organisms are no longer fit for human consumption. The toxicants found in a given industrial wastewater depends very much on the particular industry involved. In this instance the effluents are of a complex nature discharged from several industries producing fertilisers, fungisides and insecticides. The flora and fauna of this area are under stress from these effluents of a complex nature. The impact of this is so conspicuous as to cut down the productivity by about 99% at the discharge site. Productivity at the control station is generally the highest and thereon there is a progressive diminution from the control to the impact station. The upstream site of the discharge point also showed considerable decrease in production probably because of tidal influence.

In February at the control station the productivity is 204.0mg $C/m^3/hr$ but the next station shows higher value of production than that of the control station, which is anomalous. Such anomaly is common in such a system which is influenced by tidal and river flow. The area around the impact station is in a state of high flux due to the combined effect of tidal flow and river flow. During high tide the backwaters along with effluents and

river water are flushed upstream whereas in low tide, the tidal flow caused by the low tide combined with the riverflow carries the effluents rather quickly from the impact station replacing with the fresh water. Thus the upstream station, impact station and first down stream station should be viewed as a whole and the overall productivity is a combined effect of those forces acting in unison with the quantum of flora and other supporting environmental factors. The third station which is nearer to the discharge site had about 20.8% cut in production recording only 161.6 mg $C/m^3/hr$. The fourth station still closer to the discharge site had 57.8% cut in the productivity. The productivity here is 86.0 mg $C/m^3/hr$. Closer to the impact station, the productivity potential cut (ppc) is more. Thus at the impact station the ppc is 97.7% and the productivity is 4.7 mg $C/m^3/hr$. The productive potential cut may be either due to the abrupt changes in the physico-chemical parameters or due to the toxicants in the effluents or due to the combined effect of both. At the discharge site abrupt changes in the physiochemical parameters are found to occur which may be one of contributing factors of such a low production. The temperature in the control site is $30^{o}C$. While at the impact station it has increased to $33^{o}C$ posing the problem of thermal pollution. The incipient lethal temperature of most species lies within or below the range $30\text{-}35^{o}C$ so that in the tropical climates where summer water temperatures may approach this limit naturally a further temperature increase of only a few degrees centigrade may prove lethal to many organisms. Kills of shallow water corals at Kahe Point, Oahu, Hawaii (Jokiel and Coles, 1974) and of virtually the entire benthos over a large area of Biscayne Bay, Florida (FWPCA, 1970) provide two good examples of direct thermal kills of benthic organisms. Obviously there

will be no direct effect on the benthos unless the effluent is mixed to the bottom. (Laws, Edward A 1981). It is not the thermal pollution alone that cause mortality or inhibit the metabolic process but it is the combined effect of various pollutants that cause mortality. There is abrupt fluctuation in dissolved oxygen also. While it is 4.34 ml/l at the control site it has decreased to 1.44 ml/l at the impact site. Nitrite concentration in the control site is 0.32 µg at NO_2-N/l. It has dropped to 0.04 µg at NO_2-N/l at the impact station. There is fluctuation in the hydrogen ion concentration from 7.9 at the control to 5.65 µg transforming the medium to an acidic one. The inorganic phosphate too has shown considerable decrease i.e. from 4.34 µg at PO_4-P in the control site to 1.44 µg at PO_4-P in the impact station. The upstream station too showed the impact of pollution as indicated by the productivity. The production recorded is 69.6 mg $C/m^3/hr$ which is 65.9% less than that of the control site.

In March the primary organic production at the control station is 89.9 mg $C/m^3/hr$. All the other stations are influenced by pollution and hence are expected to record lower production than that of the control site. Productivity at stations 3, 5 and 6 show considerable cut in primary production due to the toxicity of the effluents. At station 3 the productivity is 16.1 mg $C/m^3/hr$ as against 89.9 µg $C/m^3/hr$ at the control. Here the cut in productivity is 82.6% at station 5 the productivity is 40.7 mg $C/m^3/hr$ the ppc being 54.7%. In the upstream station the productivity is 40.0mg $C/m^3/hr$ with the ppc 55.5%.

In April the productivity at the impact station is 6.8 mg $C/m^3/hr$. The lowest productivity recorded is at the adjacent downstream station where the

production is 3.4 mg C/m^3/hr. Though the lowest productivity is expected to be recorded at the impact station the effect occasionally is more conspicuous in the downstream station. Though the variation in the photosynthetic productivity should be the minimum at the site of impact of the effluent discharge the effect is occasionally felt at the downstream station too which is attributed to the flow of effluents along with the river flow. Since these stations have the influence of the flow of river and the tidal effect some sort of mixing of the effluents in various concentrations with the ambient water is possible which is detectable in the downstream position. The primary organic production at the control site is 137.6mg C/m^3/hr. At the second station the primary production is 77.3 mg C/m^3/hr and the ppc is 43.8%. The third station records 34.7 mg C/m^3/hr and the ppc is 74.8%. At the fourth station where the production is the lowest (3.4 mg C/m^3/hr) the ppc is 97.53%. At the impact station the productivity is 6.8 mg C/m^3/hr and the ppc is 95.1%. The upstream station records 61.5 mg C/m^3/hr and the ppc is 55.3%.

The productivity data in May show a gradual decrease in productivity from stations 1 to 6. The first station which is taken as the control site records a primary productivity of 120.0 mg C/m^3/hr. 40.1% cut in productivity is recorded at the second station reducing the productivity to 71.9 mg C/m^3/hr. The third station had a cut of 53.0% in productivity. The fourth station which is still closer to the source of pollution recorded 32.0 mg C/m^3/hr. The pollutants inhibited 73.3% of the potential productivity. At the impact station (station 5) the productivity is 25.0 mg C/m^3/hr and the ppc is 79.2%. At the upstream station during the period the productivity is less than that at the impact station. This is due to the tidal

effect where good amounts of effluents are carried upstream. Here the productivity is reduced to 14.1 mg $C/m^3/hr$ and the ppc is 88.3%.

Thus the general trend of productivity during the pre-monsoon shows that the industrial effluents are responsible for a ppc of 51.3% at station 3, 49.2% at station 4, 86.0% at station 5 and 66.4% at station 6.

In June the productivity at the control site is 41.8 mg $C/m^3/hr$. The second station showed comparatively less production indicating the impact of effluents. The productivity here is 16.0 mg $C/m^3/hr$ and the ppc is 61.7%. The third station records 6.8 mg $C/m^3/hr$ the ppc being 83.7%. At the fourth station the productivity is 9.9 mg $C/m^3/hr$ and the ppc is 76.3%. In the impact station the lowest productivity of 3.2 mg $C/m^3/hr$ is recorded with a ppc or 92.3%. At the sixth station the productivity is 15.0 mg $C/m^3/hr$ and the ppc recorded is 64.0%.

During July too the productivity values recorded are of low magnitude. In the control site the productivity is 43.2 mg $C/m^3/hr$. This is decreased to 3.8 mg $C/m^3/hr$ at the second station and the impact of pollution is so intense as to reduce the productive potential to 91.2%. The third site recorded a productivity of 25.2 mg $C/m^3/hr$ and the ppc is 41.7%. At At the fourth station which is close to the impact site the production recorded is the lowest i.e. only 0.7 mg $C/m^3/hr$. Here the toxicity of the pollutants carried downstream which may be lethal or near lethal level might have deactivated the entire flora increasing the ppc to 98.4%. At the impact station the production is 2.4 mg $C/m^3/hr$ and the ppc is 94.4%. In the upstream station the production is only 1.6 mg $C/m^3/hr$ and the ppc is 96.3%. Thus during this period the extreme low production and the high ppc values indicate a larger outflow of effluents consequent on the monsoonal phenomenon.

During August the productivity level is generally low in the entire area of the riverine system and connected backwaters. The increased river flow masks the effect of effluents and maximum productivity of 20.9 mg $C/m^3/hr$ is observed in the upstream station which may be wholly attributed to the freshwater flora recruited to the area and also due to the increased nutrients supply. The indigeneous freshwater flora become progressively less active as it is carried downstream into the brackishwater condition and the lowest rate of production recorded in the area is observed in the control station during this period.

In September the estuarine waters on regaining stable conditions and on being replenished with nutrients attain peak production reaching 409.8 mg $C/m^3/hr$. Upstream the productivity is progressively reduced depending on the intensity of mixing of effluents. Thus at the second station the productivity is only 80.9 $mgC/m^3/hr$ as against 409.8 mg $C/m^3/hr$ at the control site. Thus the ppc at this station in 80.3%. In the third station the productivity recorded is 13.1% and the ppc is 96.8%. At station 4 the productivity is 18.2 mg $C/m^3/hr$ with a ppc of 95.6%. At the impact station (Station 5) the productivity recorded is 24.8 mg $C/m^3/hr$ and the ppc is 93.9%. In the upstream station also the pollutant has reduced the productivity by 75.1%.

During monsoon the average primary organic production at the control site is 124.4 mg $C/m^3/hr$. The average productivity value at stations 2, 3, 4, 5 and 6 are 26.0, 12.0, 9.1, 8.7 and 34.9 mg $C/m^3/hr$ and their ppc are 79.1%, 90.4%, 92.7%, 93.0% and 71.9% respectively.

In October the productivity at the primary trophic level at the control site is 390.0 mg $C/m^3/hr$. At the second station where the pollution

has only slight impact the productivity is 340.4 mg $C/m^3/hr$. This decrease in production expressed in terms of production potential cut is 12.7%. The third station which is nearer to the impact station records comparatively less production than that in the second station. The production recorded at this station is 75.0 mg $C/m^3/hr$ and the ppc is 80.8%. At the fourth station which is the nearest to the impact station the productivity is only 0.4 mg $C/m^3/hr$ and the ppc is 99.9%. The impact station records only 0.3 mg $C/m^3/hr$ exhibiting a ppc of 99.9%. The highest pH value of 8.7 is recorded at this station during the period. The upstream site records a production of 21.7 mg $C/m^3/hr$. The ppc at the site is 94.4%.

In November at the control site the primary organic production is 185.0 mg $C/m^3/hr$. Gradual decrease in the primary organic production is observed in the subsequent stations. At the second station it is 113.7 mg $C/m^3/hr$. On comparison with the control this station suffers a productivity potential cut of 38.5%. The next station which is closer to the discharge point is less productive, the productivity being 46.1 mg $C/m^3/hr$. The ppc at this station is 75.1%. The impact of pollution is so severe at station four where the primary organic productions is only 1 mg $C/m^3/hr$ and the ppc is 99.5%. The next station indicates a ppc of about 80% with a productivity of 37.2 mg $C/m^3/hr$. AT the last station the productivity is 2.0 mg $C/m^3/hr$ and the ppc is about 99%.

In December the first station records a production of 288.0 mg $C/m^3/hr$. The second station records only 174.0 mg $C/m^3/hr$ and the ppc here is 39.6%. In the next station the primary productivity is 31.5 mg $C/m^3/hr$ and the ppc is 89.1%. The fourth station registers a productivity of 61.5 mg $C/m^3/hr$ with a ppc of 78.6%. In the discharge site the primary

production is 18.8 mg C/m^3/hr. Here the productivity potential is reduced to 16.5%. The inhibition is 93.5% of production potential. In the upstream station the ppc is 93.8%. Here the production is only 18.0 mg C/m^3/hr which is only 14.2% of the potential production.

In January at the control station the primary organic production is 201.0 mg C/m^3/hr. In the next station the primary organic production is 162.6 mg C/m^3/hr when the ppc is 19%. The third station has only 77.3 mg C/m^3/hr. The percentage of inhibition of potential productivity is 61.5%. In the fourth station the impact of industrial effluents decreases the productivity by 77.1% when compared to that at the control station. The primary organic production at this station is only 46.1 mg C/m^3/hr. The fifth station has yielded 49.1 mg C/m^3/hr. The reduction due to pollution is 75.6% in the productivity potential. The upstream station had a cut of 65.4% in the potential productivity recording 69.6 mg C/m^3/hr.

Thus in the post monsoon period the average productivity at the control site is 266 mg C/m^3/hr. The average primary production at the next station is 197.6 mg C/m^3/hr and the inhibition of photosynthesis here is about 15.0%. In the third station the productivity is only 57.5 mgC/m^3/hr and the ppc is about 78%. In the fourth station the average productivity is 27.3 mg C/m^3/hr. The fifth station which is the discharge point recorded an average value of 26.3 mg C/m^3/hr during post monsoon and the ppc is 90.0%. In the upstream site too the productivity potential is reduced almost to the same level as indicated by the low production of 27.8 mg C/m^3/hr. Here the ppc is 89.7%.

Devassy et al. (1986) studied the effect of industrial effluents on biota at the inshore waters off Mangalore. They observed that except

for some changes in phytoplankton population, the industrial effluent discharge has not caused any noticeable damage to the inshore seas, off Mangalore. But here the impact of industrial effluents on the productivity has not been studied. The absence of any noticeable damage may be due to the immediate dilution of the effluents as the same is discharged directly into the sea.

The present study deals with a situation where the effluents are discharged at a point in the tributary of the Periyar river which flows down about 5 kilometers to join the estuary. So the impact of the effluents on the flora and fauna can be well studied. The magnitude of damage to the populations is evident from the observations on the annual average productivity at the control site and that of other stations. The sites selected within the pollution range, are found to yield comparatively less production values depending on the intensity of pollution to which the autotrophs at the respective sites are subjected. The annual average productivity at the control site about 0.8 tonnes of carbon/m^3. The station situated at a site where the effluent containing medium joins the estuary the production is only about 75% of that at the control site. The annual organic production at this station is about 0.6 tonnes of carbon/m^3. About 25% cut in the productivity potential is observed here. The next station being nearer to the source of pollution is subjected to more stress and has only less production. The annual organic productivity at this station is about 0.2 tonnes of carbon/m^3. This is only about 25% of the productivity at the control site and the ppc is about 75%. At the fourth station the productivity is still less being further closer to the impact station. Here annual organic production estimated is 0.16 tonnes carbon/m^3. This

is only 20% of the production at the control site and the ppc is 80%. The worst affected region is the discharge point where the annual organic productivity is only 0.08 tonnes of carbon/m^3. This is only 10% of the primary organic production compared to the control site and the ppc is 90%. Thus the productivity of this region is influenced by the concentration of the effluents. The present study refers only on the impact of effluents at the primary trophic level though mortality of fish has been moticed occasionally. On analysis it is found that no flora and fauna survive at the discharge site. The worst affected are the non motile benthic organisms. One of the probable reasons of the mortality of the fish may be due to nitrogen embolism. The heated effluent is supersaturated with nitrogen gas, and excess nitrogen taken into a fish's blood tends to bubble out, leading at first to disequillibrium and ultimately to death (De Mont and Miller, 1971; Clark and Brownwell, 1973). Thus the inhibition of organic production at the primary trophic level and the mortality of various organisms at higher trophic levels are due to the stress of these industrial effluents on biota caused by the complex interactions between a variety of factors.

