GROWTH RESPONSE OF PHYTOPLANKTON EXPOSED TO INDUSTRIAL EFFLUENTS IN RIVER PERIYAR

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APRIL 1989

DECLARATION

I hereby declare that this thesis entitled "Growth response of phytoplankton exposed to industrial effluents in river Periyar" has not previously formed the basis of the award of any degree, diploma or associateship in any university.

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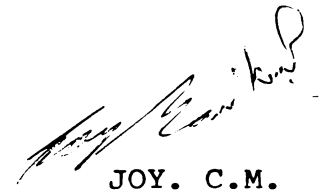

JOY. C.M.

CERTIFICATE

This is to certify that the thesis entitled "Growth response of phytoplankton exposed to industrial effluents in river Periyar" is the bonafide record of the work carried out by Sri. JOY C.M., under my supervision and guidance in the School of Environmental Studies for the Ph.D. Degree of the Cochin University of Science and Technology and no part of this has previously formed the basis for the award of any other degree in any University.

Cochin - 682 016,
April, 1989.

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PREFACE

River banks have been the cradles of civilizations since time imemmorial. In those days when the activities of man extended over cultivation of food crops and limited utilization of natural resources, the streams and lakes provided the basic amenities and added to the aesthetic quality of his surroundings; but the industrial revolution followed by rapid technological development in the 20th century indiscriminately bound the rivers with industry, as the former served a convenient medium for the transport of raw-materials and products manufactured, as well as sites for disposal of wastes.

In the years that followed the second world war, world's attention was deep-rooted in industrial development. Most of these industries were set up along the banks of rivers and estuaries and this eventually led to the deterioration of many water-ways. But the realization came only in the 1960s. In 1968, the UN Economic and Social Council identified water pollution as "impairment of water functions which has or may have an effect on subsequent water use". The conference on Human Environment held at Stockholm in 1972 focussed international attention on environmental protection. The action plan for 1982-1992 was reviewed by the Nairobi conference organised in 1982 by UNEP. In the light of these efforts, our awareness of the problem of pollution and ways and means to contain it have improved tremendously.

It is against the background of increasing reports on the environmental degradation of river Periyar due to discharge of waste water from various industries located on its banks that the candidate has taken up this investigation as a junior research fellow in the School of Environmental Studies. The response of the primary producers to industrial effluent discharges was assessed through field observations and laboratory experiments on axenic cultures. The standard algal assay procedure employed by US EPA was adopted throughout the study. The field data collected have been assessed by Page's L (trend) test to determine the seasonal spatial variation along with Multiple Regression relationship for different parameters using computer. The period of investigation was for three years from August 1985. The results of the study are compiled in seven chapters.

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I thank Prof. Y.L. Dora, former Director, School of Marine Sciences for providing the university vehicle to collect water samples. I am thankful to Prof. N.R. Menon, Head, Marine Biology Division, School of Marine Sciences, who has given the facility to make use of Hitachi Spectrophotometer to analyse the water samples.

I wish to express my gratitude to Asst. Prof. V.K. Unnithan, Kerala Agricultural University, for helping with the statistical analyses. I sincerely thank Mr. K.N. Kurup,

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I gratefully acknowledge the constant encouragement and help given by my wife Dr. Ammini Joseph, Lecturer, School of Environmental Studies, Cochin University of Science and Technology, to complete this work.

My thanks are also due to the Cochin University of Science and Technology, for awarding a research fellowship during the tenure in which the present study was carried out.

Last but not the least, I wish to thank the faculty members of School of Environmental Studies, who helped me during different phases of the study and its completion.

CONTENTS

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CHAPTER 1

INTRODUCTION

The aquatic ecosystems of the world are being subjected to increasing environmental deterioration due to human interference. The problems facing the water bodies are related to over-exploitation and disposal of refuses from community settlements, untreated wastes from industries and excess chemicals from agricultural lands. The effects of these environmental disturbances have been variously felt, as intense eutrophication and algal blooms related to nutrient loading from industrial and sewage outfalls (Rohlich, 1969), wide-spread occurrence of water-borne illnesses resulting from microbial contamination of drinking water, acute toxicity to animals and man such as that of 'Minamata' disease caused by industrial waste water discharge and alteration of the physico-chemical characteristics of the water leading to species replacement and change in community structure (Nebel, 1981; Kupchella and Hyland, 1986).

In India, it is reported that about 70 percent of the available water is polluted (Citizens' report, 1982). The chief source of pollution is identified to be sewerage which constitute 84 to 92 percent of the waste water. Industrial waste water comprises 8 to 16 percent (Chaudhuri, 1982). With rapid development in the industrial sector, it is expected that the volume of industrial waste water will increase to 33 percent by 2000 A.D.

Surveys conducted by several investigators on the water quality of some of the important rivers in India reveal that most of them are polluted. River Ganges which is one of the largest and longest rivers in India receives sewage and industrial effluents at various points throughout its course. At Kanpur, the BOD of the river has gone as high as 230 mg L^{-1} by receiving untreated wastes from forty five tanneries, ten textile mills and other several industrial units. At Calcutta, Hooghly river receives 252 million gallons of industrial wastes per day in addition to sewage wastes (Mahajan, 1988). The disposal of sewage and textile mill wastes have resulted in frequent algal blooms in river Khan (Madhya Pradesh). The ecological imbalance of this river was investigated by Rao et al. (1978). Zingde et al. (1979a) reported that water quality in river Par (Maharashtra) deteriorates in the summer months due to the effluents from a chemical complex. The coastal waters of Bombay were observed to have abnormally low levels of dissolved oxygen and high BOD during premonsoon at the regions of waste discharge (Zingde et al., 1979b). Among the major rivers in South India, river Godavari and river Cauvery are reported to be subject to industrial pollution (Mahajan, 1988). Pollution sources of selected Indian rivers are abstracted in Table 1.

TABLE 1

A selected list of Indian rivers and their source of pollutants

Name of the river	State	Source of pollutants
Cauvery	Tamil Nadu	Thermal power plant, paper mill, chemical industry, tannery and distillery units.
Chaliyar	Kerala	Rayons factory
Chambal	Rajasthan	Fertilizer factory, nuclear and thermal power plants, rayon factory.
Damodar	Bihar	Chemical, metallurgical factories and thermal power plant.
Ganga	Uttar Pradesh, Bihar, West Bengal	Sewage and industrial complexes.
Gandak	Bihar	Paper mill
Godavari	Andhra Pradesh	Paper mill
Gomati	Uttar Pradesh	Sewage and pulp, paper, sugar and cement factories.
Kali	Uttar Pradesh	Sugar factory
Kallada	Kerala	Paper mill
Kalu	Maharashtra	150 industrial units including paper mill, rayons and chemical factories.
Nandesari and Vapi	Gujarat	Chemical factories and dyeing and printing units.
Periyar	Kerala	Fertilizer, chlor-alkali, zinc, and monazite processing factories and a number of other chemical industries.
Rushikulya	Orissa	Caustic soda plant
Yamuna	Delhi	Sewage and D D T factory.

Kerala has 44 rivers of which 41 are flowing westwards and the rest towards the east (BE&S, 1978). The 'pollution map' of Kerala shows a few rivers such as Chaliyar, Kallada, Muvattupuzha and Periyar where water quality has deteriorated due to discharge of industrial effluents. Nirmala et al. (1976) observed pollution in Chaliyar, caused by the effluents from Gwalior Rayons factory. The effluents discharged from Punalur paper mills into Kallada river is found to alter the physico-chemical factors and production of plankton (Nampoothiry et al., 1976). The water quality of Muvattupuzha river is reported to be adversely affected by the discharge of pulp-paper effluents (Balchand and Nambisan, 1986).

A few aspects of water quality of river Periyar have been investigated particularly in its lower reaches by Jayapalan et al., 1976, Paul and Pillai, 1978, 1986, Sarala Devi et al., 1979 and Joseph et al., 1984. Considering the clustering of industries on the banks of river Periyar, the number of reservoirs constructed across the river and consequent decrease in water flow, a much detailed investigation into the pollution aspects of this river is imperative. The objective of the present study is to assess the water quality of river Periyar and observe the growth response of phytoplankton community so as to predict the probable effect of continued discharge of complex wastes from industries on such organisms.

A wide range of toxicity tests have been developed in the recent decades to predict the probable effects of new

chemicals and effluents on aquatic ecosystem utilizing different organisms such as algae, crustaceans, molluscs and fish (Sprague, 1973; James and Evison, 1979; Walsh et al., 1980; Pascoe and Edwards, 1984; A P H A, 1985; Reish and Oshida, 1986; Wong and Couture, 1986). When an organism is exposed to a toxicant, its metabolism undergoes change. Bayne (1976) defined this sort of 'stress' as a measurable alteration of a physiological steady state which is induced by environment change, and which renders the animal or population more vulnerable to further change. The stress response is measured by conducting bioassays. The bioassay is defined as "a test in which the quantity or strength of material is determined by the reaction of a living organism to it" (Sprague, 1973). Two types of bioassay systems are in vogue: continuous and static systems depending on whether the test water is renewed or not. The response of the organism is generally measured in terms of mortality in the case of fish or immobilization as in many invertebrates. Toxic response is usually expressed as LC_{50} (lethal concentration for 50 percent of the individuals) and ET_{50} (time taken for a concentration of pollutant to produce the measured response in 50 percent of the number of animals exposed to it).

In the case of algae, the minimum algicidal or algistatic concentrations as well as EC_{50} are calculated. EC_{50} is defined as "Interpolated or calculated concentration of a toxicant that would inhibit population growth or any other biological process of algae by 50% compared to the controls

in a specific period of time" (Walsh, 1987). The parameters of response in unicellular algae are usually cell counts and photosynthetic rate (Cheng and Antia, 1970; Stockner and Costella, 1976; Devi Prasad, 1982; Kallqvist, 1984). Measurement of adenylate energy charge is a new approach in this regard (Din and Brooks, 1986; Couture et al., 1987).

Different degrees of toxicity are recognized based on lethal threshold concentration to fish exposed for 96 hr (IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN, 1973). They are as follows:-

Ratings	TL_m Value
4. Highly toxic	<1 mg/l
3. Moderately toxic	1-10 mg/l
2. Slightly toxic	10-100 mg/l
1. Practically non-toxic	100-1000 mg/l
0. Non-hazardous	>1000 mg/l

Sprague (1969) expressed toxicity in terms of toxic units or toxic concentrations "a toxic concentration unit is usually defined as proportion of the 96 hr LC_{50} i.e.

$$TC = \frac{100}{96 \text{ hr } LC_{50} \text{ in } \%}".$$

Algal bioassays for assessing nutrient status of water bodies was introduced by Skulberg (1964). US EPA effectively applied this to counter eutrophication (EPA, 1971). Algal assays to detect toxic substances in natural waters were described by Miller et al. (1978). Joubert (1980) employed cultures of

Selenastrum capricornutum to quantify toxic effects of heavy metals and industrial wastes. Kallqvist (1984) recommended algal assays as a supplement to chemical analyses to assess pollution. Couture et al. (1987) measured the response of microbial community to industrial waste water discharge in a lotic ecosystem employing P/B ratio (microgram carbon per microgram chlorophyll a per hour) and adenylate energy charge as the parameters of growth. As Walsh et al. (1982) state "in general aquatic animals are more sensitive than algae to single pollutants and heavy metals, but there is evidence that algae are more sensitive than animals to complex wastes such as industrial and municipal effluents". Moreover, the food web relations in aquatic ecosystem depend on the standing crop and productivity of phytoplankton.

The present investigation has been conducted in two phases: field observation of physico-chemical parameters and measurement of standing crop of phytoplankton, and algal assays on pure cultures using industrial effluents. The results of the field observations are interpreted in the light of algal assays.

CHAPTER 2

AREA OF STUDY AND ENVIRONMENTAL FEATURES OF RIVER PERIYAR

River Periyar is considered to be the longest river in Kerala, traversing 244 km within the State (PWD, 1974; CESS, 1984). It originates from the Sivagiri group of hills situated at Sundaramalai in the Western Ghats at an elevation of 1830m above M.S.L. and flows westwards. The river meanders through hilly terrain for about 48 km before it receives the tributaries such as Mullayar, Perumthurai Aar, Cheruthoni Aar, Chittar, Perinjakutty Aar, Muthirapuzha, Thotti Aar and Edamalayar (Figure 1).

The river flows along almost virgin forests in places such as Kokaripara, Neriamangalam, Edamalayar and Malayattoor. At Alwaye the river bifurcates into two, Marthandavarma and Mangalapuzha branches. The Mangalapuzha branch joins Chalakudy river and empties into the Arabian Sea at Munambam while the Marthandavarma branch flows southwards, through the Udyogmandal area and joins the Cochin backwater system at Varapuzha (PVIP, 1972).

The Cochin backwater system is a part of the Vembanad lake, a tropical estuary along the south-west coast of India. It has access to Arabian Sea at Cochin and Munambam. As a result, the Cochin backwater and the lower reaches of river Periyar are subject to tidal influence. The salinity incursion

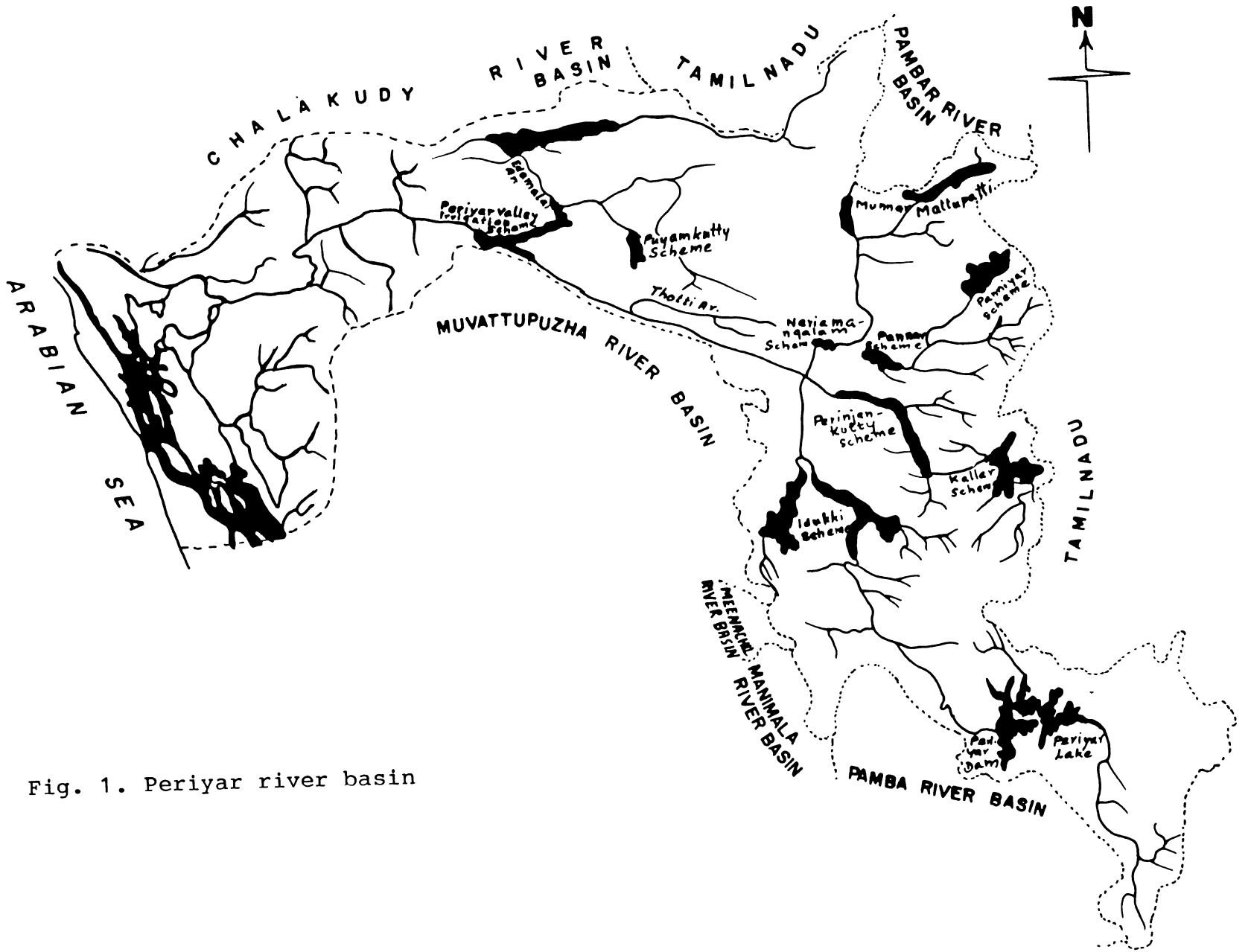

Fig. 1. Periyar river basin

reaches about 15 km upstream. Investigations show that a fresh-water discharge of 14 to 16 m^3 sec^{-1} is required to keep the salinity within the prescribed limit of 50 ppm at and around the industrial belt of the river (PVIP, 1972).

Table 2 gives the catchment area, the water potential and extent of utilization of the river (PVIP, 1972; BE&S, 1978; KSPCB, 1985a; PWD, 1986).

TABLE 2

Main features of river Periyar

Origin		Sivagiri hills in Tamilnadu
Length		244 km
Direction of flow		Westwards
Catchment area in Kerala		5284 km^2
Catchment area in Tamil Nadu		114 km^2
Average rainfall in catchment area		400 cm $year^{-1}$
Rate of flow	: Minimum	9.66 m^3 sec^{-1}
	: Maximum	1364.66 m^3 sec^{-1}
Width at Kalady		405 m
Width at Alwaye		220 m
Width at Udyogmandal		50 m
Utilization :	Domestic	260 Mm^3
	Irrigational	450 Mm^3
	Industrial	1844 Mm^3
Number of impounded reservoirs		14
Number of hydroelectric schemes		6

The Periyar river is of utmost significance in the economy of Kerala as it is the site of the largest hydroelectric project (Idukki) in the State and it flows along a region of industrial and commercial activity. The river also provides water for irrigation and domestic use throughout its course besides supporting a rich fishery. The Cochin city, in the vicinity of the river mouth draws its water supply from Alwaye, an upstream site sufficiently free of seawater intrusion. Twenty five percent of the State's industries are located along the banks of river Periyar and these are mostly crowded within a stretch of 5 km in the Eloor-Edayar region (Udyogmandal) which is only 10 km north of Cochin harbour (Figure 2). These factories depend on the river for intake of process water and disposal of effluents. A list of the major industries, the raw-materials used and their products of manufacture is given in Table 3 (KSPCB, 1985a; 1985b).

TABLE 3

Major industries located on the banks of river Periyar

Industry	Year of Establi-shment	Raw-materials	Products	Waste water discharge $x10^6 L\ day^{-1}$
Indian Aluminium Company Ltd. (IAC) Udyogmandal	1943	Alumina, Pitch, Aluminium fluoride, Cryolite	Aluminium wire rode, Aluminium ingots, Aluminium extrusion	4110

Industry	Year of Establi-shment	Raw-materials	Products	Waste water discharge $x10^6 L\ day^{-1}$
Travancore Chemical Manufacturing Company Ltd. (TCMC) Kalamassery	1943	Copper scrap, Bauxite, Sulphuric acid, Hydrochloric acid, Washed garnalite, Caustic soda, Sodium chloride	Copper oxy-chloride, Copper sulphate, Sodium aluminate, Aluminium sulphate, Sodium chlorate, Potassium chlorate	239.08
Fertilizers and Chemicals Travancore Ltd. (FACT) Udyogmandal	1947	Sulphur, Rock phosphate, Naphtha, Hydrochloric acid	Ammonia, Ammonium sulphate, Ammonium phosphate, Ammonium chloride, Sulphuric acid, Phosphoric acid, Super phosphate, Liquid sulphur-dioxide, Cryolite	20658
Travancore Rayons, Rayonapuram, Perumbavoor	1949	Cotton hinter, Sulphur, Caustic soda, Sodium sulphide, Zinc chloride, Wood pulp	Cotton pulp, Sulphuric acid, Cellulosic continuous viscose filament yarn, Carbon disulphide, cellulose film	5360.7
Travancore Cochin Chemicals Ltd. (TCC) Udyogmandal	1951	Sulphur, Soda ash, Barium carbonate, Caustic lime, Common salt	Caustic soda, Sodium sulphide, Sodium-hydro sulphite, Liquid chlorine, Hydrochloric acid	3504

Industry	Year of Establi-shment	Raw-materials	Products	Waste water discharge $x10^6 L\ day^{-1}$
Indian Rare Earths Ltd. (IRE) Udyogmandal	1951	Monazite sand, Caustic soda, Hydrochloric acid, Chloride, Nitric acid	Trisodium phosphate, Rare earths oxide, Cerium oxide, Rare earths chloride	705.1
Hindustan Insecticide Ltd. (HIL) Udyogmandal	1958	Benzene, alcohol, Chlorine, Oleum	DDT, BHC	65.6
Cominco Binani Zinc Ltd. (CBZ) Binanipuram	1967	Zinc concentrate	Zinc, Sulphuric acid, Cadmium	844.98
Periyar Chemicals Ltd. Binanipuram	1969	Caustic soda, Sulphuric acid, Stack gas containing 30% Cobalt	Formic acid, Sodium sulphate	43.2
United Catalysts India Ltd. (UCI) Binanipuram	1970	Alumina, Copper, Zinc, Iron scrap, Sulphuric acid, Graphite, Sodium chloride, Ammonia, Carbon dioxide	Catalysts for fertilizer and petrochemical industries	126

The concern about the quality of water in the lower reaches of the river began to be felt in the 1970s. Occasional reports of mass mortality of fish focussed public attention and induced scientific investigations on the causes and effects of the degradation of environmental quality in the river and its associated canals and backwater. The river being subject to tidal influx from Cochin backwater the hydrobiology of its

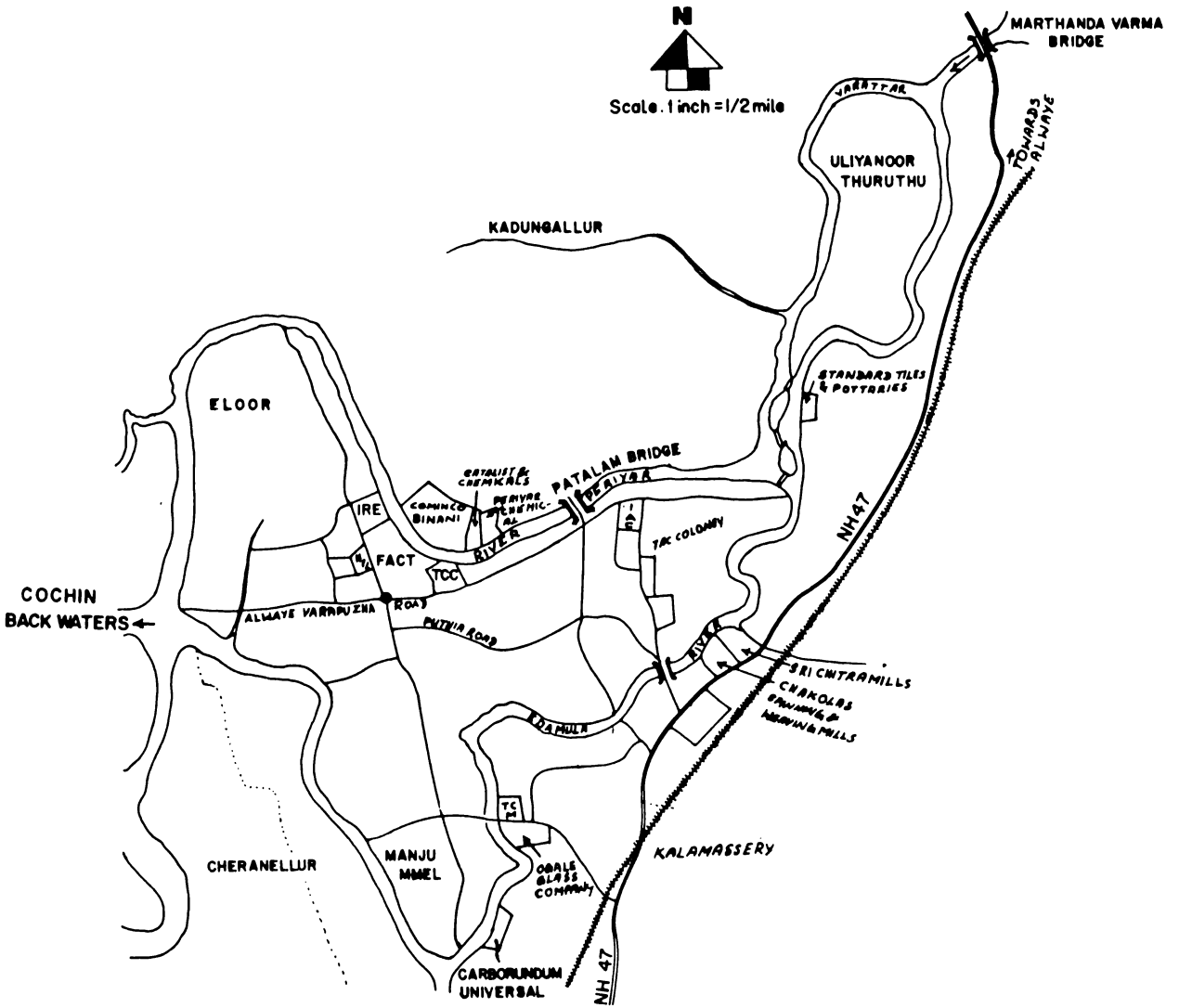

Fig. 2. Industrial zone along the banks of river Periyar

lower reaches is closely associated with that of the latter. The environmental conditions in this estuary centre around the South West monsoon and tidal oscillations. The occurrence of the South West monsoon facilitates the differentiation of the year into three seasons, namely Monsoon (June-September), Premonsoon (February-May), and Postmonsoon (October-January). During the monsoon season, salinity decreases in the Cochin backwater and it becomes freshwater dominated. In the post-monsoon and premonsoon months brackish to marine conditions are restored (Sankaranarayanan and Qasim, 1969).

Estimation of primary productivity in the estuary shows that it is a very productive region with an annual gross production of 300 g C m^{-2} (Qasim et al., 1969). Sankaranarayanan and Qasim (1969) investigated the nutrient status of Cochin backwater and reported that during monsoon the concentration of nutrients is quite high in the estuary especially in the bottom, which they reasoned, is due to river discharge and decomposition of organic matter in the bottom sediments. Ramamritham and Jayaraman (1960) had suggested that this increase in nutrients is due to the influx of upwelled water from Arabian Sea. However, recent studies on the distribution pattern of nutrients indicate an external source or rather abiogenic source of input (Joseph, 1974; Manikoth and Salih, 1974; Joseph et al., 1984; Sankaranarayanan et al., 1986; Lakshmanan et al., 1987). These authors have implicated various sources such as sewage effluents, agricultural run-off and effluent discharge

from a fertilizer factory (FACT) located on the banks of river Periyar. Unnithan et al. (1975) and Remani et al. (1983) identified organic pollution due to sewage wastes and retting of coconut husk in localised regions of Cochin backwater.

Remani et al. (1980) observed fluctuation in the composition and nature of sediments caused by industrial effluents discharged into the river Periyar. Sarala Devi et al. (1979) also have reported that the industrial effluents released into river Periyar at the Eloor industrial zone affects the hydrographical features during the Premonsoon and Postmonsoon months. Jayapalan et al. (1976) observed that during summer the river water is characterised by low dissolved oxygen, high temperature and high chloride content, while during monsoon it possesses high dissolved oxygen, has low temperature, high carbon dioxide content and low chloride. The standing crop of plankton was found to be poor in the immediate zone of pollution. Silas and Pillai (1976) and Shynamma et al. (1981) have reported 'fish mortality' in the river. The 'pollution profile' of the river Periyar as represented by Paul and Pillai (1978) reveal high concentrations of pollutants such as ^{228}Ra, Po_4, Zn and Mn in the water and sediments even at locations 2 km downstream of the industrial outfalls. Balakrishnan and Lalithambika Devi (1983) highlighted the increasing environmental problems in the river Periyar and adjoining Cochin backwater system due to industrial effluents.

Joseph et al. (1984) have studied the seasonal and spatial distribution of phytoplankton in the industrial zone of river Periyar. They observed that at the region of discharge of effluents from FACT phytoplankton is either absent or in poor concentration. This decrease is attributed to the very high concentration of ammonia and phosphate in the effluent-laden water at the site. The authors state that "the effluent was not found to inhibit the rate of production, but controlled the generation time and qualitative distribution of phyto-plankton. However, in lesser concentration the effluents enhanced the rate of production". There is no conclusive evidence that the effluents from FACT is responsible for the stimulation of phytoplankton growth, for the river at this spot receives effluents from many other industries. So a detailed study of the effect of effluents from FACT is taken up and also the water quality and phytoplankton standing crop of Periyar is assessed from a sufficiently upstream location through the industrial zone and the estuarine region.

CHAPTER 3

METHODOLOGY

3.1. Field Methods

3.1.1. Sampling Stations

After a preliminary survey, six sampling stations were identified along the course of river Periyar which included an upstream region least disturbed by human activity (Edamalayar), industrial area and a down stream site (Figure 3). The location of the stations are given in Table 4.

TABLE 4

Sampling stations identified and their locations

Sl.No.	Sampling Stations	Latitude	Longitude	Approximate distance from Cochin harbour mouth(km)
1.	Edamalayar	$10^{o}15'N$	$76^{o}43'E$	64
2.	Alwaye	$10^{o}8'N$	$76^{o}21'E$	27
3.	Pathalam	$10^{o}4'N$	$76^{o}18'E$	16
4.	Edayar	$10^{o}4'N$	$76^{o}17'E$	15
5.	Eloor	$10^{o}4'N$	$76^{o}17'E$	10
6.	Ernakulam	$9^{o}57'N$	$76^{o}15'E$	2

3.1.2. Collection of water samples

Water samples of 6000 mL were collected from surface and bottom at each station using a 'Ruttner' water sampler made of perspex. The sampler was of 1L capacity. Water samples were

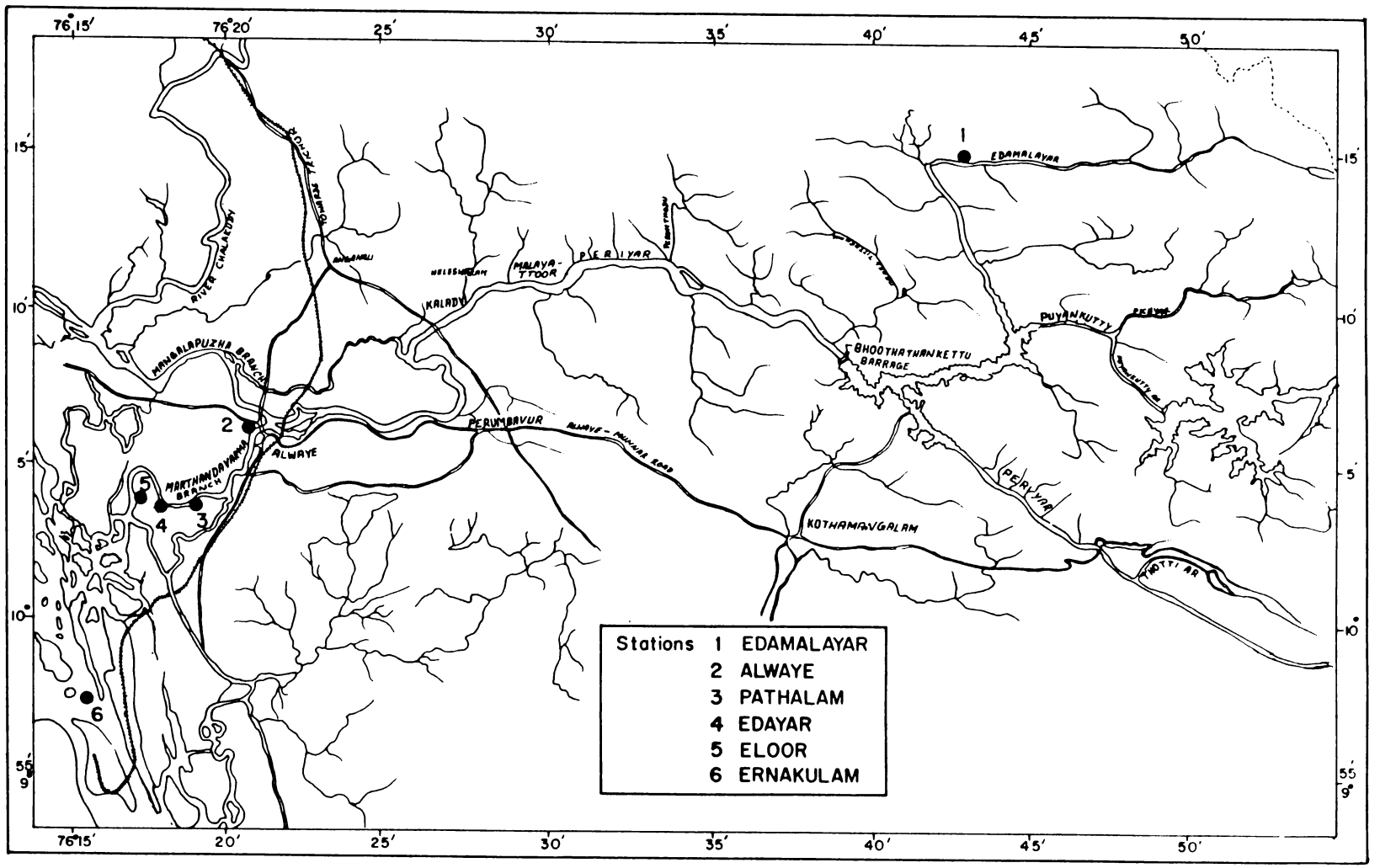

Fig. 3. Location of sampling stations

collected by lowering the sampler from a country boat at 3 points at each station, one at the midstream and others from one third distance from either bank. Sampling was done every fortnight for a period of one year starting from January 1986. The fortnightly values were averaged to find the monthly means at each station. Water temperature, pH, stream depth and Secchi disc transparency were recorded at each station during sampling. Temperature was read with a mercury thermometer calibrated $1/10^{o}C$. pH value of the samples were measured using a portable pH meter (L.G. Nester, phase IV). Stream depth was determined by lowering a weighted graduated string into the river. The depth of the light penetration was measured using Secchi disc (Welch, 1948).

The samples for analysing dissolved oxygen were siphoned into 150 mL glass bottles and fixed in manganous sulphate followed by alkali-iodide-azide reagent. The samples for salinity estimation were stored in special salinity bottles. 25 mL sample was fixed in Lugol's iodine to examine the phyto-plankton composition. The remaining samples collected were stored in polyethylene bottles and taken to the laboratory under cool dark conditions within 4 hr of collection. The samples for analysing biochemical oxygen demand (BOD) were incubated immediately after reaching the laboratory. The water samples for estimation of chlorophyll and nutrients were filtered and stored in a refrigerator until analysed.

3.1.3. Analytical Methods

The water samples were analysed for the following parameters:

Salinity, Dissolved oxygen (DO), Biochemical oxygen demand (BOD), Nitrite (NO_2^--N), Nitrate (NO_3^--N), Ammonia (NH_3 -N), Phosphate (PO_4^{3-}-P), Chlorophylls and Pheopigments.

Salinity was determined by titration with silver nitrate solution. The value for chlorinity was obtained from hydrographical tables (Knudsen, 1901).

Dissolved oxygen was determined by titration against standard sodium thiosulphate (APHA, 1985).

Biochemical oxygen demand of the undiluted samples were determined according to the method described by APHA (1985).

The procedure given by APHA (1985) was used to estimate nitrite. The method is based on the formation of a pinkish azo-dye on addition of sulphanilamide and N-(1-naphthyl)-ethylene diamine dihydrogen chloride. The optical density was measured at 543 nm in a Hitachi spectrophotometer (model 200-20).

Nitrate was reduced to nitrite by passing through a cadmium reduction column and determined as nitrite. The optical density was measured at 543 nm in spectrophotometer. The nitrate concentration was read from a standard graph (APHA, 1985).

The phenolhypochlorite method of Solórzano (1969) was used to estimate ammonia. The optical density was measured at 640 nm and the concentration was read from standard graph.

Phosphate was determined by the ascorbic acid method (APHA, 1985). The absorbance was measured at 880 nm and concentration obtained from standard graph.

Chlorophyll and pheopigments were estimated by filtering 1 L each of the samples through Whatman GF/C filter papers (pore size 0.45 μ m). 1 mL of 1% magnesium carbonate suspension was added to the samples while filtering. The filters were extracted in 90% acetone under cool dark conditions (refrigerator) for 20 hr. The acetone extracts were centrifuged at 4000 rpm for 15 minutes and the absorbance measured at 750, 664, 647 and 630 nm in a spectrophotometer. The extracts were then acidified with 1 N HCl and the absorbance read at 750 and 665 nm according to the procedure of Lorenzen (1967). The amount of pigments were computed from the equations of Jeffrey and Humphrey (1975) and Lorenzen (1967).

The water samples that were fixed in Lugol's iodine (APHA, 1985) were examined microscopically (Zeiss Telaval 2 Inverted Microscope) to assess the phytoplankton composition.

3.1.4. Analyses of Data

The monthly distribution of hydrographic features is represented graphically. The sampling year has been divided

into three seasons: monsoon (June to September), postmonsoon (October to January) and premonsoon (February to May). The data were analysed using Student's t-test to find whether there was any significant difference between surface and bottom samples. The spatial variation of the variables was assessed by Page's L (trend) test (Ray Meddis, 1975). A multiple regression relationship was set up with chlorophyll as the dependent variable and the hydrological features such as pH, temperature, dissolved oxygen, nitrite, nitrate, ammonia and phosphate as independent variables (Steel and Torrie, 1960). All calculations were done in a WIPRO PC/XT computer.

3.2. Laboratory Methods

3.2.1. Test Algae

Axenic cultures of two freshwater algae: Nitzschia palea (Kütz) W.Sm. and Oocystis pusilla Hansgirg var. major Skuja were isolated from the upstream of river Periyar. Cultures were developed according to the standard procedure (Stein, 1973). The taxonomy of the species is given below.

Division	:	Chrysophyta
Class	:	Bacillariophyceae
Order	:	Bacillariales
Family	:	Nitzschiaceae
Genus	:	Nitzschia (Hassall, 1845; W. Smith) Grunow Ch. em., 1880.

Species : palea (Kütz) W.Sm. (S.B.D., ii.,p. 89; H.V.M. Atl., pl. 69, f. 22b and 22c; in Types Nos. 165, 196, 343 and 479; different varieties in Types Nos. 411 and 413), plate 17, fig. 554.

Valves linear lanceolate with apices shortly rostrate. Length 25-65 μ m; breadth about 5 μ m; 33-36 striae per 10 μ m; freshwater in distribution (Heurck, 1896).

Division : Chlorophyta

Class : Chlorophyceae

Order : Chlorococcales

Family : Oocystaceae

Genus : Oocystis Naegeli in A. Braun, 1855, p 94.

Species : pusilla Hansgirg

A. Hansgirg, 1890, p 9; H. Printz, 1913, p 181, pl 4, f 31-32; J. Brunnthaler, 1915, p 124; G.W. Prescott, 1951, p 246, pl 51, f 15, pl 54, f 4-5 = Oocystis naegelii A. Br. var. minutissima Bernard, 1908, p 172.

Variety : major Skuja

H. Skuja, 1949, p 63 pl 9, f 18-28.

Cells solitary, elongate-ellipsoid with rounded ends measuring 6-11 μ m in length. Chromatophores 2-3, almost filling

the cell, cell division by formation of 2-4 autospores. Cell membrane thin without polar thickenings; distributed in freshwater (Philipose, 1967).

3.2.2. Maintenance medium

The algae were maintained as axenic cultures and tested for various parameters in freshwater medium, the composition of which is given below (Ward and Parrish, 1982). All nutrient solutions were prepared in glass distilled water.

Macronutrient stock solution

1. Dissolve 25.5 g $NaNO_3$ in 1 L water
2. Dissolve 12.2 g $MgCl_2 . 6 H_2O$ in 1 L water
3. Dissolve 14.7 g $MgSO_4 . 7 H_2O$ in 1 L water
4. Dissolve 4.41 g $CaCl_2 . 2 H_2O$ in 1 L water
5. Dissolve 15.0 g $NaHCO_3$ in 1 L water
6. Dissolve 1.044 g K_2HPO_4 in 1 L water

Micronutrient stock solution

1. Dissolve 0.78 g $CoCl_2$ in 1 L water
2. Dissolve 0.90 g $CuCl_2$ in 100 mL water
   Dilute 1 mL of this solution to 1 L for working stock solution
3. To 1 L water add 0.1855 g H_3BO_3, 0.2643 g $MnCl_2$, 0.0327g $ZnCl_2$, 0.0073 g $Na_2MoO_4 . H_2O$, 0.0960 g $FeCl_3$, 0.300 g Na_3 EDTA and 1 mL of micronutrient solutions (1) and (2).

The maintenance medium was prepared by adding 1 mL each of macronutrient solution and 1 mL of the micronutrient stock solution number (3) to 1 L of glass distilled water. The medium was autoclaved for 30 minutes at 121^{o}C and 1.1 kg cm^{-2}. The cool sterilised medium was equilibrated with filtered air for 24 hr. The pH of the medium was between 7.6 and 8.2. The maintenance medium was transferred to sterilised 150 mL conical flasks (Borosil glass) plugged with non-absorbent cotton. The cultures were inoculated under aseptic conditions and exposed to illumination from day-light fluorescent lamp assembly $\simeq$ 2000 μ W.cm^{-2} on a 12:12 light-dark cycle at 27 $\pm$ 1^{o}C. The cultures were shaken at 6 hr interval on a rotary shaker at 100 rpm.

3.2.3. Test Procedure

The standard procedure for algal toxicity test (Ward and Parrish, 1982) was followed throughout the study. Both the species were maintained and tested in the same medium. Axenic cultures of *Nitzschia palea* and *Oocystis pusilla* var. *major* at exponential phase of growth were inoculated into 75 mL each of test media in 150 mL culture flasks so as to yield 1 x 10^{4} cells mL^{-1}. All tests were performed in triplicate. Cultures were incubated on a uniformly illuminated rotary shaking platform under identical conditions as in the case of maintenance cultures. Test duration was 96 hr.

After incubation, aliquots of cultures were fixed in Lugol's iodine and the cell number was counted using haemocytometer.

The photosynthetic pigments were estimated by spectrophotometric method (Jeffrey and Humphrey, 1975). Cultures of N. palea (50 mL) were filtered through Whatman GF/C (pore size 0.45 μ m) and extracted in 90% acetone (Vollenweider, 1974). Cultures of O. pusilla var. major were filtered (50 mL) through Sartorius membrane filters (pore size 0.45 μ m) and extracted in dimethyl sulfoxide (DMSO) because it did not give satisfactory extraction with acetone (Burnison, 1980). The absorbance was measured in a spectrophotometer at 664, 647, 630 and 480 nm.

3.2.4. Growth kinetics of test algae

The test species were inoculated into 750 mL medium in 1 L culture flasks in triplicate and incubated for 16 days. Aliquots of culture were removed every 24 hr to enumerate the cell count which were subsequently plotted on semi-logarithmic graph paper to obtain the growth curve.

The growth rate was calculated as doublings per day (k) according to the equation of Eppley and Strickland (1968).

$$k \text{ (division/day)} = \frac{3.32}{t-t_0} (\log_{10} n_t - \log_{10} n_{t_0})$$

where time is in 24 hr day, $3.32 = \log_2 10$, n_t = final cell number, n_{t_0} = initial cell number, $t-t_0$ = final-initial (days).

The doubling time or generation time (t_g) was calculated as follows

$$t_g = \frac{\ln 2}{k} = \frac{0.69}{k} (h^{-1}) = \frac{16.5}{k} (days^{-1})$$

On alternate days, 50 mL each of the cultures was filtered to estimate chlorophyll a, b, c and carotenoid. Chlorophylls were computed using equations of Jeffrey and Humphrey (1975) and carotenoid using that of Strickland and Parsons (1968). The mean value of the replicates were plotted on a graph paper to obtain the growth curves.

3.2.5. Nitrate requirement of test species

Nitrogen starved cultures of *Nitzschia palea* and *Oocystis pusilla* var. *major* were used to determine the nitrate requirement of the species (Eppley and Thomas, 1969; Dortch, 1982). The inoculum was prepared by growing the test algae in nitrogen-free maintenance medium for 96 hr so that the cells were nitrogen starved. Nitrogen depletion was indicated by reduction of growth rate and change in colour of the culture. These were inoculated into media of nitrate concentrations 1, 3, 5, 10, 15, 20 and 25 μ g-at NO_3-N L^{-1} to give an initial cell density of 1 x 10^4 cells mL^{-1}. The test concentrations were prepared by adding the required amount of Analytical Reagent grade sodium nitrate to the maintenance medium devoid of nitrogen. The cultures were harvested after 96 hr incubation to measure the cell count and photosynthetic pigments. The growth rate was plotted as a function of nitrate on a graph

paper. Half-saturation constant (K_s) and maximum growth rate (k'_{max}) were determined graphically (Thomas, 1970).

3.2.6. Phosphate requirement of test species

Test media of phosphate concentration 0.16, 0.32, 0.48, 0.64, 0.96, 1.28 and 1.60 μ g-at PO_4-P L^{-1} were prepared by adding the required amount of Analytical Reagent grade potassium dihydrogen phosphate to the maintenance medium devoid of phosphorus. Phosphate starved cultures of Nitzschia palea and Oocystis pusilla var. major were used to determine the phosphate requirement of the species (Thomas and Anne, 1968; Qasim and Joseph, 1975). The inoculum was prepared by growing the test algae in phosphorus-free maintenance medium for 96 hr so that the cells were phosphorus starved. Phosphorus depletion was indicated by reduction of growth rate. Phosphate depleted test algae were inoculated to a final concentration of 1×10^4 cells mL^{-1} and incubated for 96 hr. The cell counts and photosynthetic pigments were determined and the data analysed as in 3.2.5.

3.2.7. Salinity tolerance

The test was conducted in maintenance media having 0, 5, 10, 15 and 20×10^{-3} salinity. The saline medium was prepared by adding Analytical Reagent grade sodium chloride to the maintenance medium. The test conducted in triplicate was of 96 hr duration. The cells were harvested after incubation

to determine the cell counts and photosynthetic pigments.

The exponential growth constant, k' was computed from the cell count using the formula

$$k' = \ln (N_{t_1}/N_0)/t_1-t_0$$

where N_{t_1} = final cell count, N_0 = initial cell count, t_1-t_0 = period of exposure in days (Reynolds, 1984). The significance of k' was tested by Student's t-test (Snedecor and Cochran, 1967).

3.2.8. Toxicity test

Algal assays were conducted to study the response of the test species to liquid wastes collected from the fertilizer factory producing nitrogen and phosphorus fertilizers located on the banks of river Periyar. The effluent collected from the discharge point every 3 hr interval were mixed to get a homogeneous sample which was then stored and kept cool in polyethylene container. In the laboratory the sample was filtered first through absorbent cotton and then through Whatman glass microfiber filters (GF/C) of pore size 0.45 μ m to remove all the suspended materials (Walsh et al., 1980). The filtrate was stored in clean polyethylene container, and kept in refrigerator at 4^{o}C until use.

The effluent was analysed immediately after filtration to estimate the following parameters: pH, Chemical Oxygen Demand (COD), ammonia, phosphate and fluoride. COD was determined

by the Open Reflux Method described by APHA (1985). The effluent was refluxed with sulphuric acid in the presence of excess potassium dichromate and titrated with ferrous ammonium sulphate.

Fluoride content was measured by complexing the acid-distilled effluent (APHA, 1985) with lanthanum - alizarin reagent according to the procedure described by Martin (1968).

The effluent was allowed to attain room temperature and further filter sterilized using Whatman GF/C filter papers. Same quantity of macro and micro nutrients used to prepare maintenance medium were added to the effluent samples for enrichment.

The enriched effluent was diluted using maintenance medium to get different dilutions of the effluent, keeping the concentration of added nutrients unaffected. These diluted effluent grades were used for the assays.

A preliminary range finding test using 10, 25, 50, 75 and 100% effluent was conducted to choose the concentrations for definitive tests. The concentrations of 5, 10, 30, 50, 70 and 90% and 5, 10, 15, 20, 25 and 30% effluent were selected for Nitzschia palea and Oocystis pusilla var. major respectively. Tests were carried out in triplicate. The maintenance medium was used as control.

The cell number and photosynthetic pigments were determined after 96 hr incubation. EC_{50} (interpolated or

calculated concentration of a toxicant that would inhibit population growth or any other biological process of algae by 50% compared to the controls in a specific period of time) was obtained graphically by plotting effluent concentration against percentage inhibition of growth (cell count) on a semi-logarithmic graph (Walsh, 1987). The exponential growth constant k' was computed and the significance tested by Student's t-test.

The values of EC_{50} were used to compute the 7 day, 10 year low-flow volume (Q_r) required for safety in the river receiving effluent, following the relation given by Walsh et al. (1982).

$$0.01 \times EC_{50} = \frac{Q_w}{Q_r + Q_w} \times 100$$

where Q_w = volume of discharge of effluent, Q_r = the 7 day, 10 year low-flow volume of the receiving water and 0.01 = a safety factor currently used by US EPA in instream waste concentration calculations for issuance of discharge permits.

In order to assess the recovery of the test species after 96 hr exposure to the effluent, in each case 1 mL of the culture was transferred aseptically to 75 mL of sterilised control medium contained in 150 mL flasks. These resuspension cultures were incubated for a period of 9 days and harvested to determine the cell number. The growth rates were compared by Student's t-test.

3.2.9. Toxicity vs. salinity

Tests were conducted to assess the variation of toxicity at EC_{50} effluent concentration in different salinities using test species. Two sets of test media were prepared, controls and treatments. Controls were prepared by adding Analytical Reagent grade sodium chloride to the maintenance medium to obtain 5, 10, 15 and 20 x 10^{-3} salinities. These were inoculated with the test species, which served as controls. Treatment media were prepared in EC_{50} concentration of effluent having the same salinities as in control. N. palea and O. pusilla var. major were acclimated for 96 hr in respective EC_{50} effluent concentrations. The acclimated species were inoculated into the treatment media. Both control and treatment cultures were incubated for 96 hr. The cultures were harvested after incubation to determine cell counts and photosynthetic pigments. The effect of salinity on effluent toxicity was evaluated statistically.

3.2.10. Toxicity at low nitrate concentration vs. ammonia

Experiments were conducted using the test species to assess the variation of toxicity at EC_{50} effluent concentration in different ammonia levels when the nitrate concentration was low. For this the maintenance medium was modified by keeping nitrate concentration at 25 μ g-at NO_3-N L^{-1}. After conducting range finding tests using Analytical Reagent grade ammonium chloride in modified maintenance medium the concentrations for definitive tests were selected. In both

test species definitive test concentrations selected were 0.04, 0.08, 0.16, 0.32, 0.64, 0.80 and 2.40 μ g-at NH_3-N L^{-1}. The modified maintenance media containing different ammonia concentrations were served as the controls. Treatment media containing selected concentrations of ammonia were prepared in the same manner by substituting the maintenance media with EC_{50} effluent concentration to which nutrient solutions having 25 μ g-at NO_3-N L^{-1} were added.

Test species acclimated for 96 hr in maintenance medium containing 25 μ g-at NO_3-N L^{-1} were inoculated into control and treatment media. These cultures were harvested after an incubation period of 96 hr to determine the cell counts and photosynthetic pigments. The data were analysed by Student's t-test.

3.2.11. Toxicity at high nitrate concentration vs. ammonia

The toxicity experiments (3.2.10) were repeated with 500 μ g-at NO_3-N L^{-1}, which is approximately the highest concentration found in the industrial area of river Periyar.

3.2.12. Toxicity at low nitrate concentration vs. phosphate

Identical toxicity experiments (3.2.10) were repeated using selected definitive test concentrations of phosphate, keeping nitrate at 25 μ g-at NO_3-N L^{-1}. Analar Reagent grade potassium dihydrogen phosphate was used to prepare concentrations

of 0.60, 1.80, 5.40, 16.20 and 48.60 μ g-at PO_4-P L^{-1}.

3.2.13. Toxicity at high nitrate concentration vs. phosphate

The experiment (3.2.12) was repeated with 500 μ g-at NO_3-N L^{-1}.

CHAPTER 4

OBSERVATIONS AND RESULTS

4.1. Field Observations

Analyses of hydrographic parameters of river Periyar indicated distinct seasonal and spatial variations in water quality. During the period of observation, this region had received ≃ 2400 mm of rainfall through the monsoon and post-monsoon months. The rate of discharge of water in the river was maximum in August (1838.92 Mm^3) and it touched the minimum (66.70 Mm^3) in April as measured at the gauging station near Kalady (PWD, 1986). The river bed was exposed at many locations upto Alwaye, the river being reduced to a narrow stream of clear shallow water during the months of April and May. In June, with the onset of South West monsoon the water level rose and the water turned muddy and reddish brown in colour due to land run off. Observations on the different parameters investigated are detailed below.

4.1.1. Depth and Secchi disc transparency

The depth of the water column at different stations varied from 75 to 420 cm (Figure 4; Appendix I). It was maximum during postmonsoon. The ratio of Secchi disc visibility to depth indicated that the extent of light penetration was high in premonsoon and low during monsoon (Table 5).

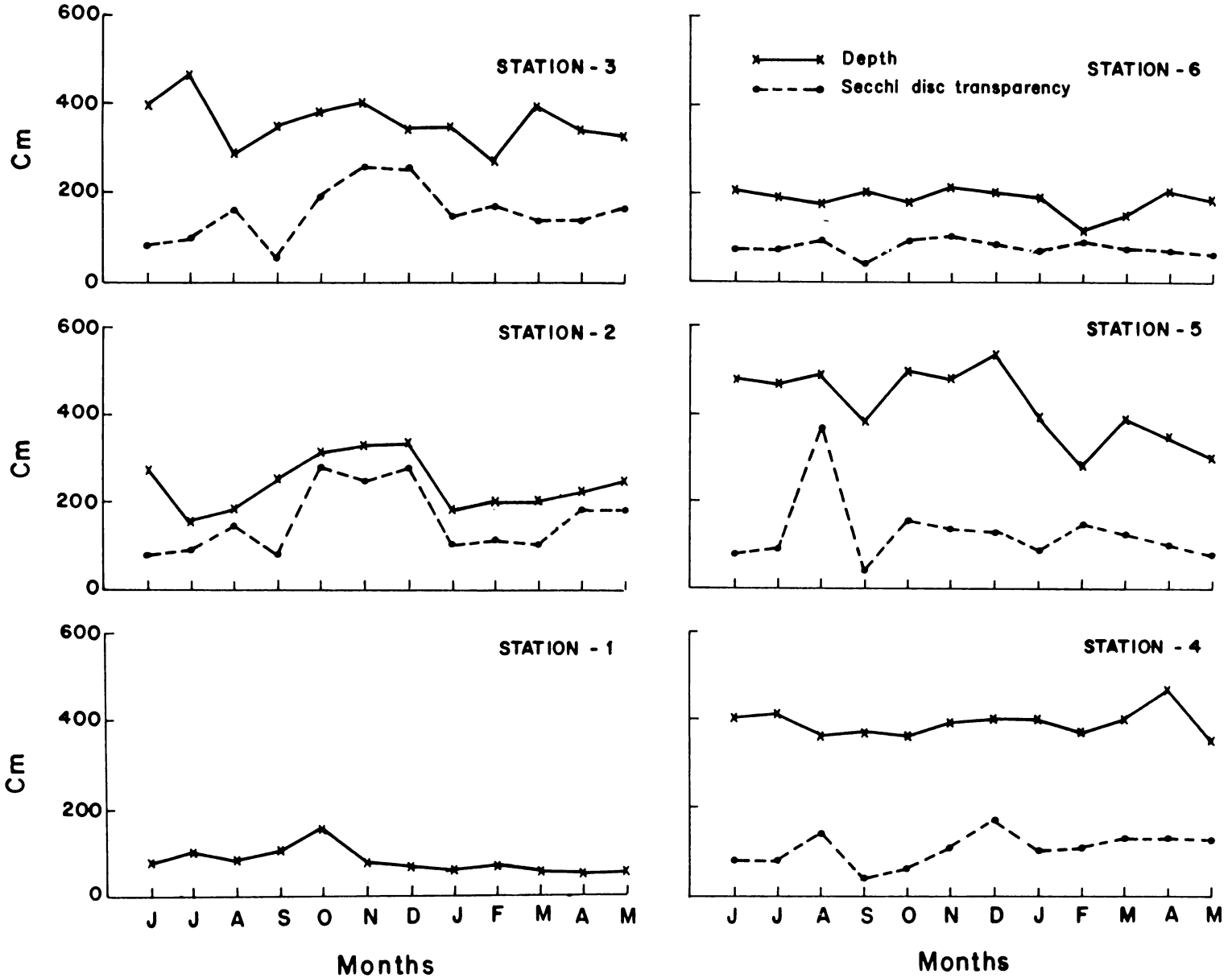

Fig. 4. Depth and secchi disc transparency at different stations during the the period January to December 1986.

Statistical analysis (Page's L (trend) test) showed that there was no significant difference in Secchi disc transparency between the stations (Table 6).

TABLE 5

Ratio of Secchi disc visibility to depth at the sampling stations for a period of one year (1986)

Sampling period	Stations 1	2	3	4	5	6
June	1.00	0.30	0.21	0.21	0.16	0.35
July	1.00	0.58	0.21	0.20	0.19	0.37
August	1.00	0.83	0.55	0.39	0.76	0.57
September	1.00	0.32	0.17	0.12	0.11	0.22
October	1.00	0.90	0.49	0.18	0.32	0.50
November	1.00	0.79	0.65	0.28	0.28	0.48
December	1.00	0.83	0.74	0.44	0.24	0.41
January	1.00	0.61	0.43	0.30	0.23	0.37
February	1.00	0.85	0.68	0.30	0.54	0.78
March	1.00	0.73	0.36	0.35	0.32	0.50
April	1.00	0.64	0.41	0.29	0.29	0.33
May	1.00	0.69	0.52	0.37	0.43	0.33

TABLE 6

Results of Page's L (trend) test showing the parameters studied and computed 'Z' values

Parameters	Computed 'Z' value
Secchi disc transparency	0.63
Temperature	3.36*
pH	1.07

Parameters	Computed 'Z' value
Salinity	2.62*
Dissolved oxygen	-1.99
Biochemical Oxygen Demand	2.84*
Nitrite	2.91*
Nitrate	-1.12
Ammonia	4.68*
Phosphate	3.21*
Chlorophylls	3.29*
Pheopigments	2.77*

* Significant at 5 percent level.

4.1.2. Temperature

Temperature of the surface and bottom layers of the water column did not differ significantly as indicated by t-test (Appendix II). Temperature was lowest during monsoon months and it gradually increased towards premonsoon (Figure 5; Appendix III). The range of temperature was from 24.5^{o} to 34.8^{o}C. There was significant spatial variation in temperature (Table 6). During the monsoon and postmonsoon seasons the temperature was lowest at station 1 and it gradually increased towards station 6. During premonsoon, station 4 recorded the highest temperature, to be followed by stations 5, 3, 6, 2 and 1 in the decreasing order.

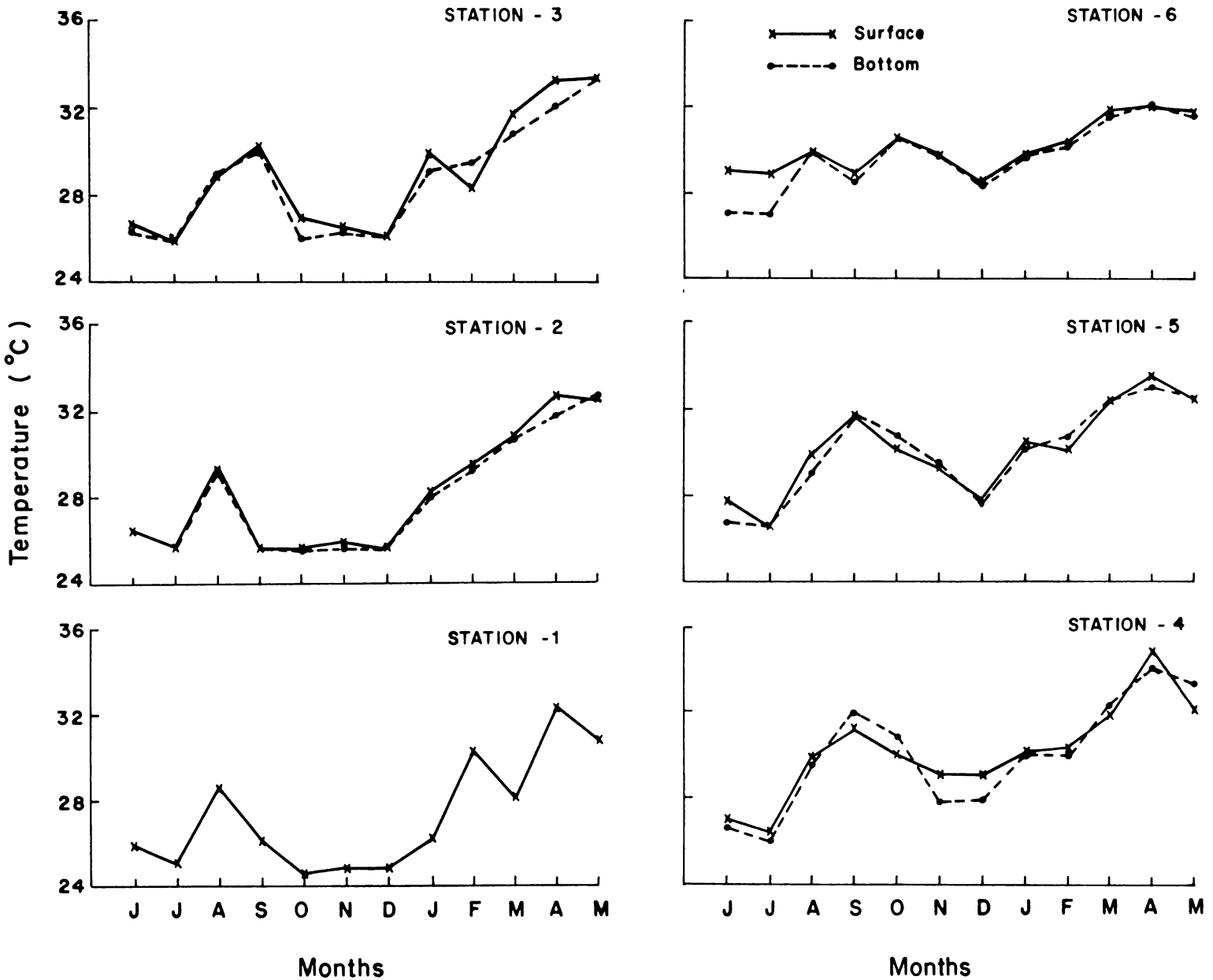

Fig. 5. Temperature recorded at different stations during 1986

4.1.3. pH

The pH of the water column did not differ significantly between surface and bottom (Appendix IV). There was no significant spatial variation as well (Table 6). The pH of the water column in the various stations was generally in the normal range (Figure 6; Appendix V). However, occasional lowering of pH was observed at stations 4 and 5 during premonsoon. The pH at station 4 was 3.94 and 3.96 in the months of May and February respectively and that at station 5 was 4.07 in April.

4.1.4. Salinity

The annual fluctuation in salinity is represented in Figure 7. The data obtained (Appendix VI) showed that stations 1 to 3 were purely freshwater regions while at station 4 the water was saline during premonsoon. At station 5, salt water intrusion occurred from postmonsoon onwards. Station 6 exhibited salinity throughout the year, ranging from 0.57×10^{-3} to 8.15×10^{-3} during monsoon, from 2.34×10^{-3} to 25.78×10^{-3} during postmonsoon and from 12.09×10^{-3} to 24.94×10^{-3} during premonsoon months. The maximum salinity observed at stations 4 and 5 were 9.78×10^{-3} and 14.79×10^{-3} respectively. It was observed that there was no significant variation in salinity between surface and bottom samples except at stations 4 and 5 (Appendix VII). In these stations, the bottom layer was more saline than the surface water. Table 7 represents the rating of the stations according to increasing salinity.

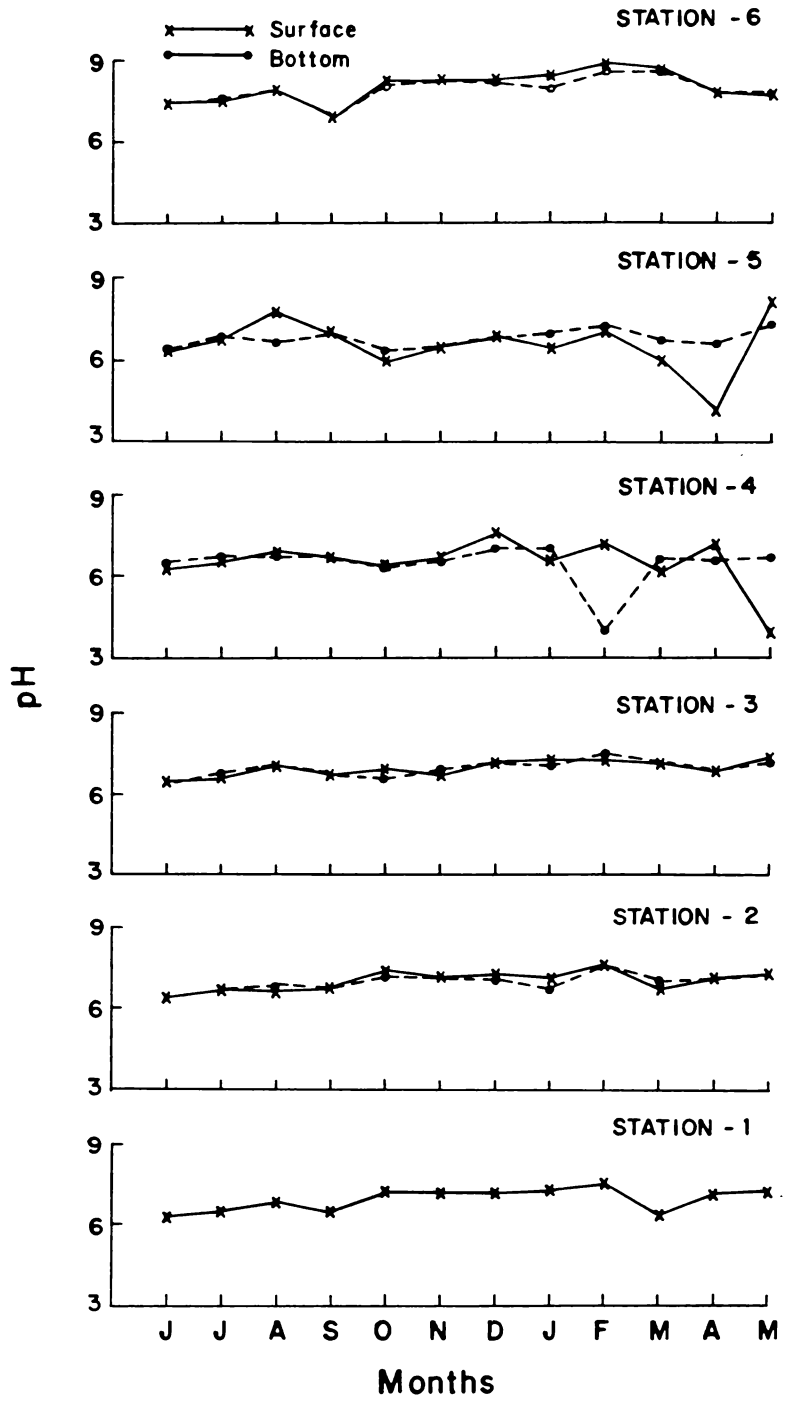

Fig. 6. pH recorded at different stations during 1986

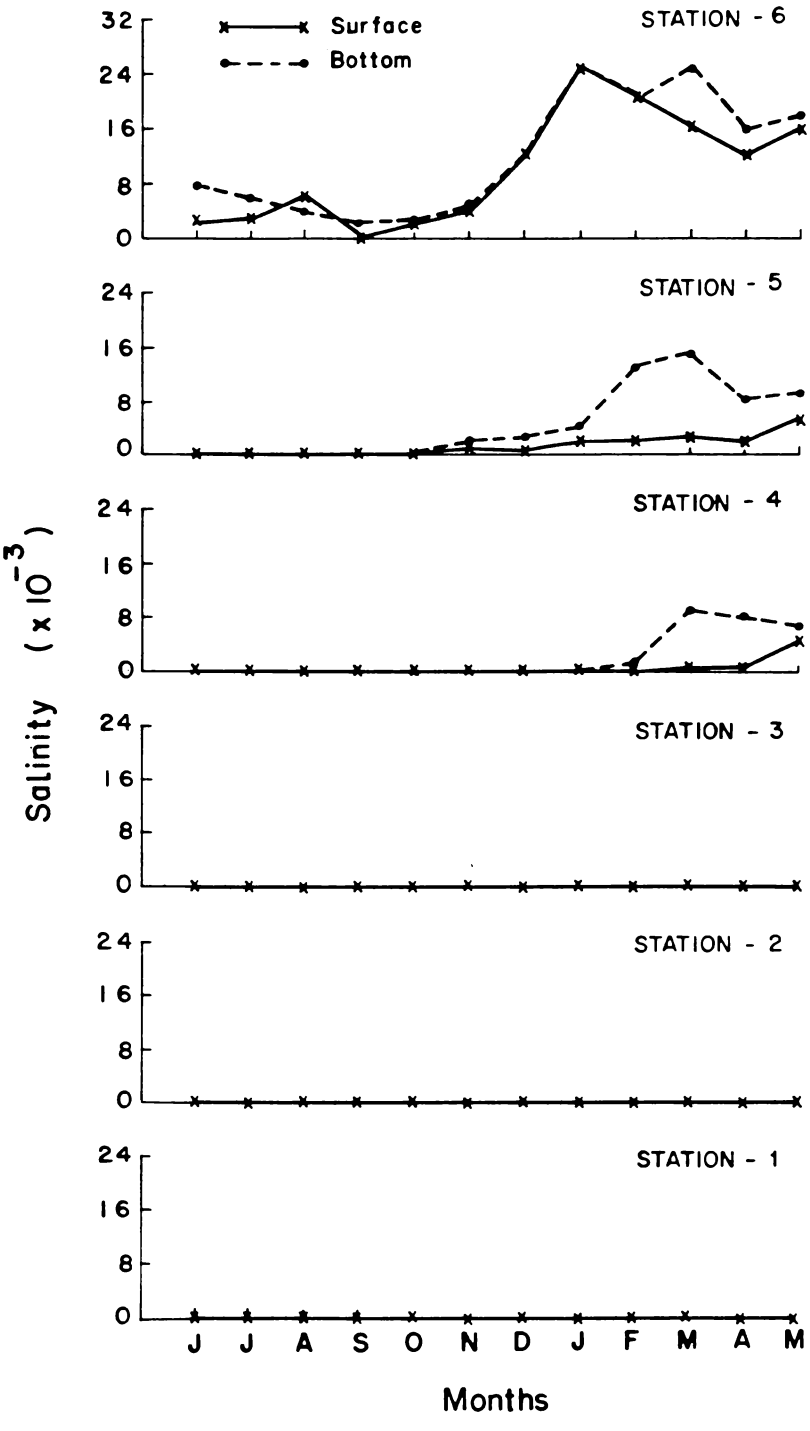

Fig. 7. Salinity recorded at different stations during 1986

TABLE 7

Ranking of the stations according to increasing salinity as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	3	3	3	3	3	6
Postmonsoon	2.5	2.5	2.5	2.5	5	6
Premonsoon	2	2	2	4	5	6

4.1.5. Dissolved Oxygen

The concentration of dissolved oxygen in the water ranged from 3 to 12.95 mg L^{-1} (Figure 8; Appendix VIII). There was no significant variation between the stations (Table 6). The oxygen level of surface and bottom waters did not differ significantly except at stations 4 and 5 (Appendix IX). At stations 4 and 5 the level of oxygen in the bottom layers was very low during the months of March, April and May. In general, the amount of dissolved oxygen was high during postmonsoon compared to the rest of the year.

4.1.6. Biochemical Oxygen Demand (BOD)

BOD ranged from 0.2 to 6.11 mg L^{-1} (Figure 9; Appendix X). Within this range there was significant variation between stations (Table 6). Station 1 had the lowest BOD during monsoon and postmonsoon. During this period station 4 and station 5 had highest BOD. In premonsoon, least BOD occurred at station 3 followed by station 1, 2, 4, 6 and 5 (Table 8).

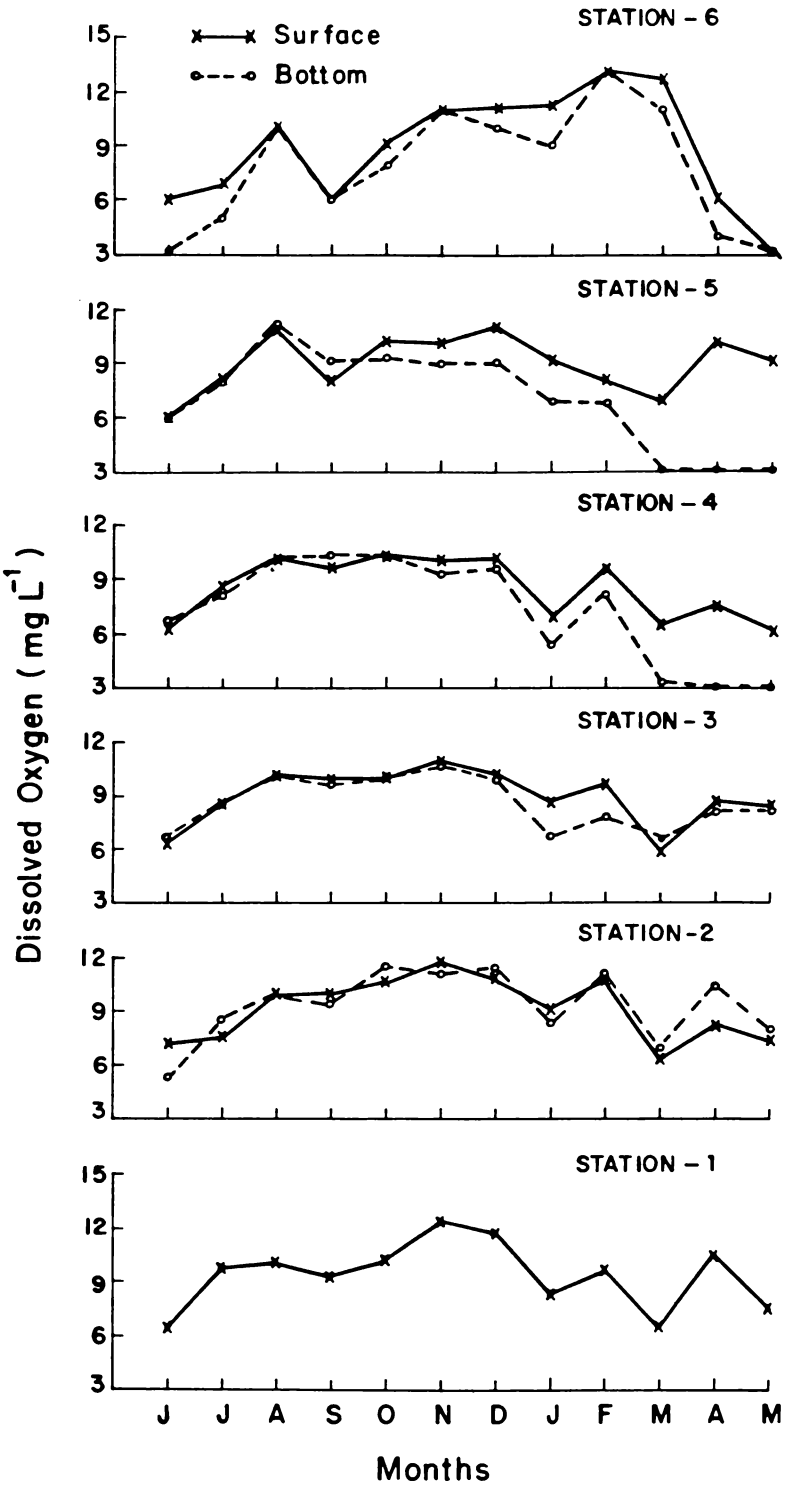

Fig. 8. Dissolved oxygen recorded at different stations during 1986

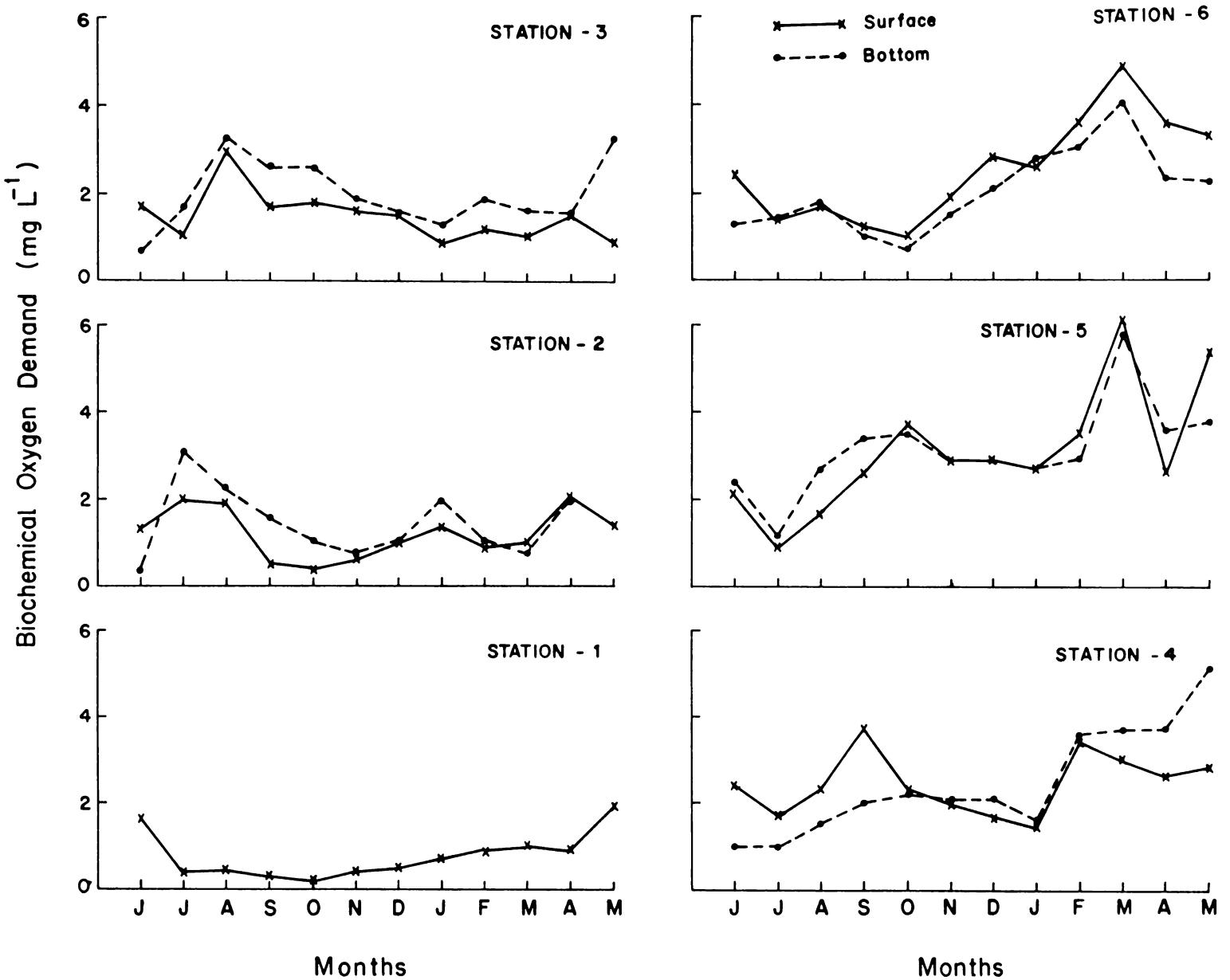

Fig. 9. Biochemical oxygen demand recorded at different stations during 1986

TABLE 8

Ranking of the stations according to increasing biochemical oxygen demand as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	1	2	5	6	4	3
Postmonsoon	1	2	3	4	6	5
Premonsoon	2	3	1	4	6	5

The surface and bottom samples did not show significant variation except at station 3, where the bottom values were higher (Appendix XI).