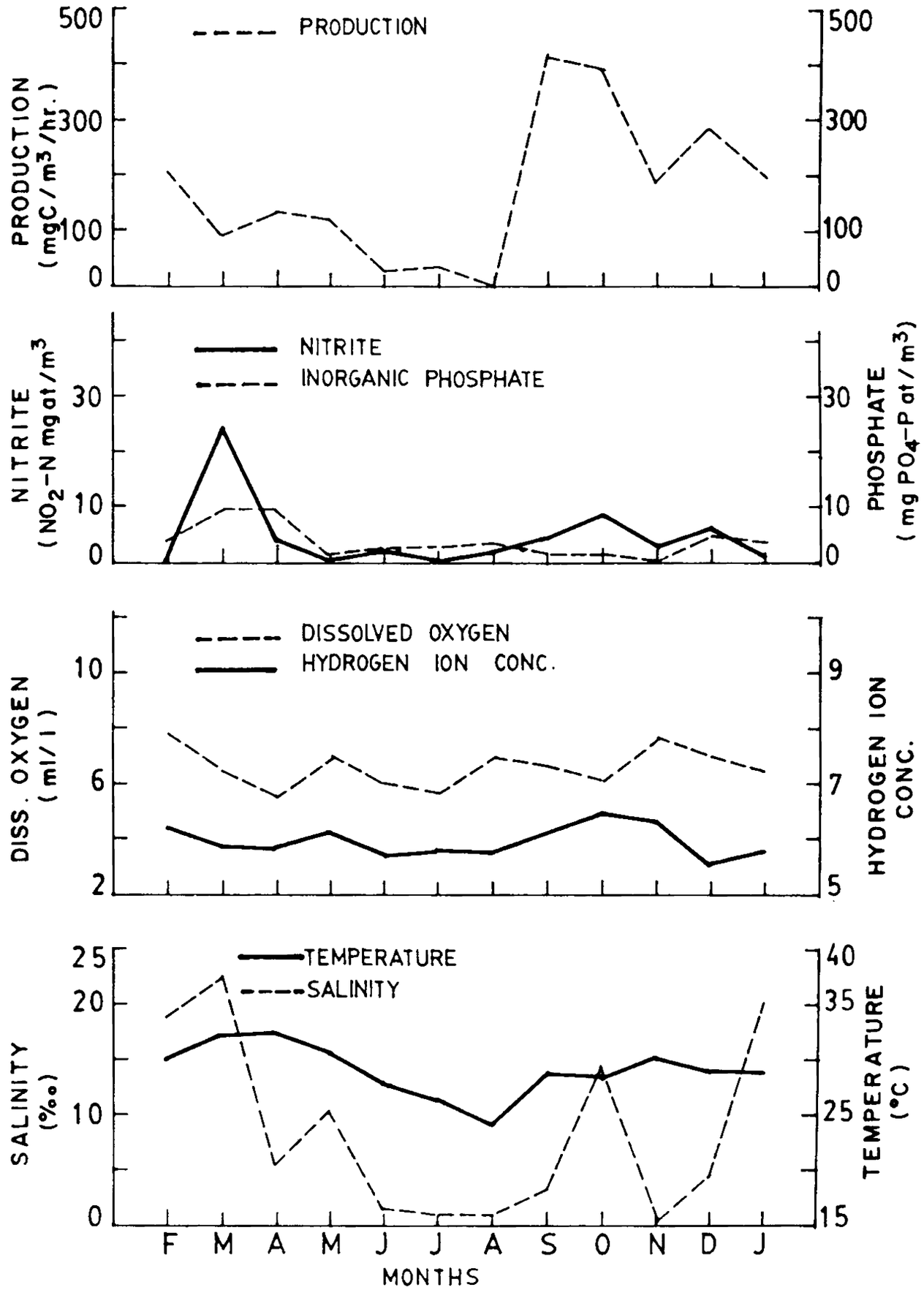

FIG. 31. STATION I

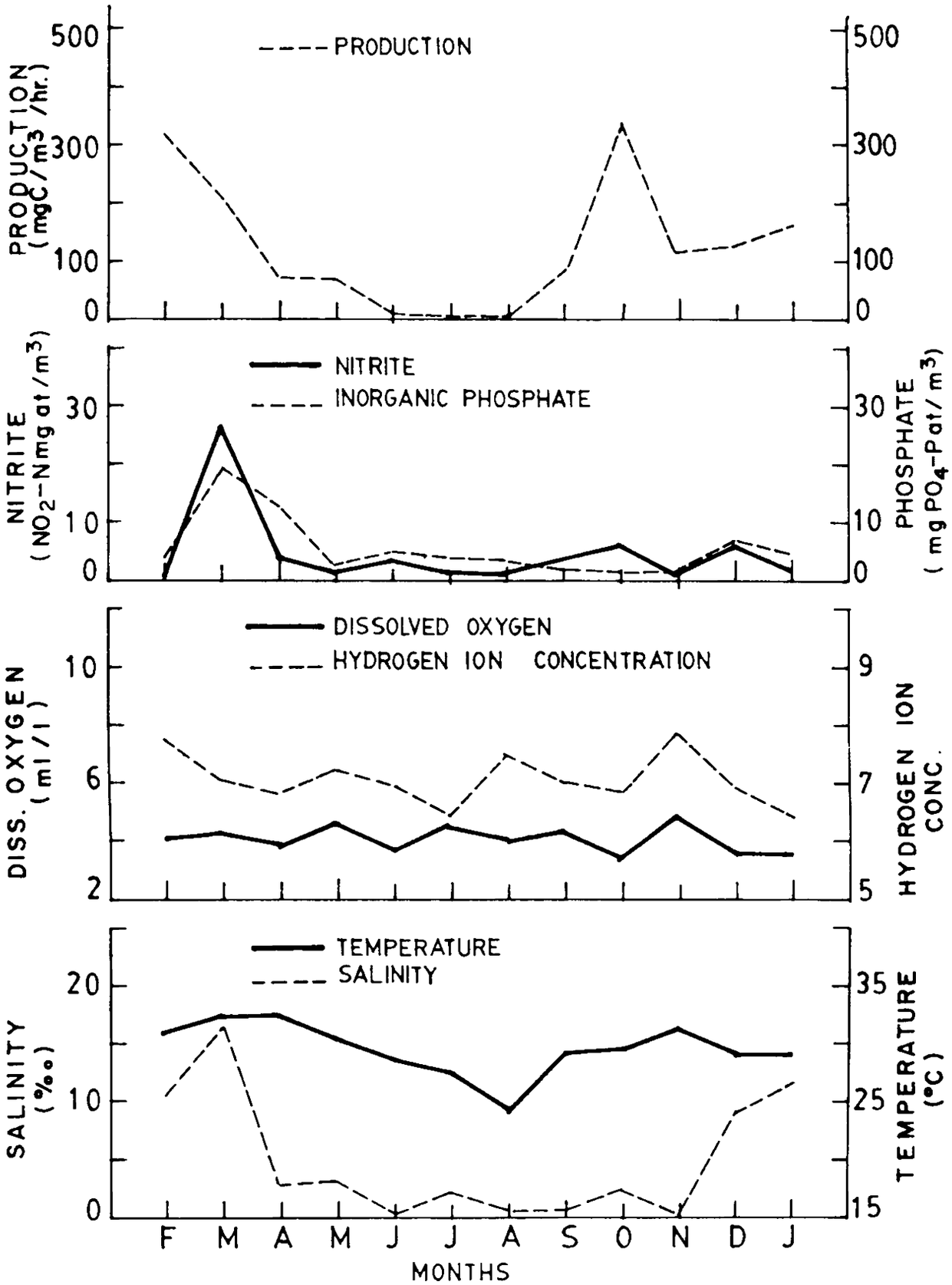

FIG. 32. STATION II

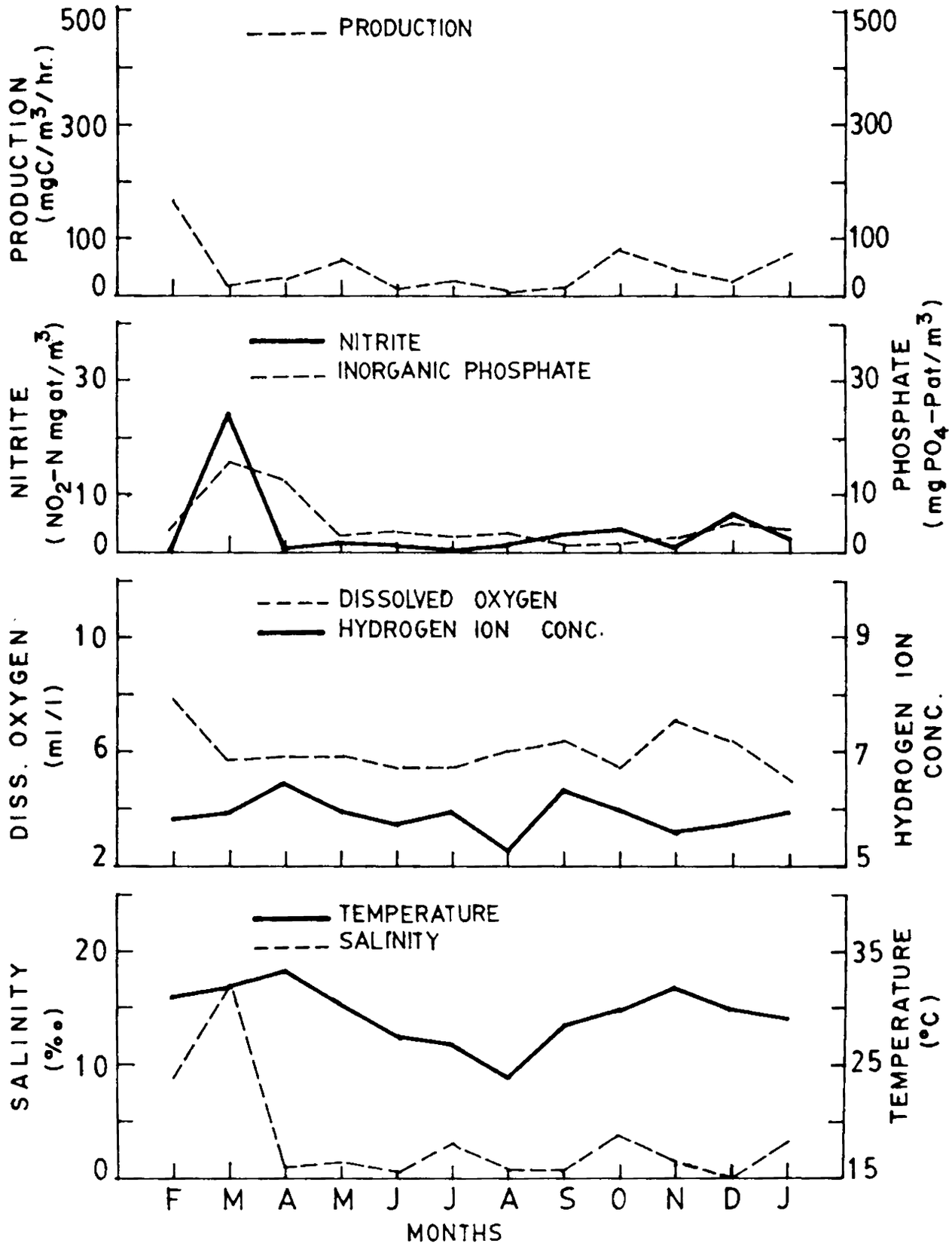

FIG. 33. STATION III

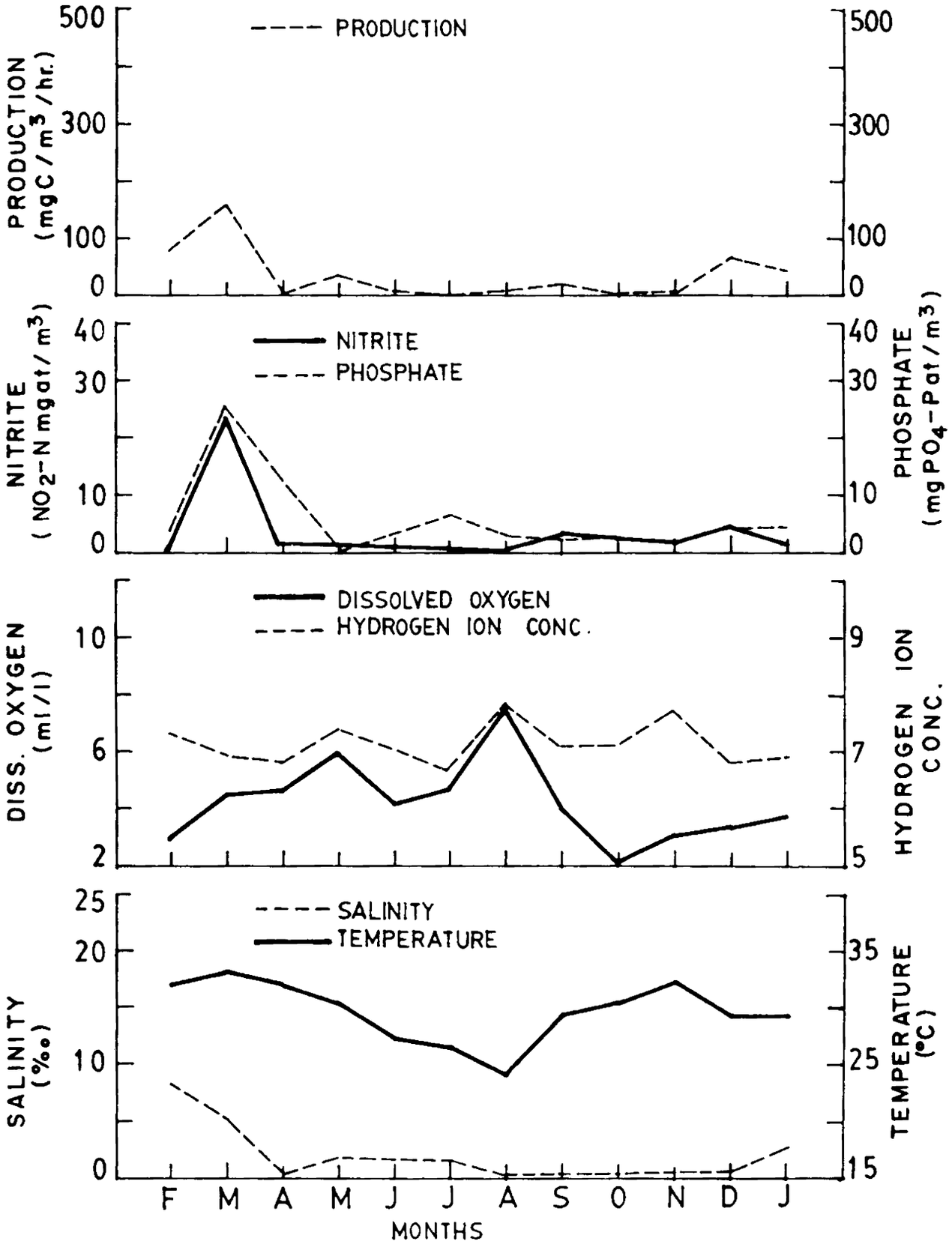

FIG. 34. STATION IV

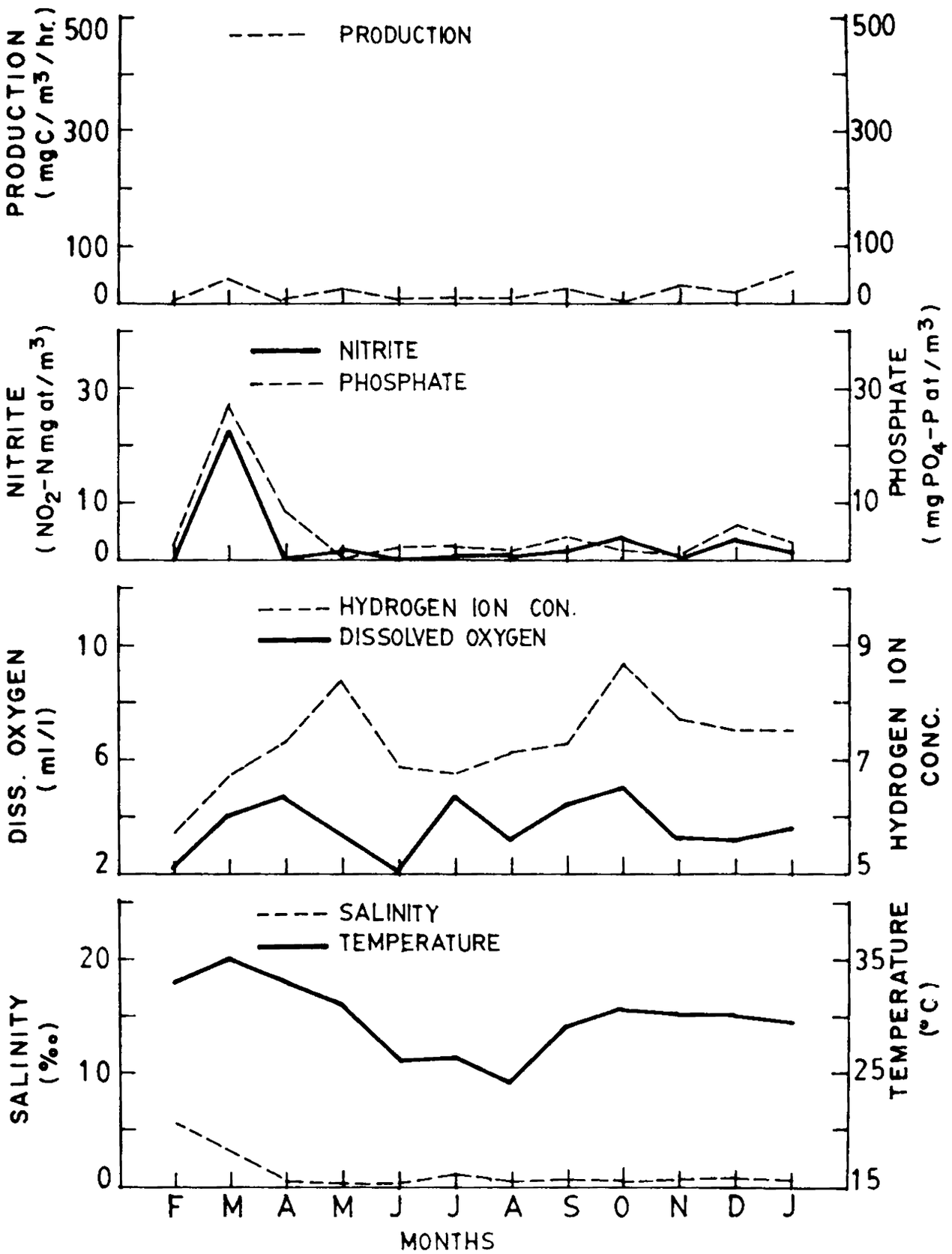

FIG. 35. STATION V

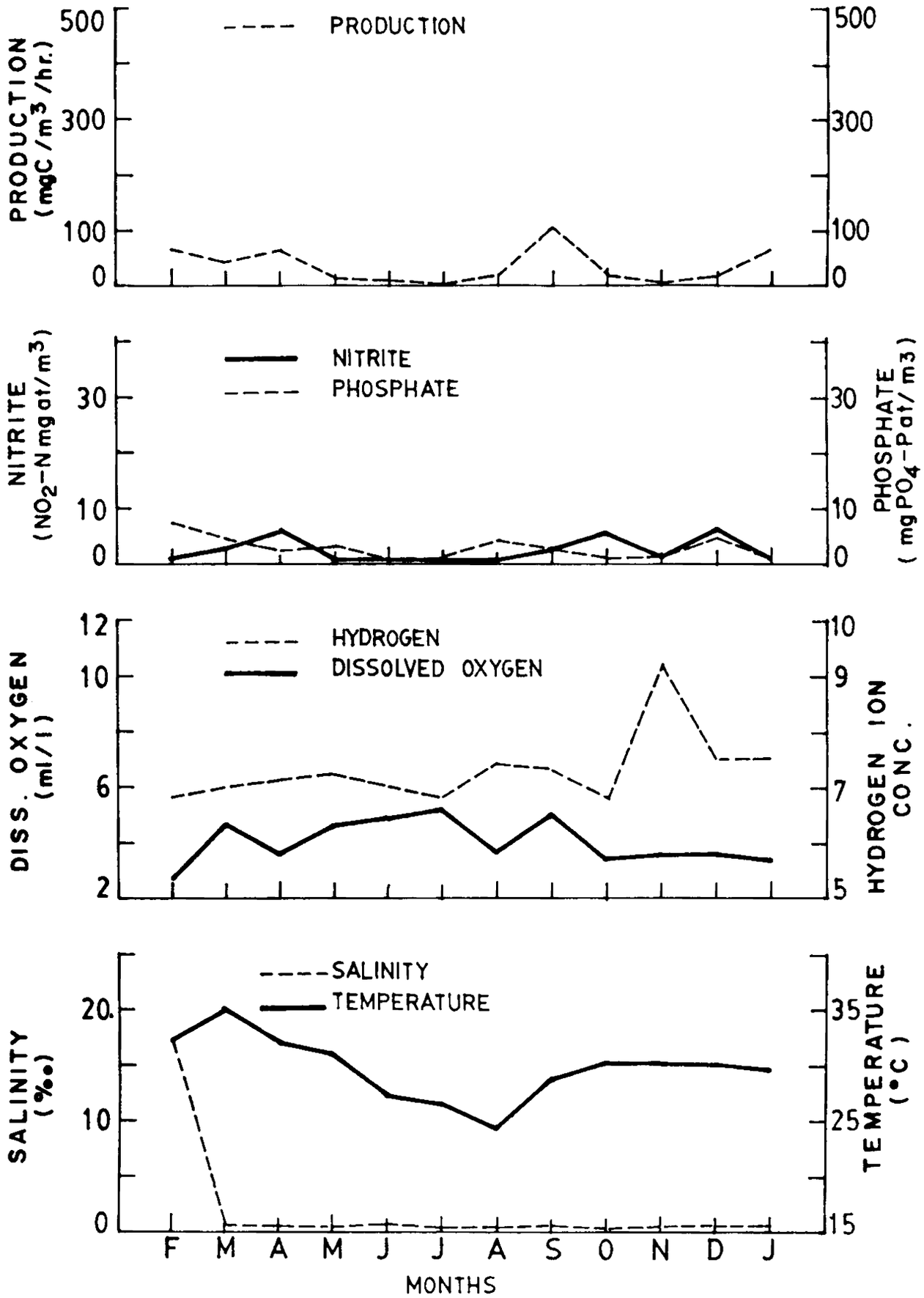

FIG. 36. STATION VI

CHAPTER VIII

CULTIVATION OF PLANKTONIC ALGAE

1. Significance of algal cultivation

Algae are the major synthesisers of food at the primary trophic level in any aquatic ecosystem, which influence the fishery resources in the concerned environment. They have been studied extensively for over eighty years, during which period progress has been made in gathering information about more than 17,000 species (Burlew, 1976) that have been described. But only a few species have been used as research tools by plant physiologists in the study of mechanism of photosynthesis. Since the introduction of a Chlorella species as an experimental tool for the investigation of photosynthesis by Warburg (1919) - because it was simple to handle under controlled conditions and gave better reproducibility than higher plants - this alga and others have become favourite organisms for elucidating photosynthetic mechanism, as well as other problems in biochemistry and cell physiology. In the present study another suitable organism introduced is a blue green alga Synechocystis salina. The investigation of Spoehr and Milner (1949) showed that the composition of an alga such as Chlorella pyrenoidosa could be controlled. This finding gave added interest to the idea that unicellular algae might be grown on a large scale as a source of food. There has developed a considerable literature on investigations into the fundamental biochemistry of photosynthesis (Brody and Brody, 1962), pigments (Schiff, 1964) metabolic pathways, and nutritional requirements (Provasoli, 1957, 1958b) and ecology (Fogg, 1975) in which microalgae are used as experimental tools. The

potential of unicellular algae as a food supplement for man in the daily diet (Osnitskaya and Goryunova, 1962) or as a food for submarine travel and space exploration has been evaluated, (Casey and Lubitz, 1963 and Casey et al 1963.). Benoit (1964) proposed that man's physiological need for oxygen, water, food and sanitation disposal could be met by a closed system involving a continuously managed culture of micro-algae. Though fresh water species of Chlorella have received most of the attention Eddy (1956) has pointed out the advantages of salt and backwater species. Recently, a concept of industrial photosynthesis has become popular that described a multidimensional process of waste water treatments, food production, and water reclamation. The major emphasis in such a system is on the algal photosynthetic conversion of solar energy into a high protein food while simultaneously reclaiming water and disposing of waste (Mattoni et al., 1965; Schmitt, 1965; Ryther et al., 1972). Marine and brackish-water algal species can be utilized directly as a food for rearing crustaceans and molluscs or the algal cultures processed and used to supplement food of other animals (Kinne, 1976).

As food requirements increase with the ever increasing population man has to explore the possibility of new sources of food which has resulted in the controlled industrial cultivation of many unicellular marine algae. The microscopic unicellular algae have a number of advantages over higher plants as a source of food. In higher plants, the sum total of the nutritive parts of the plant is usually only half or less of the total dry weight. Most of the plant structure serves only for mechanical purposes, where as the entire unicellular plants are nutritious, for little of it is devoted to indigestable structures. Dried algal cells grown under

favourable conditions contain over fifty percent protein, or more than is found in the edible parts of any of the higher plants. Further more this protein should be suitable for human consumption, for it contains ten amino acids now considered essential (Fisher and Burlew, 1976) and has a low molecular weight, which means that it can be digested readily. The possibility of growing a high protein food in large quantities is of great importance in connection with long range planning for the feeding of an ever increasing world population. Even today in several quarters of the world many people do not have access to sufficient protein. There is little hope for relief by traditional method of rearing animals for food, because of the non availability of large areas of land required to grow grass and other crops to support them. Further to fight the problem of malnutrition the local production of fish is also not always possible. In this situation to meet the ever growing food requirement of man cultivation of algae is very significant. Unicellular algae in sufficiently large quantities serve as raw material for several special substances. Porphyridium cruentum is an excellent source of the gel forming carrageens (Golueke and Oswald, 1962) Pharmaceuticals (Hutner, 1964) as provitamin A can be obtained from Dunaliella salina. Sometimes beta-carotene pigment is present in D. salina in concentrations that are ten times higher than in most green algae and leaves. Dunaliella tertriolecta and Skeletonema costatum are the source of thiamine, Cocolithus huxleyi yields B_{12}, Dunaliella tetriolecta, Phaeodactylum tricornutum and Skeletonema costatum are the source of biotin. An interesting possibility is the use of algae as source of sterol to be used as a starting material in the synthesis of cortisone (Robert and William, 1976).

As the planktonic algae being the major primary producers in the aquatic ecosystem various ecophysiological problems encountered in the studies can be tackled only in laboratory using algal cultures. For the correct interpretation of the organic production at different trophic levels and assessment of productivity of various taxonomical classes and size fractions of the producers their cultivation under controlled conditions are essential. The present work is planned to understand the growth characteristics and nutrients requirement of selected species of planktonic algal flora with special reference to their growth constants and generation time, chlorophyll 'a' and productivity under various environmental parameters and their response to varying concentrations of metallic pollutants.

2. Growth characteristics of Tetraselmis gracilis, Kylin

Natural sea water enriched with inorganic nutrients is used for culturing Tetraselmis gracilis, a Prasinophycean tetraflagellate. The culture medium, prepared in Erlenmayer's flask of three litre capacity is inoculated with sufficiently large quantity of actively dividing cells so as to have an initial concentration of 200,000 cells^{l-1}. Further concentrations have been expressed in units of 10 million cells (Table 24)). The chlorophyll a and b concentrations of the inoculum are 0.52 µg and 0.22 µg/l and for 10^7 cells chlorophyll a and chlorophyll b would be 26.0 µg and 11.0 µg respectively. The gross and net primary production values as measured by C^{14} uptake are 0.2 µg C and 0.1 ug C^{l-1} $hr-1$ respectively. For every 10^7 cells, the gross and net productivity are 10.0 µg C and 5.0 µg C^{hr-1}.

TABLE 24

Cell numbers, Chlorophyll and Production of *Tetraselmis gracilis*

Age (Days)	Cell numbers x 10^7	Chlorophyll *a* µg/l	Chlorophyll *a* µg/l 10^7 cells	Chlorophyll *b* µg/l 10^7 cells	Chlorophyll *b* µg/l 10^7 cells	Productivity (C^{14} method) Gross µgc/l/hr	Gross µgc/ 10^7 cells/hr	Net µgc/l/hr	Net µgc/ 10^7 cells	Productivity (Oxygen method) Gross µgc/l/hr	Net µgc/l/hr
0	0.02	0.52	26.0	0.22	11.0	0.2	10.0	0.1	5.0	-	-
2	0.10	2.61	26.1	1.08	10.8	1.0	10.0	0.7	7.0	-	-
3	3.00	64.62	21.54	26.70	8.9	30.0	10.0	20.0	6.67	72.00	32.00
4	4.00	83.37	20.84	35.34	8.84	-	-	-	-	-	-
5	10.00	166.32	16.63	81.82	8.18	64.0	6.4	58.0	5.80	227.00	151.00
7	33.00	548.88	16.63	270.00	8.18	141.0	4.27	128.0	3.88	306.00	241.00
9	37.00	768.36	20.77	326.96	8.84	216.0	5.84	196.0	5.30	-	-
10	39.00	840.12	21.54	347.12	8.90	186.0	4.77	169.0	4.33	407.00	349.00
11	41.00	1071.20	26.13	444.12	10.83	198.0	4.83	180.0	4.39	515.00	414.00
14	44.00	1358.20	30.87	649.84	14.77	279.0	6.34	253.0	5.75	623.00	457.00
15	49.00	1529.52	31.21	527.80	10.77	218.0	4.45	198.0	4.04	461.00	389.00
17	60.00	1693.72	28.23	619.24	10.32	-	-	-	-	461.00	360.00
19	76.00	2001.80	26.34	642.72	8.46	335.0	4.41	304.0	4.0	536.00	439.00
23	73.00	2321.72	31.80	920.72	12.61	195.0	2.68	177.0	2.42	709.00	572.00
25	73.00	2364.40	32.39	935.28	12.81	93.0	1.28	84.0	1.15	184.00	97.00
28	80.00	2594.92	32.44	1058.72	13.23	178.0	2.23	161.0	2.01	252.00	194.00
30	90.00	3017.20	33.52	1183.76	13.15	127.0	1.41	115.0	1.28	598.00	403.00

The exponentially growing cells on inoculation start growing immediately resulting in a five fold increase after 48 hours. The cell concentration on the second day is 0.1 x 10^7 $Cells^{l-1}$. The increase of cells by two days is 0.08 x 10^7 cells and the factor of increase of cells per day is 2.0 times. The chlorophyll a and b concentration are 2.61 µg and 1.08 µg/l. The concentrations for every 10^7 cells could be 26.1 µg and 10.8 µg respectively. The gross and net productions as measured by C^{14} uptake are 0.2 µg C/l/hr and 0.1 µg C/l/hr respectively. For every 10^7 cells gross and net productions are 10 µg and 50 µg C respectively.

From second to third day the increase of cells is 2.90 x 10^7 cells and the factor of increase is 29. Thus on the third day the cell concentration is 3.0 x 10^7 cells/l. The chlorophyll a and b concentrations are 64.62 µg and 26.70 µg/l. For 10^7 cells the concentrations are 21.54 µg and 8.9 µg respectively. The gross and net production as measured by C^{14} are 30 µg C/l/hr and 20 µg C/l/hr respectively. The gross and net productivity per 10^7 cells are 10 µg C and 6.6 µg C respectively.

From third to fourth day the increase is 1.0 x 10^7 cells and the factor of increase is 0.33. On the fourth day the cells concentration is 4.00 x 10^7 cells. The chlorophyil a and b concentrations 83.37 µg and 35.34 µg/l respectively. Their concentrations for every 10^7 cells are 20.84 µg and 8.84 µg respectively.

The increase of cells from fourth to fifth day is 6.0 x 10^7 cells and the factor of increase of cells is 1.5. On the fifth day the culture has established a cell concentration 10.00 x 10^7 cells/l. The chlorophyll

a concentration is 166.32 µg/l and it is 16.63 µg/10^7 cells. Chlorophyll b concentration is 81.82 and it is 8.18 µg/10^7 cells. The gross production as measured by C^{14} uptake is 64.0 µg C/l/hr and it is 6.4 µg C/10^7 cell/hr. The net productivity is 58.0 µg C/l/hr which is about 5.8 µgC/10^7 cells. Thus the exponential phase comes to an end.

There is a decline in the growth of the culture. The increase of cells for two days ie. from fifth to seventh is 23.00 x 10^7 cells/l and the factor of increase of cells per day is 1.15 times. On the seventh day the concentration of the culture is 33.00 x 10^7 cells. The chlorophyll a concentration is 548.88 µg/l and chlorophyll b is 270.0 µg/l. Their concentration for every 10^7 cells are 16.63 µg and 8.18 µg respectively. The gross production is 141.0 µg C/l/hr and it is 4.27 µg/10^7 cells/hr. The net production is 128.0 µg C/l/hr and for every 10^7 cells the net production is 3.88 µg C/hr.

The growth rate is still declined and the increase of cells for 2 days ie., from seventh to ninth day is 4.0 x 10^7 cells/l (2.0 x 10^7 cells/day). The factor of increase of cells is 0.06/day. The cell concentration on the ninth day 37.0 x 10^7 cells/l. The chlorophyll a concentration is 768.36 µg/l which amounts to be 20.77 µg/10^7 cells. The concentration of chlorophyll b is 326.96 µg/l which is 8.84 µg/10^7 cells. The gross production is 216.0 µg C/l/hr and the net production 196.0 µg/l/hr. For every 10^7 cells gross production is 5.84 µg C/hr and the net production is 5.30 µg C/hr.

From ninth to tenth day the increase of cells is 2.00 x 10^7 cells and the rate of increase of cells 0.05/day. The cell concentration of the culture on tenth day is 39.00 x 10^7 cells/l. The chlorophyll a concentration 840.12 µg/l and for every 10^7 cells it is 21.54 µg/l. The chlorophyll b present in 1 litre of the culture is 347. 12 µg and for 10^7

cells it is 8.90 µg/. The gross production as measured by C^{14} uptake is 186.0 µg C/l and for every 10^7 cells it is 4.77 µg C/hr. The net production is 169.0 µg C/l/hr and for 10^7 cells it is 4.33 µg C/hr. The growth of the culture remains almost stationary upto seventeenth day. From tenth to eleventh day the increase is 2 x 10^7 cells/l the factor of increase of cells being 0.05.

On the eleventh day the cell concentration is 41.0 x 10^7 cells/l. The chlorophyll a concentration is 1071.20 µg/l and for every 10^7 cells the chlorophyll a is 26.13 µg. The concentration of chlorophyll b is 444.12 µg/l and it is 10.83 µg/10^7 cells. The gross production estimated from C^{14} uptake is 198.0 µg C/l/hr (4.83 µg C/10^7 cells/hr) and the net production is 180.0 µg C/l/hr (4.39 µg C/10^7 cells/l).

From eleventh to fourteenthday the increase in the cell numbers is 3.00 x 10^7 cells. The factor of increase of cells per day is 0.02. The cell concentration on the fourteenth day is 44.0 x 10^7 cells/l. The chlorophyll a concentration of the culture is 1358.20 µg/l and chlorophyll b is 649.84 µg/l. Their concentration for 10^7 cells are 30.87 µg and 14.77 µg respectively. The gross primary production as estimated by C^{14} uptake is 279.0 µg C/l/hr and the net production is 253.0 µg C/l/hr. The gross and net production per 10^7 cells are 6.34 µg C/and 5.75 µgC/hr.

From fourteenth to fifteenth day the increase of cells is 5.0x10^7 cells/l, the factor of increase of cells being 0.11. The fifteen day old culture has a cell concentration 49.0 x 10^7 cells/l. The chlorophyll a concentration is 1529.52 µg/l (31.21 µg/10^7 cells) and chlorophyll b is 527.80 µg/l (10.77 µg/10^7 cells). The gross production is 218.0 µgC/l/hr

(4.45 µg C/10^7 cells) and the net production is 198.0 µg C/l/hr (4.04 µg C/10^7 cells).