4.1.7. Nitrite

The concentration of nitrite-N in the water ranged from 0.0 to 48.0 μ g-at L^{-1} (Figure 10; Appendix XII). There was no significant difference between surface and bottom samples except at station 4. At station 4, the nitrite level was high in the bottom water (Appendix XIII). Significant variation was observed to occur between the various stations (Table 6). During monsoon, the upstream stations (stations 1 to 3) showed minimum nitrite content and this increased in the order of stations 4, 5 and 6. During postmonsoon and premonsoon, station 5 recorded the maximum nitrite-N while station 3 had the least (Table 9).

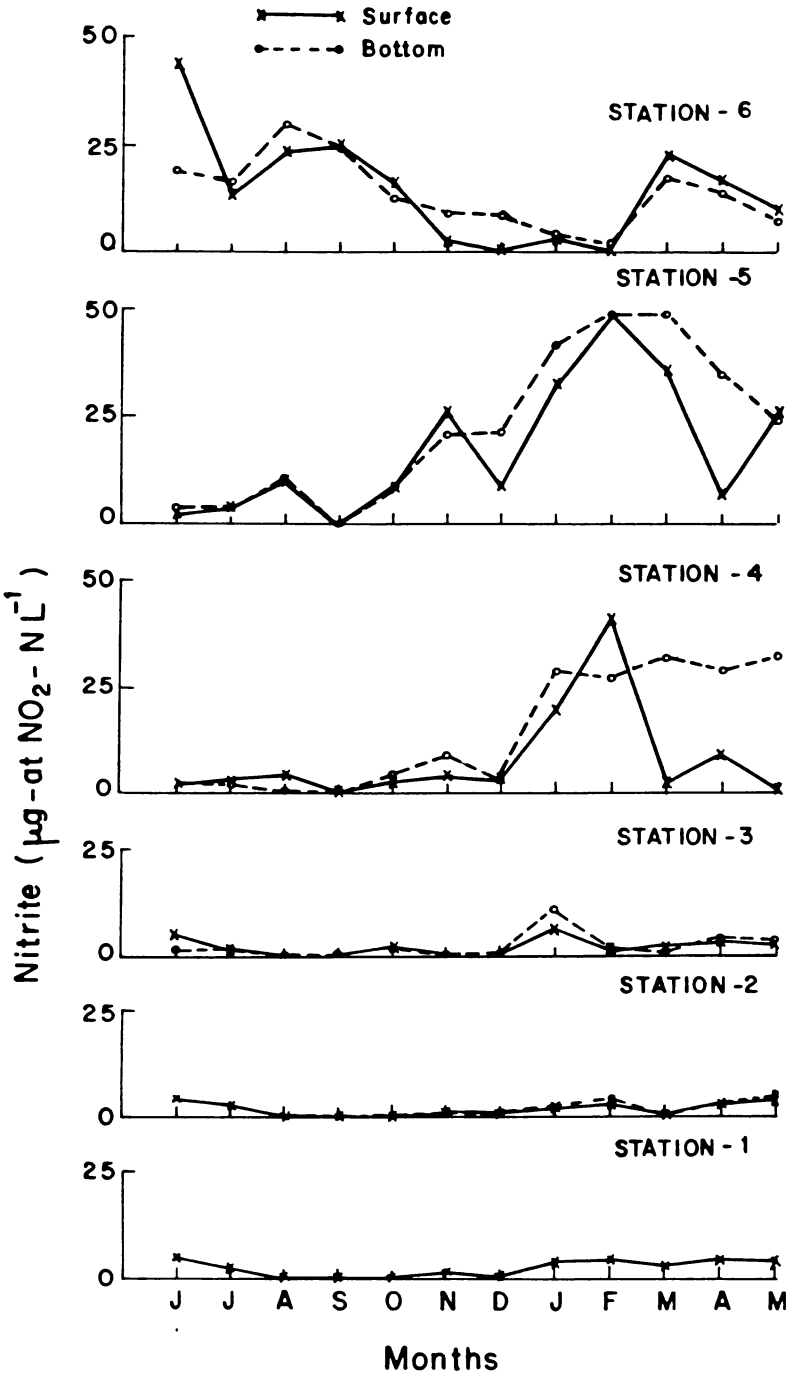

Fig. 10. Nitrite recorded at different stations during 1986

TABLE 9

Ranking of the stations according to increasing nitrite as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	2	2	2	4	5	6
Postmonsoon	1	2	3	5	6	4
Premonsoon	4	2	1	3	6	5

4.1.8. Nitrate

The level of nitrate-N in the water samples varied from 50.6 to 406.0 μ g-at L^{-1} (Figure 11; Appendix XIV). There was no significant variation between the stations (Table 6). The annual mean values of nitrate in the surface and bottom water also did not differ significantly (Appendix XV). The data revealed that the level of nitrate was high during monsoon and low during premonsoon.

4.1.9. Ammonia

The concentration of ammonia at the various sampling stations ranged from 0.0 to 65.71 μ g-at L^{-1} (Figure 12; Appendix XVI). Surface-bottom variation was significant only at stations 3 and 6 (Appendix XVII). In both these stations the amount of ammonia in the surface water was higher than the bottom layer. The result of analyses of Page's L (trend) test showed significant spatial variation (Table 6). The three upstream stations had relatively low ammonia while stations

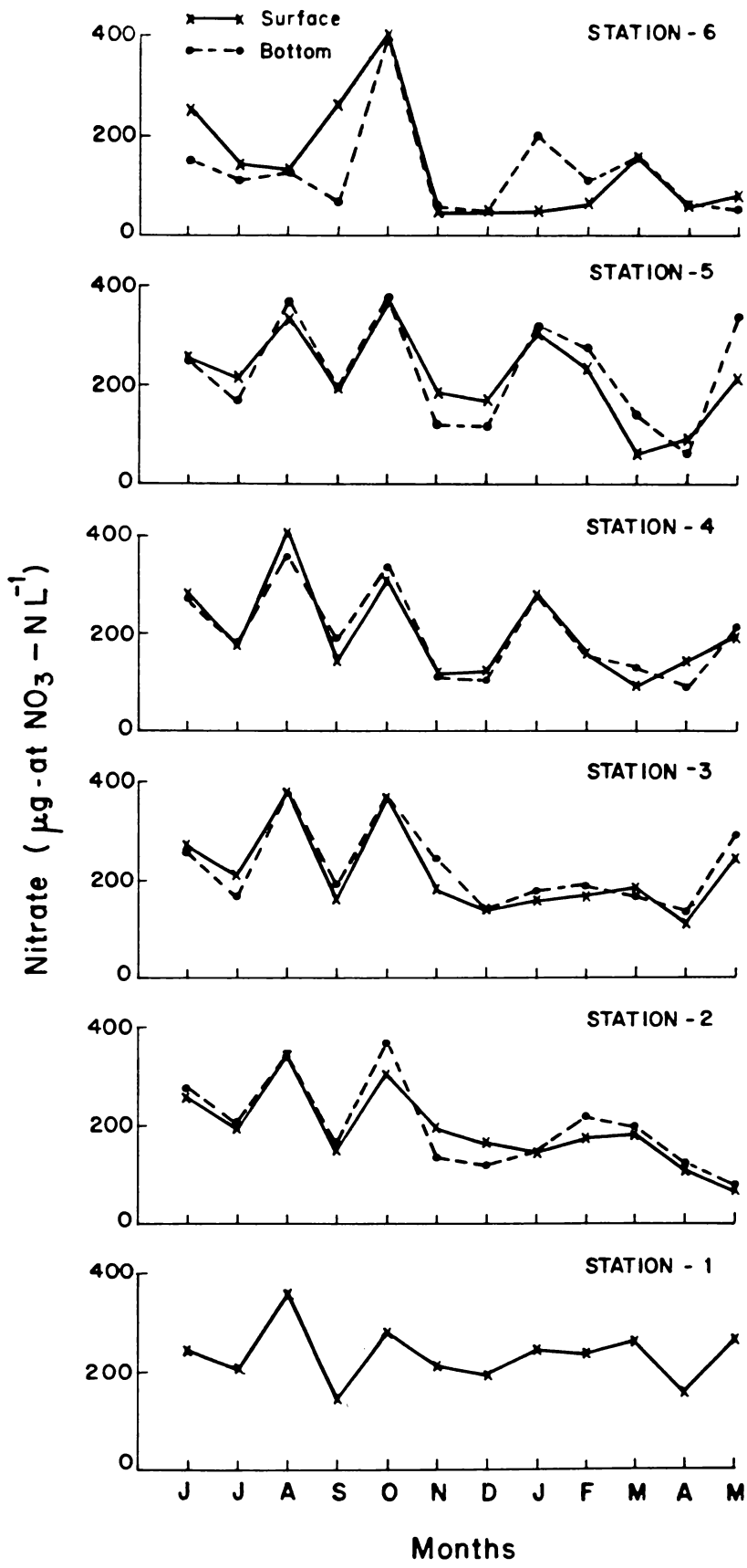

Fig. 11. Nitrate recorded at different stations during 1986

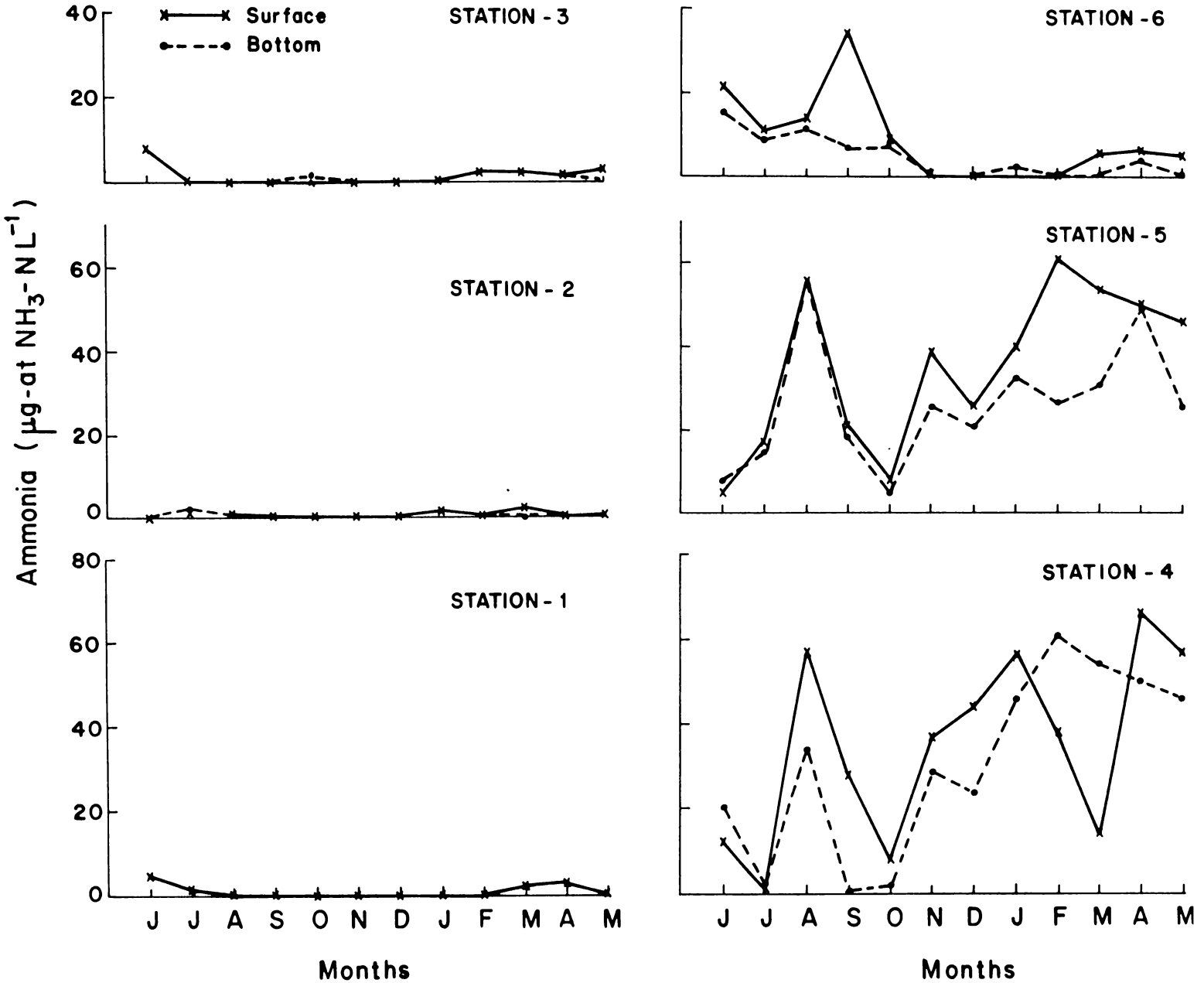

Fig. 12. Ammonia recorded at different stations during 1986

4 and 5 recorded the highest values. At these stations the level of ammonia was high during premonsoon and decreased in the monsoon months. The highest concentration of ammonia observed during monsoon and premonsoon months was at station 5 while during postmonsoon, station 4 recorded the highest (Table 10). At station 6 the concentration of ammonia was nearly same in all seasons.

TABLE 10

Ranking of the stations according to increasing ammonia as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	2	1	3	5	6	4
Postmonsoon	1	3	2	6	5	4
Premonsoon	2	1	3	5	6	4

4.1.10. Phosphate

Distribution of phosphate showed distinct seasonal (Figure 13)and spatial variation(Table 6). The values ranged from 0.0 to 64.58 μ g-at PO_4-P L^{-1} (Appendix XVIII). The phosphate level was low during monsoon and high in premonsoon. There was no significant difference between the surface and bottom samples (Appendix XIX). The phosphate content was almost undetectable in stations 1 to 3, but there was sharp increase in phosphate level at stations 4 and 5. This increase was maximum during premonsoon when station 5 recorded the highest, stations 4 and 6 following. During monsoon station 6 had the

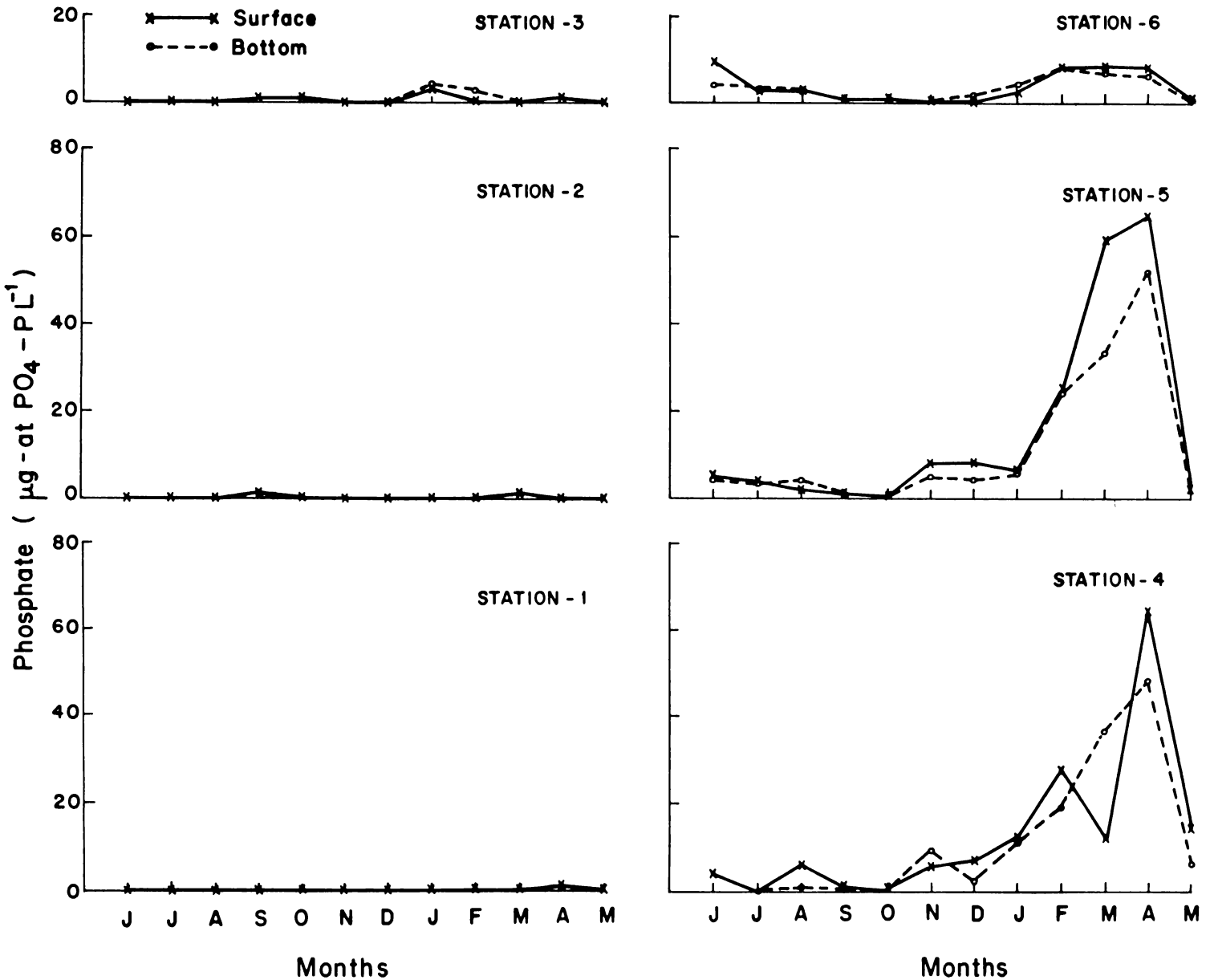

Fig. 13. Phosphate recorded at different stations during 1986

highest amount of phosphate although the magnitude was far below that of the premonsoon peaks in stations 4 and 5 (Table 11).

TABLE 11

Ranking of the stations according to increasing phosphate as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	1	3	2	4	5	6
Postmonsoon	1	2	3	6	5	4
Premonsoon	2	1	3	5	6	4

4.1.11. Species composition of phytoplankton

The distribution of phytoplankton varied qualitatively and quantitatively from stations 1 to 6. The freshwater zone upto station 3 (Pathalam) was dominated by green algae and a few diatoms, many of which were only sparsely distributed. Stations 4 and 5 were dominated by blue-green algae; diatoms and green algae occurred frequently. Chlorococcales was the predominant green algae in stations 4 and 5 while in the upstream sites desmids dominated. Station 6 had typical marine forms such as *Skeletonema costatum*, *Chaetoceros* sp., *Gymnodinium* sp. etc. The distribution of major phytoplankton species is given in Table 12.

TABLE 12

Species composition of phytoplankton at different sampling stations

+++ Abundant; ++ Frequent; + Rare; - Absent; D = Diatom; B = Blue-green algae; G = Green algae; Di = Dinoflagellate; E = Euglenineae.

Sl. No.	Name of algae	Algal group	Degree of occurrence at different stations					
			1	2	3	4	5	6
1.	Amphora coffeaeformis	D	-	-	-	-	-	++
2.	Anabaena sp.	B	-	-	+	+++	+++	-
3.	Anacystis sp.	B	+	+	+	++	++	-
4.	Asterionella japonica	D	-	-	-	+	+	++
5.	Cerataulina bergonii	D	+	+	-	-	+	+
6.	Ceratium furca	Di	-	-	-	-	-	++
7.	Chaetoceros sp.	D	-	-	-	-	+++	+++
8.	Chlamydomonas sp.	G	++	++	+	+	-	-
9.	Chlorella sp.	G	++	++	++	++	++	-
10.	Closterium sp.	G	++	++	+	+	+	-
11.	Cosinodiscus gigas	D	-	-	-	+	++	+++
12.	Cosmarium sp.	G	++	++	+	+	-	-
13.	Cyclotella maneghiniana	D	+	+	+	-	-	-
14.	Cymbella sp.	D	-	-	+	+	++	++
15.	Eudorina sp.	G	+	++	+	-	-	-
16.	Euglena viridis	E	-	-	+	++	++	+
17.	Fragilaria sp.	D	-	-	+	+	+	++
18.	Gonyaulax sp.	Di	-	-	-	-	+	++
19.	Gymnodinium sp.	Di	-	-	-	-	++	++
20.	Hydrodictyon sp.	G	++	++	+	+	+	-
21.	Lyngbya sp.	B	-	-	-	++	++	+
22.	Melosira sulcata	D	-	-	-	+	++	++
23.	Microcystis sp.	B	-	-	-	++	+++	+
24.	Mougeotia sp.	G	++	++	+	-	-	-

Sl. No.	Name of algae	Algal group	Degree of occurrence at different stations 1	2	3	4	5	6
25.	Navicula gracilis	D	-	-	-	++	++	+
26.	Netrium sp.	G	++	++	+	-	-	-
27.	Nitzschia closterium	D	-	-	-	+	++	+++
28.	Nitzschia palea	D	+	+	++	++	+	+
29.	Nostoc sp.	B	-	-	-	++	+++	-
30.	Oocystis pusilla	G	++	++	+	+	-	-
31.	Oscillatoria sp.	B	-	-	-	+++	+++	-
32.	Pandorina sp.	G	++	++	+	-	-	-
33.	Pediastrum duplex	G	++	++	+	+	+	-
34.	Peridinium sp.	Di	-	-	-	-	+	++
35.	Pinnularia sp.	D	+	+	+	-	-	-
36.	Pleodorina sp.	G	++	+	+	++	+	-
37.	Pleurosigma angulatum	D	-	-	-	+	++	+++
38.	Rhizosolenia sp.	D	-	-	-	-	+	++
39.	Rivularia sp.	B	++	++	+	++	++	-
40.	Scenedesmus quadricauda	G	+	+	+	++	++	-
41.	Skeletonema costatum	D	-	-	-	+	+++	+++
42.	Spirotaenia sp.	G	++	++	+	+	-	-
43.	Spirulina sp.	B	-	-	-	+	++	-
44.	Staurastrum sp.	G	++	++	++	-	-	-
45.	Surirella sp.	D	+	+	+	-	-	-
46.	Synechocystis sp.	B	-	-	-	-	+	++
47.	Synedra sp.	D	-	-	-	-	-	+
48.	Thalassionema sp.	D	-	-	-	+	++	++
49.	Thalassiosira pseudonana	D	-	-	-	+	++	+++
50.	Volvox sp.	G	++	++	+	-	+	-

4.1.12. Chlorophyll

The standing stock of phytoplankton in terms of chlorophyll pigments was low during monsoon. The highest

concentrations occurred in premonsoon (Figure 14, 15, 16). The amount of chlorophyll *a* varied from 0.20 to 54.48 mg m^{-3} (Appendix XX), that of chlorophyll *b* from 0.20 to 28.04 mg m^{-3} (Appendix XXI) and chlorophyll *c* from 0.11 to 22.26 mg m^{-3} (Appendix XXII). The total amount of chlorophyll (Chlorophyll *a*+*b*+*c*) did not vary significantly in the surface and bottom except at station 6 (Appendix XXIII). At station 6 the surface water was more productive than the bottom layer. Result of analysis using Page's L (trend) test showed that there was significant spatial variation in chlorophyll level (Table 6). Station 1 was the least productive while station 6 was found to be the most productive except in premonsoon. The chlorophyll values in the backwater station indicated a primary peak in premonsoon and a secondary peak in postmonsoon. In premonsoon highest amount of chlorophyll pigments were recorded in station 5, station 4 being the next highest (Table 13). Generally chlorophyll *a* occurred in greater quantity than chlorophyll *b* and chlorophyll *c*.

Estimate of chlorophyll *a* using Lorenzen's method (Lorenzen, 1967) gave slightly different values (Appendix XXIV), but it was found by Student's t-test that these values did not differ significantly from the results of trichromatic method of Jeffrey and Humphrey, 1975 (Appendix XXV).

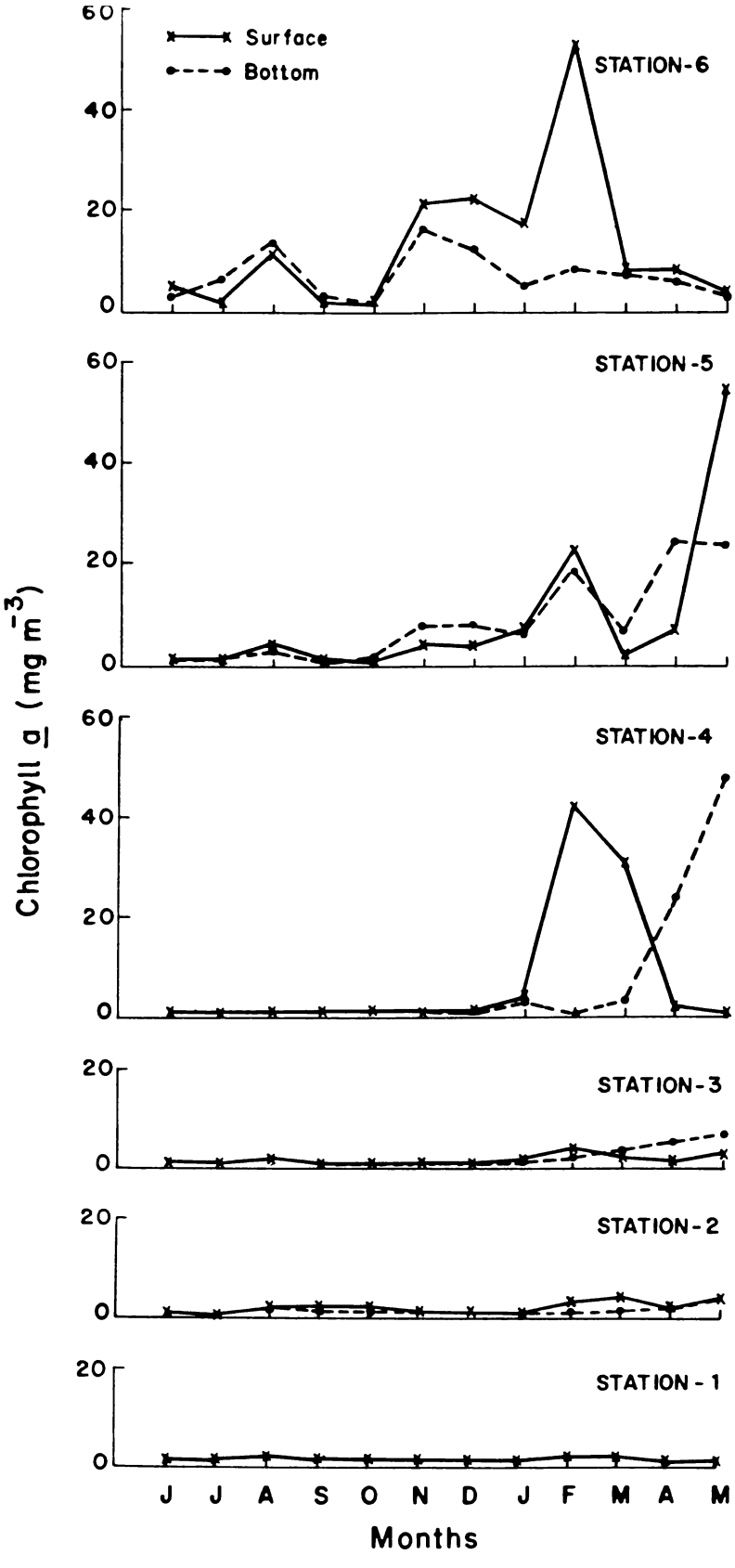

Fig. 14. Chlorophyll a recorded at different stations during 1986

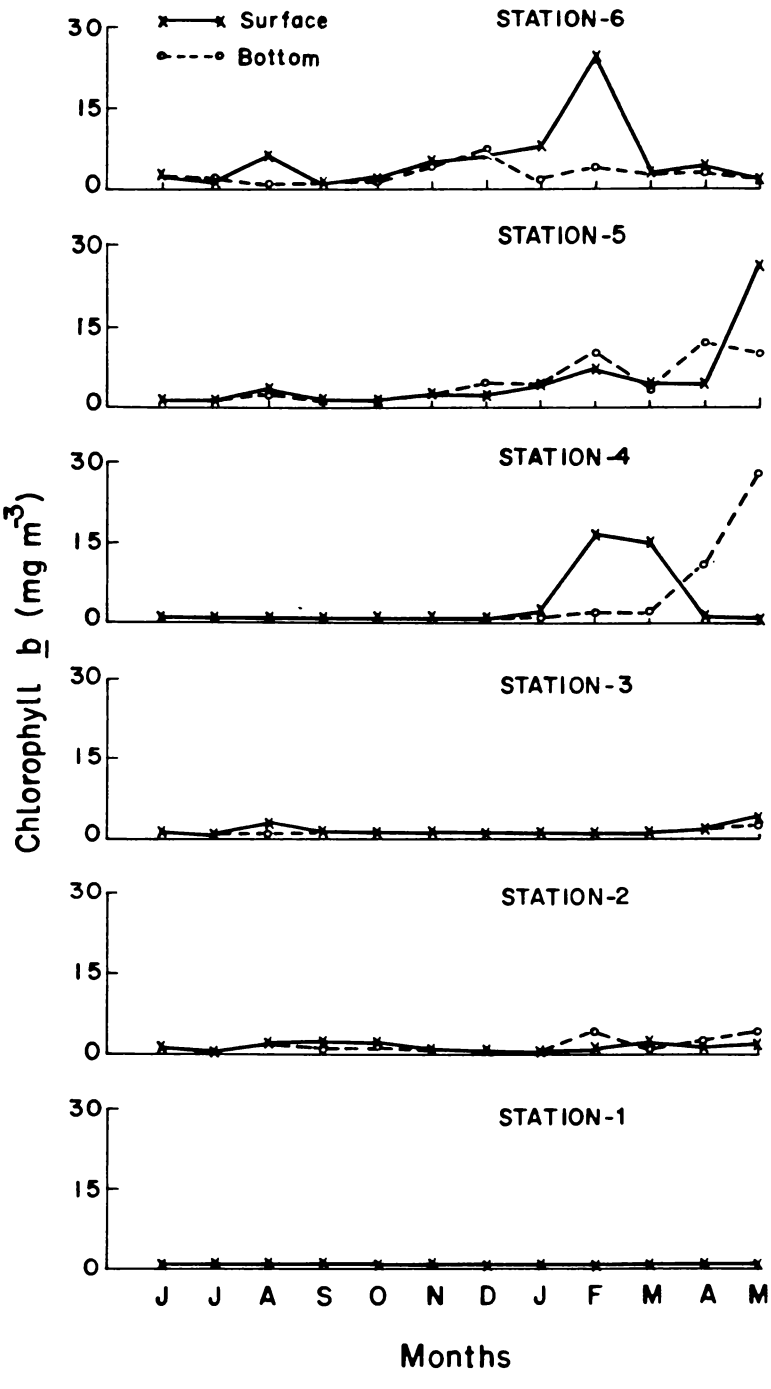

Fig. 15. Chlorophyll b recorded at different stations during 1986

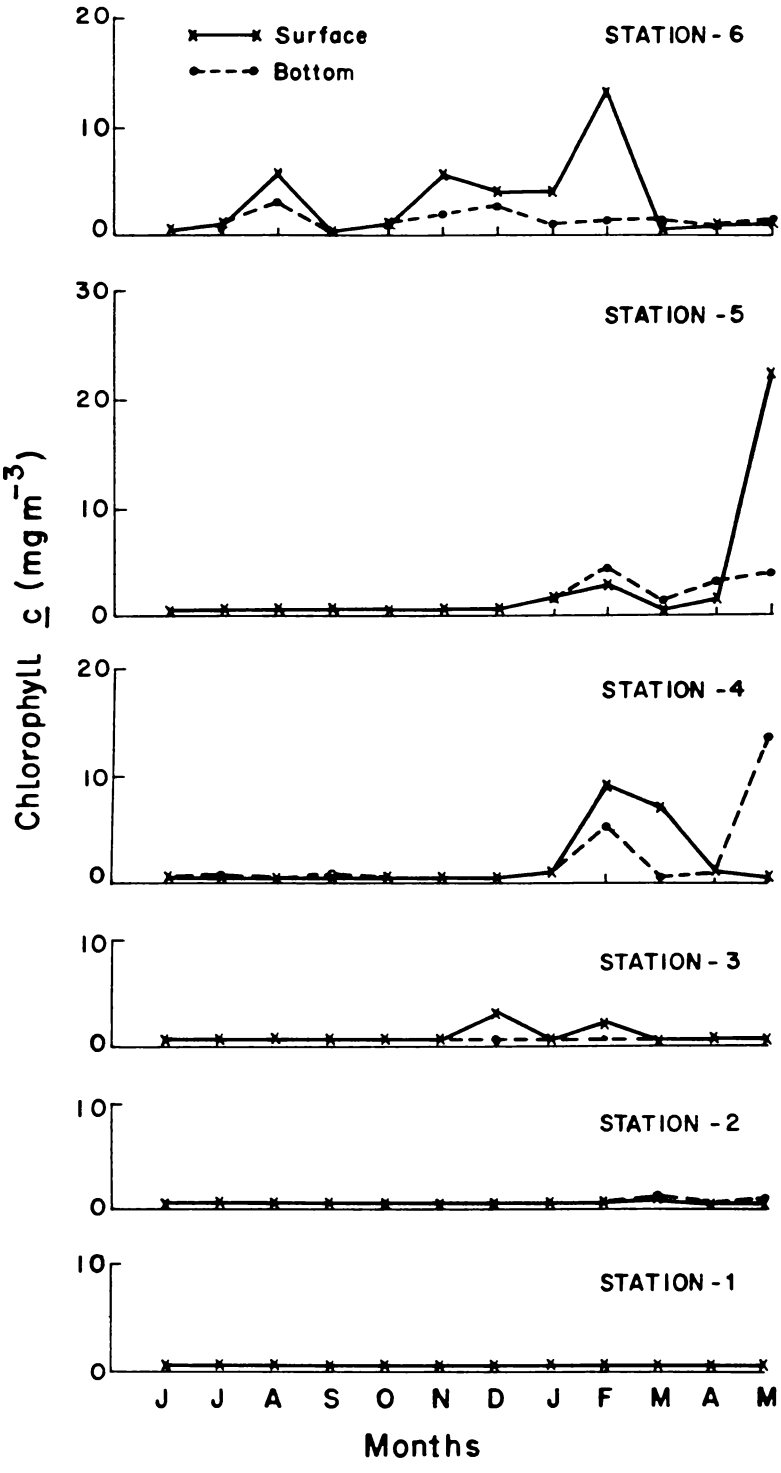

Fig. 16. Chlorophyll c recorded at different stations during 1986

TABLE 13

Ranking of the stations according to increasing chlorophyll as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	1	3	4	2	5	6
Postmonsoon	1	2	4	3	5	6
Premonsoon	1	3	2	5	6	4

4.1.13. Pheopigments

The distribution of pheopigments in the river is represented in Figure 17. Stations 1 to 3 exhibited only traces of pheopigments throughout the year. At stations 4 to 6, the magnitude of pheopigments was low during monsoon, and increased during postmonsoon and premonsoon. The values ranged from 0.03 to 54.13 mg m^{-3} (Appendix XXVI). Significant spatial variation also occurred (Table 6). During monsoon and premonsoon station 1 had the least amount of pheopigments while in postmonsoon, station 4 recorded the least. Station 6 had the highest pheopigment level in postmonsoon and premonsoon and the second highest in monsoon months (Table 14). Comparing the surface and bottom samples it was found that they were statistically same except at station 5 (Appendix XXVII).