The culture continues to exhibit stationary phase and the increase of cells from fifteenth to the seventeenth day is 11.0 x 10^7 cells/l and the factor of increase of cells per day is 0.11. The cell concentration on the seventeenth day is 60.0 x 10^7 cells/l. The chlorophyll a concentration is 1693.72 µg/l and for every 10^7 cells it is 28.23 µg. The chlorophyll b concentration is 619.24 µg/l and for 10^7 cells it is 10.32 µg.

The growth of the planktonic algae is almost stationary during the next two more days ie., from seventeenth to nineteenth day. During this period, the increase of the cells is 16.0 x 10^7 cells i.e., about 8.0x10^7 cells per day. The factor of increase of cells is 0.13/day. On nineteenth day the number of cells per litre is 76 x 10^7. The chlorophyll a concentration of the culture is 2000.80 µg/l. This is about 26.34 µg/10^7 cells. Chlrorophyll b concentration is 642.72 µg/l and for 10^7 cells this is 8.46 µg. The photosynthetic efficiency expressed in terms of gross production and net production are 335.0 µg and 304.0 µg C/l/hr. For every 10^7 cells these are 4.41 µgC and 4.0 µgC/hr respectively.

There is practically no growth during the following days. From nineteenth to twentythird there is no increase in the cell numbers. On twentythird day the cell concentration is 73.0x10^7 cells/l. The chlorophyll a concentration is 2321.72 µg/l and chlorophyll b 920.72 µg/l. Their concentration per 10^7 cells are 31.80 µg and 12.61 µg respectively. The gross production as measured by C^{14} uptake is 195.0 µg C/l/hr and it

is 2.68 µg C/10^7 cells/hr. The net production is 177.0 µg C/l/hr and it is 2.42 µg C/10^7 cells/hr.

The death phase continues and hence no increase in cell numbers is observed from twenty third to twentyfifth day. On twentyfifth day the cell concentration is same as that of twentythird day ie., 73x10^7 cells/l. The chlorophyll a concentration is 2364.40 µg/l and for 10^7 cells it is 32.39 µg. Chlorophyll b concentration is 935.28 µg/l and it is 12.81 µg for 10^7 cells. The gross production is 93.0 µg C/l/hr and the net production is 84.0 µg C/l/hr. The gross and net production expressed per 10^7 cells are 1.28 µg. and 1.15 µg C/hr respectively.

From twentyfifth to twentyeighth day the increase of cells is negligible ie. 7.00x10^7 cells for three days. So the increase of cells per day during this period is only 2.33x10^7 cells and the factor of increase is only 0.03. On twentyeighth day the cell concentration is 80.0x10^7cells/l. The chlorophyll a concentration is 2594.92 µg/l and chlorophyll b is 1058.72 µg/l. Their value per 10^7 cells are 32.44 µg and 13.23 µg respectively. The gross production is 178.0 µg C/l/hr and net production is 16.0 µg C/l/hr respectively.

The increase in cell numbers from twentyeighth to thirtieth day is negligible ie. 10x10^7 cells for two days. The factor of increase of cells is only 0.07. On thirtieth day the cell concentration is 90x10^7cells/l. The chlorophyll a concentration is 3017.20 µg/l (33.52 µg/10^7 cells) and chlorophyll b is 1183.76 µg/l (13.15 µg/10^7 cells). The gross production as calculated from C^{14} uptake is 127.0 µg C/l/hr (1.4 µg C/10^7 cells/hr) and the net production is 115.0 µg C/l/hr (1.28 µg C/10^7 cells/hr).

3. Growth constants and generation time of Tetraselmis gracilis under varying concentration of nutrients.

a. Influence of Phosphate.

Cell numbers:

The control contains 0.055 µg PO4-p at/l. Here the maximum growth constant (k^{hr-1}) of 0.021 is recorded on the second day itself and the corresponding generation time is 33.3 hours (Table 27). As the age advances the growth constants are getting reduced and on the fourteenth day it is only 0.008^{hr-1}. The doubling time of cells on the fourteenth day is 87.5 hours (Fig. 37).

The medium to which 0.5 µg PO4-p at/l is added the maximum growth constant recorded is 0.025^{hr-1} which is on the fourth day. The corresponding generation time of cells is 280 hours. The minimum growth constant of 0.009 k^{hr-1} recorded is on the fourteenth day (Fig. 38).

The medium with 1.0 µg PO4-p at/l records the highest growth constant (k^{hr-1}) of 0.03 µg PO4-P at/l on the second day. The corresponding generation time is 23.3 hrs. The lowest growth constant of 0.008^{hr-1} is recorded on the fourteenth day, the generation time being 87.5 hours.

Culture of Tetraselmis gracilis with 2.0 µg PO4-P at/l records the maximum growth constant of 0.03 (hr-1) on the second day the generation time being 23.3 hours. The lowest growth constant of 0.008 (hr-1) is recorded on the fourteenth day.

In culture with 3.0 µg PO4-P at/l the lowest generation time obtained is 29.2 hours which is on the fourth day. The corresponding

growth constant is 0.024^{hr-1}. The maximum time required for doubling the cells is 77.8 hrs. and the corresponding generation time is 0.009^{hr-1}.

The medium with 5.0 µg PO4-P at/l records the maximum growth constant (k^{hr-1}) of 0.036 on the second day the generation time (tg) being 19.4 hours. The lowest growth constant of 0.007 (hr^{-1}) is found on the fourteenth day with generation time of 100 hours.

The culture of Tetraselmis gracilis with 6.0 µg PO4-P at/l gives the maximum growth constant of 0.3^{hr-1} on the second day with the shortest generation time of 23.3 hrs. The lowest growth constant of 0.009 is recorded on tenth and fourteenth days. The corresponding generation time is 77.8 hrs.

In the culture with 10.0 µg PO4-P at/l the maximum growth constant recorded is 0.03^{hr-1} which is on the second day and the generation time is 23.3 hours. The minimum growth constant obtained is 0.006 (hr-1) which on the fourteenth day. The corresponding generation time is 116.6 hours.

Chlorophyll a

In the unenriched medium 35.0 hours is required for the doubling of the chlorophyll a on the second day. The lowest doubling time (generation time, tg) in media containing 0.5 µg, 1.0 µg, 2.0 µg, 3.0 µg, 5.0 µg, 6.0 µg, and 10.0 µg PO4-p at/l are 11.3, 10.9, 10.0,9.0,9.0, 10.9, and 8.8 hours respectively on the second day. The maximum generation time of chlorophyll a in respect of control media containing 0.50 µg, 1.0 µg, 2.0 µg, 3.0 µg, 5.0 µg, 6.0 µg, and 10.0 µg PO4-P at/l are 350.9, 77.8, 87.5, 87.5, 70.0, 63.6, 100.0 and 87.5 hours respectively (Table 26).

b. Influence of Nitrate.

Cell numbers:

The growth of Tetraselmis gracilis in varying concentration of nitrate are shown in Fig. 39. In the nutrient depleted sea water (control) tg of the alga, Tetraselmis gracilis is 26.9 hours (Table 28). The corresponding growth constant (k^{hr-1}) is 0.026. When it is two days old there is no increase in the growth constants upto the media containing 2.0 µg NO3-N at/l. In the medium containing 5.0 µg NO3-N at/l the doubling time of cells is 25.0 hours, the growth constant being 0.028^{hr-1}. In the medium containing 10.0 µgNO3-N at/l the generation time (tg) is reduced to 18.4 hours.

When it is four days old, considerable enhancement of growth as indicated by the growth constant is observed in the medium with 5.0 µg and 10.0 µg NO3-N at/l, where the growth constants are increased to 0.018 and 0.023^{hr-1} respectively, from 0.15^{hr-1} in the control.

Chlorophyll a:

The impact of NO3-N is more conspicuous in the doubling of the pigment chlorophyll a (Table 29). In the control when the culture is two days old the doubling time is 100.0 hours while it is 700 hours when it is nineteen days old and there onwards no doubling of chlorophyll a is observed (Fig. 40).

In the remaining media the increase of chlorophyll a continues even after nineteenth day unlike in control. In the medium with 2.0 µg and 5.0 µg NO3-N the doubling time of chlorophyll a is reduced to 41.2 hours. The lowest doubling time of chlorophyll a on second day is obtained in the culture with 10.0 µg NO3-N at/l.

The lowest generation time of chlorophyll a for the control and the media with 0.5 µg, 1.0 µg, 2.0 µg, 5.0 µg and 10.0 µg NO3-N at/l are 100.0, 100.0, 87.5, 41.2, 41.2 and 20.0 hours respectively (Table 25).

4. Growth constants and generation time of Thalassiosira subtilis and Synechocystis salina.

Thalassiosira subtilis, from an initial of 0.22×10^6 cells/l increases to 3.30×10^6 cells/l on the second day. The primary production, as measured by C^{14} uptake, from an initial concentration of 3.0 µg C/l/hr increases to 9.0 µg C/l/hr. On the fourth day the cell numbers are increased to 38.0×10^6 cells/l and the corresponding productivity is 1019.0 µg C/l/hr. On the sixth day the cell concentration is 55.0×10^6 cells/l and the productivity is 970 µg C/l/hr. On the eighth day the cell concentration is 120.0×10^6 cells/l and the productivity is 1000 µgC/l/hr. The tenth day records a cell concentration of 220×10^6 cells/l and the productivity is 1000 µg C/l/hr. The cell concentration, productivity, growth constants and generation time of Thalassiosira subtilis for a period of ten days is shown below.

Thalassiosira subtilis

Age in days	Cell concentration x 10^6 cells/l	Productivity µg C/l/hr	k^{hr-1}	(tg) hrs
0	0.22	3.0	-	-
2	3.30	9.0	0.056	12.5
4	38.00	1019.0	0.054	13.0
6	55.00	970.0	0.038	18.4
8	120.00	1000.0	0.033	21.2
10	220.00	1000.0	0.029	29.1

The initial concentration of Synechocystis salina is $0.5x10^6$ cells/l. It is increased to $5.0x10^6$ cells/l on the second day. The productivity as measured by C^{14} uptake is increased from 2.0 µg C/l/hr (initial) to 4.0 µg C/l/hr on the second day. On the fourth day the cell concentration is $28.0x10^6$ cell/l. The corresponding productivity is 15.0 µg C/l/hr. On the sixth day the culture registers cell concentration of $120.0x10^6$cells/l/hr with a productivity value of 81.0 µg C/l/hr. On the eighth day the cell numbers are $870.0x10^6$ cells/l and the production is 777.0 µg C/l/hr. The tenth day records cell concentration of $3300.0x10^6$ cells/l and productivity value of 1164.0 µg C/l/hr. The cell concentration, productivity, growth constants and generation time of Synechocystis salina for a period of ten days is given below:

Age in days	Cell numbers ($x10^6$ cells/l)	Productivity µg C/l/hr	K^{hr-1}	(tg) hrs
0	.51	2.0	-	-
2	5.0	4.0	0.048	14.6
4	28.0	15.0	0.042	16.7
6	120.0	81.0	0.038	18.4
8	870.0	770.0	0.039	17.9
10	3300.0	1164.0	0.037	18.9

TABLE - 25

GROWTH CONSTANTS AND GENERATION TIME OF TETRASELMIS GRACILIS

Age in days	Cell Counts		Chlorophyll a		C^{14} uptake		Average values from Cell Counts, Chlorophyll and C^{14} uptake	
	k^{-1}	tg (hrs)	k^{-1}	tg (hrs)	k^{-1}	tg (hrs)	k^{-1}	tg (hrs)
2	0.03	23.3	0.03	23.3	0.03	23.3	0.03	23.3
3	0.07	10.0	0.07	10.0	0.07	10.0	0.07	10.0
4	0.06	11.6	0.05	14.0	-	-	0.06	11.6
5	0.05	14.0	0.05	14.0	0.05	14.0	0.05	14.0
7	0.04	17.5	0.04	17.5	0.04	17.5	0.04	17.5
8	0.04	17.5	-	-	-	-	0.04	17.5
9	0.04	17.5	0.03	23.3	0.03	23.3	0.03	23.3
10	0.03	23.3	0.03	23.3	0.03	23.3	0.03	23.3
11	0.03	23.3	0.03	23.3	0.03	23.3	0.03	23.3
14	0.02	35.0	0.02	35.0	0.02	35.0	0.02	35.0
15	0.02	35.0	0.02	35.0	0.02	35.0	0.02	35.0
16	0.02	35.0	-	-	-	-	0.02	35.0
17	0.02	35.0	0.02	35.0	-	-	0.02	35.0
18	0.02	35.0	-	-	-	-	0.02	35.0
19	0.02	35.0	0.02	35.0	0.02	35.0	0.02	35.0
21	0.02	35.0	0.02	35.0	0.01	70.0	0.02	35.0
22	0.02	35.0	-	-	-	-	0.02	35.0
23	0.02	35.0	0.02	35.0	0.01	70.0	0.02	35.0
24	0.01	70.0	-	-	-	-	0.01	70.0
25	0.01	70.0	0.01	70.0	0.01	70.0	0.01	70.0
28	0.01	70.0	0.01	70.0	0.01	70.0	0.01	70.0
30	0.01	70.0	0.01	70.0	0.01	70.0	0.01	70.0
31	0.01	70.0	-	-	-	-	0.01	70.0
32	0.01	70.0	0.01	70.0	0.01	70.0	0.01	70.0
33	0.01	70.0	-	-	-	-	0.01	70.0
35	0.01	70.0	0.01	70.0	0.01	70.0	0.01	70.0

T A B L E 26

Influence of varying concentration of Phosphate (PO_4-P at/1) on Tetraselmis gracilis - cell numbers

Age in days	Unenriched		0.5 µg/1		1.0 µg/1		2.0 µg/1		3.0 µg/1		5.0 µg/1		6.0 µg/1		10.0 µg/1	
	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg (hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg (hrs)
2	0.021	33.3	0.021	33.3	0.03	23.3	0.03	23.3	0.021	33.3	0.036	19.4	0.03	23.3	0.03	23.3
4	0.026	26.9	0.025	28.0	0.022	31.8	0.024	29.2	0.024	29.2	0.024	29.2	0.025	28.0	0.022	31.8
6	0.016	43.8	0.02	35.0	0.019	36.8	0.019	36.8	0.018	38.9	0.019	36.8	0.02	35.0	0.02	35.0
8	0.012	58.3	0.012	58.3	0.012	58.3	0.012	58.3	0.012	58.3	0.012	58.3	0.013	53.8	0.013	53.8
10	0.009	77.8	0.012	58.3	0.013	53.8	0.01	70.0	0.012	58.3	0.01	70.0	0.009	77.8	0.01	70.0
14	0.008	87.5	0.009	77.8	0.008	87.5	0.008	87.5	0.009	77.8	0.007	100.0	0.009	77.8	0.006	116.6

T A B L E 27

Influence of varying concentrations of Phosphate (PO_4-P at/1) on Tetraselmis gracilis - Chlorophyll a

Age in days	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)
2	0.020	35.0	0.062	11.3	0.064	10.9	0.070	10.0	0.078	9.0	0.078	9.0	0.064	10.9	0.080	8.8
4	0.043	16.3	0.045	15.6	0.039	17.9	0.036	19.4	0.031	22.6	0.031	22.6	0.035	20.0	0.036	19.4
6	0.019	36.8	0.023	30.4	0.018	38.9	0.023	30.4	0.016	43.8	0.010	70.0	0.016	43.8	0.018	38.9
8	0.011	63.6	0.013	53.8	0.014	50.0	0.014	50.0	0.016	43.8	0.015	46.7	0.014	50.0	0.012	58.3
10	0.011	63.6	0.010	70.0	0.010	70.0	0.010	70.0	-	-	0.006	116.6	0.010	70.0	0.011	63.6
14	0.009	77.8	0.009	77.8	0.008	87.5	0.008	87.5	0.010	70.0	0.011	63.6	0.007	100.0	0.008	87.5
16	0.002	350.0	-	-	0.008	87.5	0.008	87.5	0.008	87.5	0.007	100.0	0.004	175.0	0.008	116.6

T A B L E 28

Influence of varying concentrations of Nitrate (NO_3-N at/1) on Tetraselmis gracilis - Cell numbers

Age in days	Unenriched		0.5 µg		1.0 µg		2.0 µg		5.0 µg		10.0 µg	
	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)
2	0.026	26.9	0.023	30.4	0.020	35.0	0.026	26.9	0.028	25.0	0.038	18.4
4	0.015	46.7	0.013	53.8	0.017	41.1	0.015	46.7	0.018	38.9	0.023	30.4
6	0.011	63.6	0.07	100.0	0.01	70.0	0.011	63.6	0.016	43.8	0.018	38.9
8	0.007	100.0	0.008	87.5	0.009	77.8	0.009	77.8	0.007	100.0	0.013	53.8
11	0.001	700.0	0.003	233.3	0.006	116.6	0.006	116.6	0.008	87.5	0.008	87.5
14	0.005	140.0	0.006	116.6	0.005	140.0	0.006	116.6	0.006	116.6	0.006	116.6
16	0.002	350.0	0.005	140.0	0.005	140.0	0.005	140.0	0.005	140.0	0.006	116.6
19	0.002	350.0	0.004	175.0	0.004	175.0	0.004	175.0	0.004	175.0	0.004	175.0
20	0.003	233.3	0.004	175.0	0.003	233.3	0.004	175.0	0.004	175.0	0.004	175.0
22	0.003	233.3	0.004	175.0	0.003	233.3	0.003	233.3	0.003	233.3	0.004	175.0
24	0.002	350.0	0.003	233.3	0.002	116.6	0.002	350.0	0.003	233.3	0.003	233.3