TABLE 14

Ranking of the stations according to increasing pheopigment as per Page's L (trend) test

Season	Stations					
	1	2	3	4	5	6
Monsoon	1	3	4	3	6	5

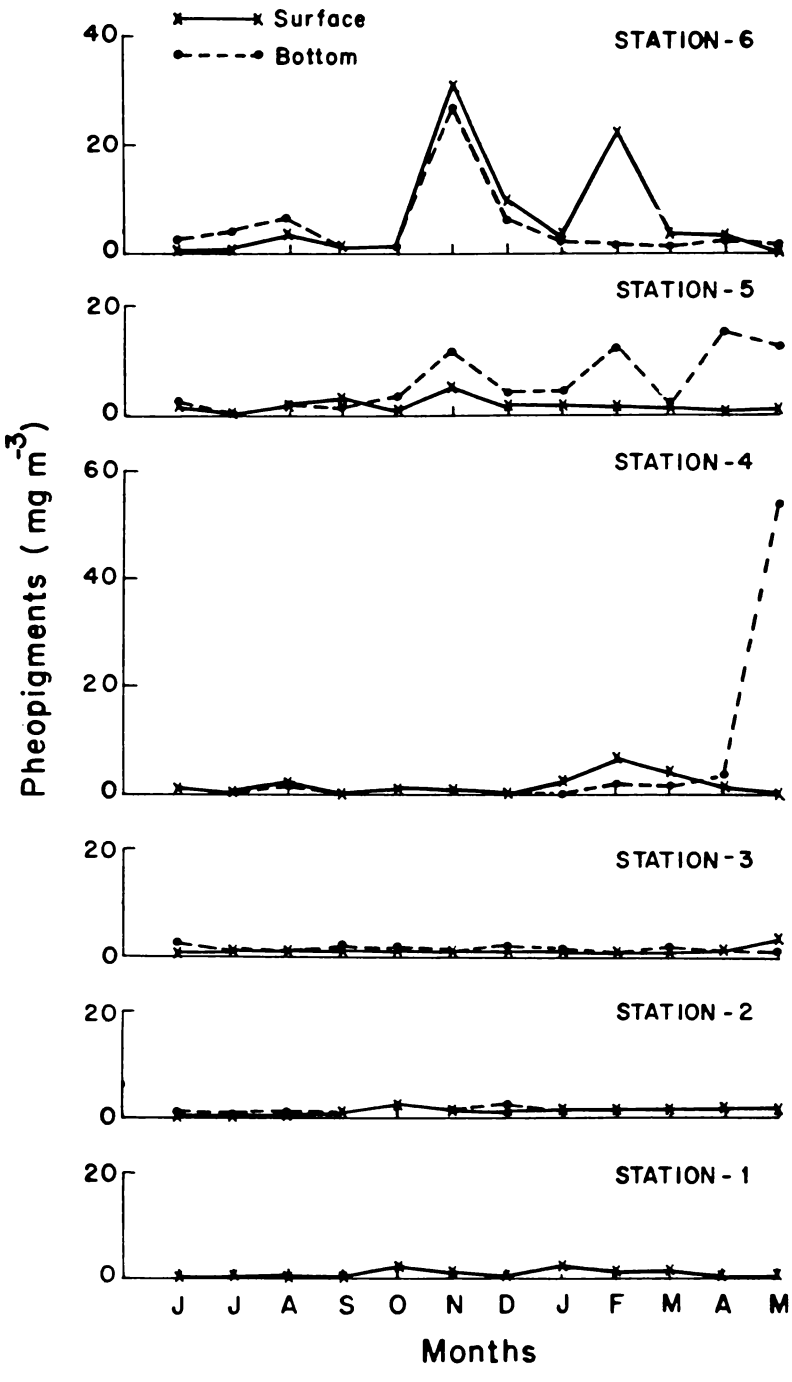

Fig. 17. Pheopigments recorded at different stations during 1986

Postmonsoon	3	2	4	1	5	6
Premonsoon	1	3	4	5	2	6

The ratio of the seasonal means of pheopigments to chlorophylls showed that the proportion of pheopigments was high during postmonsoon (Table 15). The fraction of pheopigments was less than 50% in all seasons except in stations 1 and 2 during postmonsoon.

TABLE 15

Ratio of pheopigments to total cholorophylls (%)

Stations	1	2	3	4	5	6
Monsoon	14.85	26.93	40.07	17.55	23.81	11.16
Postmonsoon	71.89	60.32	36.57	45.38	38.92	38.57
Premonsoon	31.06	21.91	21.98	19.80	4.57	19.88

Results of the multiple regression analyses revealed that phytoplankton production in the river and the estuarine zone was not under the influence of any common environmental factor, but it varied with the sampling station. This is detailed below.

Station 1. (Edamalayar)

The production of phytoplankton at station 1 was dependent on four factors such as temperature, dissolved oxygen,

nitrite and nitrate. The multiple correlation coefficient was 0.60. It was found that dissolved oxygen and nitrite were inversely proportional to chlorophyll while nitrate and temperature had positive correlation (Table 16). According to the order of importance the variables were nitrite, nitrate, temperature and dissolved oxygen.

TABLE 16

Results of multiple regression analysis of physico-chemical quality of water with chlorophyll at station 1 (Edamalayar)

Characters	Mean	Standard deviation	Regression coefficient	Standard error	Standard partial regression Coefficient	Grade
Temperature	27.27	2.58	0.12	0.04	0.40	3
Dissolved Oxygen	9.46	2.04	-0.15	0.05	0.38	4
Nitrite	2.44	2.11	-0.21	0.06	0.56	1
Nitrate	229.96	52.56	0.01	0.00	0.46	2

Station 2 (Alwaye)

The amount of chlorophyll at station 2 was dependent on six factors. They were in the order of importance of temperature, pH, dissolved oxygen, nitrate, phosphate and ammonia (Table 17). These factors had a correlation coefficient of 0.82. The regression coefficients indicated that dissolved oxygen and ammonia were negatively correlated to chlorophyll while the rest of the factors showed positive correlation.

TABLE 17

Results of multiple regression analysis of physico-chemical quality of water with chlorophyll at station 2 (Alwaye)

Characters	Mean	Standard deviation	Regression coefficient	Standard error	Standard partial regression Coefficient	Grade
pH	6.97	0.33	3.52	0.50	0.56	2
Temperature	28.06	2.59	0.47	0.05	0.58	1
Dissolved Oxygen	9.43	1.87	-0.53	0.09	0.48	3
Nitrate	200.4	78.03	0.01	0.00	0.26	4
Ammonia	0.52	0.77	-0.50	0.16	0.18	6
Phosphate	0.18	0.29	1.72	0.40	0.24	5

Station 3 (Pathalam)

At station 3 primary production was influenced by temperature, phosphate and nitrate in their order of importance (Table 18). The correlation coefficient was 0.55. Among these variables, phosphate was negatively correlated to chlorophyll, while temperature and nitrate showed positive correlation.

TABLE 18

Results of multiple regression analysis of physico-chemical quality of water with chlorophyll at station 3 (Pathalam)

Characters	Mean	Standard deviation	Regression coefficient	Standard error	Standard partial regression Coefficient	Grade
Temperature	28.84	2.57	0.63	0.00	0.75	1

Nitrate	206.39	92.40	0.004	0.00	0.17	3
Phosphate	0.65	1.05	-0.44	0.17	0.22	2

Station 4 (Edayar)

The standing stock of phytoplankton was dependent on pH, temperature, dissolved oxygen, nitrate and phosphate. The value of multiple correlation coefficient was 0.38. As per the standard partial regression coefficient the order of importance of these variables were temperature, dissolved oxygen, pH, nitrate and phosphate. Of these, dissolved oxygen, nitrate and phosphate were negatively correlated to chlorophyll while pH and temperature had positive correlation (Table 19).

TABLE 19

Results of multiple regression analysis of physico-chemical quality of water with chlorophyll at station 4 (Edayar)

Characters	Mean	Standard deviation	Regression coefficient	Standard error	Standard partial regression coefficient	Grade
pH	6.48	0.83	7.45	2.87	0.26	3
Temperature	24.99	2.41	4.80	1.27	0.49	1
Dissolved Oxygen	7.96	2.39	-3.98	1.12	0.40	2
Nitrate	203.31	88.87	-0.06	0.03	0.24	4
Phosphate	12.30	16.32	-0.58	0.21	0.40	5

Station 5 (Eloor)

At station 5 only two factors - pH and temperature were significantly affecting the chlorophyll production. The correlation coefficient was 0.45. Both these factors were positively related to chlorophyll and were of equal significance (Table 20).

TABLE 20

Results of multiple regression analysis of physico-chemical quality of water with chlorophyll at station 5 (Eloor)

Characters	Mean	Standard deviation	Regression coefficient	Standard error	Standard partial regression coefficient	Grade
pH	6.68	0.75	14.67	2.62	0.50	1
Temperature	30.06	2.20	4.99	0.89	0.50	1

Station 6 (Ernakulam)

At this station, none of the variables was found to show significant correlation with chlorophyll. The correlation coefficients were 0.25 and 0.24 in the surface and bottom samples respectively.

4.2. Laboratory Results

Results of the algal tests are given below.

4.2.1. Growth Kinetics of Test Algae

The culture of Nitzschia palea did not show a

significant lag phase. The cell number increased from 1 x 10^4 to 3.16 x 10^4 cells mL^{-1} in the first 24 hr of inoculation. The maximum growth rate occurred between the first and second day with a growth rate (k) of 2.06 divisions/day and generation time (t_g) of 8 hr. The rate of growth began to decline after four days of inoculation. The cultures attained stationary phase by the 8^{th} day and remained so till the 16^{th} day when the experiment was discontinued (Figure 18). Table 21 gives the cell counts, chlorophyll *a*, *c* and carotenoids of the species under the culture conditions. The pigments followed similar trend as that of the cell counts.

Cultures of *Oocystis pusilla* var. *major* exhibited a lag in growth in the first 24 hr following inoculation. The growth rate increased rapdily with k, 1.69 divisions/day and t_g, 10.16 hr on the second day of inoculation. Exponential growth continued on the 3^{rd} and 4^{th} days of inoculation. Stationary phase was attained by the 10^{th} day (Figure 19). Table 22 presents the variation in cell number and photosynthetic pigments in the cultures of *O. pusilla* var. *major*.

Table 23 provides a comparison between the growth rate of the two species. *O. pusilla* var. *major* built up higher biomass than *N. palea*, although the exponential growth rate was lower than the latter. The absolute amount of chlorophyll *a* was higher in *O. pusilla* var. *major* while *N. palea* had higher carotenoid content.

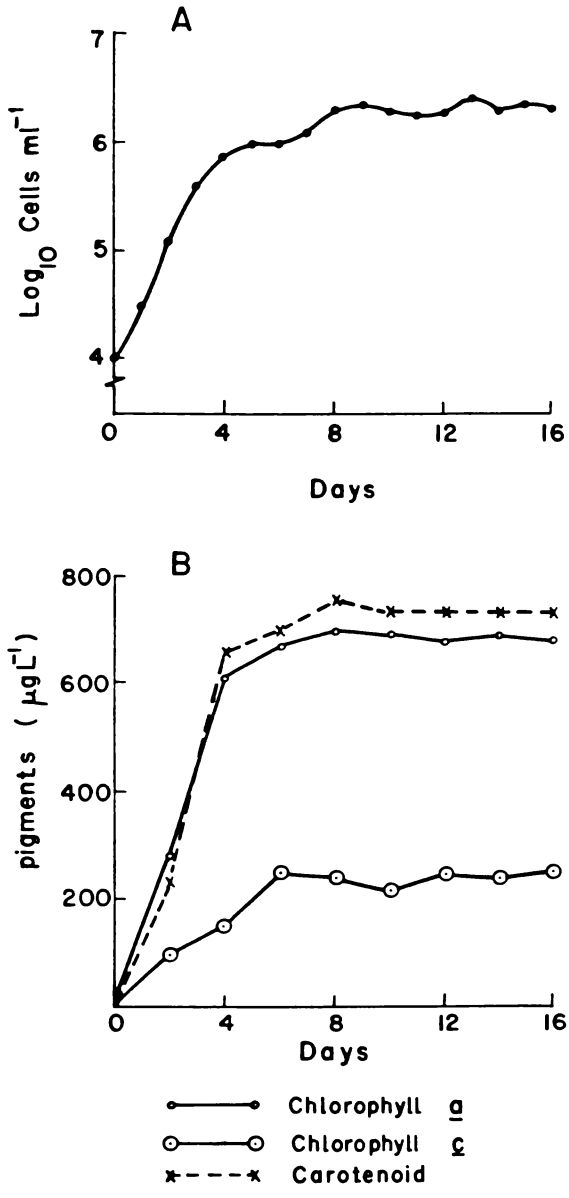

Fig. 18. Growth pattern of Nitzschia palea in axenic culture
A. Cell count B. Photosynthetic pigments

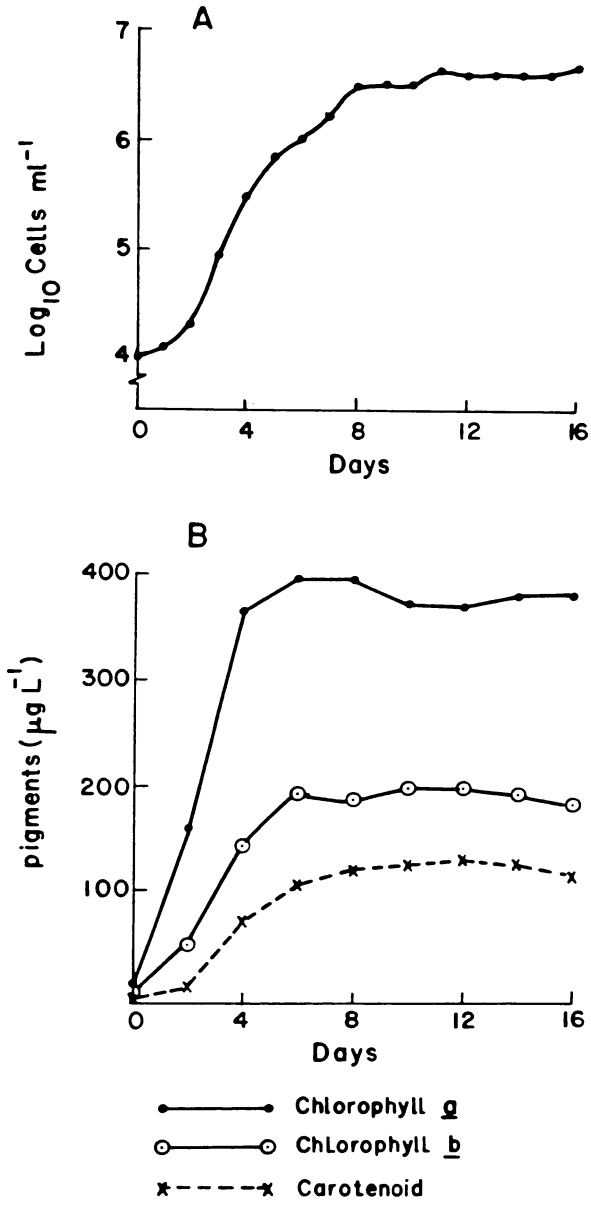

Fig. 19. Growth pattern of Oocystis pusilla var. major in axenic culture

A. Cell count B. Photosynthetic pigments

TABLE 21

Cell count and photosynthetic pigments of *Nitzschia palea* for a growth period of 16 days in axenic culture

Days	Cells mL^{-1} ($\times 10^4$)	Chlorophyll *a* ($\mu g\ L^{-1}$)	Chlorophyll *c* ($\mu g\ L^{-1}$)	Carotenoids ($\mu g\ L^{-1}$)
0	1.00	7.20	1.70	8.20
1	3.16	-	-	-
2	13.17	278.16	98.45	235.38
3	39.81	-	-	-
4	79.17	603.34	146.12	659.00
5	100.00	-	-	-
6	109.58	620.18	668.32	704.25
7	125.89	-	-	-
8	199.53	701.34	697.84	751.36
9	223.87	-	-	-
10	199.53	689.08	693.06	730.18
11	177.83	-	-	-
12	177.83	683.62	679.25	681.24
13	251.19	-	-	-
14	199.53	690.15	686.14	692.43
15	223.87	-	-	-
16	199.53	682.15	681.46	733.38

TABLE 22

Cell count and photosynthetic pigments of Oocystis pusilla var. major for a growth period of 16 days in axenic culture

Days	Cells mL^{-1} ($\times 10^4$)	Chlorophyll a ($\mu g\ L^{-1}$)	Chlorophyll b ($\mu g\ L^{-1}$)	Carotenoids ($\mu g\ L^{-1}$)
0	1.00	13.26	5.33	2.71
1	1.25	-	-	-
2	3.98	162.16	55.12	16.29
3	5.01	-	-	-
4	31.67	367.07	147.49	74.93
5	70.79	-	-	-
6	105.00	394.00	196.92	112.24
7	171.33	-	-	-
8	290.00	396.08	192.65	125.00
9	301.67	-	-	-
10	331.67	374.24	200.00	129.28
11	436.51	-	-	-
12	398.11	371.68	201.66	136.34
13	398.11	-	-	-
14	398.11	379.20	195.43	129.64
15	416.87	-	-	-
16	446.68	378.14	187.08	121.68

TABLE 23

Biomass, maximum growth rate and generation time of *Nitzschia palea* and *Oocystis pusilla* var. *major*

Species	Cell count mL^{-1} ($\times 10^4$)		Maximum k	Minimum t_g(hr)	Maximum pigment content ($pg\ cell^{-1}$)			
	Zero day	16th day			Chlorophyll a	b	c	Carotenoids
Nitzschia palea	1.00	199.53	2.06	8.00	2.11	-	0.75	1.79
Oocystis pusilla var. *major*	1.00	446.68	1.69	10.16	4.07	1.38	-	0.41

4.2.2. Nitrate requirement of test species

The growth rate of *Nitzschia palea* and *Oocystis pusilla* var. *major* increased with increasing concentration of nitrate in the medium. However, this trend was observed only upto 25 μ g-at NO_3-N L^{-1} for *N. palea* and 15 μ g-at NO_3-N L^{-1} for *O. pusilla* var. *major* (Figure 20 A and 21 A). The half-saturation constant (K_s) and maximum growth rate (k'_{max}) were determined graphically as shown in figures 20 B and 21 B. K_s was 0.43 μ g-at NO_3-N L^{-1} and k'_{max} was 0.95 for *N. palea*. *Oocystis pusilla* var. *major* had a K_s of 0.66 μ g-at NO_3-N L^{-1} and k'_{max} of 0.86.

4.2.3. Phosphate requirement of test species

The experimental data showed that presence of phosphate

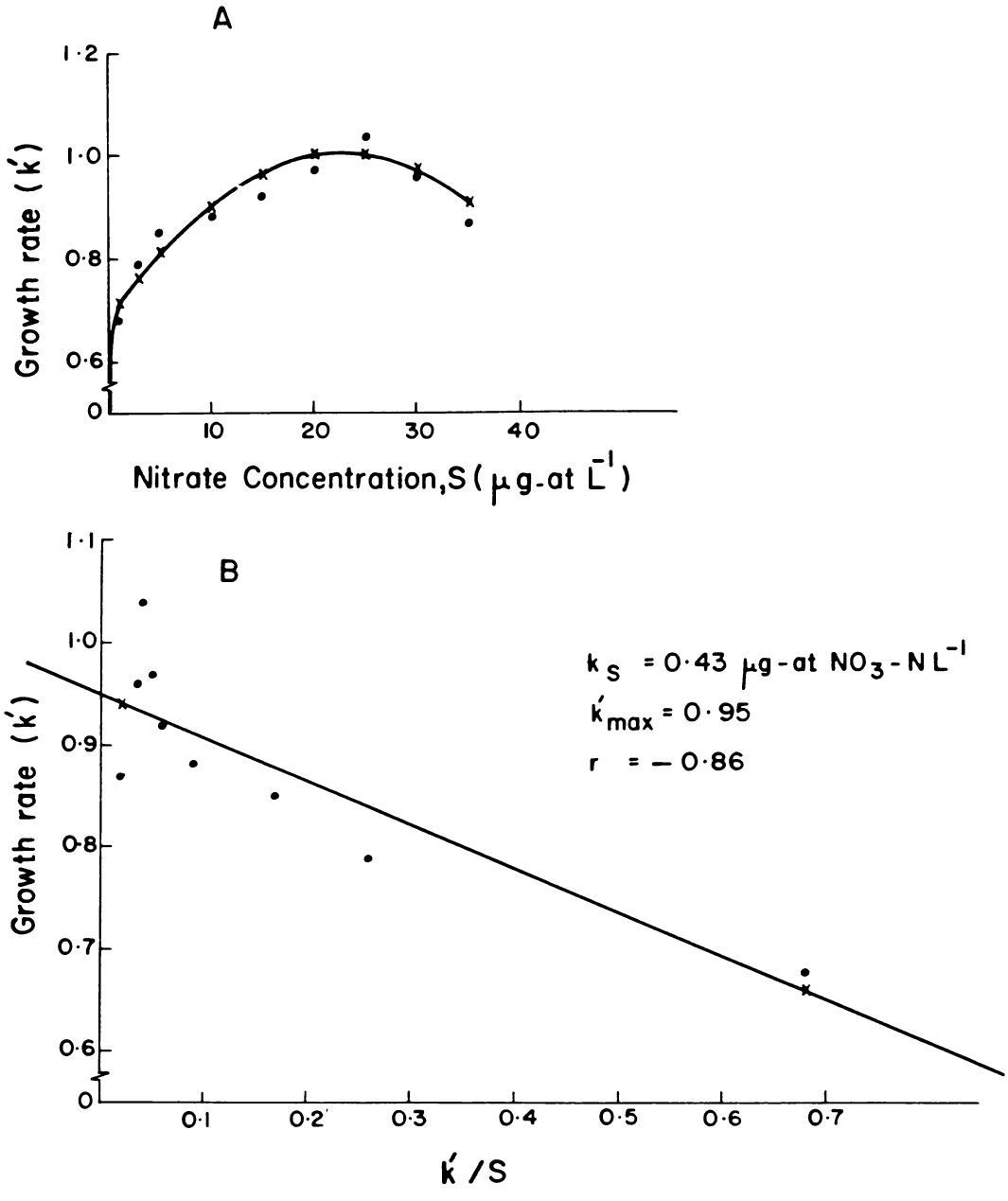

Fig. 20. A. Growth rate of Nitzschia palea as function of nitrate concentration B. Same data plotted as growth rate (k') vs. growth rate $\frac{\cdot}{\cdot}$ nitrate concentration $(\frac{k'}{S})$, K_s = half-saturation constant, k'_{max} = maximum growth rate unlimited by low nutrient concentration, r = correlation coefficient.

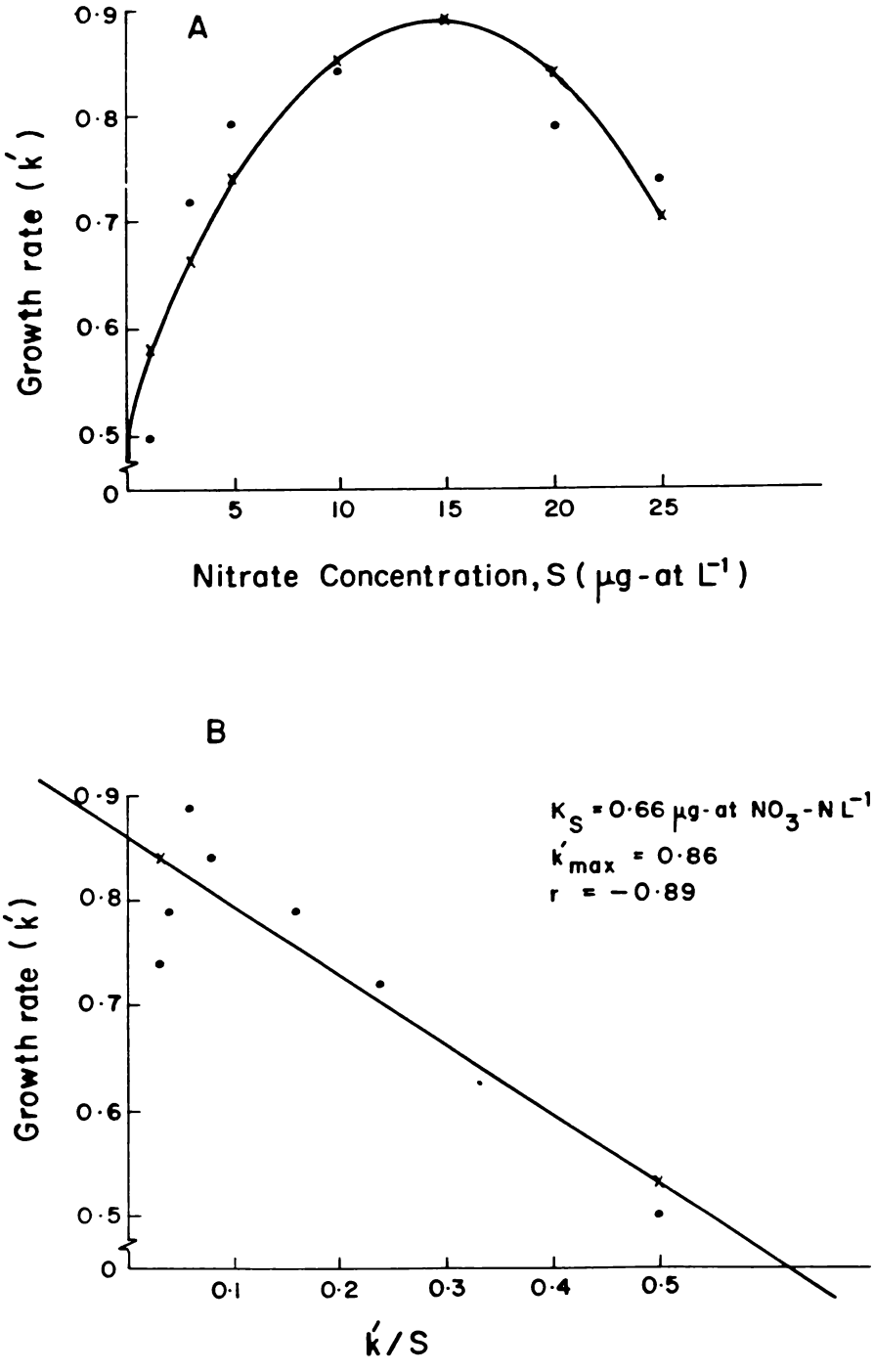

Fig. 21. A. Growth rate of Oocystis pusilla var. major as function of nitrate concentration B. Same data plotted as growth rate (k') vs. growth rate $\frac{\cdot}{\cdot}$ nitrate concentration ($\frac{k'}{S}$), K_S = half-saturation constant, k'_{max} = maximum growth rate unlimited by low nutrient concentration, r = correlation coefficient.

enhanced the growth rate of both species upto a certain level. In N. palea the growth rate decreased above a phosphate concentration of 1.28 μ g-at PO_4-P L^{-1} and in O. pusilla var. major above 1.6 μ g-at PO_4-P L^{-1}. Graphical analysis of the growth rate showed that N. palea had a half-saturation constant (K_s) of 0.39 μ g-at PO_4-P L^{-1} as against 0.26 μ g-at PO_4-P L^{-1} for O. pusilla var. major. The maximum growth rate (k'_{max}) for these species were 0.90 and 1.16 respectively (Figure 22 and 23).

4.2.4. Salinity tolerance

It was observed that Nitzschia palea did not tolerate salinity under the test conditions. At 5 x 10^{-3} salinity the biomass produced was only 28 percent of the control i.e. zero salinity; the amount of chlorophyll a was 53 percent, that of chlorophyll c 45 percent and carotenoid 34 percent. The cultures showed declining growth towards the higher salinities tested. Statistical treatment of the data is given in Table 24.

Oocystis pusilla var. major tolerated salinity upto 5 x 10^{-3}, there being statistically no difference in the cell counts from that of the control. At 10 x 10^{-3} salinity, the cell density decreased to 20.96 percent of the control; the amount of chlorophyll a was 32.23 percent, that of chlorophyll b 32.60 percent and carotenoids 57.90 percent (Table 25).

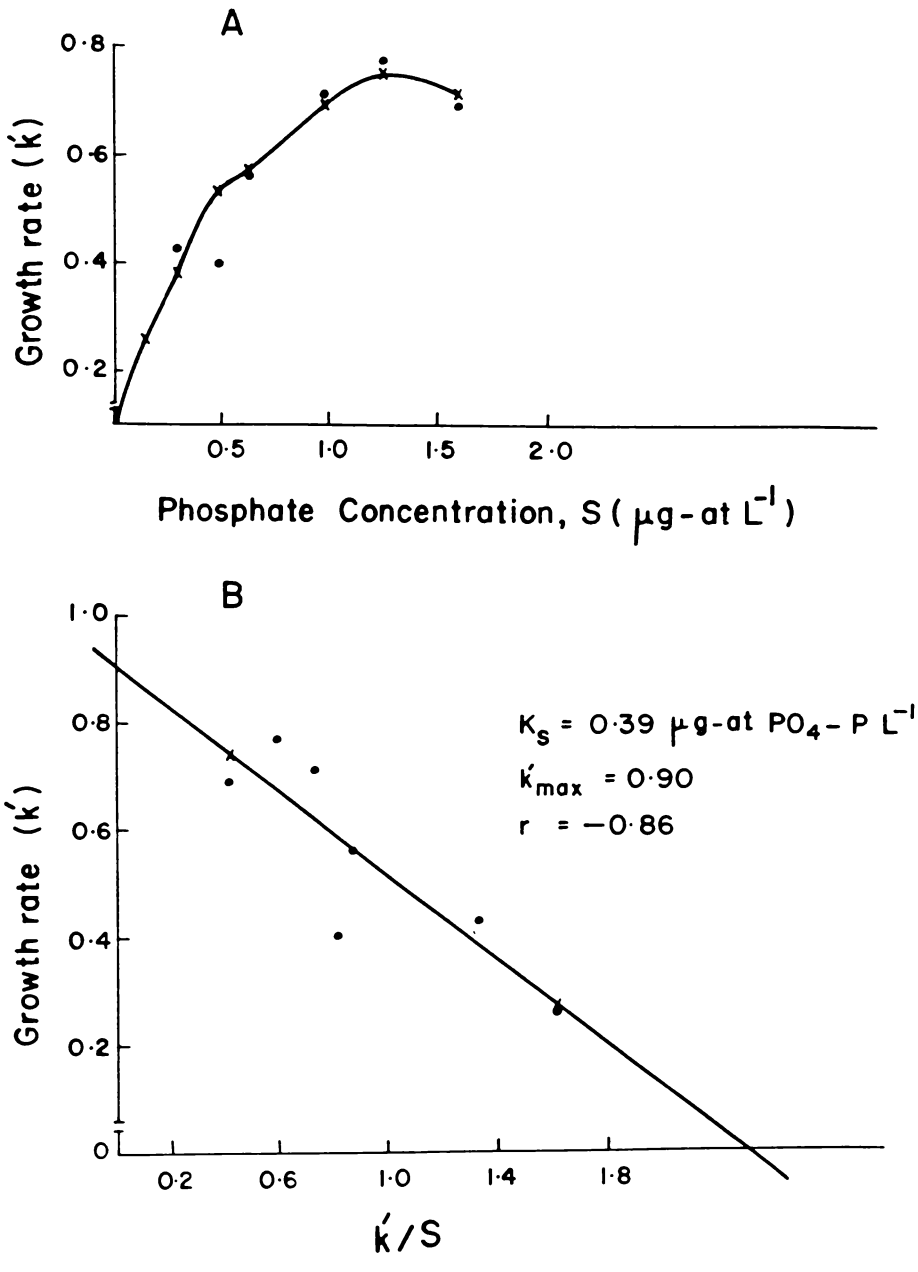

Fig. 22. A. Growth rate of Nitzschia palea as function of phosphate concentration B. Same data plotted as growth rate (k') vs. growth rate $\frac{\cdot}{\cdot}$ phosphate concentration ($\frac{k'}{S}$), K_s = half-saturation constant, k'_{max} = maximum growth rate unlimited by low nutrient concentration, r = correlation coefficient.

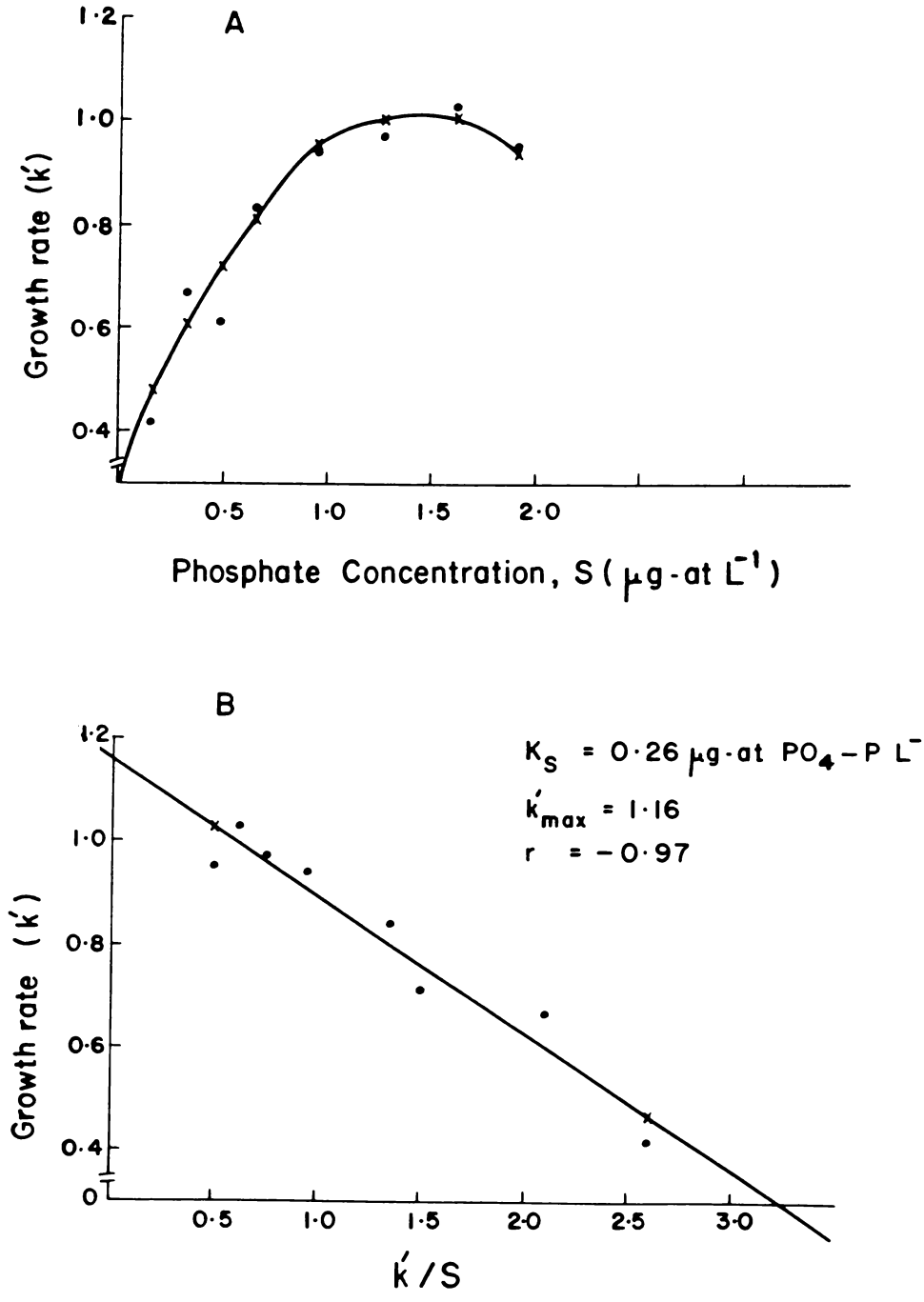

Fig. 23. A. Growth rate of Oocystis pusilla var. major as function of phosphate concentration B. Same data plotted as growth rate (k') vs. growth rate $\frac{\cdot}{\cdot}$ phosphate concentration ($\frac{k'}{S}$), K_s = half-saturation constant, k'_{max} = maximum growth rate unlimited by low nutrient concentration, r = correlation coefficient.

TABLE 24

Cell number and photosynthetic pigments of *Nitzschia palea* grown at various salinities for 96 hr

Salinity ($\times 10^{-3}$)	Cell count mL^{-1} ($\times 10^{4}$)			Mean k'
	Initial	Final		
0	1.00	78.50	78.75	76.50	1.089
5	1.00	22.50	23.25	16.75	0.757*
10	1.00	5.50	3.50	5.50	0.389*
15	1.00	2.50	1.00	1.50	0.110*
20	1.00	1.00	0.75	0.50	0.082*
	Chlorophyll *a* ($\mu g\ L^{-1}$)			
	Initial	Final		
0	7.632	598.44	596.23	589.43	1.089
5	7.632	318.68	314.17	316.63	0.931*
10	7.632	90.88	86.37	93.33	0.617*
15	7.632	19.85	15.18	20.01	0.218*
20	7.632	15.34	13.12	11.03	0.134*
	Chlorophyll *c* ($\mu g\ L^{-1}$)			
	Initial	Final		
0	1.250	100.99	96.87	94.23	1.089
5	1.250	46.59	43.21	42.72	0.891*
10	1.250	36.39	37.13	35.90	0.843*
15	1.250	38.63	34.50	30.63	0.829*
20	1.250	23.75	20.37	23.26	0.722*
	Carotenoids ($\mu g\ L^{-1}$)			
	Initial	Final		
0	8.385	656.00	650.00	654.00	1.089
5	8.385	220.00	218.00	226.00	0.818*
10	8.385	120.00	116.00	122.00	0.664*
15	8.385	40.00	42.00	38.00	0.391*
20	8.385	42.00	35.00	32.00	0.365*

* t value significant at 5% level.

TABLE 25

Cell number and photosynthetic pigments of Oocystis pusilla var. major grown at various salinities for 96 hr

Salinity ($\times 10^{-3}$)	Cell count mL^{-1} ($\times 10^{4}$)			Mean k'
	Initial	Final		
0	1.00	35.25	34.50	35.45	0.892
5	1.00	32.25	34.00	29.00	0.864
10	1.00	8.00	7.75	6.50	0.500*
15	1.00	5.50	5.25	4.25	0.401*
20	1.00	3.00	3.75	2.75	0.286*
	Chlorophyll a ($\mu g\ L^{-1}$)			
	Initial	Final		
0	10.235	358.35	369.06	361.51	0.892
5	10.235	288.63	280.32	287.79	0.832*
10	10.235	113.26	113.51	123.58	0.608*
15	10.235	35.54	38.32	36.32	0.319*
20	10.235	21.16	25.16	22.29	0.200*
	Chlorophyll b ($\mu g\ L^{-1}$)			
	Initial	Final		
0	3.092	119.06	99.47	109.81	0.891
5	3.092	108.36	123.88	93.18	0.888
10	3.092	56.82	56.82	44.27	0.707*
15	3.092	34.24	29.06	26.09	0.565*
20	3.092	17.50	23.45	28.62	0.499*
	Carotenoids ($\mu g\ L^{-1}$)			
	Initial	Final		
0	2.004	68.00	72.80	72.00	0.892
5	2.004	91.20	98.40	96.00	0.965*
10	2.004	44.00	40.80	38.40	0.755*
15	2.004	17.60	18.40	16.00	0.539*
20	2.004	15.20	14.40	13.60	0.493*

* t value significant at 5% level.

4.2.5. Toxicity Test

The characteristics of the effluent collected for the assays is given in Table 26.