TABLE 29

Influence of varying concentrations of Nitrate (NO_3-N at/1) on Tetraselmis gracilis - chlorophyll a

Age in days	Unenriched		0.5 µg		1.0 µg		2.0 µg		5.0 µg		10.0 µg	
	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)	k^{hr-1}	tg(hrs)
2	0.007	100.0	0.007	100.0	0.007	100.0	0.017	41.2	0.017	41.2	0.035	20.0
4	0.003	233.3	0.003	233.3	0.008	87.5	0.008	87.5	0.017	41.2	0.019	36.8
6	0.005	140.0	0.005	140.0	0.005	140.0	0.008	87.5	0.011	63.6	0.014	50.0
8	0.004	175.0	0.006	116.7	0.004	175.0	0.007	100.0	0.008	87.5	0.013	53.8
11	0.003	233.3	0.004	175.0	0.006	116.7	0.007	100.0	0.008	87.5	0.010	70.0
12	0.004	175.0	0.005	140.0	0.005	140.0	0.006	116.7	0.008	87.5	0.008	87.5
14	0.003	233.3	0.005	140.0	0.005	140.0	0.005	140.0	0.007	100.0	0.007	100.0
16	0.002	350.0	0.004	175.0	0.004	175.0	0.004	175.0	0.007	100.0	0.006	116.7
19	0.001	700.0	0.004	175.0	0.002	350.0	0.003	233.3	0.005	140.0	0.005	140.0
20	-	-	0.004	175.0	0.002	350.0	0.002	350.0	0.004	175.0	0.004	175.0
22	-	-	0.004	175.0	0.001	700.0	0.001	700.0	0.004	175.0	0.004	175.0
24	-	-	0.003	233.3	0.001	700.0	0.001	700.0	0.003	233.3	0.003	233.3

5. Impact of trace elements on growth constants and generation time of Synechocystis salina.

a. Impact of Copper:

Age (hrs)	Control			0.05 ppm(Cu)			0.10 ppm(Cu)		
	Cells/l ($x 10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)
0	0.13	--	--	0.13	--	--	0.13	--	--
24	0.14	.0029	241.4	0.12	--	--	0.10	--	--
72	0.18	.0044	159.1	0.14	.0009	777.8	0.10	--	--
120	0.25	.0054	129.6	0.15	.0012	583.3	0.11	--	--
144	0.26	.0047	148.9	0.16	.0014	500.0	0.12	--	--
168	0.35	.0058	120.7	0.15	.0008	875.0	0.12	--	--
192	0.40	.0058	120.7	0.18	.0016	437.5	0.14	--	--
240	0.30	.0034	205.9	0.12	--	--	0.10	--	--
288	0.20	.0014	500.0	0.10	--	--	0.10	--	--

Results of experiments with 0.05 ppm and 0.1 ppm copper are presented in the above table. When copper at 0.05 ppm is found to inhibit the growth to some extent, at 0.1 ppm it is found to be lethal to the alga Synechocystis salina. Even at 0.05 ppm during the first 24 hours no growth is observed. On the third day the cell concentration is $0.14x10^6$/l as against $0.18x10^6$/l in the control. The growth constant and generation time in the control are 0.0044 k^{hr-1} and 159.1 hrs respectively. At 0.05 ppm of the heavy metal the growth constant is reduced to 0.0009^{hr-1} and generation time is increased to 777.8 hrs. On the fifth day the cell concentration in the control is $0.25x10^6$ cells/l. The

growth constant is 0.0054^{hr-1} and generation time is 129.6 hrs. At 0.05 ppm concentration of Cu the cell concentration is $0.15x10^6$ cells/l, the growth constant is 0.0012^{hr-1} and generation time is 583.3 hrs. On the sixth day for the control the cell concentration is $0.26x10^6$ cells/l, the growth constant is 0.0047^{hr-1} and the generation time is 148.9 hrs. For 0.05 ppm the values are $0.16x10^6$ cells/l, 0.008^{hrs-1} and 875 hrs respectively. On the seventh day, for the control, the cell concentration is $0.35x10^6$ cells/l, the growth constant (k) is 0.0058^{hr-1} and the generation time (tg) is 120.7 hrs. The corresponding values for 0.05 ppm are $0.15x10^6$ cells/l, 0.0008^{hr-1} and 875 hrs respectively. On the eighth day for the control the cell concentration, growth constant and generation time are $0.40x10^6$ cells/l, 0.0058^{hr-1} and 120.7 hrs respectively. The corresponding value for 0.05 ppm are $0.18x10^6$ cells/l, 0.0016^{hr-1} and 437.5 hrs. On the tenth and twelth days when the cells in control are still growing, in the culture containing 0.05 ppm of Cu., the cells had already entered the phase of degeneration.

b. Impact of Mercury:

Age	Control			0.05 ppm (Hg)			0.10 ppm (Hg)		
(hrs)	Cells/l ($x10^6$)	k^{hr-1}	t_g (hrs)	Cells/l ($x10^6$)	k^{hr-1}	t_g (hrs)	Cells/l ($x10^6$)	k^{hr-1}	t_g (hrs)
0	0.19	--	--	0.19	--	--	0.19	--	--
24	0.19	--	--	0.185	--	--	0.18	--	--
72	0.26	.0043	162.8	0.20	.0007	1000.0	0.19	--	--
120	0.35	.0051	140.0	0.28	.0032	218.7	0.25	.0022	318.1
168	0.48	.0055	127.3	0.38	.0041	170.7	0.34	.0035	200.0
192	0.48	.0048	145.8	--	--	--	0.36	.0033	212.1
216	0.47	.0042	166.7	0.38	.0032	218.7	0.34	.0027	259.2
240	0.45	.0036	194.4	--	--	--	0.30	.0019	368.4
288	0.40	.0036	269.2	0.33	.0020	350.0	0.30	.0016	437.5

Results of experiment with 0.05 ppm and 0.1 ppm mercury are presented in the above table. In the control from an initial concentration of $0.19x10^6$/l, the cells have attained a maximum concentration of $0.48x10^6$/l on seventh day, the growth constant and generation time being 0.0055^{hr-1} and 127.3 hrs respectively. This is the maximum growth constant and minimum generation time recorded for the control. The maximum growth constant recorded for 0.05 ppm Hg, is only 0.041^{hr-1} the generation time (tg) being 170.7 hrs. The maximum growth constant (k^{hr-1}) for 0.10 ppm Hg, is only 0.0035, the corresponding generation time being 200 hours.

c. Impact of Zinc:

Results of experiment with 0.05 ppm and 0.1 ppm zinc are presented in the table below:

Age	Control			0.05 ppm (Zn)			0.10 ppm (Zn)		
(hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)
0	0.19	--	--	0.19	--	--	0.19	--	--
24	0.24	.002	350.0	0.195	.0008	875.0	0.17	--	--
72	0.28	.0053	132.0	0.24	.0032	218.7	--	--	--
120	0.39	.006	116.6	0.30	.0038	184.2	0.28	.0032	218.1
168	0.48	.0055	127.3	0.40	.0044	159.0	0.37	.0039	179.5
216	0.48	.0043	162.8	0.43	.0038	184.2	0.40	.0034	205.9
240	0.45	.0036	194.4	0.42	.0033	212.1	0.39	.003	233.3
288	0.43	.0028	250.0	0.39	.0025	280.0	0.38	.0024	291.7

In the control from an initial concentration of $0.19x10^6$ the cells have attained the maximum concentration of $0.48x10^6$ cells/l on the seventh day. The maximum growth constant (k^{hr-1}) of 0.006 recorded is on the fifth day and the corresponding generation time is 116.6 hrs. The maximum cell concentration, for 0.05 ppm Zn, is $43x10^6$ cells/l which is recorded on the ninth day. The maximum growth constant recorded for 0.05 ppm Zn is 0.044^{hr-1} which is on the seventh day. The corresponding generation time is 159.0 hrs. The maximum cell numbers attained for 0.1 ppm Zn is $0.4x10^6$ cells/l which is also on the ninth day.

d. Impact of Lead:

Results of experiments with 0.05 ppm and 0.1 ppm are presented below:

Age	Control			0.05 ppm(pb)			0.10 ppm (pb)		
Hrs	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)	Cells/l ($x10^6$)	k^{hr-1}	tg (hrs)
0	0.23			0.23			0.23	--	--
24	0.23	--	--	0.22	--	--	0.20	--	--
48	0.24	0.0008	875	0.22	--	--	--	--	--
72	0.24	0.0005	1400	0.20	--	--	0.15	--	--
96	0.245	0.0006	1166	--	--	--	--	--	--
120	0.25	0.0007	1000	0.16	--	--	0.10	--	--
144	0.30	0.0018	388.9	0.17	--	--	0.09	--	--
192	0.50	0.0040	175.0	0.17	--	--	0.08	--	--
240	0.55	0.0036	194.4	0.18	--	--	0.08	--	--
288	0.48	0.0025	280.0	0.15	--	--	0.08	--	--
336	0.40	0.0016	437.5	0.15	--	--	0.08	--	--

Synechocystis salina in the control gives the maximum growth constant of 0.004^{hr-1} on eighth day with the corresponding shortest generation time of 175.0 hrs. With both 0.05 ppm and 0.1 ppm of Pb, the algae do not show any sign of growth. In both the cases the degeneration of cells starts within the first twentyfour hours which shows that Pb at these concentrations is lethal to the species.

DISCUSSION

The alga Tetraselmis gracilis is a tetraflagellate of the order Pyramimonadales in the class Prasinophyceae (Stewart, 1974, Raymont, 1980). This nanoplankton of about 6 um in diameter forms one of the dominant flora in the Cochin estuary and inshore waters of the southwest coast of India. In the present study on algal plankton, this species is recorded in the above ecosystems in considerably large numbers. In the estuary, during the month of February, their density of population is 3.21×10^5 cells^{l-1} and in March they are 3.10×10^5 cells^{l-1}. In coastal waters during June their concentration is 4.1×10^4 cells^{l-1}. The presence of this species in both the environments in considerable numbers justify its selection for isolation and subsequent experiments.

Miquel's medium as modified by Ketchum and Redfield bas been used for culturing the flora. The medium taken in Erlenmayer's flask of three litre capacity is inoculated with sufficiently large quantity of actively dividing cells as to have an initial concentration of 200,000 cells^{l-1}.

The inoculam collected is from the exponentially growing parent culture. On inoculation the cells started growing immediately resulting in a five-fold increase after 48 hours. Thus the culture from its initial concentration of $.02 \times 10^7$ cells^{l-1} has attained the concentration of 0.1×10^7 cells^{l-1} on the second day. In fact there is no conspicuous lag phase either apparent or real. The growth rate expressed by the measure of growth ie., growth constant k^{-1} is 0.03 which is about half of the

average k^{-1} value of the subsequent 3 days (Table 25). Hence all the cells inoculated are viable as they are collected from the exponentially growing culture and hence there is no possibility of having apparent lag phase due to the presence of nonviable cells in the inoculum. If the non viable cells are present the cell numbers will then remain stationary until the viable cells more or less reach the number equal to the total inoculated. The active exponential phase really starts on the third day when the generation time is only 10 hours (Fig. 41), the shortest time recorded coupled with maximum growth constant of 0.07^{hr-1} (Fig. 42). The duration of the lag phase or even its presence or absence is mainly dependent on the physiological state of the inoculum and the extent of variation of the fresh medium with respect to the original one from which the inoculum is collected. It was observed in Anabaena cylindrica (Fogg, 1944) in Phaeodactylum tricornutum (Nitzschia closterium forma minutissima) (Spencer, 1954) that the length of the lag phase was dependent on the age of the inoculum, diminishing as this entered the exponential phase of growth being zero if the inoculum had been growing exponentially then increasing according to the duration of the stationary phase. Gerloff, et al., (1950) observed that sufficiently large inoculum is required for establishing certain cultures of planktonic blue green algae. In the present experiment sufficient number of exponentially growing cells are inoculated in natural sea water enriched with nutrients and incubated at a light intensity of 20 k.lux. Under these optimum conditions the cells have started multiplying exponentially, apparently eliminating the lag phase.

The active exponential phase really starts on the third day when the generation time is only 10 hours which is the shortest time recorded. Here the measure of growth expressed as growth constant^{k-1} is 0.07 which is the maximum on this day and the total number of cells are $3.0x10^7$ cells^{l-1}. The second day of the exponential phase showed a growth constant of 0.055 and the generation time is 12.7 hours. The cells number has increased to $4.0x10^7$ cells^{l-1} which by the next 24 hours, has increased to $10.0x10^7$ cells^{l-1}. On the fifth day of inoculation the growth constant is 0.052 which shows a tendency of gradual decline from those of the early stage of the exponential phase. During this phase all the parameters are also at optimum level.

A conspicuous decline in the growth rate is observed from seventh to tenth days inspite of the increase in cell numbers. The doubling time of cells has increased from the minimum observed value of 10 hours in the early part of exponential phase to about 22.0 hours in the later part of the stationary phase. On the seventh day at the beginning of the stationary phase the cell concentration is $33x10^7$ cells^{l-1}. The growth constant k^{-1} is 0.044 and the generation time is 16 hours. On the 8th daywhich happens to be the second day of the stationary phase, the density of the population should have been more than that on the previous day as the growth has taken place, though at a lower rate as indicated by the growth constant of 0.038 and the generation time of 18.4 hours. On the 9th day the density of the culture is increased to $37 x10^7$ cells$^{l=1}$ with a growth constant of 0.035 and generation time of 20 hours. The next day in the declining phase growth constant k^{-1} shows a slight decline

from 0.035 to 0.032 and the generation time has increased to 22 hours. On the eleventh day too this conspicuous declining trend is evident. This is due to the overcrowding of cells resulting in mutual shading.

From an intial concentration of only 200000 cells ml^{-1} the cells have increased very much recording 33 $x10^7$ l^{-1} on the seventh day. Though this culture is exposed to light intensity of 20 k.lux. due to overcrowding the cells are shaded mutually. Due to this mutual shading the effective illumination per cell may be below optimum for the total metabolism leading to cell synthesis. With the increase in population more nutrients are utilized resulting in the depletion of nutrients and retardation in growth rate.

Though the factor of increase generally exhibits a decreasing trend throughout, there appears a phase from 14th day onwards with almost constant values. This phase may be designated as stationary phase. When the cell numbers are $44x10^7$ $cells^{l-1}$ on 14th day the growth constant k^{-1} is 0.023 and the generation time is 30.4. Next day the cell concentration has increased to 49 $x10^7$ .l-1 with a growth constant hr^{-1} of 0.022 and generation time (tg) of 31.8 hrs. From 16th to 19th the cell concentrations are 52 $x10^7$, $60x10^7$, 74 $x10^7$ and 76 $x10^7$ with growth constants of 0.02, 0.02, 0.019, 0.018 respectively which represents a more or less stationary phase. The corresponding generation time (tg) too does not exhibit wide fluctuation, the values being 35.0, 35.0, 36.8 and 38.9 hours respectively. From 21st to 23rd day the density of population per ml is $77x10^7$, $73x10^7$ and 73 $x10^7$ cells. The growth constant k^{-1} for these days are 0.016, 0.016 and 0.015 and generation time 43.8, 43.8 and 46.7 hours.

From 14th to 23rd the growth constants have been more or less constant ie., 0.02^{hr-1} irrespective of the gradual decrease of cell number this phase can be designated as the stationery phase with the generation time of 35 hours. The population density during these days fluctuates from $4{\cdot}4x10^{7}$ $cells^{l-1}$ on 14th day to $7{\cdot}3x10^{7}$ $cells^{l-1}$ on the 23rd day.

From 24th day onwards the growth rate is found to be considerably decreased requiring much more time for doubling the cells. This phase leads to the elimination or death of the cells due to the extreme overcrowding of the cells ultimately causing the depletion of nutrients and non availability of light energy for cell synthesis. These limiting factors check further growth of the algae. The cell numbers vary from $7{\cdot}3x10^{7}$ $cells^{l-1}$ on 24th day to $9{\cdot}7x10^{7}$ $cells^{l-1}$ on 35th day. During the period the growth constant k^{-1} values are found to be 0.01 with a corresponding generations time (tg) of 70 hours.

The chloroplasts in this Prasinophycean algae appear green and contain chlorophyll a and b as in the case of Chlorophycean algae. Of other pigments, β-carotene is important; with some α-carotene; Boney (1970) describes a protochlorophyll like pigment also in Prasinophyceae. Riley and Wilson (1965, 1967) and Riley and Segar (1969) confirmed in general that the carotenoid composition resembled that of Chlorophyceae, with lutein as the chief xanthophyll and with minor amounts of neoxanthin and violaxanthin. Similar to Chlorophycean algae in this Prasinophycean Tetraselmis gracilis chlorophyll a forms the major pigment and b forms only a minor component Table24gives chlorophyll a (μg) and production (μgC) with the age of culture. As chlorophyll content is an index of the photosynthetic potential its increase represents the multiplication and growth of the algae, simultaneous measurements of cell counts,

chlorophyll a and b and productivity measurements by C^{14} and oxygen methods are used. Chlorophyll a and chlorophyll b per litre show progressive increase along with the cell numbers. But the productivity values do not always record such a direct relationship with either the cell numbers or the chlorophyll. Chlorophyll a per litre shows a progressive increase from an initial concentration of 0.52 μg^{l-1} with cell concentration of $0.02x10^7$ $cells^{l-1}$ to 3017.20 μg^{l-1} with a cell concentration of $90x10^7$ $cells^{l-1}$ on 30th day. Corresponding values of chlorophyll 'b' is 0.022 mg^{l-1} initially and 1183.76 mg^{l-1} on the 30th day. All the three parameters are found to have direct relationship and act as complimentary to each other. Thus for the first 48 hours the cell numbers, chlorophyll and C^{14} uptake show lag in doubling. The cell counts, chlorophyll a and production values are found to have a five fold increase. Thus cell counts have increased from $0.02x10^7$ to $0.1x10^7$ $cells^{l-1}$. Corresponding increase of chlorophyll a is from 0.052 to 2.61 μg^{l-1} and the net production is from 0.1 to 0.7 mg C^{l-1} hr-1. On the third day too this direct relationship among the three parameters, is observed. The cell numbers are $3x10^7$, chlorophyll a concentration is 64.62 µg/l and the net production is 20.0 µg C/l/hr. Hence the increase uniformly is about thirty times. The cell numbers have increased by $2.90x10^{7l-1}$ and the chlorophyll to by 62.01 μg^{l-1} and production by 13.0 ug C/l/hr. Here also a direct relationship is observed as evidenced by the proportionate increase in their values. Such an increasing trend, in an exponential manner is found for 3 to 9 days. From 10th to 11th day there is slight decline in the growth of the culture as indicated by the cell numbers, Chlorophyll a concentration and primary production. On seventh day

the cell concentration is $33x10^7$ $cells^{l-1}$ the chlorophyll a is $548.88/m^{l=1}$ and the net production is 13 mg C/l/hr.

During the next 48 hours the cells have increased by $4.00x10^7$ $cells^{l-1}$ the chlorophyll a by 219.48 μg^{l-1} and the net production by 68.0 µg C/l/hr. Though there is increase in the cell number, chlorophyll concentration and primary production a decline in the rate of increase is observed. Next day too this declining trend is noticed in the increase of cell numbers. The production has infact gone down to 169.0 µg C/l/hr from 196 µg C/l/hr on the previous day.

Considerable increase in cell concentration, or chlorophyll or production is not observed from 14th day onwards announcing the onset of a stationary phase. On 14th day of cell numbers recorded are $44x10^7$ $cells^{l-1}$ and the growth constants recorded is 0.02 and the generation time (Table 25) is 35 hours. Though the cells have increased to $49x10^7$ $cells^{l-1}$ on the next day with the net increase of $5.00x10^7$ $cells^{l-1}$ the doubling of cell takes place only at the same rate as that on the previous day. This rate remains stationary till 23rd day thus demarcating a stationary phase for ten days towards the end of which the cell concentration is found to be $73x10^7$ l^{-1}. In respect of chlorophyll a also the stationary phase starts on the 14th day with the same growth constant k^{-1} value of 0.02 and generation time (tg) of 35 hours. The chlorophyll 'a' concentration recorded on 14th day is 1358.20 µg/l. The concentration has increased to 1529.52 μg^{l-1} with a net increase of 171.32 μg^{l-1} by 24 hours. For the doubling of chlorophyll 'a' the time required is 35 hours and the measure of growth in terms of growth $constant^{k-1}$ is 0.02 and these values of k^{-1} & tg remained same for 10 days ie., upto

23rd day when the chlorophyll 'a' concentration obtained is 2321.72 μg^{l-1}. Production rates too showed this same trend The net production on the 14th day is 253.0 $\mu g\ C^{l-hr}$. The rate of increase of production and the doubling time are found to be stationary only for 6 days ie. upto 19th day and increase the production shows considerable decrease in the rate. There is reduction in the growth rate.Thus though the stationary phase starts on the same day with the same growth constants and generation time the duration of the phase is different as far as the production is concerned. The abrupt fall in the production rate may be due to the depletion of the nutrients in the medium. Besides due to the mutual shading as a result of the overcrowding the effective illumination per cell may be below optimum. Hence inspite of having large cell numbers with enough photosynthetic pigment the rate of photosynthesis is very much retarded so as to commence as early death phase with respect to the production.

The cell numbers show considerable fall in the growth rate from 24th onwards as indicated by the growth constant k^{-1} of 0.01 which is only just half of that on the previous day. The generation time also is consequently doubled as that of the previous day and it takes 70 hrs for the doubling of the cell. This extremely slow rate of multiplication of cells is found to be prolonged till the end of the experiment. On the 24th day the cell concentration is 73.0×10^7 $cells^{l-1}$. The growth constant k^{-1} of 0.01 is only just half of that recorded on the 23rd the last day of the stationary phase. So also it takes double the time for doubling compared to the previous stage, during this period of stunted growth

rather death phase. Towards the end of the stationary phase chlorophyll a concentration is 2321.72 μg^{1-1}. At the beginning of the death phase it's concentration is 2363.40 μg^{1-1}. But the rate of increase is found to be less as indicated by k^{-1} and tg values calculated from chlorophyll a concentration.

The chlorophyll a concentration for 10^7 cells is found to vary from 16.63 µg on the 5th day in the exponential phase to 33.5 µg on the 30th day in the comparatively inactive phase. The average chlorophyll a value in the first two days is 26.0 µg per 10^7 cells, 19.0 µg during the exponential phase 23 µg in the declining phase, 30.0 µg in the stationary phase and 3.20 µg in the last phase. Chlorophyll b too shows the same trend and its corresponding concentration per 10^7 cells are 10.8 µg, 8.8 µg, 10 µg, 11 µg and 12 µg respectively. The minimum value of chlorophyll b recorded per the unit number of cells is 8.2 µg which is during the exponential phase and its maximum value of 13.2 µg recorded is during the death phase. The average value of chlorophyll a, and chlorophyll b for the whole duration of the experiment are 26.06 µg, 10.6 µg respectively.

In green algae though light is absorbed by chlorophyll a and b, chlorophyll a is the only pigment which can transform light energy directly to chemically bound energy. Light energy absorbed by other pigments are converted via. chlorophyll a (Rabinowitch, 1951). In Tetraselmis gracilis the ratio of chlorophyll a and chlorophyll b is the same since the chlorophyll composition is similar to that of Chlorophyceae. The ratio or chlorophyll b to chlorophyll a varies with the growth phase of the culture. In the exponential and declining phases chlorophyll b occurs

only in 1:2.4 ratio with that of chlorophyll a. But with the advent of the stationary phase with respect to cell numbers chlorophyll concentration and primary production the chlorophyll b concentration per unit number of cells is decreased and chlorophyll a is found to be increased as indicated by the b to a ratio of 1:2.9 on 15th day 1 : 3 on 19th day and so on. On the 35th day the chlorophyll a per $1x10^7$ cells is 32.1 ug and chlorophyll b per the same unit number of cells 10.8 giving a 1 : 3 ratio.

It may be pointed out that in nature concentation of chlorophyll per unit volume of water for the upper part of the euphotic zone vary throughout the day more or less in accordance with the variation in the rate of potential photosynthesis. This phenomenon is observed even in bodies of water enclosed in bags also (Yentsch and Ryther - 1957). The variation in the chlorophyll concentration in culture can be attributed to the multiplication, growth and subsequent decline in the cell.

The gross production in terms of carbon values per litre per hour ranges from an initial value of 0.0002 µg/C/l to 0.335 µg C/l/hr on the 19th day. There is an insignificant lag in the beginning when the production increases slowly from an initial productivity of 0.0002mg C/l/hr to 0.001 mg C/l/hr by two days.

The measure of metabolism leading to production in terms of growth constants k and the time required for doubling the production in terms of generation time (tg) have been measured. In the first two days the growth constant is 0.03. The process of production is comparatively slow and taking place almost at the same speed as that is taking place in the declining phase as indicated. There is an active exponential phase from 3rd to 7th day where the growth constants are 0.07, 0.06, 0.05 and 0.04 and the corresponding growth time are 10.0, 11.6, 14.0 and 17.5 hours. The highest growth constant is 0.07 with the shortest

generation time tg of 10 hours. The identical value of k and tg with respect to cell numbers and chlorophyll concentration indicate that these are directly proportionate under the optimum conditions. From 9th to 11th the rate of production shows a decreasing trend and the growth constant in 0.03 with a generation time of 23.3 hours. From 14th to 19th the growth constant (k) of 0.02 is stationary from 21st onwards the production rate is very much decreased with growth constant of only 0.01 depicting a death phase.

The carbon values per litre per hour ranges from 0.07 to 0.79 (gross production) by the oxygen technique and the corresponding net production values 0.032 and 0.598 mg C/l/hr. The production values calculated from oxygen technique shows the same trend as that of C^{14} technique. C^{14} technique registered lower values constantly in all the observations. In most of the observation it is about 50%. The difference may be the comulative effect of various factors such as possible higher PQ of the cultures, secretion of labelled carbohydrate in dissolved form, or rupture of fragile membrane during filtration. The percentage of extracellular products varies from 1 to 20% (Samuel et al., 1971). For the estimation of absolute value of production of fragile cultures of flagellate like Tetraselmis gracilis necessary correction is to be applied for extra cellular products. Net production values given in Table 24 arecomputed using empirical formula given by Steemann Nielsen (1964). The respiration rate has been observed to be about 30%. For short term experiments this rate of higher utilization of photozynthetic products by Tetraselmis gracilis compared to other algal plankton such as diatoms

cannot also be discounted since Tetraselmis gracilis cells are motile. Hence the application of a constant arbitrarily in order to derive net production in areas where such nanoplankters abound would naturally renders the values of net production an over estimation.

One of the simple approaches to study the growth of unialgal cultures is by determining the growth constant and generation time (tg). The experimental populations show an initial lag phase in growth followed by a vigorous logarithmic growth phase and finally a decline in growth introduced as a result of depletion of nutrients or trace elements. Growth constant (k) is a measure of total metabolism of the algae and the mean generation time (tg) is the average time taken for the cells to divide.

Growth constants (k) and generation time (tg) vary with species. For Chlorella pyrenoidosa the relative growth constant (k) in continuous light intensities approximately saturating, for photosynthesis is 0.12 at $10^{o}C$ (Fogg and Belcher, 1961). For the diatom Asterionella japonica the growth constant recorded is 0.52 in continuous light intensities approximately saturating for photosynthesis at $20-25^{o}C$ (Kain and Fogg, 1960).

The intial concentration of PO4-P in the medium is 0.05 µg at/l. In the control the highest k^{hr-1} and the lowest tg (hours) are 0.026 and 26.9 respectively (Fig. 31 & 32). With 1 µg PO4-P at./l growth constant k is increased to 0.03^{hr-1} and the generation time of cells is reduced to 23 hours. A further increase in the growth constant k (0.036^{hr-1}) and a reduction in generation time (19 hours) is observed with 5.0 µg PO4-P at/l. Further addition of PO4-P does not enhance the growth rate of Tetraselmis gracilis significantly (Table 27). The impact of enrichment of phosphate (PO4-P) is more conspiciuous in the chlorophyll

concentration. This is understood by comparing the highest k^{hr-1} and lowest tg. The sum total of metabolic activities leading to chlorophyll synthesis is enhanced by enrichment of phosphate as indicated by the increase in growth constant and decrease in the generation time. In the unenriched medium the highest growth constant is 0.043 hr^{-1} and the corresponding generation time is 16.3 hours (Fig. 33). With 0.50 µg PO4-P at the maximum growth constant is increased to $0.062^{hr=1}$ and the generation time is 11.3 hrs. A further enhancement in the metabolic activities leading to chlorophyll synthesis is observed with 1 µg PO4-P at/l. Here the growth constant is 0.06^{hr-1} and the generation time is 10.9 hours. The culture with 2.0 µg PO4-P at/l shows a further enhancement in the growth constant. Hence the growth constant is $0.070^{(hr-1)}$ and the lowest generation time of 10.0 hours on second day. With higher concentrations increase in the growth constants and decrease in the generation time is observed. With 10 µg PO4-P at/l the doubling time of chlorophyll is only 8.8 hours and the corresponding growth constant is 0.08^{hr-1}.

In the present study the growth constants and generation times of Tetraselmis gracilis at various phases of growth, in varying concentrations of nitrate are discussed (Fig. 34).

Initial concentration of nitrate nitrogen present in the medium is 0.076 µg at/l. This when enriched with varying concentrations of nitrate gives high growth constant and low generation time. In the control, the highest growth constant and corresponding shortest generation time are 0.026^{hr-1} and 26.9 hours (Fig. 35 & 36). But the culture with 5.0 µg NO3-N at/l showed a slight increase in the growth constant and decrease in the generation time their values being 0.028^{hr-1} and 25.0

hours. In the culture with 10.0 µg NO3-N at/l the growth constant (k^{hr-1}) is increased to 0.038 and the generation time (tg) is decreased to 18.4 hours.

The enrichment of the culture with varying concentrations of nitrate is found to have profound influence on the metabolism leading to chlorophyll synthesis. This is understood by analysing the doubling time of chlorophyll. On the second day, in the unenriched medium and also with 0.50 µg and 1.0 µg NO3-N at/l the doubling time for chlorophyll is 100 hours, the growth constant being 0.007^{hr-1}. With 5.0 ug NO3-N at/l the doubling time for chlorophyll is reduced to 41.2 hours. The corresponding growth constant is 0.017^{hr-1}. With 10.0 µg at/l the doubling time is reduced to 20 hours the growth constant being 0.035^{hr-1}. Lack of adequate concentration of nitrate curtails the log phase, retards the metabolic process leading to synthesis of chlorophyll and primary food and sooner the cells enter the death phase. In the unenriched medium the synthesis of chlorophyll does not proceeed beyond nineteenth day, when the generation time is 700 hrs. With higher concentrations, the growth and synthesis of chlorophyll continues till the end of the experiment (24 days). With high concentrations of 5.0 µg and 10.0 µg NO3-N at/l the tg for chlorophyll was 233.3 hours at the end of the experimental period.

The shortest generation time (tg) recorded by Thalassiosira subtilis is 12.5 hours which is on the second day. The corresponding growth constant (k^{hr-1}) is 0.056. As the age of the culture advances the growth constants decrease. Due to the over crowding of the cells the effective illumination available per each cell will be below optimum; the nutrients get depleted, and consequently the generation time shows a progressive

increase. Thus on the tenth day the generation time is 29.1 hours the corresponding growth constant being 0.029^{hr-1}. The primary production per unit number of cells is more in the beginning than that at the end.

Synechochystis salina from an initial concentration of 0.51×10^6 cells/l reaches 3300.0×10^6 on the tenth day. The highest growth constant of 0.048^{hr-1} is recorded when the culture is two days old. The generation time of cells then is 14.6 hours. As the cell number increases, growth constants are found to decrease. This is due to the depletion of nutrients and the absence of adequate effective illumination.

The growth constant of algae in eutrophic environment under optimum conditions is as high as 0.06. The generation time for a Chlorophycean flagellate Dunaliella euchlora is 12 hours indicating a growth constant of 0.06 (Mc Leod, 1957). k value for warm waters will be several times greater than temperature waters (Wood, 1958). For temperate waters k for natural phytoplankton population has been estimated as 0.035 (Harvey, 1953).

Different experiments with fresh water and marine algae revealed that the toxic sequence of heavy metals varies from one to the other taxonomic group or even from species to species (Rosko and Rachlin 1975, 1977, Fisher and Frood 1980, Rachlin et al. 1982,a,b, 1983, 1984). It is also noted that the toxicity of a metal is determined by the form in which the metal ions are present, free or chelated (Steemann Nielsen and Wium Anderson 1970). Larry et al. (1986) found that the major trend phytoplankton in their resistance to copper toxicity was a phylogenetic one, with Cyanobacteria being the most sensitive, diatoms the least sensitive and coccolithophores and dinoflagellates intermediate in sensitivity.

The effect of four potentially toxic heavy metals viz. Cu, Hg, Zn and Pb on the growth constant, and generation time of the blue green alga Synechocystis salina is studied at two different concentrations of each metal. It is observed that the rate of toxicity is proportional to the added metal concentrations. With 0.05 ppm Cu the cells require more doubling time. The cells enter the death phase much earlier than that in the control. 0.10 ppm Cu is found to be lethal to the alga.

Mercury at both 0.05 ppm and 0.1 ppm concentration inhibits the metabolic processes leading to cell synthesis. Consequently the growth constant is decreased and the generation time is increased. This is easily uderstood by comparing the growth constants and generation time at the end of the experiment. In the control when the growth constant is 0.0036^{hr-1}, it is 0.0020^{hr-1} with 0.05 ppm (Hg) and 0.0016^{hr-1} with 0.10 ppm (Hg), the corresponding generation time being 269.2 hours 350.0 hours and 437.5 hours respectively.

The doubling time increases with the increase of zinc concentration. The lowest generation time observed in the control is 116.6 hours, with 0.05 ppm (Zn) it is 159.0 hours and with 0.1 ppm (Zn) the lowest generation time is 179.5 hours. The corresponding growth constants for the control, with 0.05 ppm (Zn) and with 0.1 ppm (Zn) are 0.006^{hr-1}, 0.0044^{hr-1} and 0.0039^{hr-1} respectively.