TABLE 26

Analytical data of effluent collected for algal assays

pH	4.88
Colour	Pale yellow
C O D	110 mg L^{-1}
Ammonia	3 mg L^{-1}
Phosphate	266.6 mg L^{-1}
Fluoride	79 mg L^{-1}

The results of the range finding test using N. palea indicated that the effluent inhibited growth, and EC_{50} was between 50 percent and 75 percent of effluent (Table 27).

TABLE 27

Cell yield of Nitzschia palea after 96 hr exposure to effluent (range finding test)

Effluent %	Mean cell count mL^{-1} ($\times 10^4$)
0	84.0
10	66.0
25	64.0
50	55.0
75	43.0
100	9.0

This observation was confirmed in the definitive test. The cell count and the amount of chlorophyll a, c and carotenoids decreased significantly with increasing concentration of the effluent (Table 28). The EC_{50} was found to be 74 percent of the effluent (Figure 24). As computed from the EC_{50} value, this particular effluent which is being discharged from the factory at a rate of 36000 m^3 day^{-1} requires a minimum volume (Q_r) of 4.80 Mm^3 day^{-1} of water in the river to dilute it to safe level.

When cultures grown in the effluent were resuspended in control medium, growth was found to resume in all except those treated with 90 percent effluent. Growth was significantly inhibited at this concentration (Table 29).

TABLE 28

Cell count and photosynthetic pigments of Nitzschia palea in different effluent dilutions after 96 hr exposure (definitive test)

Effluent %	Cell count mL^{-1} ($\times 10^4$) Initial	Final		Mean k'
0	1.00	81.00	83.50	85.50	1.106
5	1.00	69.38	65.55	67.57	1.053*
10	1.00	68.81	66.94	66.00	1.052*
30	1.00	69.75	63.75	63.75	1.046*
50	1.00	53.06	58.69	54.94	1.004*
70	1.00	48.37	45.19	44.06	0.956*
90	1.00	18.00	19.31	16.69	0.722*

	Initial		Final		
		Chlorophyll a (μg L^{-1})			
0	7.236	599.29	598.94	610.83	1.106
5	7.236	570.35	566.41	559.56	1.090*
10	7.236	565.85	554.86	561.42	1.088*
30	7.236	497.75	500.13	506.03	1.060*
50	7.236	430.46	414.01	428.00	1.018*
70	7.236	290.99	279.12	290.99	0.920*
90	7.236	72.61	80.45	69.67	0.582*
	Initial		Final		
		Chlorophyll c (μg L^{-1})			
0	1.756	140.59	148.97	149.49	1.106
5	1.756	144.04	146.57	147.69	1.105
10	1.756	129.20	139.44	133.96	1.084*
30	1.756	130.67	125.17	132.42	1.075*
50	1.756	107.13	110.30	105.36	1.029*
70	1.756	75.29	83.38	65.29	0.936*
90	1.756	20.85	15.50	17.22	0.578*
	Initial		Final		
		Carotenoids (μg L^{-1})			
0	7.904	656.00	662.00	658.00	1.106
5	7.904	588.00	570.00	582.00	1.074*
10	7.904	582.00	576.00	588.00	1.075*
30	7.904	528.00	524.00	530.00	1.050*
50	7.904	430.00	426.00	418.00	0.996*
70	7.904	308.00	320.00	318.00	0.922*
90	7.904	74.00	72.00	66.00	0.547*

* t value significant at 5% level.

TABLE 29

Nine day cell count of Nitzschia palea in resuspension cultures

Effluent	Cell count mL^{-1} (x 10^4)						Mean k'
	Initial			Final			
0	1.08	1.11	1.14	169.31	167.44	158.25	0.556
5	0.93	0.87	0.90	139.22	149.52	137.68	0.562
10	0.92	0.89	0.88	146.25	139.87	138.19	0.562
30	0.93	0.85	0.85	145.12	130.43	146.25	0.567
50	0.71	0.78	0.73	101.44	102.56	108.56	0.550
70	0.65	0.60	0.59	102.19	102.00	104.25	0.569
90	0.24	0.26	0.22	26.92	26.50	21.00	0.510*

* t value significant at 5% level.

Unlike Nitzschia palea, the culture of Oocystis pusilla var. major was more sensitive to the effluent with EC_{50} at 21 percent (Figure 25). The results of the range finding and definitive tests are given in Table 30 and 31 respectively.

TABLE 30

Cell yield of Oocystis pusilla var. major after 96 hr exposure to effluent (range finding test)

Effluent %	Mean cell count mL^{-1} x 10^4
0	32.0
10	26.0
25	13.0
50	6.0
75	2.0
100	0.0

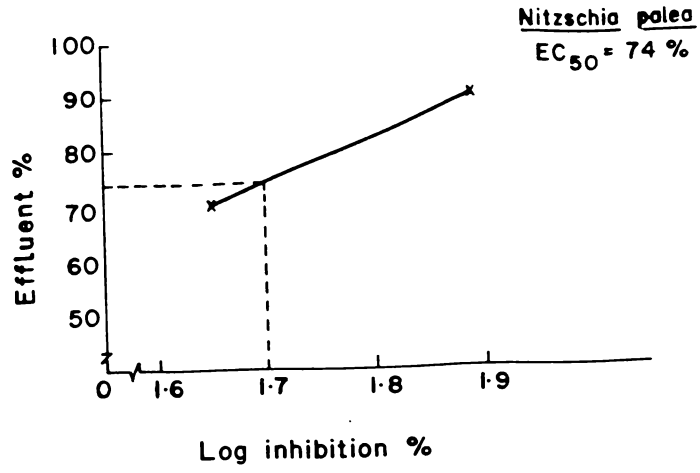

Fig. 24. Effect of effluent on growth of Nitzschia palea in axenic culture. EC_{50} = calculated concentration that would inhibit growth by 50%.

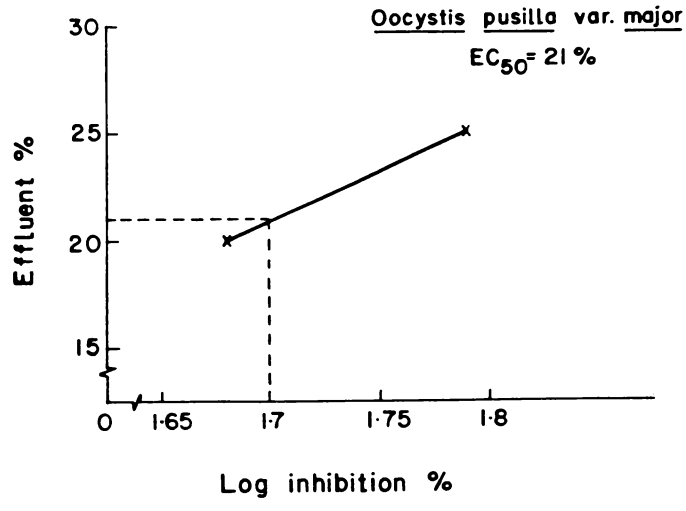

Fig. 25. Effect of effluent on growth of Oocystis pusilla var. major in axenic culture. EC_{50} = calculated concentration that would inhibit growth by 50%.

TABLE 31

Cell count and photosynthetic pigments of *Oocystis pusilla* var. *major* in different effluent dilutions after 96 hr exposure (definitive test)

Effluent %	Initial	Final			Mean k'
	Cell count mL^{-1} ($\times 10^4$)				
0	1.00	35.50	29.00	30.00	0.862
5	1.00	45.57	48.53	48.61	0.965*
10	1.00	22.21	28.30	25.09	0.806
15	1.00	20.00	20.10	23.20	0.762*
20	1.00	16.90	17.60	14.64	0.698*
25	1.00	11.29	12.20	13.38	0.627*
30	1.00	9.10	8.77	11.44	0.568*
	Initial	Final			
	Chlorophyll *a* ($\mu g\ L^{-1}$)				
0	11.340	356.42	369.51	345.72	0.862
5	11.340	182.00	195.61	194.70	0.706*
10	11.340	98.77	109.93	94.77	0.547*
15	11.340	95.02	86.46	94.70	0.523*
20	11.340	69.61	83.09	78.77	0.479*
25	11.340	67.86	75.09	57.16	0.441*
30	11.340	42.00	50.00	46.00	0.349*
	Initial	Final			
	Chlorophyll *b* ($\mu g\ L^{-1}$)				
0	4.414	139.42	121.70	156.03	0.861
5	4.414	275.45	280.33	266.81	1.032*
10	4.414	137.48	140.14	131.54	0.858
15	4.414	109.72	118.14	108.21	0.808
20	4.414	108.09	96.30	97.76	0.782*
25	4.414	54.38	74.42	71.00	0.676*
30	4.414	62.41	74.30	68.36	0.684*

	Carotenoids (μ g L^{-1})			
	Initial	Final		
0	2.650	78.40	88.00	84.00	0.862
5	2.650	91.20	94.40	92.80	0.889*
10	2.650	58.40	62.40	59.20	0.780*
15	2.650	48.80	55.20	49.60	0.740*
20	2.650	46.40	40.00	40.80	0.693*
25	2.650	32.80	39.20	33.60	0.646*
30	2.650	28.00	30.40	30.40	0.603*

* t value significant at 5% level.

At low concentration (5%) the effluent stimulated the growth of O. pusilla var. major and at 10 percent, the rate of growth was similar to that of the control. As the concentration increased the growth rate declined. However, the amount of chlorophyll a was found to be significantly low at 5 percent effluent. The other pigments i.e. chlorophyll b and carotenoids exhibited similar trend as that of the cell count. The value of Q_r computed from the EC_{50} of 21 percent was 17.11 Mm^3 day^{-1}.

The cultures resuspended in the control medium regained original growth rate except at concentrations 25 and 30 percent. In these concentrations growth rate was significantly inhibited (Table 32).

TABLE 32

Nine day cell count of Oocystis pusilla var. major in resuspension cultures

Effluent %	Cell count mL^{-1} ($\times 10^4$) Initial			Final			Mean k'
0	0.473	0.387	0.400	150.00	153.85	156.50	0.656
5	0.608	0.647	0.648	244.32	241.54	253.79	0.663
10	0.296	0.377	0.335	153.50	149.00	148.10	0.679
15	0.267	0.268	0.309	83.67	84.51	91.99	0.633
20	0.225	0.235	0.195	66.86	58.96	60.94	0.628
25	0.151	0.163	0.178	26.61	28.43	26.24	0.569*
30	0.121	0.117	0.153	14.84	16.09	21.70	0.544*

* t value significant at 5% level.

4.2.6. Toxicity vs. salinity

The test concentration of the effluent inhibited the growth of N. palea in freshwater medium (4.2.5). As stated in 4.2.4 this species did not tolerate salinity. In the presence of effluent N. palea showed similar cell counts as that of the respective controls at the test salinities (Table 33). Contrary to the cell counts the amount of photosynthetic pigments were significantly enhanced at salinities 5 x 10^{-3} and 10 x 10^{-3}. However at 15 x 10^{-3} and 20 x 10^{-3} the amount of chlorophyll a, c and carotenoids did not differ from that of the respective controls (Table 34, 35, 36).

TABLE 33

Effect of salinity on effluent toxicity in terms of cell yield of Nitzschia palea for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Cell counts (cells mL^{-1}) $\times 10^4$			Mean k'
		Initial	Final		
Control	5	1 22.50	23.25	16.75	0.757
Treatment	5	1 19.75	22.00	19.25	0.753
Control	10	1 5.50	3.50	5.50	0.399
Treatment	10	1 6.25	6.75	7.75	0.483
Control	15	1 2.25	1.00	1.50	0.101
Treatment	15	1 3.75	2.25	2.25	0.245
Control	20	1 1.00	0.75	0.50	0.082
Treatment	20	1 0.50	1.00	0.75	0.082

TABLE 34

Effect of salinity on effluent toxicity measured in terms of chlorophyll a of Nitzschia palea for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Chlorophyll a ($\mu g\ L^{-1}$)			Mean k'
		Initial	Final		
Control	5	7.632 318.68	314.17	316.63	0.931
Treatment	5	7.632 338.31	331.27	335.70	0.946*
Control	10	7.632 90.88	86.37	93.33	0.617
Treatment	10	7.632 108.75	104.16	110.89	0.662*
Control	15	7.632 19.85	15.18	20.01	0.217
Treatment	15	7.632 22.22	19.93	24.67	0.267
Control	20	7.632 15.34	13.12	11.07	0.134
Treatment	20	7.632 11.07	15.18	10.75	0.117

* t value significant at 5% level.

TABLE 35

Effect of salinity on effluent toxicity measured in terms of chlorophyll c of Nitzschia palea for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Chlorophyll c ($\mu g\ L^{-1}$) Initial	Final			Mean k'
Control	5	1.250	46.59	43.21	42.72	0.891
Treatment	5	1.250	54.02	50.51	51.01	0.931*
Control	10	1.250	36.39	37.13	35.90	0.843
Treatment	10	1.250	42.01	48.37	42.26	0.891*
Control	15	1.250	38.63	34.50	30.63	0.829
Treatment	15	1.250	40.63	48.37	40.12	0.884
Control	20	1.250	23.75	20.37	23.26	0.722
Treatment	20	1.250	24.33	25.35	27.09	0.755

* t value significant at 5% level.

TABLE 36

Effect of salinity on effluent toxicity measured in terms of carotenoids of Nitzschia palea for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Carotenoids ($\mu g\ L^{-1}$) Initial	Final			Mean k'
Control	5	8.385	220.0	218.0	226.0	0.818
Treatment	5	8.385	262.0	259.0	266.0	0.861*
Control	10	8.385	120.0	116.0	122.0	0.664
Treatment	10	8.385	180.0	160.0	182.0	0.758*
Control	15	8.385	40.0	42.0	38.0	0.390
Treatment	15	8.385	44.0	40.0	48.0	0.414
Control	20	8.385	42.0	36.0	32.0	0.367
Treatment	20	8.385	32.0	42.0	36.0	0.367

* t value significant at 5% level.

Toxicity of effluent to O. pusilla var. major was low in saline medium. As seen in 4.2.4. this species tolerated salinity of 5 x 10^{-3}. In the presence of effluent, the cell multiplication and the amount of pigments were significantly enhanced (Table 37, 38, 39, 40). At still higher salinities the growth rate was reduced (4.2.4.), but this reduction in growth was less pronounced in the presence of effluent.

TABLE 37

Effect of salinity on effluent toxicity measured in terms of cell yield of Oocystis pusilla var. major for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Cell count mL^{-1} ($\times 10^4$)			Mean k'
		Initial	Final		
Control	5	1.00	32.25	34.00	29.00	0.864
Treatment	5	1.00	38.50	40.00	39.70	0.918*
Control	10	1.00	8.00	7.75	6.50	0.500
Treatment	10	1.00	14.50	13.25	16.00	0.669*
Control	15	1.00	5.50	5.25	4.25	0.401
Treatment	15	1.00	8.50	10.50	8.00	0.548*
Control	20	1.00	3.00	3.75	2.75	0.286
Treatment	20	1.00	3.25	3.50	4.00	0.318

* t value significant at 5% level.

TABLE 38

Effect of salinity on effluent toxicity measured in terms of chlorophyll a of Oocystis pusilla var. major for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Chlorophyll a ($\mu g\ L^{-1}$)				Mean k'
		Initial	Final			
Control	5	10.235	228.63	280.32	287.79	0.813
Treatment	5	10.235	352.18	342.25	348.95	0.881*
Control	10	10.235	113.26	113.51	123.58	0.608
Treatment	10	10.235	159.12	165.83	134.88	0.656*
Control	15	10.235	35.54	38.32	36.32	0.319
Treatment	15	10.235	78.18	85.79	63.47	0.499*
Control	20	10.235	21.16	25.16	22.27	0.200
Treatment	20	10.235	26.77	28.39	34.32	0.266*

* t value significant at 5% level.

TABLE 39

Effect of salinity on effluent toxicity measured in terms of chlorophyll b of Oocystis pusilla var. major for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Chlorophyll b ($\mu g\ L^{-1}$)				Mean k'
		Initial	Final			
Control	5	3.092	108.36	123.88	93.18	0.888
Treatment	5	3.092	184.21	192.68	170.12	1.019*
Control	10	3.092	56.82	56.82	44.27	0.707
Treatment	10	3.092	78.51	85.95	93.58	0.831*
Control	15	3.092	34.24	29.06	26.09	0.565
Treatment	15	3.092	41.84	57.80	52.51	0.697*
Control	20	3.092	17.50	23.45	28.62	0.499
Treatment	20	3.092	30.49	37.54	23.12	0.566

* t value significant at 5% level.

TABLE 40

Effect of salinity on effluent toxicity measured in terms of carotenoids of Oocystis pusilla var. major for a test period of 96 hr

Medium	Salinity ($\times 10^{-3}$)	Carotenoids (μ g L^{-1}) Initial	Final		Mean k'
Control	5	2.004	91.20	98.40	96.00	0.965
Treatment	5	2.004	116.00	112.80	114.40	1.011*
Control	10	2.004	44.00	40.80	38.40	0.755
Treatment	10	2.004	57.60	56.80	66.40	0.850*
Control	15	2.004	17.60	18.40	16.00	0.539
Treatment	15	2.004	30.40	37.60	25.60	0.683*
Control	20	2.004	15.20	14.40	13.60	0.493
Treatment	20	2.004	14.40	13.60	16.80	0.501

* t value significant at 5% level.

4.2.7. Toxicity at low nitrate concentration vs. ammonia

The rate of cell division of N. palea was reduced significantly on addition of ammonia to the culture medium even at concentrations as low as 0.04 μ g-at L^{-1} (Table 41). The amount of chlorophyll a, chlorophyll c and carotenoids were not affected at 0.04 μ g-at NH_3-N L^{-1}. As the concentration of ammonia increased, the amount of pigments decreased similar to that of the cell counts (Table 42). When ammonia and effluent were present together in the medium, toxicity of the effluent was not altered upto an ammonia level of 0.32 μ g-at L^{-1} as indicated by the cell counts (Table 43), but production of pigments was enhanced significantly. As the concentration of

ammonia was increased from 0.64 to 2.40 μ g-at L^{-1}, the toxicity of the effluent was reduced. In these concentrations of ammonia, the treatment cultures had higher cell count and photosynthetic pigments than the respective controls (Table 44, 45, 46).

TABLE 41

Cell yield of Nitzschia palea grown in various ammonia concentrations at low nitrate level for 96 hr

Ammonia concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} ($\times 10^4$) Initial	Final		Mean k'
0.00	1.00	62.00	68.00	68.00	1.047
0.04	1.00	41.50	46.75	41.75	0.942*
0.08	1.00	52.50	48.76	47.94	0.977*
0.16	1.00	51.32	55.00	53.67	0.994*
0.32	1.00	48.75	41.50	45.74	0.953*
0.64	1.00	32.72	30.50	31.79	0.864*
0.80	1.00	13.72	16.35	11.18	0.652*
2.40	1.00	13.00	15.60	11.75	0.648*

* t value significant at 5% level.

TABLE 42

Photosynthetic pigments of Nitzschia palea grown in various ammonia concentrations at low nitrate level for 96 hr

Ammonia concentrations (μ g-at NH_3-N L^{-1})	Chlorophyll a (μ g L^{-1}) Initial	Final		Mean k'
0.00	1.411	97.19	92.77	90.72	1.049
0.04	1.411	88.27	93.19	88.35	1.039

0.08	1.411	84.00	76.88	83.84	1.014*
0.16	1.411	79.41	78.27	70.31	0.996*
0.32	1.411	79.57	78.93	75.49	1.003*
0.64	1.411	61.46	68.92	61.22	0.953*
0.80	1.411	33.69	39.85	39.93	0.821*
2.40	1.411	24.75	27.96	28.36	0.738*

Chlorophyll c ($\mu g\ L^{-1}$)

	Initial		Final		
0.00	0.619	43.99	39.50	39.11	1.047
0.04	0.619	39.77	33.50	33.37	1.012
0.08	0.619	34.86	35.73	35.99	1.013*
0.16	0.619	32.35	33.99	37.48	1.006*
0.32	0.619	32.74	32.35	37.62	1.003*
0.64	0.619	32.66	31.03	29.46	0.979*
0.80	0.619	17.74	19.09	19.08	0.851*
2.40	0.619	11.29	13.65	10.42	0.735*

Carotenoids ($\mu g\ L^{-1}$)

	Initial		Final		
0.00	1.747	112.00	118.00	116.00	1.047
0.04	1.747	102.00	110.00	110.00	1.029
0.08	1.747	104.00	108.00	100.00	1.022*
0.16	1.747	98.00	96.00	100.00	1.007*
0.32	1.747	94.00	98.00	92.00	0.998*
0.64	1.747	76.00	72.00	74.00	0.937*
0.80	1.747	24.00	26.00	28.00	0.675*
2.40	1.747	18.00	20.00	22.00	0.609*

* t value significant at 5% level.

TABLE 43

Effect of ammonia on effluent toxicity measured in terms of cell yield of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4)			Mean k'
		Initial	Final		
Control	0.04	1.00	41.50	46.75	41.75	0.942
Treatment	0.04	1.00	43.75	49.50	44.49	0.956
Control	0.08	1.00	52.50	48.76	47.94	0.977
Treatment	0.08	1.00	56.72	59.35	51.69	1.006
Control	0.16	1.00	51.32	55.00	53.67	0.994
Treatment	0.16	1.00	54.60	58.75	48.95	0.997
Control	0.32	1.00	48.75	41.50	45.74	0.953
Treatment	0.32	1.00	48.55	49.20	47.75	0.970
Control	0.64	1.00	32.72	30.50	31.79	0.864
Treatment	0.64	1.00	52.75	56.35	49.15	0.991*
Control	0.80	1.00	13.72	16.35	11.18	0.652
Treatment	0.80	1.00	52.90	53.75	51.84	0.992*
Control	2.40	1.00	13.00	15.60	11.75	0.648
Treatment	2.40	1.00	53.50	52.00	52.00	0.990*

* t value significant at 5% level.

TABLE 44

Effect of ammonia on effluent toxicity measured in terms of chlorophyll *a* of *Nitzschia palea* for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll *a* (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	1.411	88.27	93.19	88.35	1.039
Treatment	0.04	1.411	153.73	150.20	156.61	1.172*
Control	0.08	1.411	84.00	76.88	83.84	1.014
Treatment	0.08	1.411	143.24	149.88	149.48	1.162*
Control	0.16	1.411	79.41	78.27	70.31	0.996
Treatment	0.16	1.411	133.51	149.96	145.54	1.154*
Control	0.32	1.411	79.57	78.93	75.49	1.003
Treatment	0.32	1.411	137.85	133.03	137.57	1.142*
Control	0.64	1.411	61.46	68.92	61.22	0.953
Treatment	0.64	1.411	136.12	147.11	138.17	1.150*
Control	0.80	1.411	33.69	39.85	39.93	0.821
Treatment	0.80	1.411	138.49	149.40	133.99	1.150*
Control	2.40	1.411	24.75	27.96	28.36	0.738
Treatment	2.40	1.411	131.53	126.38	128.84	1.129*

* t value significant at 5% level.

TABLE 45

Effect of ammonia on effluent toxicity measured in terms of chlorophyll c of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})		Chlorophyll c (μ g L^{-1})			Mean k'
		Initial		Final		
Control	0.04	0.619	39.77	33.50	33.37	1.012
Treatment	0.04	0.619	69.35	65.34	60.49	1.163*
Control	0.08	0.619	34.86	35.73	35.99	1.013
Treatment	0.08	0.619	57.81	63.31	61.68	1.147*
Control	0.16	0.619	32.35	33.99	37.48	1.006
Treatment	0.16	0.619	51.17	47.27	54.64	1.103*
Control	0.32	0.619	32.74	32.35	37.62	1.003
Treatment	0.32	0.619	42.19	52.56	48.81	1.086*
Control	0.64	0.619	32.66	31.03	29.46	0.979
Treatment	0.64	0.619	48.04	38.46	40.21	1.055*
Control	0.80	0.619	17.74	19.09	19.08	0.851
Treatment	0.80	0.619	33.98	33.84	40.84	1.016*
Control	2.40	0.619	11.29	13.65	10.42	0.735
Treatment	2.40	0.619	40.95	43.33	35.43	1.041*

* t value significant at 5% level.

TABLE 46

Effect of ammonia on effluent toxicity measured in terms of carotenoids of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Carotenoids (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.04	1.747	102.0	110.0	110.0	1.029
Treatment	0.04	1.747	162.0	156.0	158.0	1.127*
Control	0.08	1.747	104.0	108.0	100.0	1.022
Treatment	0.08	1.747	152.0	158.0	146.0	1.116*
Control	0.16	1.747	98.0	96.0	100.0	1.007
Treatment	0.16	1.747	140.0	140.0	148.0	1.101*
Control	0.32	1.747	94.0	92.0	98.0	0.998
Treatment	0.32	1.747	133.0	140.0	142.0	1.093*
Control	0.64	1.747	76.0	72.0	74.0	0.937
Treatment	0.64	1.747	142.0	138.0	140.0	1.096*
Control	0.80	1.747	24.0	26.0	28.0	0.675
Treatment	0.80	1.747	116.0	122.0	118.0	1.055*
Control	2.40	1.747	18.0	20.0	22.0	0.609
Treatment	2.40	1.747	122.0	118.0	112.0	1.052*

* t value significant at 5% level.

The cultures of O. pusilla var. major exhibited enhanced growth in the presence of ammonia. The stimulatory effect was more evident in the pigment production rather than the cell count (Table 47). When effluent was present along with ammonia, the growth rate was rather increased (Table 48, 49, 50, 51).

TABLE 47

Cell yield and photosynthetic pigments of *Oocystis pusilla* var. *major* grown in various ammonia concentrations at low nitrate level for 96 hr

Ammonia concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} ($\times 10^4$)			Mean k'
	Initial	Final		
0.00	1.00	20.55	25.36	25.34	0.791
0.04	1.00	35.75	30.66	28.33	0.862*
0.08	1.00	28.50	29.00	38.56	0.864
0.16	1.00	29.00	25.50	25.00	0.819
0.32	1.00	19.75	25.50	23.51	0.782
0.64	1.00	18.50	24.55	20.70	0.762
0.80	1.00	18.50	22.75	17.76	0.743
2.40	1.00	12.95	13.65	17.41	0.669*
	Chlorophyll *a* (μ g L^{-1})			
	Initial	Final		
0.00	3.080	72.30	68.16	79.02	0.792
0.04	3.080	95.64	98.40	92.65	0.859*
0.08	3.080	95.26	95.33	97.72	0.860*
0.16	3.080	90.56	81.09	88.25	0.834*
0.32	3.080	112.04	123.12	111.58	0.960*
0.64	3.080	116.42	115.19	112.81	0.905*
0.80	3.080	108.42	106.50	104.65	0.886*
2.40	3.080	99.26	102.49	100.11	0.872*
	Chlorophyll *b* (μ g L^{-1})			
	Initial	Final		
0.00	1.299	30.07	30.84	31.65	0.792
0.04	1.299	45.26	53.40	52.30	0.914*
0.08	1.299	64.30	63.55	60.68	0.969*
0.16	1.299	75.55	83.33	80.03	1.029*
0.32	1.299	45.70	47.57	45.01	0.892*
0.64	1.299	40.53	36.46	37.56	0.845*
0.80	1.299	55.68	64.84	59.67	0.958*
2.40	1.299	45.77	50.10	51.20	0.907*

	Carotenoids (μ g L^{-1})			
	Initial	Final		
0.00	1.415	30.40	36.00	34.40	0.791
0.04	1.415	42.40	47.20	44.80	0.864*
0.08	1.415	39.20	44.00	39.20	0.840*
0.16	1.415	39.20	41.60	39.20	0.835*
0.32	1.415	38.40	44.00	44.80	0.849*
0.64	1.415	40.80	44.00	37.60	0.840*
0.80	1.415	41.60	37.60	40.80	0.835*
2.40	1.415	36.00	42.40	41.60	0.835

* t value significant at 5% level.

TABLE 48

Effect of ammonia on effluent toxicity measured in terms of cell yield of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Ammonia Concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4)			Mean k'
		Initial	Final		
Control	0.04	1.00	28.50	29.00	38.56	0.864
Treatment	0.04	1.00	36.50	39.65	40.61	0.915
Control	0.08	1.00	35.75	30.66	28.33	0.862
Treatment	0.08	1.00	45.00	41.50	31.01	0.914
Control	0.16	1.00	29.00	25.50	25.00	0.819
Treatment	0.16	1.00	34.56	37.00	38.18	0.900*
Control	0.32	1.00	19.75	25.50	23.51	0.782
Treatment	0.32	1.00	32.50	36.75	34.76	0.886*
Control	0.64	1.00	18.50	24.55	20.70	0.762
Treatment	0.64	1.00	28.50	35.90	33.85	0.871*

Control	0.80	1.00	18.50	22.75	17.76	0.743
Treatment	0.80	1.00	35.00	30.75	33.01	0.873*
Control	2.40	1.00	12.95	13.65	17.41	0.669
Treatment	2.40	1.00	23.75	27.50	26.51	0.813*

* t value significant at 5% level.

TABLE 49

Effect of ammonia on effluent toxicity measured in terms of chlorophyll a of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Chlorophyll a (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.04	3.080	95.64	98.40	92.65	0.859
Treatment	0.04	3.080	189.37	196.98	199.37	1.037*
Control	0.08	3.080	95.26	95.33	97.72	0.860
Treatment	0.08	3.080	124.81	130.28	128.81	0.932*
Control	0.16	3.080	90.56	81.09	88.25	0.834
Treatment	0.16	3.080	127.19	121.58	127.97	0.927*
Control	0.32	3.080	112.04	123.12	111.58	0.906
Treatment	0.32	3.080	126.06	140.52	132.28	0.940*
Control	0.64	3.080	116.42	115.19	112.81	0.905
Treatment	0.64	3.080	147.89	148.91	131.51	0.960*
Control	0.80	3.080	108.42	106.50	104.65	0.886
Treatment	0.80	3.080	122.98	116.63	106.65	0.924*
Control	2.40	3.080	99.26	102.49	100.11	0.872
Treatment	2.40	3.080	98.11	91.65	90.11	0.853

* t value significant at 5% level.

TABLE 50

Effect of ammonia on effluent toxicity measured in terms of chlorophyll b of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll b (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	1.299	45.26	53.40	52.30	0.914
Treatment	0.04	1.299	72.35	88.31	87.21	1.037*
Control	0.08	1.299	64.30	63.55	60.68	0.970
Treatment	0.08	1.299	73.21	75.43	71.61	1.010*
Control	0.16	1.299	75.55	83.33	80.03	1.029
Treatment	0.16	1.299	90.30	104.19	99.23	1.080*
Control	0.32	1.299	45.70	47.57	45.01	0.892
Treatment	0.32	1.299	62.61	67.78	62.28	0.980*
Control	0.64	1.299	40.53	36.46	37.56	0.845
Treatment	0.64	1.299	54.29	41.30	46.14	0.897
Control	0.80	1.299	55.68	64.84	59.67	0.958
Treatment	0.80	1.299	58.65	67.47	60.79	0.970
Control	2.40	1.299	45.77	50.10	51.20	0.907
Treatment	2.40	1.299	48.23	49.77	51.20	0.911

* t value significant at 5% level.

TABLE 51

Effect of ammonia on effluent toxicity measured in terms of carotenoids of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Carotenoids (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.04	1.415	42.40	47.20	44.80	0.864
Treatment	0.04	1.415	63.20	60.80	62.40	0.946*
Control	0.08	1.415	39.20	44.00	39.20	0.840
Treatment	0.08	1.415	49.60	55.20	53.60	0.905*
Control	0.16	1.415	39.20	41.60	39.20	0.835
Treatment	0.16	1.415	46.40	45.60	45.60	0.870*
Control	0.32	1.415	38.40	44.00	44.80	0.849
Treatment	0.32	1.415	52.00	48.00	53.60	0.897*
Control	0.64	1.415	40.80	44.00	37.60	0.840
Treatment	0.64	1.415	52.20	51.20	49.60	0.901*
Control	0.80	1.415	36.00	42.40	41.60	0.835
Treatment	0.80	1.415	55.20	57.60	57.60	0.923*
Control	2.40	1.415	41.60	37.60	40.80	0.835
Treatment	2.40	1.415	48.80	49.60	49.60	0.888*

* t value significant at 5% level.

4.2.8. Toxicity at high nitrate concentration vs. ammonia

Addition of ammonia to the culture medium affected the growth rate of N. palea. The cell number and the pigment content were significantly reduced with increasing levels of ammonia (Table 52). Similar reduction in growth rate and pigment

content was observed in the presence of effluent as well (53, 54, 55, 56).

TABLE 52

Cell yield and photosynthetic pigments of Nitzschia palea grown in various ammonia concentrations at high nitrate level for 96 hr

Ammonia concentrations (μg-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4) Initial	Final		Mean k'
0.00	1.00	80.57	86.45	86.99	1.110
0.04	1.00	65.60	68.75	71.90	1.057*
0.08	1.00	62.13	68.25	60.61	1.038*
0.16	1.00	49.50	46.00	46.15	0.964*
0.32	1.00	40.55	40.75	42.19	0.929*
0.64	1.00	34.55	33.57	35.69	0.886*
0.80	1.00	30.50	40.75	32.71	0.884*
2.40	1.00	28.10	35.50	23.91	0.840*
	Chlorophyll a (μg L^{-1}) Initial	Final		
0.00	3.672	307.47	319.61	305.53	1.110
0.04	3.672	279.60	281.74	278.13	1.083*
0.08	3.672	261.25	268.23	261.59	1.069*
0.16	3.672	279.44	275.91	279.76	1.082*
0.32	3.672	262.90	259.60	254.98	1.064*
0.64	3.672	205.90	207.67	208.59	1.009*
0.80	3.672	82.05	87.95	87.95	0.788*
2.40	3.672	75.65	75.09	72.95	0.753*
	Chlorophyll c (μg L^{-1}) Initial	Final		
0.00	1.486	128.67	127.41	121.28	1.110
0.04	1.486	124.41	119.63	126.23	1.105
0.08	1.486	108.34	104.15	113.14	1.073*

0.16	1.486	111.89	106.57	109.25	1.074*
0.32	1.486	114.53	112.61	109.80	1.081*
0.64	1.486	99.65	106.73	101.65	1.059*
0.80	1.486	38.95	33.47	39.62	0.805*
2.40	1.486	34.22	36.06	37.06	0.795*

	Carotenoids (μ g L^{-1})			
	Initial	Final		
0.00	3.543	296.00	296.00	308.00	1.110
0.04	3.543	283.00	285.00	290.00	1.098*
0.08	3.543	276.00	268.00	264.00	1.083*
0.16	3.543	270.00	276.00	264.00	1.083*
0.32	3.543	220.00	212.00	214.00	1.027*
0.64	3.543	214.00	212.00	216.00	1.025*
0.80	3.543	114.00	124.00	112.00	0.873*
2.40	3.543	114.00	112.00	110.00	0.863*

* t value significant at 5% level.

TABLE 53

Effect of ammonia on effluent toxicity measured in terms of cell yield of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4)			Mean k'
		Initial	Final		
Control	0.04	1.00	80.60	75.75	91.90	1.103
Treatment	0.04	1.00	60.15	55.00	50.15	1.002*
Control	0.08	1.00	70.13	78.25	80.61	1.083
Treatment	0.08	1.00	50.55	48.65	37.54	0.953*
Control	0.16	1.00	79.50	86.00	76.15	1.097
Treatment	0.16	1.00	35.75	45.70	45.81	0.935*

Control	0.32	1.00	70.55	80.75	70.19	1.075
Treatment	0.32	1.00	45.55	50.75	49.71	0.971*
Control	0.64	1.00	84.55	83.50	85.69	1.109
Treatment	0.64	1.00	50.00	43.25	42.50	0.952*
Control	0.80	1.00	30.50	40.75	32.71	0.884
Treatment	0.80	1.00	18.00	24.00	22.00	0.763*
Control	2.40	1.00	28.10	35.50	23.91	0.840
Treatment	2.40	1.00	14.50	16.00	12.00	0.336*

* t value significant at 5% level.

TABLE 54

Effect of ammonia on effluent toxicity measured in terms of chlorophyll a of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll a (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	3.672	279.60	281.74 278.13	1.083
Treatment	0.04	3.672	161.75	157.74 166.26	0.947*
Control	0.08	3.672	261.25	268.23 261.59	1.069
Treatment	0.08	3.672	131.69	140.87 152.10	0.913*
Control	0.16	3.672	279.44	275.91 279.76	1.082
Treatment	0.16	3.672	142.52	156.29 149.56	0.926*
Control	0.32	3.672	262.90	259.60 254.98	1.064
Treatment	0.32	3.672	120.38	131.29 133.48	0.888*
Control	0.64	3.672	295.90	307.67 298.59	1.101
Treatment	0.64	3.672	132.25	136.84 139.08	0.903*
Control	0.80	3.672	82.05	87.95 87.95	0.788
Treatment	0.80	3.672	53.10	56.94 53.67	0.675*

Control	2.40	3.672	75.65	75.09	72.95	0.753
Treatment	2.40	3.672	43.57	47.24	42.40	0.623*

* t value significant at 5% level.

TABLE 55

Effect of ammonia on effluent toxicity measured in terms of chlorophyll c of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll c (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	1.486	124.41	119.63 126.23	1.105
Treatment	0.04	1.486	69.09	72.08 66.96	0.960*
Control	0.08	1.486	108.34	104.15 113.14	1.073
Treatment	0.08	1.486	60.14	69.88 62.53	0.941*
Control	0.16	1.486	111.89	106.57 109.25	1.074
Treatment	0.16	1.486	63.92	55.05 67.69	0.933*
Control	0.32	1.486	114.53	112.61 109.80	1.081
Treatment	0.32	1.486	60.33	62.82 63.92	0.934*
Control	0.64	1.486	99.65	106.73 101.65	1.059
Treatment	0.64	1.486	58.46	53.96 60.97	0.915*
Control	0.80	1.486	38.95	33.47 39.62	0.805
Treatment	0.80	1.486	18.57	19.85 17.31	0.631*
Control	2.40	1.486	34.22	36.06 37.06	0.795
Treatment	2.40	1.486	11.85	12.70 13.30	0.535*

* t value significant at 5% level.

TABLE 56

Effect of ammonia on effluent toxicity measured in terms of carotenoids of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μ g-at NH_3-N L^{-1})	Carotenoids (μ g L^{-1})				Mean k'
		Initial	Final			
Control	0.04	3.543	308.0	296.0	299.0	1.111
Treatment	0.04	3.543	170.0	166.0	172.0	0.967*
Control	0.08	3.543	276.0	268.0	264.0	1.023
Treatment	0.08	3.543	166.0	170.0	175.0	0.968*
Control	0.16	3.543	270.0	276.0	264.0	1.083
Treatment	0.16	3.543	174.0	168.0	173.0	0.970*
Control	0.32	3.543	220.0	212.0	214.0	1.027
Treatment	0.32	3.543	136.0	144.0	145.0	0.922*
Control	0.64	3.543	214.0	212.0	216.0	1.025
Treatment	0.64	3.543	126.0	122.0	129.0	0.892*
Control	0.80	3.543	114.0	124.0	112.0	0.873
Treatment	0.80	3.543	90.0	92.0	88.0	0.809*
Control	2.40	3.543	114.0	112.0	110.0	0.863
Treatment	2.40	3.543	104.0	106.0	108.0	0.850*

* t value significant at 5% level.

The growth of O. pusilla var. major was stimulated on addition of 0.04 μ g-at NH_3-N L^{-1}. Towards the higher concentrations, growth rate was significantly reduced (Table 57). In the presence of effluent there was absolutely no reduction in cell counts or in pigments. Cell count was

significantly enhanced upto 0.32 μ g-at NH_3-N L^{-1}. At still higher levels of ammonia growth stimulation was less pronounced (Table 58). The amount of pigments was higher than the respective controls, at all levels of ammonia tested (Table 59, 60, 61).

TABLE 57

Cell yield and photosynthetic pigments of Oocystis pusilla var. major grown in various ammonia concentration at high nitrate level for 96 hr

Ammonia concentrations (μ g-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4) Initial	Final		Mean k'
0.00	1.00	45.50	50.65	51.60	0.974
0.04	1.00	48.50	52.50	51.76	0.982
0.08	1.00	47.42	41.50	47.34	0.954
0.16	1.00	43.50	47.60	44.65	0.953
0.32	1.00	38.75	43.50	40.75	0.928*
0.64	1.00	37.50	41.50	40.49	0.921*
0.80	1.00	37.75	42.00	38.75	0.919*
2.40	1.00	19.00	15.00	15.00	0.697*
	Chlorophyll a (μ g L^{-1}) Initial	Final		
0.00	9.104	446.39	456.32	442.46	0.974
0.04	9.104	454.39	448.07	458.85	0.977
0.08	9.104	423.76	418.14	431.69	0.961*
0.16	9.104	161.44	155.12	163.51	0.717*
0.32	9.104	182.60	176.60	184.67	0.748*
0.64	9.104	171.21	168.44	178.21	0.736*
0.80	9.104	133.19	140.90	132.19	0.675*
2.40	9.104	89.33	97.72	94.49	0.583*

	Chlorophyll b (μg L^{-1})			
	Initial	Final		
0.00	2.682	132.06	130.62	133.51	0.974
0.04	2.682	155.84	154.61	156.18	1.015*
0.08	2.682	141.21	148.22	139.76	0.994*
0.16	2.682	68.94	67.70	70.38	0.812*
0.32	2.682	71.58	82.66	77.88	0.840*
0.64	2.682	63.76	60.02	69.71	0.795*
0.80	2.682	60.20	49.59	57.26	0.758*
2.40	2.682	44.49	50.30	40.21	0.704*
	Carotenoids (μg L^{-1})			
	Initial	Final		
0.00	2.128	140.80	136.00	145.60	1.048
0.04	2.128	143.20	148.00	134.40	1.050
0.08	2.128	133.60	128.00	136.80	1.033
0.16	2.128	120.80	128.00	123.00	1.016*
0.32	2.128	102.40	107.20	98.40	0.969*
0.64	2.128	83.20	88.80	84.00	0.923*
0.80	2.128	79.20	80.80	86.40	0.913*
2.40	2.128	35.20	41.60	40.80	0.728*

* t value significant at 5% level.

TABLE 58

Effect of ammonia on effluent toxicity measured in terms of cell yield of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Cell count mL^{-1} (x 10^4)				Mean k'
		Initial		Final		
Control	0.04	1.00	48.50	52.50	51.76	0.982
Treatment	0.04	1.00	56.50	61.75	60.76	1.020*

Control	0.08	1.00	47.42	41.50	47.34	0.954
Treatment	0.08	1.00	58.42	59.65	60.60	1.020*
Control	0.16	1.00	43.50	47.60	44.65	0.953
Treatment	0.16	1.00	48.75	49.00	50.99	0.976*
Control	0.32	1.00	38.75	43.50	40.75	0.928
Treatment	0.32	1.00	45.50	49.50	48.25	0.966*
Control	0.64	1.00	37.50	41.50	40.49	0.921
Treatment	0.64	1.00	40.50	45.75	39.99	0.934
Control	0.80	1.00	37.75	42.00	38.75	0.919
Treatment	0.80	1.00	43.00	38.75	42.00	0.930
Control	2.40	1.00	19.00	15.00	15.00	0.697
Treatment	2.40	1.00	18.75	21.25	21.25	0.755

* t value significant at 5% level.

TABLE 59

Effect of ammonia on effluent toxicity measured in terms of chlorophyll a of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll a (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	9.104	454.39	448.07 458.85	0.977
Treatment	0.04	9.104	580.53	569.20 576.67	1.037*
Control	0.08	9.104	423.76	418.14 431.69	0.961
Treatment	0.08	9.104	586.18	602.18 598.01	1.045*
Control	0.16	9.104	161.44	155.12 163.51	0.717
Treatment	0.16	9.104	562.46	551.76 541.44	1.026*

Control	0.32	9.104	182.60	176.60	184.67	0.748
Treatment	0.32	9.104	488.71	496.32	499.86	0.999*
Control	0.64	9.104	171.21	168.44	178.21	0.736
Treatment	0.64	9.104	540.83	528.43	526.65	1.017*
Control	0.80	9.104	133.19	140.90	132.19	0.675
Treatment	0.80	9.104	520.74	515.20	522.29	1.011*
Control	2.40	9.104	89.33	97.72	94.49	0.583
Treatment	2.40	9.104	208.53	218.46	205.37	0.785*

* t value significant at 5% level.

TABLE 60

Effect of ammonia on effluent toxicity measured in terms of chlorophyll b of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Chlorophyll b (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	2.682	155.84	154.61	156.18	1.015
Treatment	0.04	2.682	164.10	180.06	166.74	1.038*
Control	0.08	2.682	141.21	148.22	139.76	0.994
Treatment	0.08	2.682	185.90	192.22	184.44	1.062*
Control	0.16	2.682	68.94	67.70	70.38	0.812
Treatment	0.16	2.682	139.80	136.65	135.94	0.984*
Control	0.32	2.682	71.58	82.66	77.88	0.840
Treatment	0.32	2.682	89.06	90.12	94.52	0.882*
Control	0.64	2.682	63.76	60.02	69.71	0.795
Treatment	0.64	2.682	84.00	81.62	89.16	0.864*

Control	0.80	2.682	60.20	49.59	57.26	0.757
Treatment	0.80	2.682	90.92	91.26	84.63	0.875*
Control	2.40	2.682	44.48	50.30	40.20	0.704
Treatment	2.40	2.682	56.88	58.41	56.13	0.765*

* t value significant at 5% level.

TABLE 61

Effect of ammonia on effluent toxicity measured in terms of carotenoids of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Ammonia concentrations (μg-at NH_3-N L^{-1})	Carotenoids (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.04	2.128	143.20	148.00	134.40	1.050
Treatment	0.04	2.128	162.80	165.20	160.00	1.084*
Control	0.08	2.128	133.60	128.00	136.80	1.033
Treatment	0.08	2.128	168.00	163.00	170.16	1.091*
Control	0.16	2.128	120.80	128.00	123.00	1.016
Treatment	0.16	2.128	148.60	156.40	151.00	1.067*
Control	0.32	2.128	102.40	107.20	98.40	0.969
Treatment	0.32	2.128	132.00	126.40	130.40	1.027*
Control	0.64	2.128	83.20	88.80	84.00	0.923
Treatment	0.64	2.128	122.40	126.40	116.80	1.012*
Control	0.80	2.128	79.20	80.80	86.40	0.913
Treatment	0.80	2.128	94.00	98.00	97.20	0.953*
Control	2.40	2.128	35.20	41.60	40.80	0.728
Treatment	2.40	2.128	65.60	62.40	60.00	0.846*

* t value significant at 5% level

4.2.9. Toxicity at low nitrate concentration vs. phosphate

Cultures of N. palea were found to respond positively to increasing phosphate concentration in the culture medium. There was significant increase in cell number, chlorophyll a, c and carotenoids (Table 62). Addition of effluent did not alter the cell counts at any phosphate concentration tested (Table 63). However, the pigment content was found to decrease significantly in the presence of effluent (Table 64, 65, 66).

TABLE 62

Cell yield and photosynthetic pigments of Nitzschia palea grown in various phosphate concentrations at low nitrate level for 96 hr

Phosphate concentrations (μg-at PO_4-P L^{-1})	Cell count mL^{-1} ($\times 10^4$) Initial	Final		Mean k'
0.00	1.00	7.75	4.25	5.25	0.429
0.60	1.00	34.54	39.65	34.80	0.898*
1.80	1.00	52.75	57.85	56.14	1.004*
5.40	1.00	49.76	43.82	46.43	0.960*
16.20	1.00	47.08	48.15	52.01	0.973*
48.60	1.00	40.00	46.50	35.00	0.924*
	Chlorophyll a (μg L^{-1}) Initial	Final		
0.00	4.062	22.46	20.41	27.21	0.436
0.60	4.062	124.57	120.06	119.98	0.850*
1.80	4.062	145.06	147.77	142.68	0.894*
5.40	4.062	132.90	131.37	139.76	0.875*
16.20	4.062	124.49	135.56	124.49	0.863*
48.60	4.062	120.06	122.20	129.08	0.854*

	Initial	Chlorophyll c (μ g L^{-1}) Final			
0.00	3.077	21.77	17.90	13.40	0.432
0.60	3.077	56.41	53.03	57.90	0.724*
1.80	3.077	61.28	68.16	69.28	0.767*
5.40	3.077	59.44	53.78	62.06	0.736*
16.20	3.077	60.19	56.41	59.04	0.736*
48.60	3.077	53.03	59.79	58.28	0.730*
	Initial	Carotenoids (μ g L^{-1}) Final			
0.00	4.058	24.00	22.00	24.00	0.437
0.60	4.058	136.00	130.00	130.00	0.871*
1.80	4.058	136.00	148.00	136.00	0.885*
5.40	4.058	152.00	160.00	150.00	0.909*
16.20	4.058	136.00	138.00	136.00	0.879*
48.60	4.058	128.00	139.00	138.00	0.876*

* t value significant at 5% level.

TABLE 63

Effect of phosphate on effluent toxicity measured in terms of cell yield of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Cell count mL^{-1} (x 10^4) Initial	Final		Mean k'
Control	0.60	1.00	34.54	39.65	34.80	0.898
Treatment	0.60	1.00	45.50	39.60	36.40	0.924
Control	1.80	1.00	52.75	57.85	56.14	1.004
Treatment	1.80	1.00	48.72	55.50	53.54	0.990

Control	5.40	1.00	49.76	73.82	46.43	1.004
Treatment	5.40	1.00	46.75	42.85	44.41	0.950
Control	16.20	1.00	47.08	48.15	52.01	0.973
Treatment	16.20	1.00	45.25	49.65	47.60	0.965
Control	48.60	1.00	40.00	46.50	35.00	0.924
Treatment	48.60	1.00	37.75	41.25	40.76	0.922

TABLE 64

Effect of phosphate on effluent toxicity measured in terms of chlorophyll a of Nitzschia palea for test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Chlorophyll a (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.60	4.062	124.57	120.06 119.98	0.850
Treatment	0.60	4.062	104.72	110.89 106.38	0.819*
Control	1.80	4.062	145.06	147.77 142.68	0.894
Treatment	1.80	4.062	124.41	124.65 133.67	0.862*
Control	5.40	4.062	132.90	131.37 139.76	0.875
Treatment	5.40	4.062	111.09	109.06 101.80	0.818*
Control	16.20	4.062	124.49	135.56 124.49	0.863
Treatment	16.20	4.062	99.74	95.81 94.32	0.792*
Control	48.60	4.062	120.06	122.20 129.08	0.854
Treatment	48.60	4.062	83.36	81.37 82.69	0.753*

* t value significant at 5% level.

TABLE 65

Effect of phosphate on effluent toxicity measured in terms of chlorophyll c of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Chlorophyll c (μg L^{-1})				Mean k'
		Initial	Final			
Control	0.60	3.077	56.41	53.03	57.90	0.724
Treatment	0.60	3.077	63.11	56.01	55.63	0.735
Control	1.80	3.077	61.28	68.16	69.28	0.767
Treatment	1.80	3.077	56.15	51.54	58.30	0.722*
Control	5.40	3.077	59.44	53.78	62.06	0.736
Treatment	5.40	3.077	38.55	39.44	37.30	0.631*
Control	16.20	3.077	60.19	59.04	56.41	0.736
Treatment	16.20	3.077	23.93	27.78	24.68	0.528*
Control	48.60	3.077	53.03	59.79	58.28	0.730
Treatment	48.60	3.077	16.28	15.93	12.45	0.392*

* t value significant at 5% level.

TABLE 66

Effect of phosphate on effluent toxicity measured in terms of carotenoids of Nitzschia palea for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Carotenoids (μg L^{-1})				Mean k'
		Initial	Final			
Control	0.60	4.058	136.00	130.00	130.00	0.871
Treatment	0.60	4.058	137.00	133.00	138.00	0.878
Control	1.80	4.058	136.00	148.00	136.00	0.885
Treatment	1.80	4.058	110.00	118.00	114.00	0.834*

Control	5.40	4.058	152.00	160.00	150.00	0.909
Treatment	5.40	4.058	128.00	119.00	125.00	0.855*
Control	16.20	4.058	136.00	138.00	136.00	0.879
Treatment	16.20	4.058	102.00	101.64	100.18	0.804*
Control	48.60	4.058	128.00	139.00	138.00	0.876
Treatment	48.60	4.058	83.00	89.00	90.00	0.767*

* t value significant at 5% level.

Though phosphate had a stimulatory effect on the growth of O. pusilla var. major, significant enhancement in cell number was observed only at 48.60 μ g-at PO_4-P L^{-1}. At lower concentrations, the cell number was similar to that of the control (Table 67). Compared to the cell counts, the pigments were more sensitive to increase of phosphate in the medium. The amount of chlorophyll a increased significantly as concentration of phosphate increased. The rate of stimulation of chlorophyll b and carotenoids was slow in that significant increase in these pigments occurred only from 5.4 μ g-at PO_4-P L^{-1}. In the presence of effluent, the species showed higher growth rate from the lowest to the highest levels of phosphate tested. In this respect, both cell counts and the pigments responded similarly (Table 68, 69, 70, 71).

TABLE 67

Cell yield and photosynthetic pigments of Oocystis pusilla var. major grown in various phosphate concentrations at low nitrate level for 96 hr

Phosphate concentrations (μ g-at PO_4-P L^{-1})	Cell count mL^{-1} (x 10^4)				Mean k'
	Initial	Final			
0.00	1.00	3.55	2.25	1.46	0.205
0.60	1.00	2.50	3.00	2.24	0.235

1.80	1.00	2.17	3.25	1.09	0.170
5.40	1.00	3.75	5.25	3.24	0.346
16.20	1.00	3.25	5.50	6.01	0.390
48.60	1.00	10.15	7.85	8.49	0.543*

Chlorophyll a ($\mu g\ L^{-1}$)

	Initial		Final		
0.00	5.959	16.00	15.61	17.54	0.253
0.60	5.959	22.32	18.39	21.93	0.313*
1.80	5.959	25.54	20.39	24.70	0.342*
5.40	5.959	28.77	20.39	25.16	0.354*
16.20	5.959	33.86	37.09	31.32	0.435*
48.60	5.959	63.72	51.02	53.79	0.560*

Chlorophyll b ($\mu g\ L^{-1}$)

	Initial		Final		
0.00	3.389	10.87	7.94	8.02	0.240
0.60	3.389	10.09	8.99	9.98	0.262
1.80	3.389	8.67	11.91	11.79	0.287
5.40	3.389	17.01	14.57	13.63	0.372*
16.20	3.389	15.91	17.61	15.81	0.395*
48.60	3.389	23.46	24.65	24.36	0.491*

Carotenoids ($\mu g\ L^{-1}$)

	Initial		Final		
0.00	5.236	12.00	15.20	13.60	0.238
0.60	5.236	16.00	12.80	14.40	0.252
1.80	5.236	16.40	16.00	14.00	0.270
5.40	5.236	19.60	17.20	17.20	0.308*
16.20	5.236	21.60	22.60	19.60	0.350*
48.60	5.236	25.60	23.20	23.20	0.380*

* t value significant at 5% level.

TABLE 68

Effect of phosphate on effluent toxicity measured in terms of cell yield of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Cell count mL^{-1} (x 10^4)			Mean k'
		Initial	Final		
Control	0.60	1.00	2.50	3.00	2.24	0.235
Treatment	0.60	1.00	50.25	46.75	49.99	0.973*
Control	1.80	1.00	2.17	3.25	1.09	0.170
Treatment	1.80	1.00	43.25	47.75	45.74	0.955*
Control	5.40	1.00	3.75	5.25	3.24	0.346
Treatment	5.40	1.00	40.50	36.75	36.75	0.909*
Control	16.20	1.00	3.25	5.50	6.01	0.390
Treatment	16.20	1.00	25.52	23.00	18.98	0.777*
Control	48.60	1.00	10.15	7.85	8.49	0.543
Treatment	48.60	1.00	22.75	19.70	19.56	0.757*

* t value significant at 5% level.

TABLE 69

Effect of phosphate on effluent toxicity measured in terms of chlorophyll a of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Chlorophyll a (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.60	5.959	22.39	18.39	21.93	0.313
Treatment	0.60	5.959	227.23	222.39	214.07	0.904*

Control	1.80	5.959	25.54	20.39	24.70	0.342
Treatment	1.80	5.959	198.12	193.76	189.60	0.871*
Control	5.40	5.959	28.77	20.39	25.16	0.354
Treatment	5.40	5.959	144.28	147.51	137.58	0.795*
Control	16.20	5.959	33.86	37.09	31.32	0.435
Treatment	16.20	5.959	78.32	86.56	79.54	0.654*
Control	48.60	5.959	63.72	51.02	53.79	0.560
Treatment	48.60	5.959	76.95	72.56	73.02	0.630*

* t value significant at 5% level.

TABLE 70

Effect of phosphate on effluent toxicity measured in terms of chlorophyll b of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Chlorophyll b (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.60	3.389	10.09	8.99	9.98	0.262
Treatment	0.60	3.389	84.17	89.09	89.41	0.813*
Control	1.80	3.389	8.67	11.91	11.79	0.287
Treatment	1.80	3.389	67.30	75.88	76.54	0.768*
Control	5.40	3.389	17.01	14.57	13.63	0.372
Treatment	5.40	3.389	78.50	64.52	79.26	0.770*
Control	16.20	3.389	15.91	17.61	15.81	0.395
Treatment	16.20	3.389	42.52	54.73	48.38	0.664*
Control	48.60	3.389	23.46	24.65	24.36	0.491
Treatment	48.60	3.389	33.72	40.71	33.25	0.589*

* t value significant at 5% level.

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TABLE 71

Effect of phosphate on effluent toxicity measured in terms of carotenoids of Oocystis pusilla var. major for a test period of 96 hr at low nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Carotenoids (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.60	5.236	19.60	17.20	17.20	0.308
Treatment	0.60	5.236	60.00	66.40	60.80	0.619*
Control	1.80	5.236	16.40	16.00	14.00	0.270
Treatment	1.80	5.236	48.00	52.80	55.20	0.574*
Control	5.40	5.236	16.00	12.80	14.40	0.252
Treatment	5.40	5.236	23.20	28.00	23.20	0.388*
Control	16.20	5.236	21.60	22.60	19.60	0.350
Treatment	16.20	5.236	32.60	33.58	32.00	0.548*
Control	48.60	5.236	25.60	23.20	23.20	0.380
Treatment	48.60	5.236	32.60	30.60	36.80	0.462*

* t value significant at 5% level.

4.2.10. Toxicity at high nitrate concentration vs. phosphate

The growth rate of N. palea increased with increasing concentration of phosphate in the medium (Table 72). The enhancement of growth was reflected both in cell counts and photosynthetic pigments. In presence of effluent, the cell counts were found to be higher than the respective controls at 0.60 and 1.80 μ g-at PO_4-P L^{-1}. At higher concentrations of phosphate the presence of effluent did not affect growth (Table 73). The amount of chlorophyll a increased at 0.60 μ g-at PO_4-P L^{-1} followed by significant reduction in all higher levels of phosphate tested (Table 74). Chlorophyll c was found to be significantly reduced at all phosphate

concentrations (Table 75). Carotenoids behaved similar to that of chlorophyll a (Table 76).

TABLE 72

Cell yield and photosynthetic pigments of Nitzschia palea grown in various phosphate concentrations at high nitrate level for 96 hr

Phosphate concentrations (μg-at PO_4-P L^{-1})	Cell count mL^{-1} ($\times 10^4$)				Mean k'
	Initial		Final		
0.00	1.00	16.10	19.76	18.38	0.723
0.60	1.00	37.35	41.75	41.75	0.924*
1.80	1.00	45.50	41.35	42.90	0.942*
5.40	1.00	49.75	53.25	50.30	0.983*
16.20	1.00	48.75	44.55	45.45	0.958*
48.60	1.00	37.56	43.55	42.19	0.929*
	Chlorophyll a (μg L^{-1})				
	Initial		Final		
0.00	3.755	70.31	68.92	64.42	0.724
0.60	3.755	121.21	126.78	122.52	0.873*
1.80	3.755	219.05	215.45	214.79	1.014*
5.40	3.755	263.14	261.99	265.57	1.063*
16.20	3.755	217.34	222.32	220.50	1.018*
48.60	3.755	119.48	118.67	114.56	0.861*
	Chlorophyll c (μg L^{-1})				
	Initial		Final		
0.00	1.565	31.01	27.87	25.98	0.723
0.60	1.565	75.43	76.15	70.16	0.964*
1.80	1.565	83.73	82.89	87.97	0.998*
5.40	1.565	93.78	87.71	87.92	1.012*
16.20	1.565	87.38	83.78	89.48	1.004*
48.60	1.565	68.11	71.89	74.15	0.955*

	Carotenoids (μg L^{-1})			
	Initial	Final		
0.00	2.581	48.00	40.00	52.00	0.722
0.60	2.581	140.00	142.00	146.00	1.003*
1.80	2.581	230.00	226.00	236.00	1.123*
5.40	2.581	274.00	279.00	275.00	1.168*
16.20	2.581	248.00	252.00	242.00	1.141*
48.60	2.581	205.00	210.00	211.00	1.098*

* t value significant at 5% level.

TABLE 73

Effect of phosphate on effluent toxicity measured in terms of cell yield of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Cell count mL^{-1} (x 10^4)			Mean k'
		Initial	Final		
Control	0.60	1.00	37.35	41.75	41.75	0.924
Treatment	0.60	1.00	49.75	55.25	52.74	0.990*
Control	1.80	1.00	45.50	41.35	42.90	0.942
Treatment	1.80	1.00	49.25	55.75	53.01	0.991*
Control	5.40	1.00	49.75	53.25	50.30	0.983
Treatment	5.40	1.00	52.75	54.85	53.30	0.996
Control	16.20	1.00	48.75	44.55	45.45	0.958
Treatment	16.20	1.00	47.95	51.55	50.26	0.978
Control	48.60	1.00	37.56	43.55	42.19	0.929
Treatment	48.60	1.00	45.84	49.55	46.36	0.964

* t value significant at 5% level.

TABLE 74

Effect of phosphate on effluent toxicity measured in terms of chlorophyll *a* of *Nitzschia palea* for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Chlorophyll *a* (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.60	3.755	121.21	126.78 122.52	0.873
Treatment	0.60	3.755	179.55	182.66 182.75	0.970*
Control	1.80	3.755	219.05	215.45 214.79	1.014
Treatment	1.80	3.755	188.00	174.64 189.89	0.970*
Control	5.40	3.755	263.14	261.99 265.57	1.063
Treatment	5.40	3.755	163.25	174.48 168.16	0.951*
Control	16.20	3.755	217.34	222.32 220.50	1.018
Treatment	16.20	3.755	172.34	181.44 176.85	0.963*
Control	48.60	3.755	119.48	118.67 114.56	0.861
Treatment	48.60	3.755	77.09	70.53 76.93	0.748*

* t value significant at 5% level.

TABLE 75

Effect of phosphate on effluent toxicity measured in terms of chlorophyll *c* of *Nitzschia palea* for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Chlorophyll *c* (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.60	1.565	75.43	76.15 70.16	0.964
Treatment	0.60	1.565	65.10	66.99 68.48	0.939*

Control	1.80	1.565	83.73	82.89	87.97	0.998
Treatment	1.80	1.565	74.24	66.36	64.50	0.944*
Control	5.40	1.565	93.78	87.71	87.92	1.012
Treatment	5.40	1.565	50.87	56.62	46.61	0.872*
Control	16.20	1.565	87.38	83.78	89.48	1.004
Treatment	16.20	1.565	63.22	64.10	52.24	0.910*
Control	48.60	1.565	68.11	79.89	74.15	0.964
Treatment	48.60	1.565	53.38	55.62	53.01	0.885*

* t value significant at 5% level.

TABLE 76

Effect of phosphate on effluent toxicity measured in terms of carotenoids of Nitzschia palea for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Carotenoids (μg L^{-1})			Mean k'
		Initial	Final		
Control	0.60	2.581	140.0	142.0	146.0	1.003
Treatment	0.60	2.581	146.0	150.0	143.0	1.009
Control	1.80	2.581	230.0	226.0	236.0	1.123
Treatment	1.80	2.581	199.0	196.0	205.0	1.088*
Control	5.40	2.581	274.0	279.0	275.0	1.168
Treatment	5.40	2.581	178.0	188.0	184.0	1.066*
Control	16.20	2.581	248.0	252.0	242.0	1.141
Treatment	16.20	2.581	196.0	188.0	198.0	1.080*
Control	48.60	2.581	205.0	210.0	211.0	1.098
Treatment	48.60	2.581	186.0	192.0	182.0	1.070*

* t value significant at 5% level.

Addition of 0.60 and 1.80 μ g-at PO_4-P L^{-1} to the culture medium did not affect the cell doubling rate of O. pusilla var. major; but there was significant enhancement of growth at higher levels of phosphate. There was significant enhancement in the amounts of chlorophyll a and b at all levels of phosphate tested (Table 77). The amount of carotenoids increased above the phosphate level of 1.80 μ g-at PO_4-P L^{-1}. When phosphate was added in the presence of effluent the rate of cell multiplication and the amount of pigments were enhanced significantly over that of the respective controls (Table 78, 79, 80, 81).

TABLE 77

Cell yield and photosynthetic pigments of Oocystis pusilla var. major grown in various phosphate concentrations at high nitrate level for 96 hr

Phosphate concentrations (μ g-at PO_4-P L^{-1})	Cell count mL^{-1} ($\times 10^4$) Initial	Final			Mean k'
0.00	1.00	1.75	2.50	1.75	0.170
0.60	1.00	3.55	1.72	3.49	0.255
1.80	1.00	5.00	4.55	2.45	0.335
5.40	1.00	5.50	3.75	2.75	0.337*
16.20	1.00	24.55	29.75	28.95	0.830*
48.60	1.00	18.55	22.75	20.95	0.757*
	Chlorophyll a (μ g L^{-1}) Initial	Final			
0.00	6.575	15.93	10.39	13.16	0.170
0.60	6.575	19.16	17.16	22.32	0.271*
1.80	6.575	32.63	32.32	29.16	0.390*
5.40	6.575	49.40	50.63	47.86	0.504*
16.20	6.575	149.58	155.12	158.98	0.789*
48.60	6.575	123.19	117.97	116.42	0.742*

	Chlorophyll b (μg L^{-1})				
	Initial	Final			
0.00	4.808	9.44	10.79	8.62	0.172
0.60	4.808	14.53	11.56	15.29	0.262*
1.80	4.808	17.60	20.15	19.39	0.344*
5.40	4.808	23.24	19.49	24.66	0.384*
16.20	4.808	71.02	72.56	71.84	0.677*
48.60	4.808	48.34	41.28	47.57	0.563*
	Carotenoids (μg L^{-1})				
	Initial	Final			
0.00	3.200	5.60	7.20	6.40	0.172
0.60	3.200	5.60	6.40	7.20	0.172
1.80	3.200	18.40	15.20	16.80	0.414*
5.40	3.200	13.60	15.20	19.60	0.402*
16.20	3.200	30.80	28.40	26.40	0.547*
48.60	3.200	36.00	31.20	31.20	0.581*

* t value significant at 5% level.

TABLE 78

Effect of phosphate on effluent toxicity measured in terms of cell yield of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μg-at PO_4-P L^{-1})	Cell count mL^{-1} (x 10^4)				Mean k'
		Initial	Final			
Control	0.60	1.00	3.55	1.72	3.49	0.255
Treatment	0.60	1.00	75.83	72.15	73.78	1.076*
Control	1.80	1.00	5.50	3.75	2.75	0.337
Treatment	1.80	1.00	68.62	73.96	70.18	1.066*
Control	5.40	1.00	5.00	4.55	2.45	0.335
Treatment	5.40	1.00	69.76	65.87	66.63	1.053*

Control	16.20	1.00	24.55	29.75	28.95	0.830
Treatment	16.20	1.00	55.50	46.70	47.05	0.976*
Control	48.60	1.00	18.55	22.75	20.95	0.757
Treatment	48.60	1.00	43.55	36.72	37.48	0.917*

* t value significant at 5% level.

TABLE 79

Effect of phosphate on effluent toxicity measured in terms of chlorophyll a of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Chlorophyll a (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.60	6.575	19.16	17.16	22.32	0.271
Treatment	0.60	6.575	436.90	437.83	442.81	1.050*
Control	1.80	6.575	32.63	32.32	29.16	0.390
Treatment	1.80	6.575	391.90	381.58	384.21	1.018*
Control	5.40	6.575	49.40	50.63	47.86	0.504
Treatment	5.40	6.575	425.69	431.30	432.07	1.045*
Control	16.20	6.575	149.58	155.12	158.98	0.789
Treatment	16.20	6.575	419.34	421.20	416.43	1.039*
Control	48.60	6.575	123.19	117.97	116.42	0.724
Treatment	48.60	6.575	219.30	217.30	212.14	0.873*

* t value significant at 5% level.

TABLE 80

Effect of phosphate on effluent toxicity measured in terms of chlorophyll b of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Chlorophyll b (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.60	4.808	14.53	11.56 15.29	0.262
Treatment	0.60	4.808	209.76	210.20 208.28	0.944*
Control	1.80	4.808	17.60	20.15 19.39	0.344
Treatment	1.80	4.808	150.32	152.86 149.03	0.861*
Control	5.40	4.808	23.24	19.49 24.66	0.384
Treatment	5.40	4.808	130.85	133.84 135.69	0.831*
Control	16.20	4.808	71.02	72.56 71.84	0.676
Treatment	16.20	4.808	119.59	124.42 126.22	0.811*
Control	48.60	4.808	48.34	41.28 47.57	0.563
Treatment	48.60	4.808	88.74	90.63 86.90	0.729*

* t value significant at 5% level.

TABLE 81

Effect of phosphate on effluent toxicity measured in terms of carotenoids of Oocystis pusilla var. major for a test period of 96 hr at high nitrate level

Medium	Phosphate concentrations (μ g-at PO_4-P L^{-1})	Carotenoids (μ g L^{-1})			Mean k'
		Initial	Final		
Control	0.60	3.200	5.60	6.40 7.20	0.172
Treatment	0.60	3.200	110.40	116.00 116.80	0.894*
Control	1.80	3.200	18.40	15.20 16.80	0.414
Treatment	1.80	3.200	87.20	92.00 89.60	0.833*

Control	5.40	3.200	13.60	15.20	19.60	0.402
Treatment	5.40	3.200	72.80	68.00	72.80	0.766*
Control	16.20	3.200	30.80	28.40	26.40	0.547
Treatment	16.20	3.200	44.00	39.20	41.60	0.641*
Control	48.60	3.200	36.00	31.20	31.20	0.581
Treatment	48.60	3.200	40.80	44.80	44.00	0.651*

* t value significant at 5% level.

CHAPTER 5

DISCUSSION

Observations on the physico-chemical quality of water in river Periyar reveal that the river has a freshwater regime upto station 3 (Pathalam). The industrial effluents discharged from the factories located downstream do not reach above station 3. This observation is in agreement with the conclusion of Jayapalan *et al*. (1976) that the river is devoid of industrial pollution beyond Pathalam. The downstream course of the river was subjected to salt water incursion from the Cochin backwater during postmonsoon and premonsoon months. The influx of salinity occurred upto station 4 (Edayar) during premonsoon where the salinity ranged between 0.44 and 9.78 x 10^{-3}. However, Sankaranarayanan *et al*. (1986) have reported salinity upto a distance> 25 km from the Cochin harbour mouth.

Reduction in river discharge during the premonsoon months is cited as a reason for the incursion of saline water towards upstream (Sankaranarayanan, *et al*., 1986). The data on water discharge in river Periyar (PWD, 1986) during the sampling year show a premonsoon average of 79.34 Mm^3 per month as against 410.95 Mm^3 in postmonsoon and 951.34 Mm^3 in monsoon. The intrusion of seawater upto station 4 during premonsoon might be attributed to very low freshwater discharge from upstream.

The seasonal fluctuation of salinity at station 6 (Cochin backwater) observed in the present investigation conforms

to the reports of previous investigators (Sankaranarayanan and Qasim, 1969; Balakrishnan and Shynamma, 1976; Gopinathan et al., 1984). With the onset of monsoon salinity decreases rapidly. As monsoon recedes, the influx of marine water from the Arabian Sea predominates over the freshwater discharge and hence salinity rises to nearly marine conditions. Sankaranarayanan and Qasim (1969) have observed homogeneity in vertical distribution of salinity during premonsoon and stratification of the water column during monsoon with bottom water being more saline. In the present study it was found that the salinity of bottom layers tend to be higher throughout the year. However, the annual means of surface and bottom salinities did not differ significantly. Sankaranarayanan and Qasim (1969) have reported that in shallow regions of the backwater stratification of the water column is less evident.

The annual range of temperature observed in the river and adjacent backwater was 24.5^{o} to 34.8^{o}C. The lowest values occurred in monsoon and the highest during premonsoon. Station 1 (Edamalayar) had the lowest temperature throughout the year in comparison with other sampling sites. This could be due to the comparatively high altitude. The spatial variation in temperature progressively increased from station 1 to station 6 during monsoon and postmonsoon periods. The pattern of distribution of temperature changed during premonsoon. The highest temperature was at station 4 and this decreased towards both station 3 and station 5. Station 4 (Edayar) is the region

of immediate outfall of effluents from at least three major chemical factories (FACT, TCC and Cominco Binani Zinc Ltd.). Probably, the discharge of heated effluents at a time when river discharge is low would have raised the ambient temperature of the river at this station. Sarala Devi et al. (1979) have also reported elevated temperature at the industrial discharge area of river Periyar in the nonmonsoon months. According to them it was partly due to the shallow nature and absence of strong tidal influence in this region.

Although the seasonal means of pH indicated no spatial variation and was within the normal range, exceptionally low pH occurred at stations 4 and 5 in certain months during the premonsoon season. According to the observations of Jayapalan et al. (1976), the pH of the region during the period 1968-'71 was in the normal range and did not affect the biological community adversely. Silas and Pillai (1976) have reported large scale fish mortality in the region of river Periyar between FACT and TCC (location of station 4 in the present study) which was attributed to highly acidic water. Sarala Devi et al. (1979) found erratic fluctuation of pH during nonmonsoon months in the industrial zone. These authors have suggested that the lowering of pH could be due to acidic effluents discharged from the industries at this location. In station 4, during the month of February, the bottom water was acidic when the surface remained almost neutral. This cannot be explained by industrial discharge alone.

The water in the river as well as that of the estuary was well oxygenated for most of the year. A comparison of the values with that of the standard values presented by Fox (1907) shows that there occurs supersaturation of oxygen which is of rather erratic occurrence throughout the stations. Similar instance of supersaturation of dissolved oxygen has been reported from Muvattupuzha river emptying into Cochin backwater by Balchand and Nambisan (1986). However, at stations 4 and 5 the amount of dissolved oxygen lowered to 3 mg L^{-1} in the bottom layer during the months of March, April and May. This suggests the probable occurrence of high levels of microbial activity in the bottom sediments. Probably this would partly explain the lowering of pH in the bottom water of this region which is subjected to less flushing during the premonsoon. A similar reduction of dissolved oxygen occurs in station 6 throughout the water column in the month of May. Sankaranarayanan and Qasim (1969) have reported values as low as 1 to 2 ml L^{-1} in the bottom water of Cochin backwater in August-October months. Balakrishnan and Shynamma (1976) explain that in the backwater, under-saturation of dissolved oxygen results from the decomposition of organic matter. In contrast to these observations, Sarala Devi et al. (1979) and Gopinathan et al. (1984) did not observe any depletion of dissolved oxygen in the river and backwater zone.

The data on BOD indicate that there is no serious organic load so as to deplete the oxygen content. BOD values were only slightly above the permitted limit of 3 mg L^{-1}

(IS: 2296-1982). Perhaps the water column is relatively free of organic wastes, due to rapid settling of any land-based source so that microbial activity is concentrated on the sediment surface which may lead to oxygen depletion under exceptional conditions.

The nutrient content of Cochin backwater and the lower reaches of river Periyar have been studied by various investigators. According to Sankaranarayanan and Qasim (1969) the nutrient level in Cochin backwater is high during monsoon and low in premonsoon season. The seasonal rhythm is induced by local precipitation, land run off and probably by the invasion of upwelled water from the Arabian Sea.

The present data on the distribution of nitrite show that the stretch of the river upto Pathalam (stations 1 to 3) has very low level of nitrite. But during monsoon months, the amount of nitrite in the water increased in the order of stations 4, 5, and 6. The magnitude of nitrite was high at station 6 i.e. 26.55 μ g-at NO_2-N L^{-1} as against 4.75 μ g-at NO_2-N L^{-1} at station 5. It is quite evident from this that the high rate of river discharge during monsoon does not account for the elevated level of nitrite in the backwater. Joseph (1974) assumes that either nitrate reduction or arrested oxidation of organic matter occurring locally might account for the nitrite maxima in Cochin backwater. Lakshmanan et al. (1987) also concluded that other than riverine inputs localised effects appear to be pronounced. During postmonsoon and

premonsoon the nitrite content of the backwater station decreased whereas station 5 (Eloor) recorded high value (29.25 μ g-at NO_2-N L^{-1}) to be followed closely by station 4 (Edayar). This data confirm the view that neither tidal water nor riverine flow from the upstream sites contributes to these localised rise in nitrite levels.