Lead, at both the concentrations tested, is found to be lethal as the cells in both cases are found to decay. At the end of the experiment i.e. on the fourteenth day when the cell concentration of the control is 0.40×10^6 cells/l, it is 0.15×10^6 cells/l with 0.05 ppm (Pb) and only 0.08×10^6 cells/l with 0.1 ppm.

In all the cases the growth inhibition is higher in the earlier and latter phases as can be observed from the growth constant and generation time. This should be considered as typical of the oligotrophic condition as the one which is simulated here with low concentration of inoculum. In the eutrophic condition where the cell numbers are very high, usually in the range of 10^6 ml^{-1} the algal exudates act as a good chelating agent (Sunda and Guillard, 1976, Sueur et al. 1982). This leads to the gradual decrease in the effect of metal as free metal ion concentration decreases (Sunda and Guillard, 1976).

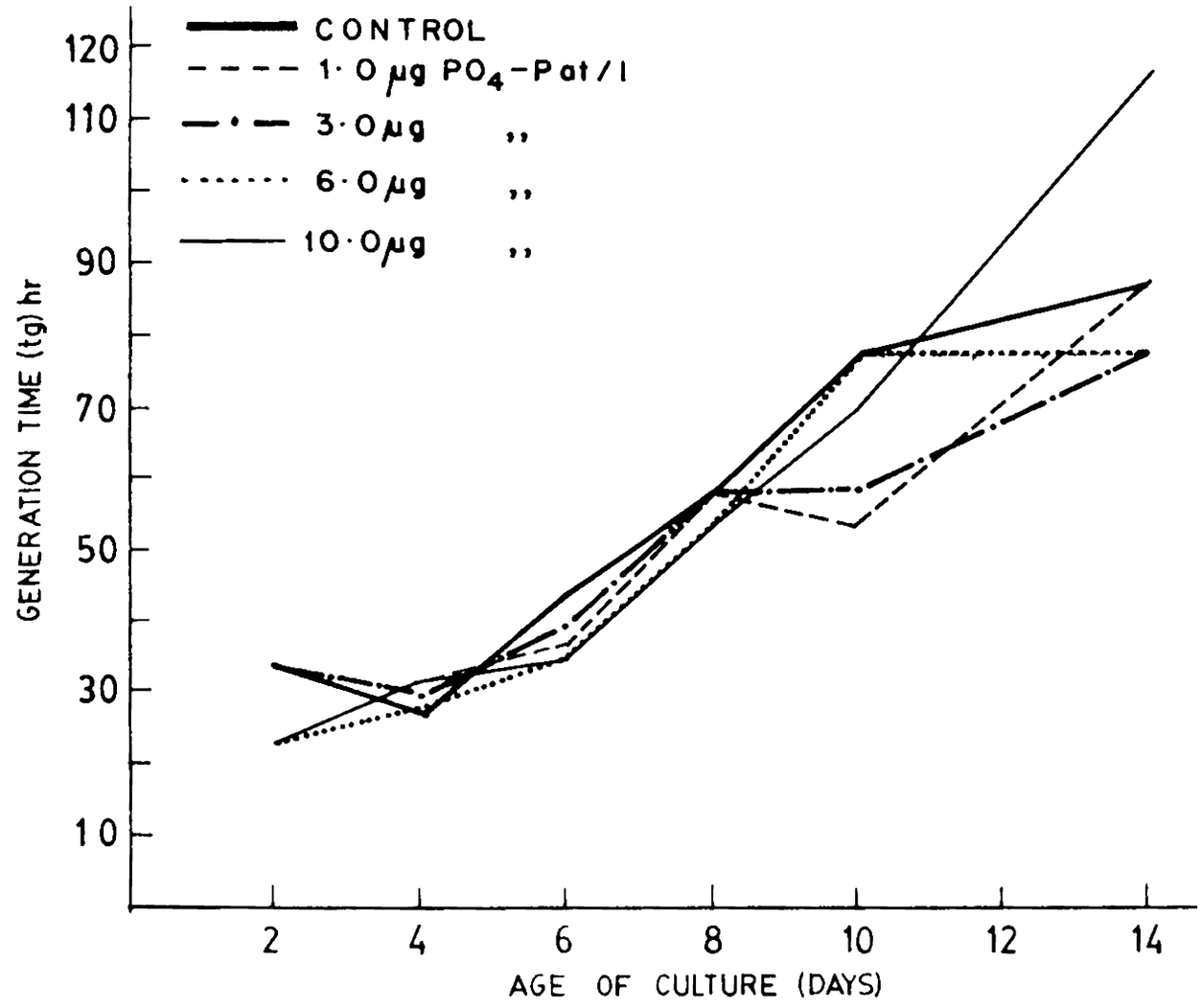

FIG. 37. IMPACT OF VARYING CONCENTRATIONS OF PO_4-P ON GENERATION TIME

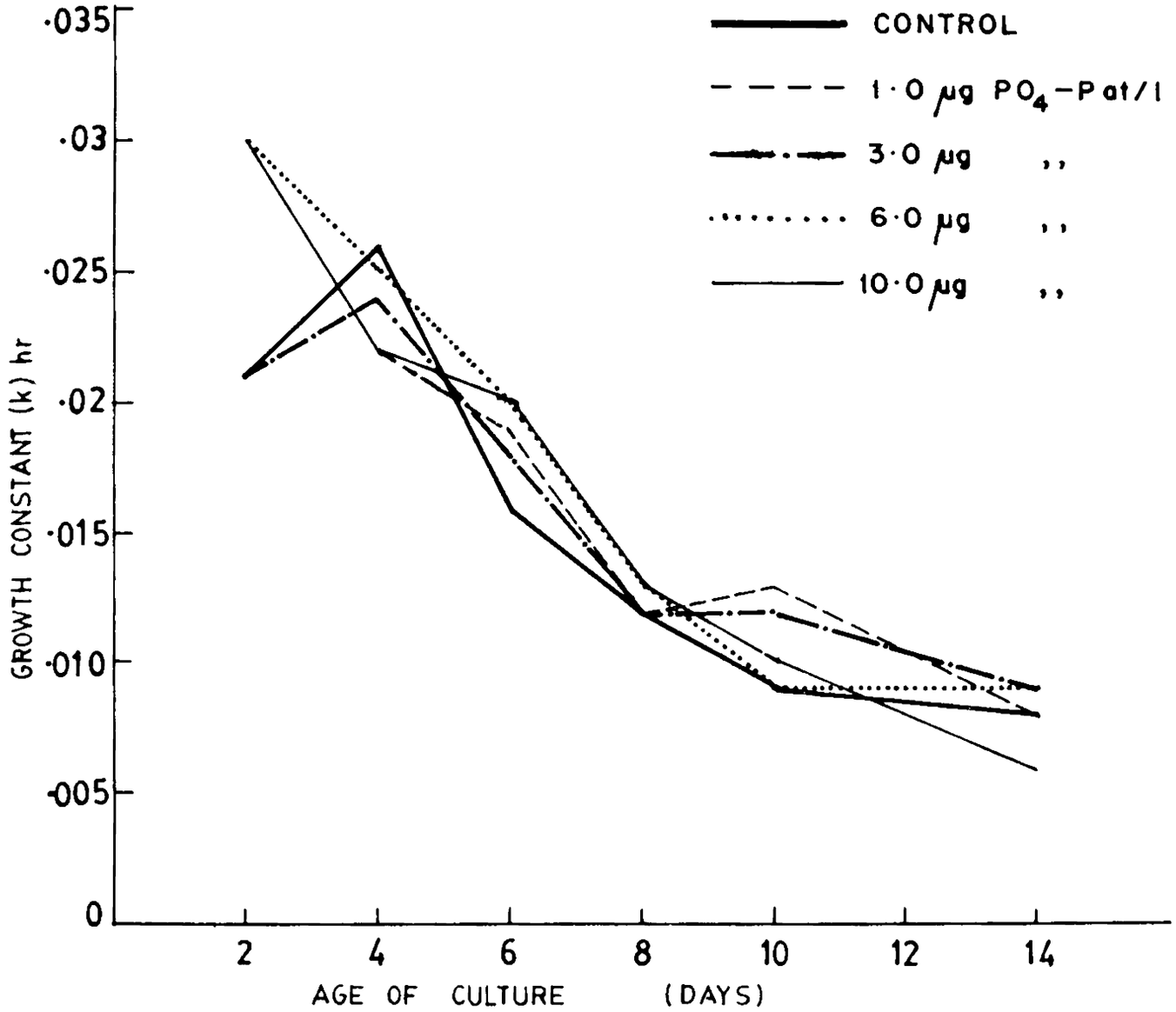

FIG. 38. IMPACT OF VARYING CONCENTRATIONS OF PO_4-P ON GROWTH CONSTANT

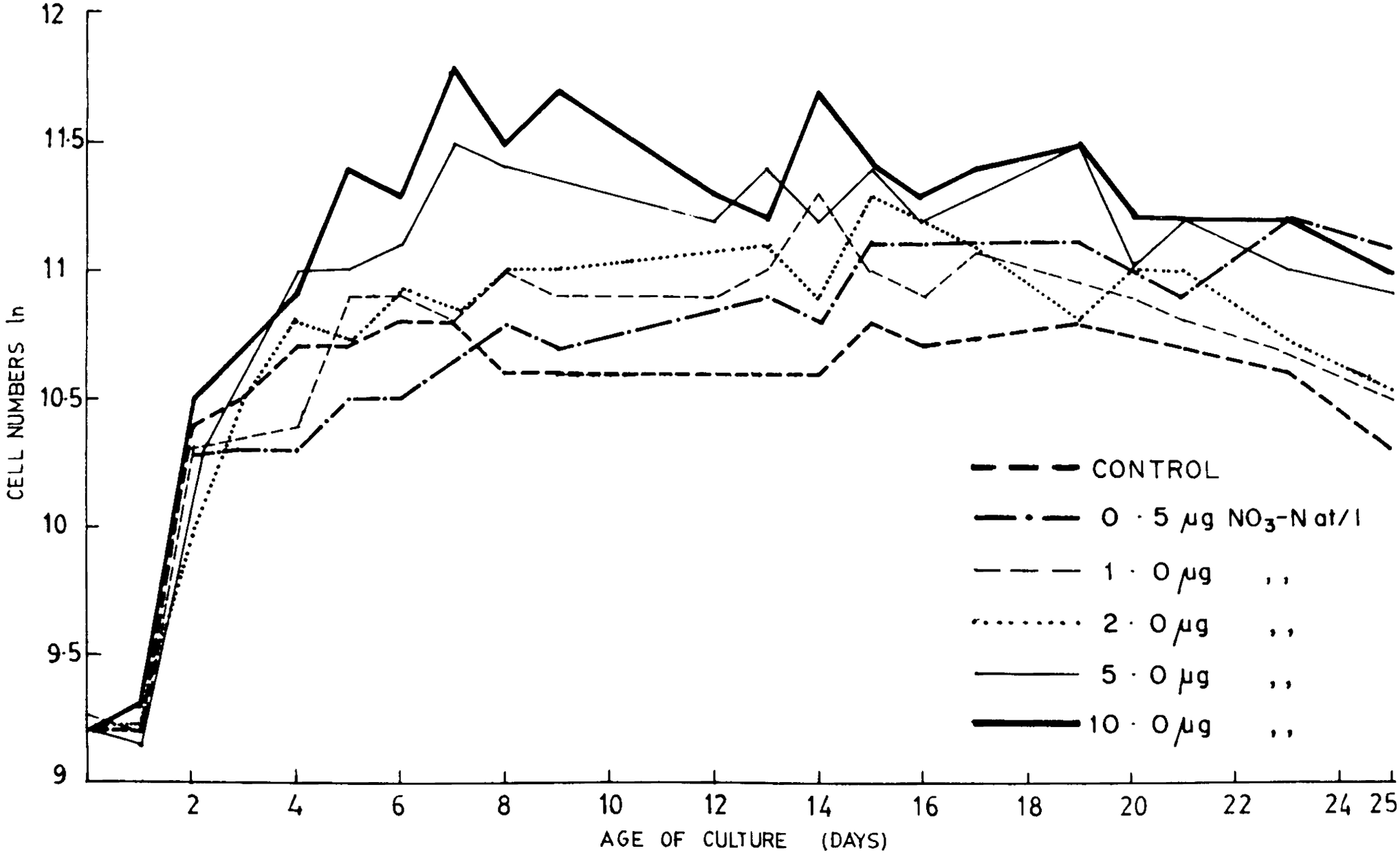

FIG. 39. IMPACT OF VARYING CONCENTRATIONS OF NO_3–N at/l ON THE GROWTH OF

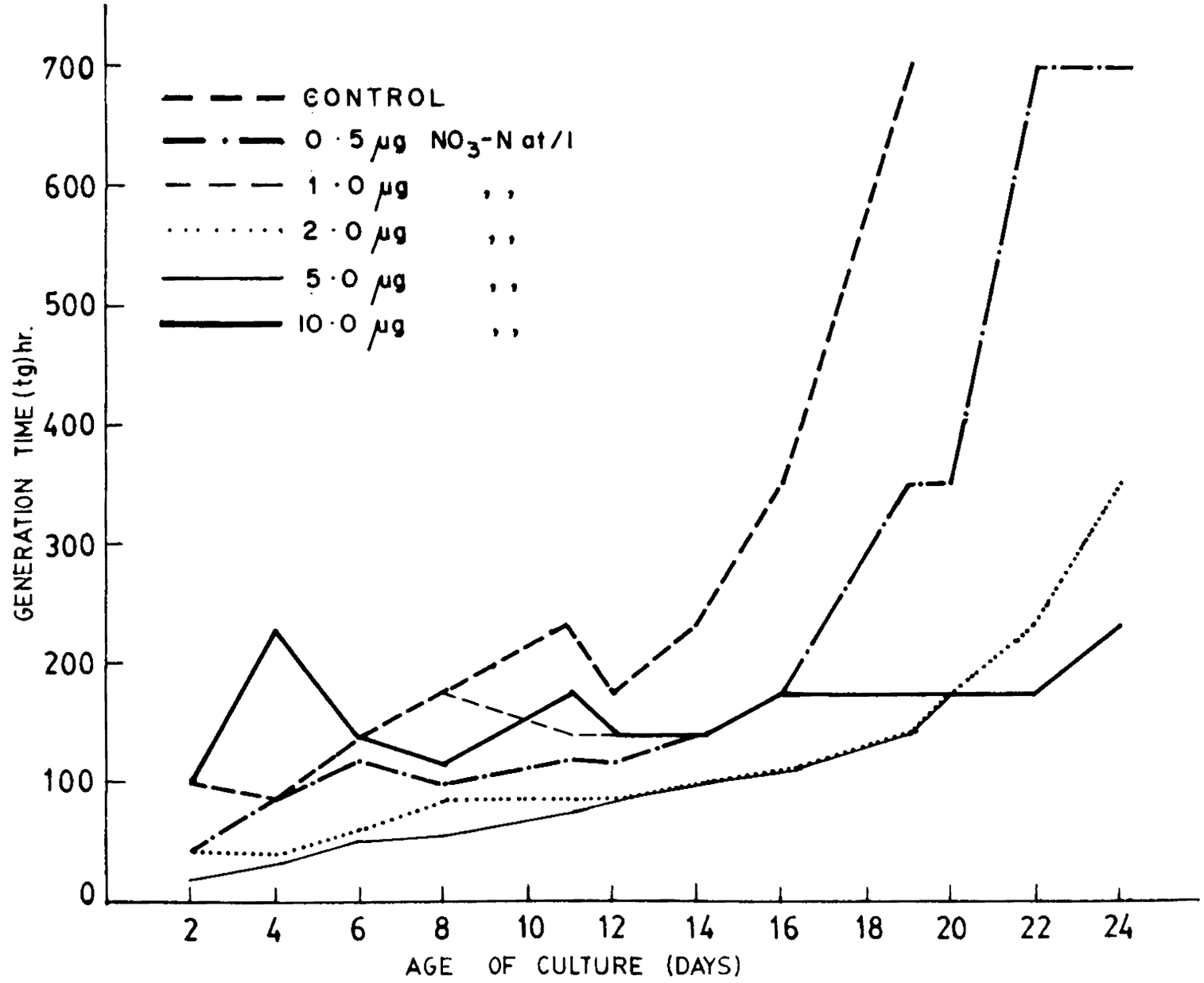

FIG. 40. IMPACT OF VARYING CONCENTRATIONS OF NO_3-Nat/l ON GENERATION TIME

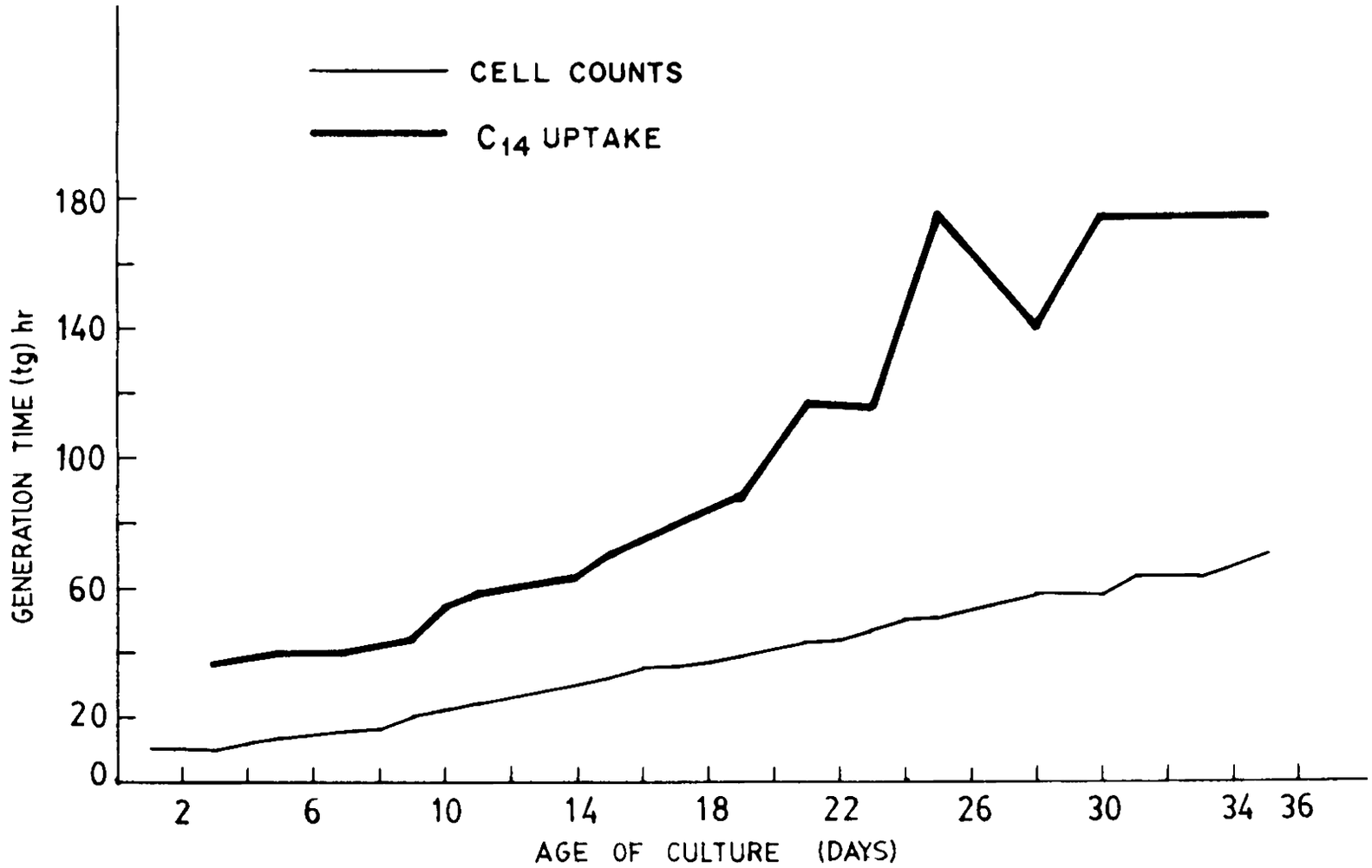

FIG. 41. DOUBLING OF CELL NUMBERS AND C_{14} UPTAKE

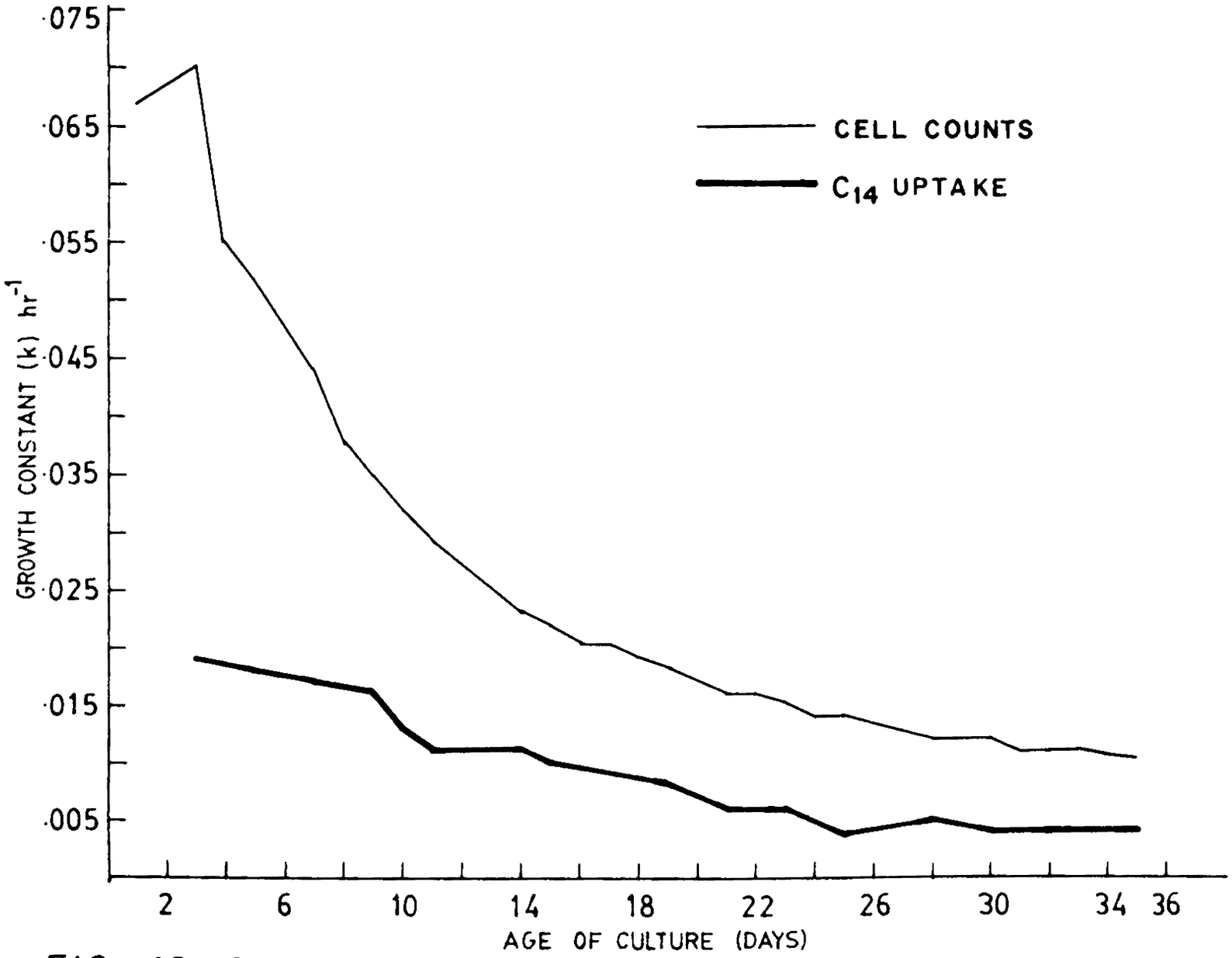

FIG. 42. GROWTH CONSTANTS CALCULATED FROM CELL

CHAPTER IX

SUMMARY

The present work deals with the results of investigations, on various aspects of algal plankton such as size spectrum of some estuarine and neritic species, floristic composition of planktonic algae in the near-shore waters, temporal and spatial variation of microplankton, chlorophyll and primary production in the Cochin estuary, carried out for the last few years. Besides, the productivity in a polluted ecosystem and growth characteristics of a few cultivated species have also been studied.

The study of floristic size spectrum of the estuarine algal plankton and their specific contribution to the production in terms of cell numbers, chlorophyll and primary food is a useful tool for the estimation of fishery resources. The planktonic flora in a selected station in Cochin estuary have been isolated by fractional filtration and classified into four size groups (SG.) $\lesssim$60 (SG.1), 60 - 75 (SG.2), 76 - 99 (SG.3) and $>$99(SG.4). SG.1 forms the nanoplankton and the remaining size groups from the microplankters. Observations show that the nanoplankters constitute the major flora in the estuary. They form an average of 70.7% of the total floristic composition with the maximum value of 95.7% in July. The estuarine nanoplankton contribute 69.5% of the total chlorophyll a and 73.0% of the total organic production.

On analysing the size spectrum of the planktonic algae it is observed that the largest number of species is constituted by diatoms. Out of thirty one species of planktonic algae recorded, twenty species belong to the class Bacillariophyceae, four species belong to Cyanophyceae, three species each belong to Pyrrophyceae and Chlorophyceae and one species belongs to the class Prasinophyceae. All these taxonomic classes are represented in all the size groups of algal plankton.

The inter and intra specific quantitative analysis of twenty six species of planktonic algae recorded in the inshore waters show that they are distributed in all the size groups. Among these, twenty one species belong to the taxonomic class Bacillariophyceae, two species each belong to the classes Cyanophyceae, Pyrrophyceae and one species belongs to the class Prasinophyceae.

Inspite of low numerical representation of the nanoplankters, they are found to be very effective primary producers as evidenced by their high percentage contribution to the total production. The average nanoplankton production is found to be 31.5 $mgC/m^3/day$ out of the total 50.3 $mgC/m^3/day$, ie. 62.6%.

The nanoplankton contribution of about 63.0% expressed in terms of chlorophyll a and carbon assimilation is inclusive of autotrophic forms of size Ca 1 um which are called picoplankton.

The present observation on nanoplankton contribution in terms of population density of 14.9% is exclusive of picoplankton and hence is infact an under estimation. Assuming that there exists 1:1:1 ratio among population density, chlorophyll a concentration and primary organic production under average optimum conditions as is usually observed, the population densities of the nanoplankton and microplankton are estimated to be 63.0% and 37.0% respectively.

The microplankters and the chlorophyll exhibit both temporal and spatial variations in Cochin estuary. As the estuarine flora include marine forms recruited from the near-shore waters due to tidal effect, fresh water species recruited along with the river water and the typical estuarine species, their relative distribution is very much influenced by the salinity fluctuations.

The annual average chlorophyll concentrations at seven selected stations extending from Alleppey to Azhikode are 5.7, 6.8, 11.9, 10.1, 11.1, 11.0 and 5.1 mg/m^3 respectively. While at the first station the salinity is less, at the last station salinity is very high. The areas of intermediate salinity record comparatively high chlorophyll a concentrations. The average chlorophyll a concentration for the entire estuary extending from Alleppey in the south to Azhikode in the north has been estimated at 9.1 mg/m^3 for the pre-monsoon, 13.9 mg/m^3 for the monsoon and 3.3 mg/m^3 for the post-monsoon.

The mean value of the productivity of the estuarine ecosystem extending from Alleppey to Azhikode comprising 300 Km^2 is computed at 48.6 $mgC/m^3/hr$ and the estimated annual production for the estuary is about 53,000 tonnes of carbon for the surface waters within one metre depth. The depth of the euphotic zone varies from about 1.5 to 3.0 metres depending on the season and the annual organic production for the water column as a whole is estimated at 100,000 tonnes.

Separate studies on primary productivity at the southern part of the estuary represented by 5 stations have been carried out for a period of two years and the results indicated an average productivity of 44.24 $mgC/m^3/hr$.