The present observation on nitrate level of river Periyar reveals that the concentration has increased considerably during the past decade. During the year 1976-1977, it was found that the maximum value was $\simeq$ 18 μ g-at NO_3-N L^{-1} in the northern region (industrial zone of river Periyar) of Cochin backwater (Lakshmanan et al., 1987), whereas during the present observation the highest concentration recorded was 406.0 μ g-at NO_3-N L^{-1}. Reports on Cochin backwater by many investigators point out that there is a rise in nitrate level of the estuary during monsoon season (Sankaranarayanan and Qasim, 1969; Devassy and Bhattathiri, 1974; Remani et al., 1980; Lakshmanan et al., 1987). The reason for this has variously been assigned to nitrates in the industrial effluents discharged into river Periyar, sewage outlets, fishery wastes and coconut retting grounds. The present investigation has shown that there is no spatial variation in the distribution of nitrate. High concentrations occurred even at Edamalayar, a location least affected by any industrial discharge, sewage disposal or such related activities. So the reasons cited by the above authors is not sufficient to explain the high nitrate level in the river as well as the backwater.

The dissolution of nitrate in the watershed of the river intensified by the large scale clearance of forests and consequent land run off may be responsible for the observed result. This is supported by the fact that the monsoon values are higher than that of the premonsoon months.

The concentration of ammonia at station 1 to 3 was negligible. Stations 4 and 5 exhibited a prominent premonsoon peak while at station 6 the amount of ammonia was almost uniform throughout the year. The range of concentrations indicates that Edayar-Eloor region of the river has higher ammonia content than the backwater. Joseph et al. (1984) have reported an ammonia concentration of 288 μ g NH_3-N L^{-1} in this region. However, the present results show only lesser amounts i.e. 0.14 to 65.71 μ g-at NH_3-N L^{-1}. Sarala Devi et al. (1979) have reported the presence of ammonia in the effluents of many factories situated here. They observed the level of ammonia in the river water to be between 0.1 and 3.0 ppm. Eventhough ammonia level is high in the water body perhaps it does not occur in the unionised form at the existing pH of the water. It is generally recognized that the unionised ammonia alone is injurious to organisms (Boyd, 1982; Crumpton and Isenhart, 1988).

Regarding the distribution of phosphorus the main feature was that the stretch of the river from Edamalayar to Pathalam had only negligible amounts while stations at Edayar and Eloor exhibited typical premonsoon maxima (highest recorded

value = 64.58 μ g-at PO_4-P L^{-1}) with low values during the rest of the year. In the backwater station high concentrations occurred during premonsoon, the magnitude being less than that of Edayar and Eloor. Jayapalan et al. (1976) observed only traces of inorganic phosphate in the industrial zone of river Periyar. However, later investigations conducted in this stretch of the river reveal increasing amounts of phosphate in the water. Paul and Pillai (1976) state that random discharges mainly from industries result in high values of phosphate in the region of river Periyar between industrial outfalls and Cochin backwater. Joseph et al. (1984) have recorded a maximum value of 955 μ g-at PO_4-P L^{-1} in this region. The data presented by Sankaranarayanan et al. (1986) show the highest level of phosphate in this locality to be $\leq$ 81 μ mol L^{-1} while according to Lakshmanan et al. (1987) the range is between 60 and 150 μ g-at PO_4-P L^{-1} during the period 1976-'77. The latter authors point out that such phosphate levels result from sewage input and industrial waste disposal.

The seasonal fluctuation of phosphate in the backwater station showed peak values in premonsoon in contrast to the reports of Sankaranarayanan and Qasim (1969) and Devassy and Bhattathiri (1974). The premonsoon maximum observed at present is supported by the observation of Joseph (1974) that in Cochin backwater the phosphate levels exceed the limit of water pollution standards during premonsoon.

The overall picture that emerges from the analyses of physico-chemical properties of water is that the first three sampling stations (Edamalayar to Pathalam) is free of pollution. At the region of immediate effluent discharge from the industries (station 4) and also at station 5 which is 5 km downstream of the former, there is occasional increase in temperature, lowering of pH and exceptionally low oxygen in bottom water during the premonsoon season. The distribution of nutrients is such that nitrate is high and uniformly distributed from the headwater downwards whereas nitrite, ammonia and phosphate exhibit localised increase at stations 4 and 5 during premonsoon period. In the backwater station, nitrite and ammonia are high in monsoon while phosphate maximum occur in premonsoon. The magnitude of ammonia and phosphate are less than that of station 5. It is evident that during premonsoon period the river discharge and tidal incursion are not sufficient to dilute the localised inputs of nutrients in the lower reaches of river Periyar.

The phytoplankton composition in stations 1 to 3 were indicative of clean water frequented by green algae (desmids) and diatoms while at stations 4 and 5 Cyanobacteria dominated. In the opinion of Palmer (1980) streams are not characterised by any species peculiar to it as they are subject to fluctuating conditions. Normally phytoplankton population in rivers comprise of diatoms, green algae and blue-green algae. When they are enriched with nutrients certain species tend to overgrow. Species of Oscillatoria, Nitzschia, Navicula, Surirella etc.

occur in abundance in such areas. The present observation is that stations 4 and 5 exhibit abundance of Anabaena, Microcystis, Nostoc and Oscillatoria during premonsoon. Jayapalan et al. (1976) have reported Oscillatoria blooms from the Edayar region of river Periyar. Sarala Devi et al. (1979) also observed termination of an algal bloom in this locality accompanied by increasing organic load.

Freshwater systems receiving large inputs of phosphorus are seen to be dominated by species of Anabaena, Aphanizomenon, Gleotrichia, Microcystis and Oscillatoria (Paerl, 1988). Investigation on the plankton community of river Cauvery which is polluted by a paper mill and a fertilizer factory and that of river Kapila receiving effluents from textile and paper factories showed that species of Cyanophyceae dominated the polluted sites (Somashekar, 1988). As presented by Sankaran (1988) the plankton genera comprising Microcoleus, Cyclotella, Navicula, Fragilaria and occasionally Euglena survive the effect of paper mill effluents in river Cauvery. Palharya and Malviya (1988) observed that in river Narmada the distribution of species of Myxophyceae and Bacillariophyceae indicated the extent of pollution.

The backwater station investigated had a predominance of diatoms. Bloom of Skeletonema costatum occurred in the month of February. These observations are in conformity to that of Gopinathan et al. (1974; 1984). A comparison of Cochin backwater with Ashtamudi estuary in this regard shows that the phyto-

plankton community of the latter is dominated by Cyanophyceae followed by Chlorophyceae and Bacillariophyceae (Mathew and Nair, 1980).

The seasonal fluctuation of chlorophyll pigments was such that the magnitude was low during monsoon and high during premonsoon. Stations 1 to 3 had low standing stock of chlorophylls (< 5.45 mg m^3) compared to that of stations 4 to 6. At the Edayar-Eloor stretch of the river, there was significantly high proportion of chlorophylls than that of the backwater during premonsoon period. This suggests a localised stimulation of primary production in the region. Among the two sites, Edayar and Eloor, the latter was more productive. Joseph et al. (1984) observed only poor concentration of phytoplankton near the effluent discharge site of FACT in river Periyar (station 4 in the present investigation). They have reasoned that this adverse effect on phytoplankton flora is due to the inhibitory action of high level of phosphate. They have recorded a maximum phosphate concentration of 955 μ g-at PO_4-P L^{-1} as against 64.58 μ g-at PO_4-P L^{-1} in the present observation. At such a high level of phosphate in the water as observed by Joseph et al. (1984) probably algal community would have been adversely affected. Effluents released from another unit of FACT located on the southern part of Cochin harbour have been reported to stimulate phytoplankton production (Nair et al., 1988) in the vicinity of the outfalls in Cochin backwater.

The seasonal pattern of distribution of chlorophyll pigments at station 6 indicated high values of chlorophyll a, b and c during premonsoon while the magnitude was low during monsoon months. This observation differs from that of Gopinathan et al. (1984) that chlorophyll a and b show primary peak in monsoon whereas chlorophyll c was exceptionally high during premonsoon. The same authors observed increase in primary production in the Cochin backwater during premonsoon. According to Joseph and Pillai (1975) the chlorophyll, cell count and primary production are of low magnitude during the monsoon period.

The qualitative distribution of chlorophyll pigment was such that chlorophyll a dominated in the ecosystem. This is in contrast to the observations of Gopinathan et al. (1984) that chlorophyll c is the predominant pigment in the backwater system. The conclusion that the increase in chlorophyll c is due to the presence of plenty of degrading chlorophyll cannot be accepted in the light of the present observation that the amount of pheopigments is comparatively low, as the chlorophyll a computed by Lorenzen's method did not differ significantly from that of the trichromatic method of Jeffrey and Humphrey. The magnitude of pheopigments even at station 4 does not indicate any abnormally high disintegration processes occurring. However, it has to be realised that year to year variation can possibly occur depending on the climatic and hydrographic features. As per the data collected during the present investigation, the stretch of river Periyar from Edayar to Eloor supports

enhanced phytoplankton growth during premonsoon. Although the chlorophyll values indicate eutrophication and algal bloom, it has not grown into that proportion of forming nuisance scums on the water surface.

Multiple regression analyses of the data show that the factors responsible for phytoplankton production varies with the location. Gopinathan et al. (1984) have remarked that even within the Cochin backwater, locations are independent of each other and the probable reason for this is the dynamic nature of the backwater. Temperature is the only factor that is common to all the five riverine stations and this exerts a positive effect on the production of chlorophylls. It is well established that many cellular processes of phytoplankton are temperature-dependent and their rates are accelerated with increasing temperature, especially between 25° and 40°C (Reynolds, 1984). However, it is observed that temperature acts in combination with other factors that differ from station to station. Thus in station 1 nitrate has a positive effect while dissolved oxygen and nitrite have negative effect on chlorophyll production. Probably the low temperature (annual average = 27.26°C) would explain the reduced standing crop at this locality. In station 2, nitrate and phosphate act positively together with pH while ammonia has negative effect. The N:P ratio is quite high; probably the inadequacy of phosphate would have resulted in reduced algal biomass. At station 3, where nitrate and phosphate positively affect chlorophyll

together with temperature, it is found that the low concentration of phosphate is limiting the phytoplankton production. Paerl (1988) states that the slow moving rivers and some reservoirs exhibit relatively high N:P ratios (> 30:1) and such waters are dominated by non-cyanobacterial species. This explanation fits well to the situation at station 2 and station 3. At station 4 (Edayar) pH acts positively with temperature while dissolved oxygen, nitrate and phosphate have negative effect. The N:P ratio is 16:1, something expected in highly productive waters. As pH, nitrate and dissolved oxygen do not show any spatial variation, temperature and phosphate should be the critical factors at this region. During the premonsoon period, both these factors were high at station 4. The high temperature with the right N:P ratio would have accelerated the algal growth. As the two factors i.e. temperature and phosphate are locally created, probably by the industrial discharges or microbial activity it may be expected that any further increase in phosphate would offset the algal biomass in the negative direction, probably a bit counterbalanced by the increased temperature.

At station 5 (Eloor) pH and temperature are the only contributing factors and as these have positive effect on chlorophyll standing stock, it may be assumed that when compared to station 4, the higher values of pH and temperature might have resulted in increased production during the premonsoon. The data on the phytoplankton biomass of the backwater station show that it

is not dependent on any of the environmental factors investigated. As stated by Sankaranarayanan and Qasim (1969) the instantaneous concentration of nutrients in Cochin backwater as inorganic salts did not have any significant relation to primary production. Gopinathan et al. (1984) have however, observed correlation between primary productivity and environmental factors such as phosphate, nitrate, oxygen and temperature in this region of the backwater. It should be remembered that this locality is subject to considerable mixing of seawater from the Arabian Sea so that the ecosystem is in a dynamic state.

The causative factors of enhanced phytoplankton crop in the Edayar-Eloor stretch of river Periyar may be partly attributed to the effluents discharged from the factories nearby. However, the data reveal that during premonsoon when the dilution rate is minimum in the river, station 4 which is close to the fertilizer factory (FACT) has less of phosphate and ammonia compared to station 5 which is 5 km away and subject to more tidal action. At this station the concentration of nitrite is also comparatively high. Therefore, the waste discharge from industrial concerns alone cannot be implicated to be responsible for the observed changes in water quality. Perhaps, the accumulation of other land-based wastes - domestic and municipal - aided by rapid microbial degradation at the elevated temperature also contribute to the situation.

It is reported by Raman and Ganapati (1986) that successive blooms of Skeletonema costatum and chlorophyll a

values as high as 49.41 mg m^{-3} occur in Visakhapatanam harbour due to the discharge of untreated sewage and a fertilizer factory effluent. Probably a similar situation exists here. Although the primary producers are stimulated to grow, the occasional reports of fish mortality reveal that this region is prone to environmental degradation. The exceptionally low pH and dissolved oxygen observed at times supports this reasoning. The fact that these hazards occur only during the premonsoon months points to the necessity for increased dilution of the external inputs in the industrial area of river Periyar.

It may be argued that when compared to the level of pollution in other Indian rivers such as Ganges, Yamuna, Godavari, Cauvery etc. (Trivedy, 1988) the situation in river Periyar is less hazardous. However, the sporadic instances of fish mortality, high loading of phosphate and ammonia during premonsoon and the development of Cyanophycean blooms necessitate vigil and concern about the water quality of this region.

The axenic cultures of Nitzschia palea and Oocystis pusilla var. major employed to assess the effect of fertilizer factory effluent showed the typical growth characteristics expected of batch cultures (Fogg, 1975). The rate of growth was maximum during the exponential phase; this was followed by stationary phase towards the end of which alteration in the relative proportion of pigments began to be observed. The amount of carotenoids increased with age of the cultures. Species specific differences occurred in growth rate, pigment

content as well as environmental requirements. N. palea showed faster rate of growth than O. pusilla var. major especially during exponential phase. However, O. pusilla var. major produced more biomass (cell number) than N. palea as stationary phase progressed. Reynolds (1984) has reported maximum growth rate ranging from 1 to 11 divisions/day in freshwater algae. Besides the physiological and metabolic factors, the size and structural organization of the cell also seem to control the growth rate.

Nitzschia palea did not tolerate salinity while Oocystis pusiila var. major tolerated salinity upto 5×10^{-3}. The half-saturation constants for utilization of nitrate and phosphate indicate that N. palea can exploit lower levels of nitrate better than O. pusilla var. major, though the reverse holds good for phosphate. The half-saturation constant gives a measure of the limiting concentration of the nutrient in the particular system and it is important in interpreting the adaptation of populations to variations in nutrient concentrations (Raymont, 1980). As in the case of growth rate, the nutrient utilization capacity also differs among species. Eppley, et al. (1969) have concluded that in marine phytoplankton the capacity to utilize nitrogen increases with cell size and growth rate; generally it is lower among species of nutrient-deficient Oceans.

The toxicity studies revealed that the effluent collected from the fertilizer factory inhibited growth of

N. palea at 5 percent concentration. The EC_{50} value was 74 percent of the effluent. In contrast, growth of O. pusilla var. major was enhanced at 5 percent effluent. But as the effluent concentration increased, rapid inhibition of growth occurred and the biomass was reduced by 50 percent at 21 percent effluent, suggesting that the effect of an effluent is dependent upon species as well as concentration of the toxicant. Walsh et al. (1980; 1982) have observed that phytoplankton, whether freshwater, estuarine or marine respond to industrial effluents either by stimulation only or by stimulation at low concentration and inhibition at higher. Stockner and Cliff (1976) have stated that algae can adapt to relatively high concentrations of effluent. Wang (1986) concludes that acclimation of the test species to a toxicant has an important effect on its response to toxicity.

In natural ecosystem algae may be adversely affected or stimulated to grow under the influence of environmental contaminants (Palmer, 1980). Stockner and Cliff (1976) observed that industrial effluents affect primary production either by increased light attenuation or direct phytotoxicity or physiological stress. The stimulation of growth by industrial effluents cannot be easily explained. Gaur and Kumar (1981) reported that growth regulators in the effluents when present at a particular concentration can enhance growth rate. It is pointed out that the bioactivity of an effluent is related to the interactions of its various components in relation to its

physical properties (Walsh and Merrill, 1984). Inhibition of growth and reproduction may be brought about by sublethal effects on metabolism. The direct effects of environmental contaminants include inhibition of photosynthesis, suppression of nucleic acid synthesis, reduction of protein synthesis and inhibition of nutrient uptake as explained by various researchers (Boyle, 1984).

Based on the EC_{50} values obtained for N. palea and O. pusilla var. major in the present investigation, it was found that a minimum volume of 4.8 to 17.11 Mm^3 day^{-1} of water is required in river Periyar for effective dilution of this particular effluent. During the sampling year 1986, the lowest 7-day volume of water recorded in river Periyar was 1.10 Mm^3 day^{-1}. During the decade 1977-1986, the lowest discharge rate observed was 0.58 Mm^3 day^{-1}. These data clearly reveal that the water discharge in river Periyar during premonsoon months is inadequate to effect dilution of the effluent to safe level. It should be mentioned that the effluent used for the assay forms only a minor fraction of the total industrial waste entering the river.

The toxic effect of the effluent on the species tested was a temporary response at least at the lower concentrations tested. N. palea exposed to < 90 percent effluent recovered growth when resuspended in control medium. O. pusilla var. major showed similar behaviour at < 25 percent effluent. The situation in river Periyar is that the phytoplankton community

is constantly subject to the effluents from the factories which is likely to be diluted to safe levels only during monsoon and postmonsoon seasons. During premonsoon period neither the river discharge nor the tidal influx in the vicinity of industrial installations can restore the water to normal conditions.

The test results using N. palea and O. pusilla var. major revealed that the toxicity of the effluent was influenced by environmental variables. Salinity of the culture medium reduced the toxicity of the effluent. This observation leads to the assumption that the tidal incursion in river Periyar would reduce the toxic effects besides effecting dilution. Addition of ammonium to the culture medium inhibited the growth of N. palea irrespective of nitrate content of the medium. In contrast, growth rate of O. pusilla var. major was enhanced with increasing ammonium in the medium when nitrate was low. Even at high nitrate concentration, ammonia stimulated growth of the species at the lower levels tested. Inhibition of growth occurred at higher levels of ammonia. It is widely accepted that algal species, usually utilize inorganic nitrogen compounds in the form of nitrite, nitrate or ammonia of which ammonia is preferred form (Strickland et al., 1969; Goldman, 1976). However, exceptions to this have also been reported where ammonium yielded less growth than nitrate as the nitrogen source (Raymont, 1980; Reynolds, 1984). The test results showed that the presence of ammonia decreased the toxicity of the effluent to N. palea when nitrate was low, whereas the reverse effect occurred at high nitrate level.

The toxicity of the effluent to O. pusilla var. major was low in the presence of ammonia irrespective of the nitrate concentration. However, the magnitude of reduction in toxicity was less towards the higher concentrations of ammonia. There is probably a complex interaction between nitrate and ammonia to modify the response of the algae to the effluent. Various phosphate levels did not exert any effect on the toxicity of effluent to the cell division rate of N. palea when nitrate content was low. However, the amount of photosynthetic pigments decreased in the presence of effluents at high phosphate level, with respect to the control. It may be assumed that at still higher levels of phosphate the toxicity may increase. Similar trend occurred at high nitrate level also. In contrast to that of N. palea, in the cultures of O. pusilla var. major, increasing levels of phosphate seemed to reduce the toxicity of the effluent irrespective of nitrate content.

The situation in river Periyar is that there is high nitrate, ammonia and phosphate in the industrial zone. If the data obtained in the laboratory assays is extrapolated to the field conditions, it should be concluded that a species like Nitzschia palea will be adversely affected, whereas those having physiological needs similar to Oocystis pusilla var. major will be stimulated to grow by the presence of high core of nutrients. However, the behaviour of axenic cultures need not be parallel to that of the diverse interacting phytoplankton community in natural ecosystem. It may be stated that the response is variable and the environmental conditions have a significant role in deciding the toxicity of an industrial effluent.

CHAPTER 6

CONCLUSION

The water quality of river Periyar is highly influenced by the rate of discharge, the latter being dependent on the monsoon rains. The river is in spate during the monsoon period whereas in premonsoon months the discharge is low so that saline water from Cochin backwater penetrates upto ≃ 15 km into the interior of the river. Beyond this region, the upstream is freshwater zone free of pollution. In the industrial zone of the river, which is also the region of salinity incursion, the water quality is considerably altered during premonsoon so that there is occasional increase in temperature, lowering of pH and dissolved oxygen and high core of nutrients such as nitrite, ammonia and phosphate. The physico-chemical conditions in the backwater are quite dynamic and the trends in many cases are not similar to that of the industrial region of river Periyar. Therefore, it is concluded that the changes in water quality of the latter region are locally induced probably by industrial discharges. A distinct observation in the present study is that the distribution of nitrate is uniform throughout the system and the magnitude is quite high. It may be attributed to the high rate of dissolution of nitrate in the watershed of the river aided by large scale clearance of forests and consequent land run off.

The phytoplankton flora of the industrial belt of river Periyar has responded to the hydrological conditions by

a change in species composition in favour of Cyanophyceae and Chlorococcales, accompanied by intense growth leading to bloom conditions. However, the system restores following the monsoon rains and ambient conditions similar to that of upstream are established.

Algal toxicity studies revealed that a discharge rate of 4.80 to 17.11 Mm^3 day^{-1} is required in the river for effective dilution of the industrial effluent concerned, whereas during the sampling year the rate of flow had decreased to 1.10 Mm^3 day^{-1}. It is also concluded from the assays that the toxicity of an effluent varies considerably with species as well as the environmental variables. Toxicity of the effluent was reduced under saline conditions. This leads to the assumption that the tidal incursion in river Periyar would reduce the toxic effects besides effecting dilution. Test results at various nutrient levels indicate that there is probably a complex interaction between nitrate, ammonia and phosphate to modify the response of the algae to the effluent. A species such as Nitzschia palea may be adversely affected under elevated levels of phosphate, nitrate and ammonia while those with physiological needs similar to Oocystis pusilla var. major will be stimulated. Ultimately, it is the competitive ability of such species that can tolerate 'conditions of stress' that determine the response of the community as such.

CHAPTER 7

SUMMARY

1. The objective of the present investigation was to assess the water quality of river Periyar and observe the growth response of phytoplankton community so as to predict the probable effect of continued discharge of complex wastes from industries on such organisms.

2. The work was carried out in two phases:
   a) field observations of physico-chemical characteristics of water and its correlation to standing stock of phytoplankton
   b) algal assays on pure cultures using industrial effluent.

3. The field observations were conducted during January to December 1986. Six sampling stations, from Edamalayar to Cochin harbour mouth were identified. Water samples were collected fortnightly and analysed in the laboratory. The following parameters were studied : salinity, temperature, pH, dissolved oxygen, biochemical oxygen demand, nitrite, nitrate, ammonia, phosphate, chlorophyll and pheopigments.

4. The experimental work was conducted on axenic cultures of Nitzschia palea and Oocystis pusilla var. major. These species were isolated from the upstream of river Periyar.

5. Effluent for the algal assays were collected from the fertilizer factory located on the bank of river Periyar. The toxicity of the effluent to the plankton species were assayed under different environmental conditions employing standard algal bioassay procedure.

6. The field observations revealed that river Periyar has a freshwater regime upto Pathalam. The river is subject to salinity incursion during postmonsoon and premonsoon months. The intrusion of seawater occurs upto 15 km (Edayar) into the river during premonsoon months. It is in this region that many chemical factories are located. They are mostly crowded within a 5 km stretch extending from Edayar to Eloor. The annual range of salinity in the backwater was from 0.57×10^{-3} to 25.78×10^{-3}.

7. The temperature of the water ranged from 24.5^{o} to $34.8^{o}C$. During monsoon and postmonsoon, lowest temperature was recorded in station 1 and this increased progressively towards station 6. During premonsoon highest temperature occurred at station 4 to be followed by stations 5 and 3.

8. The pH of the water samples ranged from 3.94 to 8.92. The seasonal average of pH in the different sampling stations did not differ significantly; but exceptionally low pH ($\simeq$ 4) was observed at stations 4 and 5 in the months of February, April and May.

9. The concentration of dissolved oxygen ranged from 3 to 12.95 mg L^{-1}. Undersaturation of oxygen occurred in the bottom layer at stations 4 and 5 in the months of March, April and May. Except for this the water was well oxygenated throughout the stations.

10. BOD did not indicate severe organic load in the water column. The range of values was from 0.23 tc 6.11 mg L^{-1}.

11. The freshwater zone of the river exhibited only traces of nitrite, ammonia and phosphate. In contrast, the industrial zone of the river and the backwater had higher levels of these nutrients and they showed considerable seasonal fluctuation. The concentration of nitrite ranged from 0.0 to 48.0 μ g-at L^{-1}, that of ammonia from 0.0 to 65.71 μ g-at L^{-1} and that of phosphate from 0.0 to 64.58 μ g-at L^{-1}. The backwater exhibited peak nitrite and nitrate during monsoon while the distribution of ammonia was almost uniform throughout the year. Peak values of phosphate were observed during premonsoon period. During the premonsoon and postmonsoon months the industrial zone of river Periyar had higher nitrite and phosphate than the backwater. Ammonia was higher in the industrial zone throughout the year, the magnitude being 24.54 μ g-at L^{-1} (station 4) during monsoon to 49.29 μ g-at L^{-1} (station 5) during premonsoon. The distribution of nitrate did not show any spatial variation; the values ranged from

50.6 to 406.0 μ g-at L^{-1}, being higher in monsoon months than in premonsoon.

12. The phytoplankton community comprised of Chlorophyceae especially desmids and members of Bacillariophyceae in the freshwater region of river Periyar. In the industrial zone members of Cyanophyceae, Chlorococcales and diatoms occurred frequently. Cyanophyceae was the most abundant group. The backwater station was dominated by diatoms.

13. The magnitude of chlorophyll pigments was low during monsoon, the peak values were exhibited during premonsoon. The amount of chlorophyll a varied from 0.20 to 54.48 mg m^{-3}, that of chlorophyll b from 0.20 to 28.04 mg m^{-3} and chlorophyll c from 0.11 to 22.26 mg m^{-3}. The freshwater zone of the river had relatively low productivity (total chlorophyll $\leq$ 5.45 mg m^{-3}). In the industrial zone the amount of chlorophylls was $\leq$ 6.71 mg m^{-3} in the monsoon and postmonsoon, but it increased to 31.11 mg m^{-3} (station 4) and 38.34 mg m^{-3} (station 5) during premonsoon period. The backwater station exhibited a range of 9.64 mg m^{-3} during monsoon to 30.19 mg m^{-3} during premonsoon.

14. The ratio of pheopigments to chlorophylls ranged from 4.57 to 71.89%. The fraction of pheopigments was less than 50% of the total chlorophyll except in stations 1 and 2 during postmonsoon.

15. The annual averages of the various parameters studied did not differ significantly in the surface and bottom layers of the water column except in a few cases. The bottom water at stations 4 and 5 were more saline and had less of dissolved oxygen than that of the surface. BOD was lower at station 3 in the bottom water. Stations 3 and 6 had higher surface values of ammonia. At station 6, surface water was more productive.

16. Results of the multiple regression analyses revealed that phytoplankton production in the river and backwater was not under the influence of any common environmental factor, but it varied with the sampling station. The different variables in their order of importance are given below:

Station 1. nitrite*, nitrate*^, temperature*^, dissolved oxygen*

Station 2. temperature*^, pH*^, dissolved oxygen*, nitrate*^, phosphate*^, ammonia*

Station 3. temperature*^, phosphate*, nitrate*^

Station 4. temperature*^, dissolved oxygen*, pH*^, nitrate*, phosphate*

Station 5. temperature*^, pH*^

Station 6. none of the factors investigated affected chlorophyll.

* negative correlation

*^ positive correlation

17. Nitzschia palea exhibited maximum growth rate between the first and second day following inoculation with a maximum growth rate of 2.06 divisions/day and a minimum generation time of 8 hr. Cultures attained stationary phase within 8 days of inoculation. The species did not tolerate salinity. The half-saturation constant for nitrate utilization was 0.43 μ g-at NO_3-N L^{-1} and that of phosphate was 0.39 μ g-at PO_4-P L^{-1} with a maximum growth rate of 0.95 and 0.90 respectively.

18. Oocystis pusilla var. major had growth rate of 1.69 divisions/day and a minimum generation time of 10.16 hr on the second day of inoculation. Stationary phase was reached after ten days following inoculation. The species tolerated salinity upto 5×10^{-3}. The half-saturation constant for nitrate utilization was 0.66 μ g-at NO_3-N L^{-1} and that of phosphate was 0.26 μ g-at PO_4-P L^{-1} with a maximum growth rate of 0.86 and 1.16 respectively.

19. The growth rate of N. palea was reduced by 50% at an effluent concentration of 74% and that of O. pusilla var. major at 21%. The growth of O. pusilla var. major was stimulated at 5% effluent, while that of N. palea inhibited. The cultures of N. palea exposed to < 90% effluent recovered growth when resuspended in normal culture medium. O. pusiila var. major also recovered growth at < 25% effluent on resuspension in normal culture medium.

20. The toxicity of the effluent did not differ with salinity of the medium as indicated by cell counts of N. palea. However, the production of pigments was enhanced showing a reduction of toxicity in salinities 5×10^{-3} and 10×10^{-3}. In the presence of effluents, the cell counts and phytosynthetic pigments of O. pusilla var. major were significantly enhanced at all test salinities.

21. The growth rate of N. palea decreased in the presence of ammonia, both at low and high nitrate levels. The toxicity of the effluent was increased with increasing levels of ammonia at high nitrate level. With increasing phosphate in the medium, toxicity of the effluent increased irrespective of nitrate content of the culture medium.

22. Addition of ammonia to the cultures of O. pusilla var. major enhanced growth rate at low nitrate level and inhibited the same at high nitrate concentration. The toxicity of effluent decreased in the presence of ammonia at low as well as high nitrate level. The toxic effect of effluent decreased with increasing phosphate in the culture medium at low as well as high nitrate level.

23. The field observations as well as the laboratory assays confirm that the rate of discharge in river Periyar during premonsoon is insufficient to effect dilution of waste-water received in the industrial zone. The phytoplankton community respond to this situation by enhanced growth accompanied by change in the composition of population.

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APPENDIX I

Sampling period	Depth (cm)						Secchi disc transparency (cm)					
	Stations						Stations					
	1	2	3	4	5	6	1	2	3	4	5	6
June	75	274	400	400	480	210	75	81	84	82	78	74
July	100	156	472	410	466	190	100	90	100	80	90	70
August	82	180	290	360	490	176	82	150	160	142	370	88
September	100	250	350	370	380	200	100	80	58	44	42	44
October	150	310	386	360	500	180	150	280	190	65	160	90
November	70	328	400	390	480	210	70	250	260	110	135	100
December	60	334	348	400	538	200	60	280	258	176	130	82
January	50	180	350	400	390	190	50	100	150	110	90	70
February	60	200	270	365	280	115	60	110	170	110	150	90
March	50	200	400	400	390	150	50	100	145	140	125	75
April	50	220	344	466	350	205	50	182	140	135	100	68
May	50	247	330	350	300	180	50	180	170	130	78	60

APPENDIX II

TEMPERATURE (°C)

STATION 2

Surface												MEAN	SD
28.20	28.40	28.10	29.50	29.50	29.50	30.80	30.70	30.90	32.70	32.50	32.90		
32.50	32.50	32.50	26.40	26.50	26.30	25.70	25.60	25.80	29.30	29.30	29.30		
25.60	25.50	25.70	25.60	25.60	25.50	25.90	25.90	25.90	25.70	25.70	25.70	28.16	2.63
Bottom													
28.00	28.10	27.90	29.20	29.20	29.20	30.70	30.70	30.70	31.80	31.80	31.80		
32.40	32.30	32.50	26.40	26.40	26.50	25.60	25.50	25.60	29.10	29.10	29.20		
25.60	25.40	25.80	25.40	25.40	25.50	25.60	25.70	25.60	25.60	25.60	25.60	27.96	2.52
STATION 3													
29.90	29.80	30.00	28.30	28.40	28.20	31.80	31.80	31.70	33.30	33.40	33.20		
33.30	33.30	33.30	26.60	26.50	26.70	25.90	25.90	25.80	28.80	28.70	28.80		
30.20	30.20	30.10	26.90	26.90	26.80	26.50	26.50	26.60	26.10	26.20	26.10	28.96	2.61
29.00	29.30	29.00	29.70	29.50	29.60	30.90	30.90	30.90	32.00	31.90	32.40		
33.00	33.50	33.40	26.10	26.50	26.30	25.90	25.90	25.90	29.00	29.50	28.80		
30.10	29.50	30.40	26.40	25.90	25.80	26.80	25.90	26.20	26.30	25.90	25.80	28.72	2.50
STATION 4													
30.00	30.40	29.90	30.10	30.50	30.30	31.80	32.10	31.80	34.60	35.00	34.80		
32.00	32.30	32.30	37.00	27.10	26.90	26.40	26.30	26.50	29.80	29.70	30.20		
31.30	31.20	31.40	30.00	29.90	30.10	28.00	27.80	28.20	28.00	27.80	28.20	30.27	2.52
29.80	30.00	29.90	29.90	29.80	30.00	32.10	32.00	32.80	34.00	33.80	34.20		
33.30	33.30	33.30	26.60	26.50	26.70	25.90	26.00	26.10	29.40	29.60	29.50		
32.00	31.90	32.10	30.70	30.70	31.00	27.70	27.80	27.90	27.80	27.90	28.00	30.00	2.49

STATION 5												MEAN	SD
30.20	30.80	30.50	30.20	30.20	30.20	32.30	32.50	32.40	33.50	33.60	33.70		
32.20	32.50	32.80	27.80	27.80	27.80	26.50	26.50	26.50	29.50	30.00	30.20		
31.50	31.90	32.00	30.50	30.00	30.10	29.70	29.30	29.50	27.90	27.30	28.20	30.23	2.05
30.00	30.40	30.50	30.90	30.80	30.70	32.50	32.40	32.30	33.00	33.10	33.20		
32.00	32.70	33.10	26.70	26.80	26.80	26.50	26.50	26.50	29.10	29.00	28.90		
31.70	31.20	31.90	30.90	30.70	30.80	27.50	27.90	27.70	27.10	27.90	27.80	29.93	2.26
STATION 6													
29.80	29.80	29.80	30.10	30.50	30.60	31.60	32.00	32.10	32.00	32.60	31.70		
32.90	31.00	31.50	29.60	28.90	28.50	28.90	28.80	29.00	29.70	29.90	30.10		
28.70	29.30	28.70	30.80	30.10	30.60	29.80	29.80	29.80	29.80	28.40	28.50	30.16	1.22
29.50	29.90	29.70	30.10	30.60	30.20	31.30	31.90	31.60	32.00	32.60	32.70		
31.40	31.90	32.10	26.90	27.40	27.00	26.90	27.30	27.10	30.20	29.90	29.90		
28.30	28.70	28.50	31.00	30.70	30.10	29.50	29.90	29.70	28.40	28.30	28.20	29.76	1.69

APPENDIX III

Temperature (°C)

Sampling Period	Surface						Bottom					
	STATIONS											
	1	2	3	4	5	6	1	2	3	4	5	6
June	25.9	26.4	26.6	27.0	27.8	29.0	25.0	26.4	26.3	26.6	26.8	27.1
July	25.1	25.7	25.9	26.4	26.5	28.9	25.1	25.6	25.9	26.0	26.5	27.1
August	28.6	29.3	28.8	29.9	29.9	29.9	28.6	29.1	29.1	29.5	29.0	30.0
September	26.0	25.6	30.2	31.3	31.8	28.9	26.0	25.6	30.0	32.0	31.6	28.5
October	24.5	25.6	26.9	30.0	30.2	30.5	24.5	25.4	26.0	30.8	30.8	30.6
November	24.8	25.9	26.5	28.0	29.5	29.8	24.8	25.6	26.3	27.8	29.7	29.7
December	24.8	25.7	26.1	28.0	27.8	28.5	24.8	25.6	26.0	27.9	27.6	28.3
January	26.2	28.2	29.9	30.1	30.5	29.8	26.2	28.0	29.1	29.9	30.3	29.7
February	30.2	29.5	28.3	30.3	30.2	30.4	30.2	29.2	29.5	29.9	30.8	30.3
March	28.1	30.8	31.8	31.9	32.4	31.9	28.1	30.7	30.9	32.3	32.4	31.6
April	32.2	32.7	33.3	34.8	33.6	32.1	32.2	31.8	32.1	34.0	33.1	32.1
May	30.7	32.5	33.3	32.2	32.5	31.8	30.7	32.4	33.3	33.3	32.6	31.8

APPENDIX IV

pH

STATION 2												MEAN	SD
Surface													
6.97	7.10	6.90	7.64	7.63	7.62	6.94	6.96	6.98	7.10	7.12	7.11		
7.21	7.21	7.21	6.30	6.35	6.31	6.67	6.66	6.65	6.59	6.55	6.60		
6.68	6.73	6.00	6.72	7.32	7.32	7.32	7.04	7.09	7.11	7.11	7.18	6.95	0.39
Bottom													
6.85	6.69	6.65	7.49	7.61	7.59	6.98	6.98	6.98	7.00	7.02	7.01		
7.00	7.20	7.10	6.30	6.27	6.29	6.78	6.70	6.74	6.80	6.83	6.83		
6.66	6.66	6.66	7.25	7.29	7.30	7.13	7.14	7.15	7.15	7.15	7.15	6.96	0.32
STATION 3													
7.23	7.19	7.18	7.25	7.29	7.27	7.09	7.09	7.09	6.87	6.88	6.89		
7.26	7.28	8.00	6.33	6.39	6.36	6.61	6.61	6.61	6.91	6.96	7.10		
6.70	6.78	6.71	6.90	6.93	6.90	6.69	6.65	6.70	7.10	7.14	7.09	6.95	0.32
6.89	7.91	6.14	7.37	7.68	6.57	6.89	7.01	7.04	6.77	6.77	6.77		
7.00	7.10	7.05	6.39	6.37	6.32	6.65	7.00	6.42	7.01	7.03	7.02		
6.68	6.67	6.69	6.64	6.62	6.63	6.81	6.85	6.83	7.11	7.13	7.09	6.86	0.35
STATION 4													
6.54	6.55	6.55	7.24	7.23	7.24	6.18	6.17	6.18	7.07	7.06	7.07		
3.94	3.94	3.94	6.30	6.32	6.34	6.48	6.55	6.53	6.92	6.89	6.89		
6.71	6.65	6.68	6.35	6.39	6.40	6.68	6.65	6.65	7.59	7.64	7.60	6.50	0.87
6.91	6.98	6.99	3.91	3.97	4.00	6.56	6.57	6.58	6.64	6.64	6.64		
6.59	6.69	6.73	6.57	6.60	6.60	6.80	6.83	6.80	6.65	6.71	6.68		
6.60	6.68	6.64	6.28	6.30	6.32	6.56	6.58	6.54	7.01	7.01	7.01	6.45	0.77