Studies on the impact of industrial effluents (pollutants) on bio-productivity near the industrial belt at Alwaye in the tributary of Periyar river and adjacent Cochin estuary for a period of one year show that near the source of pollution the primary productivity recorded is comparatively the least (217.2 $mgC/m^3/day$). The four down stream stations show gradual increase of production depending on the distance

from the source of pollution and consequent degree of dilution of pollutants, their values beings 426.0 $mgC/m^3/day$, 542.2 $mgC/m^3/day$, 1557.6 $mgC/m^3/day$ and 2113.2 $mgC/m^3/day$ respectively, the last station being a pollution-free site reckoned as the control station. The corresponding productivity potential cut (ppc) are 90.0%, 80.0%, 75.0%, 25.0% and nil respectively. In the upstream station beyond the impact site the productivity is 435.6 $mgC/m^3/day$ and the ppc is about 80.0%. Thus the inhibition of organic production at the primary trophic level is due to the stress of the industrial effluents on biota caused by ecophysiological factors.

T. gracilis showed an increase in growth constant with increase of PO_4 concentration upto 5 ug. In the control when the growth constant is 0.026 hr/1, with 1 ug PO_4 - P at./1 it is 0.030 hr^{-1}, with 5 ug PO_4 - P at./1 it is 0.36 hr^{-1}, but with higher concentration of phosphate the metabolic activities leading to cell synthesis is not accelerated. The impact of enrichment of phosphate is more conspicuous in the doubling of chlorophyll concentration.

Growth constants and generation time vary with the different species of phytoplankton. The shortest generation time (tg) recorded by Thalassiosira subtilis is 12.5 hours with a growth constant k of 0.056 hr^{-1}. The shortest generation time of Synechocystis salina is 14.6 hours and the corresponding maximum growth constant (K) is 0.048 hr^{-1}.

The effect of four potentially toxic metals viz., Cu, Hg, Zn and Pb on the growth constant and generation time of the blue green alga Synechosystis salina has been studied at two different concentrations

of each metal. It is observed that the rate of toxicity is proportional to the added metal concentrations. With 0.05 ppm Cu the cells generally require more doubling time and 0.10 ppm Cu is found to be lethal to the alga. Thus on the seventh day generation time for the control and 0.05 ppm Cu are 120.7 and 857.0 (hrs) respectively. Mercury at both 0.05 ppm and 0.1 ppm concentrations inhibits the metabolic processes leading to cell multiplication. In the control when the growth constant (K) is 0.0036 hr^{-1} it is 0.0020 hr^{-1} with 0.05 ppm (Hg) and 0.0016 $hr^{=1}$ with 0.10 ppm (Hg). The doubling time increases with the increase of zinc concentration. The lowest generation time observed in the control is 116.6 hours, with 0.05 ppm (Zn) it is 159.0 hours and with 0.1 ppm (Zn) it is 179.5 hours. Lead at both the concentrations tested are found to be lethal.

The various planktonic algal flora of different size fractions synthesise food at the primary trophic level contributing to the total organic production of the concerned ecosystem. The relevance of the contribution of various size fractions is more in the selectivity of diet of consumers. As the major pelagic fishes in the south-west coast of India spawn throughout the year the larvae that hatch out need extremely small size of phytoplankton, their requirements increase with the increasing size of the larvae. Since these various size fractions of the algal flora forming the food of different varieties of consumers, many of them being selective feeders, this study of the various size fractions of the primary producers and their proportionate contribution to the organic production at the primary trophic level, is a useful tool for the estimation of not only the quantum but also the type of fishery, provided the selectivity of diet of the concerned consumers are known.

The bioproductivity of the estuarine system at the primary trophic level as a whole being the order of 100,000 tonnes annually can sustain a rich biota inclusive of several penaeid and non-penaeid prawns and estuarine fishes through an intricate food web and still leave surplus of organic matter for recycling. However the study also reveals that impact of industrial pollutants can inhibit the bioproductivity in restricted areas.

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* Not refered in the original.

APPENDIX

LIST OF PUBLICATIONS

1. Seasonal and spatial distribution of phytoplankton in Cochin backwater (With V.K. Pillai. 1975). Bull.Dept.Mar.Sci.Univ.Cochin, 7, 177-180.

2. Growth characteristics of certain estuarine phytoplankters. (With P.V.R. Nair. 1975). Bull.Dept.Mar.Sci.Univ.Cochin, 7, 161-170.

3. Studies on phytoplankton in polluted waters. (With P.N.K. Nambisan, C.S. Shyanamma and P.T. Lakshmanam. 1988). J.Mar.Biol.Ass.India, 26 (1 & 2), 42-46.

4. Standardization and intercalibration trials with C^{14} isotope. (With Nair, P.V.R. 1975). Proc. Symp. Use of Radiations and Radioisotopes in studies on animal production. IVRI, Izatnagar, 421-430.

5. Utilization of nitrate and phosphate by the green alga Tetraselmis gracilis Kylin. (With Qasim, S.Z. 1975). Indian J.Mar.Sci., 161-164.

6. Preliminary studies on nanoplankton productivity. (With Vijayaraghavan,S and V.K. Balachandran. 1974). Mahasagar, Bull.Nat.Inst.Oceanogr., 7, 125-129.

7. Contribution of microplankton and nanoplankton in the waters of tropical estuary. (With Qasim, S.Z., S. Vijayaraghavan, and V.K. Balachandran. 1974. Indian J.Mar.Sci., 3, 146-149.

8. Studies on dissolved carbohydrate content (DCHO) in a tropical estuary. (With Vijayaraghavan, S., D.C.V. Easterson, and V.K. Balachandran.1975). J.Mar.Biol.Ass.India, 14 (2), 864-866.

9. A study on the primary production in the Vembanad Lake. (With Nair, P.V.R., V.K. Balachandran and V.K. Pillai. 1975). Bull.Dept.Mar. Sci.Univ.Cochin., 7, 161-170.

10. The plankton production in the Vembanad Lake and adjacent waters in relation to the environmental parameters. Bull.Dept.Mar.Sci.Univ. Cochin, 7, 137-150.

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12. Primary production and potential fishery resources in the seas around India. (With Nair, P.V.R., S. Samuel, and V.K. Balachandran. 1968). Proc. Symp.Living Resources.Seas around India, Cochin., 184-198.

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