STATION 5												MEAN	SD
6.54	6.54	6.54	7.05	7.01	7.03	5.91	6.01	6.08	3.96	4.21	4.04		
8.16	8.20	8.18	6.41	6.42	6.40	6.74	6.76	6.78	7.75	7.78	7.81		
6.94	6.98	6.96	6.01	6.02	6.03	6.41	6.49	6.54	6.89	6.93	6.91	6.60	0.98
6.95	6.95	6.95	7.34	7.32	7.33	6.75	6.71	6.76	6.52	6.58	6.58		
7.26	7.14	7.35	6.41	6.71	6.41	6.96	5.89	7.70	6.71	6.41	6.56		
6.91	6.79	6.88	6.31	6.40	6.46	6.36	6.35	6.34	6.71	6.67	6.69	6.75	0.37
STATION 6													
8.51	8.51	8.51	8.89	8.97	8.90	8.61	8.71	8.69	7.68	7.81	7.82		
7.56	7.71	7.80	7.41	7.31	7.36	7.39	7.51	7.48	7.78	7.91	7.89		
5.81	6.93	7.99	8.19	8.19	8.19	8.31	8.28	8.31	8.36	8.25	8.29	8.00	0.62
8.02	8.02	8.02	8.86	8.82	8.84	8.62	8.62	8.62	7.76	7.77	7.78		
7.79	7.79	7.79	7.37	7.36	7.38	7.59	7.57	7.55	7.74	7.79	7.81		
6.99	6.99	6.99	8.09	8.10	8.11	8.28	8.25	8.25	8.06	8.07	8.08	7.93	0.49

APPENDIX V

pH

Sampling Period	Surface						Bottom					
	STATIONS											
	1	2	3	4	5	6	1	2	3	4	5	6
June	6.26	6.32	6.36	6.32	6.41	7.36	6.26	6.29	6.36	6.59	6.51	7.37
July	6.50	6.66	6.61	6.52	6.76	7.46	6.50	6.74	6.69	6.81	6.85	7.57
August	6.66	6.58	6.99	6.90	7.78	7.86	6.66	6.82	7.02	6.68	6.56	7.78
September	6.41	6.71	6.73	6.68	6.96	6.91	6.41	6.66	6.69	6.64	6.86	6.99
October	7.06	7.32	6.91	6.38	6.02	8.19	7.06	7.28	6.63	6.30	6.39	8.10
November	7.13	7.08	6.68	6.66	6.48	8.30	7.13	7.14	6.83	6.54	6.35	8.26
December	7.11	7.15	7.11	7.61	6.91	8.30	7.11	7.15	7.10	7.01	6.69	8.07
January	7.18	6.99	7.20	6.55	6.54	8.51	7.18	6.73	6.98	6.96	6.95	8.02
February	7.47	7.63	7.27	7.24	7.03	8.92	7.47	7.59	7.54	3.96	7.33	8.84
March	6.71	6.96	7.09	6.18	6.00	8.67	6.71	6.98	6.98	6.57	6.74	8.62
April	7.14	7.11	6.89	7.00	4.07	7.77	7.14	7.02	6.77	6.64	6.56	7.77
May	7.24	7.21	7.28	3.94	8.18	7.69	7.24	7.10	7.05	6.67	7.25	7.79

APPENDIX VI

Salinity (x 10^{-3})

Sampling Period	Surface						Bottom					
	STATIONS											
	1	2	3	4	5	6	1	2	3	4	5	6
June	0.00	0.00	0.00	0.00	0.00	2.47	0.00	0.00	0.00	0.00	0.00	8.15
July	0.00	0.00	0.00	0.00	0.00	2.74	0.00	0.00	0.00	0.00	0.00	5.59
August	0.00	0.00	0.00	0.00	0.00	5.81	0.00	0.00	0.00	0.00	0.00	4.36
September	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	1.93
October	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00	0.00	0.00	3.01
November	0.00	0.00	0.00	0.00	1.25	4.36	0.00	0.00	0.00	0.00	2.34	4.51
December	0.00	0.00	0.00	0.00	0.84	11.55	0.00	0.00	0.00	0.00	3.55	11.94
January	0.00	0.00	0.00	0.00	2.34	25.21	0.00	0.00	0.00	0.00	4.09	25.78
February	0.00	0.00	0.00	1.30	1.93	20.61	0.00	0.00	0.00	1.11	12.90	21.29
March	0.00	0.00	0.00	0.44	3.01	24.13	0.00	0.00	0.00	9.78	14.79	24.81
April	0.00	0.00	0.00	0.58	1.65	12.09	0.00	0.00	0.00	7.88	8.03	15.61
May	0.00	0.00	0.00	5.17	5.05	24.94	0.00	0.00	0.00	6.94	8.57	18.04

APPENDIX VII

SALINITY (x 10^{-3})

STATION 4

Surface												MEAN	SD
0.00	0.00	0.00	1.30	1.40	1.20	0.44	0.43	0.45	0.58	0.56	0.60		
5.10	5.21	5.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	1.42
Bottom													
0.00	0.00	0.00	1.10	1.18	1.05	9.65	9.86	9.83	7.80	8.10	7.74		
6.90	7.14	6.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.13*	3.54
STATION 5													
2.13	2.51	2.38	1.79	2.10	1.90	3.13	2.98	2.92	1.58	1.76	1.61		
5.10	4.92	5.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	1.23	1.29	1.23	0.78	0.91	0.83	1.34	1.51
3.56	5.16	3.55	11.76	13.40	13.54	13.71	15.67	14.99	8.00	8.10	7.99		
8.10	7.97	9.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	2.31	2.98	1.73	3.16	3.91	3.58	4.52*	5.13
STATION 6													
27.13	23.26	25.24	19.13	21.36	19.99	21.37	26.38	24.64	11.98	13.61	10.68		
22.91	26.13	25.78	1.91	2.68	2.82	3.00	2.64	2.58	4.61	6.13	6.69		
0.52	0.63	0.86	1.83	2.51	2.68	3.61	5.81	3.66	10.89	12.69	11.15	11.37	9.40
23.68	27.70	25.96	19.23	23.61	21.03	23.61	25.60	25.22	13.81	16.71	16.31		
17.83	19.13	17.16	7.89	9.00	7.56	4.91	6.00	5.86	4.00	4.81	4.27		
1.00	1.97	2.82	3.03	3.01	2.99	3.79	4.67	5.07	11.00	12.21	12.61	12.09	8.43

* t value significant at 5% level.

APPENDIX VIII

Dissolved Oxygen (mg O_2L^{-1})

Sampling Period	Surface						Bottom					
	STATIONS											
	1	2	3	4	5	6	1	2	3	4	5	6
June	6.61	7.32	6.61	6.33	6.05	5.91	6.61	5.47	6.75	6.75	5.77	3.39
July	9.79	7.83	8.72	8.54	8.01	7.12	9.79	8.72	8.72	8.54	8.37	5.34
August	9.97	9.97	10.15	9.97	10.68	10.32	9.97	9.97	10.15	9.97	9.61	10.15
September	9.26	9.97	10.32	9.61	8.37	6.05	9.26	9.43	9.79	10.50	9.08	5.87
October	10.32	10.86	9.97	10.50	10.50	8.72	10.32	11.75	10.15	10.32	9.43	8.19
November	12.28	11.75	11.04	10.32	10.15	10.86	12.28	11.39	10.68	9.43	9.08	10.50
December	11.92	11.04	10.32	10.32	10.68	10.49	11.92	11.57	9.97	9.61	9.08	10.15
January	8.37	9.08	8.93	7.12	8.73	11.21	8.37	8.70	6.95	5.68	6.59	8.75
February	9.71	11.33	9.71	9.71	8.10	12.95	9.71	11.21	8.10	8.10	6.48	12.95
March	6.59	6.59	5.87	6.59	7.12	12.64	6.59	6.94	6.59	3.38	3.00	11.39
April	10.86	8.73	8.92	7.76	10.28	5.82	10.86	10.73	8.15	3.33	3.00	3.49
May	7.93	7.93	8.55	6.06	9.33	3.42	7.93	8.09	8.55	3.00	3.00	3.27

APPENDIX IX

DISSOLVED OXYGEN (mg O_2 L^{-1})

STATION 2												MEAN	SD
Surface													
9.01	10.10	8.13	11.20	11.41	11.38	6.40	6.72	6.65	9.41	8.52	8.26		
8.12	7.68	7.99	7.35	7.31	7.30	8.81	7.85	7.83	10.00	9.95	9.96		
9.91	9.99	10.01	10.87	10.86	10.85	11.71	11.79	11.75	11.00	11.10	11.02	9.39	1.64
Bottom													
8.10	8.90	9.10	11.27	10.98	11.38	5.69	7.00	8.13	10.73	10.73	10.73		
8.10	7.91	8.26	5.49	5.38	5.54	7.67	9.61	8.88	8.71	10.61	10.43		
10.11	9.00	9.18	12.35	10.67	12.23	11.41	9.61	13.15	12.37	10.68	11.66	9.49	2.03
STATION 3													
8.95	9.31	8.53	9.91	9.68	9.54	5.78	5.91	5.92	8.89	8.96	8.91		
8.51	8.59	8.55	6.58	6.69	6.56	8.69	8.76	8.71	10.09	10.20	10.16		
10.29	10.37	10.30	9.95	10.10	9.86	11.10	10.99	11.03	10.21	11.42	9.33	9.09	1.50
6.89	6.99	6.97	7.78	8.91	7.61	6.00	7.60	6.17	8.60	7.98	7.87		
8.51	8.62	8.52	5.98	6.97	7.30	8.63	9.13	8.40	10.00	10.21	10.24		
9.69	10.13	9.55	10.00	10.25	10.20	10.76	9.99	11.29	9.67	10.00	10.24	8.71	1.44
STATION 4													
7.09	7.15	7.12	9.69	9.73	9.71	6.54	6.61	6.62	6.71	7.79	7.78		
6.00	6.09	6.09	6.31	6.33	6.35	8.51	8.58	8.53	9.91	10.00	10.00		
9.57	9.66	9.60	10.47	10.52	10.51	10.28	10.36	10.44	10.38	10.30	10.28	8.54	1.66
5.48	5.71	5.85	7.78	8.12	8.40	3.28	3.41	3.45	3.32	3.42	3.25		
3.60	2.80	2.60	6.51	6.91	6.83	7.54	9.81	8.27	10.11	11.21	8.59		
10.00	11.00	10.50	10.30	10.36	10.30	9.38	10.48	8.43	9.41	10.11	9.31	7.38*	2.80

STATION 5												MEAN	SD
8.68	8.83	8.68	8.60	7.91	7.79	7.18	6.98	7.20	10.31	10.25	10.28		
9.35	9.28	9.36	6.01	6.09	6.05	8.09	7.78	8.16	10.61	10.96	10.47		
8.21	8.97	7.93	9.87	11.21	10.42	10.35	9.36	10.74	10.78	9.98	11.28	9.00	1.49
6.36	7.10	6.31	6.66	6.36	6.42	2.91	3.61	2.48	3.71	2.81	2.48		
3.82	2.98	2.20	5.71	5.96	5.64	8.21	8.49	8.41	8.68	10.19	9.96		
9.09	9.07	9.08	9.51	9.11	8.90	8.79	10.60	7.85	9.10	8.71	9.43	6.85*	2.57
STATION 6													
9.87	12.13	11.63	11.97	12.99	13.89	12.78	12.51	12.63	5.71	6.16	5.59		
3.00	3.51	3.75	4.98	6.00	6.75	7.21	6.99	7.16	9.87	11.13	9.96		
5.19	6.23	6.73	7.99	9.68	8.49	9.68	11.31	11.59	9.79	10.61	11.07	8.79	3.00
7.58	8.01	10.66	11.96	13.10	13.79	11.00	11.87	11.30	3.00	3.96	3.51		
3.75	3.46	2.60	3.39	3.39	3.39	4.71	6.70	4.61	11.50	8.70	10.25		
5.01	6.71	5.89	7.10	8.22	9.25	9.30	11.00	11.20	10.70	9.98	9.77	7.79	3.35

* t value significant at 5% level.

APPENDIX X

Biochemical Oxygen Demand (mg O_2L^{-1})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	1.68	1.26	1.68	2.42	2.10	2.42	0.42	0.67	1.00	2.42	1.26
July	0.44	2.00	1.07	1.67	0.94	1.42	3.11	1.69	0.97	1.17	1.36
August	0.39	1.94	4.91	2.32	1.67	1.72	2.31	3.30	1.47	2.72	1.83
September	0.26	0.48	1.68	3.67	2.61	1.23	1.60	2.63	2.01	3.44	1.01
October	0.23	0.35	1.76	2.31	3.67	0.99	1.06	2.63	2.71	3.51	0.67
November	0.37	0.58	1.56	2.00	2.89	1.89	0.83	1.94	2.61	2.93	1.51
December	0.47	1.01	1.00	1.69	2.92	2.83	0.96	1.57	2.60	2.90	2.09
January	0.68	1.39	0.94	1.36	2.69	2.62	2.00	1.31	1.56	2.71	2.81
February	0.93	0.90	1.24	3.39	3.49	3.61	1.14	1.89	3.63	2.89	3.11
March	1.02	0.99	0.98	2.99	6.11	4.94	0.83	1.57	3.68	5.81	4.08
April	0.88	2.03	1.45	2.64	2.60	3.58	1.99	1.56	3.68	3.62	2.42
May	1.86	1.40	0.93	2.79	5.38	3.26	1.40	3.26	5.12	3.79	2.33

APPENDIX XI

B O D

STATION 2												MEAN	SD
Surface													
1.26	2.00	1.94	0.48	0.35	0.58	1.01	1.39	0.90	0.99	2.03	1.40	1.19	0.56
Bottom													
0.42	3.11	2.31	1.60	1.06	0.83	0.96	2.00	1.14	0.83	1.99	1.40	1.47	0.73
STATION 3													
1.68	1.07	2.91	1.68	1.76	1.56	1.00	0.94	1.24	0.98	1.45	0.93	1.43	0.54
0.67	1.69	3.30	2.63	2.63	1.94	1.57	1.31	1.89	1.57	1.56	3.26	2.00*	0.76
STATION 4													
2.42	1.67	2.32	3.67	2.31	2.00	1.69	1.36	3.39	2.99	2.64	2.79	2.44	0.67
1.00	0.97	1.47	2.01	2.71	2.61	2.60	1.56	3.63	3.38	3.68	5.12	2.59	0.62
STATION 5													
2.10	0.94	1.67	2.61	3.67	2.89	2.92	2.69	3.49	6.11	2.60	5.38	3.09	1.39
2.42	1.17	2.72	3.44	3.51	2.93	2.90	2.71	2.89	5.81	3.62	3.79	3.16	1.04
STATION 6													
2.42	1.42	1.72	1.23	0.99	1.89	2.83	2.62	3.61	4.94	3.58	3.26	2.54	1.12
1.26	1.36	1.83	1.01	0.67	1.51	2.09	2.81	3.11	4.08	2.42	2.32	2.04	0.93

* t value significant at 5% level.

APPENDIX XII

Nitrite (μg-at NO_2-N L^{-1})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	5.2	4.0	4.8	3.0	3.6	44.0	2.6	1.8	2.6	4.8	19.0
July	1.8	3.0	2.2	3.0	4.4	13.2	2.6	2.2	2.2	4.4	16.4
August	0.0	0.0	0.0	4.2	11.0	24.0	0.0	0.0	0.0	11.2	30.0
September	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	24.0
October	0.4	0.8	2.6	3.2	8.4	16.8	0.8	1.4	4.4	7.2	12.8
November	1.4	1.4	0.4	4.4	26.0	2.6	1.4	1.4	9.2	22.0	10.6
December	0.2	1.4	0.4	4.4	8.0	0.04	1.4	1.4	2.6	22.2	8.0
January	4.0	2.6	7.0	18.6	32.0	3.6	2.2	11.0	28.0	40.0	4.4
February	4.0	3.0	2.2	2.0	48.0	1.0	3.6	3.0	26.0	48.0	2.6
March	2.6	1.8	2.6	2.2	36.0	22.2	1.2	1.0	31.0	48.0	16.4
April	4.8	3.6	4.0	8.0	7.0	14.6	3.0	4.0	26.0	34.0	13.2
May	4.8	4.0	3.0	1.0	26.0	9.8	4.8	4.0	31.0	24.0	7.6

APPENDIX XIII

NITRITE (μ g-at NO_2-N L^{-1})

STATION 2												MEAN	SD
Surface													
2.00	2.80	3.00	3.50	2.80	2.70	1.30	1.90	2.20	3.70	3.10	4.00		
4.30	3.70	4.00	3.80	4.60	3.60	2.70	3.10	3.20	0.00	0.00	0.00		
0.00	0.00	0.00	0.80	0.80	0.80	1.20	1.80	1.20	1.30	1.70	1.20	2.13	1.41
Bottom													
2.00	2.40	2.20	2.70	3.90	4.20	1.60	1.00	1.00	2.70	3.50	2.80		
5.20	4.10	5.10	3.00	2.10	2.70	2.10	3.00	2.70	0.00	0.00	0.00		
0.00	0.00	0.00	0.60	0.90	0.90	1.20	1.60	1.40	1.60	1.10	1.50	1.97	1.42
STATION 3													
6.10	8.30	6.66	1.90	2.60	2.10	2.10	2.90	2.80	3.80	4.30	3.80		
2.90	3.60	5.50	4.10	3.70	6.60	2.10	2.20	2.30	0.00	0.00	0.00		
0.00	0.00	0.00	2.70	2.10	3.00	0.30	0.70	0.20	0.60	0.30	0.30	2.52	2.16
8.00	12.00	13.00	2.98	4.00	2.02	1.00	2.00	0.00	3.60	4.10	4.30		
3.90	4.40	3.70	1.40	2.00	2.00	2.40	1.89	2.31	0.00	0.00	0.00		
0.00	0.00	0.00	1.60	1.20	1.40	1.80	1.20	1.20	1.30	1.70	1.20	2.60	2.92
STATION 4													
18.81	16.58	20.41	2.12	1.98	1.90	2.46	2.13	2.01	7.78	8.93	7.29		
0.98	1.60	0.42	2.53	3.12	3.35	3.31	2.91	2.78	4.23	4.13	4.24		
0.00	0.00	0.00	3.41	2.86	3.33	4.21	4.61	4.38	4.11	4.48	4.61	4.50	4.70
27.70	29.10	27.70	28.60	25.90	23.50	29.60	32.60	30.80	25.10	27.60	25.30		
29.10	32.00	31.90	2.40	2.80	2.60	2.10	2.30	2.20	0.00	0.00	0.00		
0.00	0.00	0.00	4.10	4.60	4.50	10.10	8.91	8.60	1.98	2.96	2.86	13.60*	12.85

STATION 5												MEAN	SD
33.00	31.00	32.00	51.00	45.00	48.00	42.00	31.00	35.00	7.00	7.00	7.00		
21.20	29.10	27.70	3.81	2.93	4.06	4.13	5.61	3.46	11.31	10.89	10.80		
0.00	0.00	0.00	9.31	8.10	7.79	25.30	27.30	25.40	7.90	9.70	6.40	17.53	14.91
36.00	44.00	40.00	39.00	49.00	56.00	52.00	41.00	51.00	39.00	31.00	32.00		
29.00	21.00	22.00	3.91	5.60	4.89	4.00	5.60	3.60	10.70	12.10	10.80		
0.00	0.00	0.00	6.90	8.70	6.00	20.60	24.50	20.90	21.70	23.60	21.30	22.15	16.75
STATION 6													
3.10	3.80	3.84	1.00	1.00	1.00	20.60	23.80	22.20	12.30	16.70	14.80		
8.90	10.10	10.40	41.00	45.00	46.00	13.30	13.20	13.10	20.10	26.00	25.90		
23.60	26.10	25.30	15.60	17.10	17.70	2.10	3.00	2.70	0.04	0.04	0.04	14.74	12.35
4.20	4.40	4.60	2.80	2.10	2.90	15.90	17.30	16.00	12.20	13.80	13.60		
8.10	7.10	7.60	18.90	19.20	18.90	15.90	17.80	15.50	28.99	31.00	30.01		
24.50	23.60	23.90	11.91	13.23	13.29	9.76	10.88	11.16	0.80	0.80	0.80	13.15	8.36

* t value significant at 5% level.

APPENDIX XIV

Nitrate (μg-at NO_3-N L^{-1})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	244.8	256.0	270.2	275.0	256.4	246.0	277.4	263.2	272.4	254.2	151.0
July	206.2	197.0	207.8	181.0	212.6	138.8	213.4	167.8	182.8	167.8	111.6
August	355.0	345.0	380.0	406.0	334.0	131.0	345.0	380.0	360.0	374.0	125.0
September	140.0	150.0	160.0	145.0	190.0	260.0	160.0	190.0	190.0	195.0	71.0
October	279.6	309.2	367.4	306.8	376.6	398.2	369.2	373.6	335.6	382.8	400.2
November	208.6	193.6	179.6	120.6	179.0	53.7	133.6	206.6	110.8	118.0	58.9
December	194.8	163.6	139.6	120.6	167.0	50.6	118.6	143.6	104.9	116.3	50.75
January	246.0	147.4	158.0	281.4	305.0	51.2	185.0	176.0	278.0	322.0	205.0
February	236.0	177.0	165.8	158.0	237.0	68.0	215.0	187.0	154.0	275.0	110.0
March	261.4	178.2	109.4	92.8	62.0	162.8	189.8	169.0	139.0	137.0	173.6
April	155.2	111.4	106.0	137.0	88.0	60.4	123.0	126.0	91.0	61.0	69.8
May	265.2	71.0	245.0	194.0	214.0	80.2	180.2	296.0	209.0	336.0	57.4

APPENDIX XV

NITRATE (μ g-at NO_3-N L^{-1})

STATION 2												MEAN	SD
Surface													
142.10	150.10	150.00	172.00	182.00	177.00	176.10	180.00	178.50	110.10	114.30	109.80		
68.00	75.00	70.00	254.00	258.00	256.00	191.00	200.00	200.00	341.00	346.00	348.00		
146.00	154.00	150.00	301.10	312.40	314.10	190.10	196.00	194.70	160.10	166.70	164.00	191.62	75.01
Bottom													
189.00	186.00	180.00	211.00	219.00	215.00	181.70	193.70	194.00	121.00	128.00	120.00		
176.70	184.70	179.20	282.10	273.60	276.50	211.70	217.60	210.90	360.00	339.00	336.00		
158.00	162.00	160.00	351.70	372.70	383.20	130.50	136.70	133.60	116.70	119.10	120.00	209.18	78.91
STATION 3													
156.00	160.00	158.00	163.50	167.20	166.70	111.00	108.50	108.70	106.80	105.40	105.80		
242.00	247.00	246.00	272.10	268.10	270.40	206.70	209.40	207.30	385.00	378.60	376.40		
163.00	158.00	159.00	368.40	362.70	371.10	182.00	178.50	178.30	140.10	138.70	140.00	207.40	87.78
182.00	171.00	175.00	189.00	181.00	191.00	167.00	171.00	169.00	123.00	129.00	126.00		
299.00	291.00	298.00	265.00	261.30	263.30	165.90	169.30	168.20	383.00	379.00	378.00		
192.00	182.00	195.00	377.70	369.30	373.80	201.70	208.10	210.00	140.50	145.70	144.60	223.21	82.14
STATION 4													
278.10	283.70	282.40	156.10	159.30	158.60	90.61	94.41	93.38	135.00	139.00	137.00		
192.00	196.00	194.00	276.10	274.00	275.00	179.00	183.00	181.00	401.00	407.00	410.00		
142.00	147.00	146.00	301.80	308.10	310.50	118.70	123.60	119.50	121.60	119.60	120.60	201.52	91.00
268.00	284.00	282.00	150.00	158.00	154.00	134.00	141.00	143.00	93.00	87.00	93.00		
201.00	210.00	216.00	268.70	278.10	270.40	180.70	186.70	181.00	366.00	358.00	356.00		
184.00	196.00	190.00	334.60	336.70	335.50	109.10	111.00	112.30	102.70	106.81	105.19	202.32	86.89

STATION 5												MEAN	SD
301.00	310.00	304.00	239.00	231.00	241.00	67.00	61.00	58.00	89.00	78.00	97.00		
211.00	221.00	210.00	241.00	259.00	269.20	202.20	216.70	218.50	331.00	338.00	333.00		
197.00	188.00	185.00	379.00	371.00	379.80	186.00	171.00	180.00	171.00	165.00	165.00	218.46	88.80
320.00	326.00	320.00	280.00	265.00	280.00	130.00	142.00	139.00	57.00	68.00	58.00		
334.00	339.00	335.00	250.20	258.70	253.70	165.80	169.10	168.50	369.00	378.00	375.00		
189.00	198.00	198.00	378.60	384.70	385.10	112.00	120.00	122.00	114.50	119.00	115.40	228.26	105.80
STATION 6													
48.70	52.10	52.80	67.90	70.80	65.30	161.70	163.60	163.10	59.40	61.70	60.10		
79.20	81.40	80.00	245.10	247.60	245.30	137.80	139.00	139.60	129.10	132.30	131.60		
259.70	262.10	258.20	396.70	400.00	397.90	56.70	52.50	51.75	49.70	51.60	50.50	141.74	104.61
202.00	208.00	205.00	112.00	108.00	110.00	170.60	175.10	175.10	68.70	70.10	70.60		
56.10	58.00	58.10	148.00	154.00	151.00	110.10	112.00	112.70	123.00	126.00	126.00		
68.00	72.00	73.00	398.50	402.10	400.00	57.80	59.10	59.80	48.71	51.72	51.82	132.02	93.73

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APPENDIX XVI

Ammonia (μ g-at NH_3-N L^{-1})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	5.43	0.00	7.57	12.43	5.43	21.43	1.29	0.00	20.0	7.57	15.00
July	1.14	1.29	0.00	0.71	16.71	11.43	2.57	1.29	2.29	15.14	8.57
August	0.00	0.00	0.00	57.14	55.71	14.29	0.00	0.00	34.29	56.79	11.43
September	0.00	0.00	0.00	27.86	21.43	33.57	0.00	0.00	0.00	19.29	7.14
October	0.00	0.00	0.79	7.57	8.29	9.14	0.00	0.71	1.57	5.71	8.43
November	0.00	0.14	0.00	37.14	38.57	1.43	0.14	0.14	28.86	25.71	0.71
December	0.00	0.00	0.00	44.29	25.71	0.00	0.00	0.00	24.29	21.43	0.00
January	0.00	1.43	0.00	55.71	40.29	0.71	1.00	0.00	45.71	33.43	2.29
February	0.00	0.00	1.57	37.14	30.0	0.00	0.00	0.29	61.43	27.0	0.86
March	2.00	1.57	1.86	14.43	64.29	6.43	1.14	1.71	54.29	31.43	1.14
April	3.26	0.29	1.00	65.71	60.00	6.86	1.64	1.29	50.00	48.57	5.43
May	0.00	0.00	2.57	57.14	42.86	5.71	0.00	0.00	45.71	25.71	1.57

APPENDIX XVII

AMMONIA (μ g-at NH_3-N L^{-1})

STATION 2												MEAN	SD
Surface													
1.40	1.46	1.43	0.00	0.00	0.00	1.51	1.63	1.57	0.25	0.30	0.32		
0.00	0.00	0.00	0.00	0.00	0.00	1.11	1.32	1.44	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.16	0.15	0.00	0.00	0.00	0.39	0.61
Bottom													
2.00	1.00	0.00	0.00	0.00	0.00	1.00	1.21	1.21	1.61	2.00	1.31		
0.00	0.00	0.00	1.21	1.35	1.31	2.41	2.61	2.69	0.00	0.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.16	0.15	0.00	0.00	0.00	0.65	0.87
STATION 3													
0.00	0.00	0.00	1.49	1.59	1.63	1.89	1.76	1.93	1.50	0.90	0.60		
2.59	2.57	2.55	7.60	7.51	7.60	0.00	0.00	0.00	0.00	0.00	0.00		
0.00	0.00	0.00	0.75	0.81	0.81	0.00	0.00	0.00	0.00	0.00	0.00	1.28	2.08
0.00	0.00	0.00	0.25	0.31	0.31	1.68	1.77	1.68	1.31	1.21	1.35		
0.00	0.00	0.00	0.00	0.00	0.00	1.25	1.33	1.29	0.00	0.00	0.00		
0.00	0.00	0.00	0.68	0.79	0.66	0.19	0.12	0.11	0.00	0.00	0.00	0.45*	0.61
STATION 4													
53.61	57.92	55.60	37.11	39.68	34.63	12.23	16.71	14.35	67.91	62.71	66.51		
55.17	59.77	56.48	10.71	14.61	11.97	0.52	0.91	0.70	58.13	56.19	57.10		
25.18	29.23	29.17	7.38	8.26	7.07	35.13	39.23	37.06	41.69	46.78	44.40	34.77	21.20
47.78	49.67	49.68	59.71	63.42	61.16	52.31	56.71	53.85	46.70	52.70	50.60		
43.78	47.79	45.86	18.78	21.11	20.11	2.13	2.56	2.18	34.13	36.23	32.51		
0.00	0.00	0.00	1.51	1.79	1.41	24.64	29.81	32.13	22.61	26.71	23.55	30.99	20.89

STATION 5												MEAN	SD
40.20	40.31	40.35	28.70	32.50	28.80	66.31	61.71	64.85	59.50	62.70	57.80		
45.87	40.41	42.30	5.61	4.98	5.70	16.91	14.76	18.46	56.50	54.47	56.16		
21.31	22.00	20.98	8.36	7.99	8.52	40.10	36.70	38.91	27.81	23.50	25.82	34.11	18.81
32.60	35.10	32.59	29.60	25.40	26.00	30.71	33.60	29.98	47.51	50.61	47.59		
24.71	28.49	23.93	7.59	8.91	6.25	14.75	16.97	13.70	54.71	57.69	57.97		
20.46	18.76	18.65	4.79	6.67	5.67	26.65	24.78	25.74	20.31	23.43	20.55	26.48	14.43
STATION 6													
0.59	0.78	0.76	0.00	0.00	0.00	6.31	7.00	5.98	6.71	6.90	6.97		
5.61	5.81	5.71	19.76	22.00	22.53	11.00	11.78	11.51	13.71	15.67	13.49		
32.10	34.60	34.01	8.97	10.10	8.35	1.00	1.47	1.82	0.00	0.00	0.00	9.25	9.60
1.36	2.51	3.00	0.82	0.88	0.88	1.00	1.81	0.61	4.98	5.76	5.55		
2.00	1.25	1.46	12.50	16.00	16.50	7.91	9.12	8.68	10.43	12.00	11.86		
7.00	7.68	6.74	7.96	9.10	8.23	0.69	0.74	0.70	0.00	0.00	0.00	5.21*	4.74

* t value significant at 5% level.

APPENDX XVIII

Phosphate (μg-at PO_4-P L^{-1})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.27	0.00	0.39	4.01	4.84	9.49	0.07	0.39	4.52	3.81	4.33
July	0.00	0.20	0.07	0.07	3.62	3.04	0.00	0.20	0.58	2.97	2.65
August	0.00	0.00	0.00	5.81	2.07	2.71	0.00	0.00	1.03	4.10	2.71
September	0.00	1.29	0.52	1.29	1.03	0.52	0.52	1.00	0.52	0.78	0.39
October	0.00	0.26	0.52	0.26	0.97	0.90	0.00	0.39	0.03	0.52	1.23
November	0.00	0.00	0.00	5.81	8.40	0.45	0.00	0.00	9.69	5.17	0.00
December	0.00	0.00	0.00	7.10	8.40	0.00	0.00	0.00	2.45	4.39	1.68
January	0.20	0.07	3.23	12.27	5.35	3.04	0.11	3.45	11.11	4.96	4.15
February	0.26	0.20	0.32	27.12	25.19	8.40	0.21	3.10	19.37	24.12	7.51
March	0.39	0.32	0.21	12.29	59.41	8.40	0.58	0.21	36.80	32.94	7.10
April	0.58	0.20	0.94	63.58	64.58	8.40	0.20	0.61	48.43	52.31	6.40
May	0.20	0.00	0.00	14.21	1.87	0.71	0.00	0.00	5.81	2.52	0.39

APPENDIX XIX

PHOSPHATE (μ g-at PO_4-P L^{-1})

STATION 2												MEAN	SD
Surface													
0.09	0.05	0.07	0.20	0.20	0.20	0.41	0.22	0.33	0.21	0.18	0.21		
0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.22	0.20	0.00	0.00	0.00		
1.21	1.32	1.34	0.21	0.29	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.35
0.14	0.09	0.10	0.19	0.23	0.21	0.59	0.51	0.64	0.20	0.20	0.20		
0.00	0.00	0.00	0.05	0.09	0.07	0.00	0.00	0.00	0.00	0.00	0.00		
0.49	0.55	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.20
STATION 3													
3.00	4.10	2.59	0.31	0.32	0.33	0.21	0.21	0.21	0.90	0.98	0.94		
0.00	0.00	0.00	0.33	0.42	0.42	0.07	0.00	0.14	0.00	0.00	0.00		
0.48	0.55	0.53	0.55	0.48	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.88
3.26	3.61	3.48	3.41	2.99	2.90	0.19	0.26	0.18	0.58	0.65	0.60		
0.00	0.00	0.00	0.26	0.43	0.48	0.18	0.26	0.16	0.00	0.00	0.00		
1.60	0.96	0.44	0.37	0.45	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.78	1.17
STATION 4													
14.23	11.13	11.45	25.13	29.63	26.60	11.74	38.13	12.00	62.75	68.76	62.23		
12.11	17.81	12.71	4.00	3.81	4.22	0.07	0.07	0.07	4.86	6.71	5.86		
1.21	1.41	1.25	0.21	0.31	0.26	4.86	6.81	5.76	6.89	7.31	7.10	13.60	17.74
9.91	12.13	11.29	18.36	20.13	19.62	34.81	38.74	36.85	50.83	46.13	48.33		
4.13	6.24	7.06	5.57	4.09	3.90	0.48	0.61	0.65	1.21	0.98	0.90		
0.48	0.55	0.53	0.03	0.03	0.03	7.71	10.12	11.24	2.00	2.48	2.87	11.70	15.07

STATION 5												MEAN	SD
5.21	5.13	5.17	23.19	27.61	24.77	55.41	62.73	60.09	62.51	68.71	62.52		
1.58	1.91	2.12	4.76	6.78	2.98	3.67	4.57	2.62	2.01	2.89	1.31		
1.11	0.96	1.02	0.91	1.00	1.00	8.31	8.71	8.18	8.67	8.13	8.40	15.46	21.80
3.79	5.43	5.66	22.47	26.72	23.17	35.10	31.74	30.78	50.76	54.25	51.92		
1.97	2.78	2.81	2.87	4.16	4.40	2.19	3.00	3.72	4.00	3.97	4.33		
0.76	0.81	0.77	0.48	0.55	0.53	3.71	6.42	5.38	5.19	3.47	4.51	11.52	15.59
STATION 6													
2.98	3.10	3.04	7.91	8.80	8.49	8.00	8.70	8.50	8.10	8.90	8.20		
0.68	0.73	0.71	8.79	9.61	10.07	3.00	3.13	2.99	2.53	2.91	2.69		
0.43	0.61	0.52	0.90	0.90	0.90	0.37	0.47	0.51	0.00	0.00	0.00	3.84	3.57
3.87	4.25	4.33	9.52	9.53	9.53	6.91	7.61	6.78	5.80	6.80	6.60		
0.28	0.41	0.48	3.89	4.76	4.34	2.00	3.00	2.95	1.43	2.82	3.88		
0.37	0.41	0.39	1.00	1.50	1.19	0.00	0.00	0.00	1.56	1.72	1.76	3.38	2.91

APPENDIX XX

Chlorophyll a (mg m^{-3})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.70	1.21	0.87	1.31	1.31	4.63	0.20	1.43	0.89	0.83	3.17
July	0.63	0.54	0.46	0.52	0.59	2.31	0.32	0.42	0.31	0.46	5.86
August	1.62	2.03	2.29	1.16	3.68	11.17	1.60	2.06	1.73	2.81	12.82
September	1.30	1.66	1.53	1.06	0.95	2.40	1.18	1.30	1.06	1.31	2.98
October	0.97	1.71	1.20	0.94	1.17	2.10	1.16	1.03	1.11	1.74	2.31
November	1.00	1.09	1.45	1.00	4.22	21.01	0.89	1.09	1.20	7.61	16.12
December	0.73	1.07	1.44	1.12	4.07	21.56	0.99	1.21	1.53	8.29	12.51
January	1.08	1.30	2.36	3.81	6.75	16.76	1.09	1.42	2.78	5.61	4.54
February	1.79	2.62	3.79	42.35	22.48	52.30	3.79	2.18	0.51	18.72	7.81
March	1.97	3.69	2.08	30.82	2.16	7.50	1.09	2.74	2.74	6.72	6.82
April	0.44	2.28	1.43	1.74	6.56	7.88	1.59	4.49	24.09	24.80	6.13
May	1.11	3.73	2.52	0.32	54.48	3.73	4.15	6.49	48.29	24.28	3.15

APPENDIX XXI

Chlorophyll b (mg m^{-3})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.27	0.53	0.56	0.71	0.71	2.00	0.23	0.63	0.41	0.56	1.76
July	0.62	0.25	0.21	0.48	0.59	0.91	0.13	0.30	0.46	0.42	2.37
August	1.16	1.70	2.83	1.16	2.49	5.96	1.37	1.36	1.13	1.90	1.02
September	0.23	0.36	0.50	0.74	0.58	1.38	0.42	0.68	0.38	0.71	1.29
October	0.75	1.60	1.06	1.11	0.98	2.36	1.19	1.48	0.43	1.13	2.62
November	0.30	0.64	0.48	0.28	1.48	4.79	0.33	0.61	0.61	1.66	4.18
December	0.22	0.28	0.45	0.22	1.93	5.70	0.46	0.56	0.82	3.54	7.17
January	0.49	0.32	1.08	1.82	3.76	7.99	0.32	0.63	1.00	3.71	2.02
February	0.52	1.43	1.04	16.15	6.92	23.99	1.79	1.30	0.65	9.89	3.67
March	0.97	1.88	1.09	14.99	4.33	3.19	5.20	1.37	1.40	2.70	3.01
April	0.20	1.41	2.43	1.02	3.70	4.10	0.81	2.40	11.44	12.29	3.24
May	0.40	1.91	3.86	0.23	25.50	1.80	2.22	2.89	28.04	10.06	1.84

APPENDIX XXII

Chlorophyll c (mg m^{-3})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.12	0.59	0.52	0.25	0.25	0.81	0.55	0.48	0.21	0.42	0.43
July	0.50	0.67	0.49	0.32	0.46	1.27	0.66	0.69	0.70	0.98	0.99
August	0.22	0.58	0.21	0.36	0.46	5.60	0.14	0.74	0.30	0.73	3.44
September	0.31	0.26	0.52	0.59	0.23	0.12	0.17	0.55	0.83	0.25	0.20
October	0.14	0.53	0.51	0.26	0.19	1.11	0.11	0.23	0.19	0.44	1.32
November	0.15	0.11	0.13	0.28	0.20	5.82	0.30	0.36	0.22	1.64	2.05
December	0.11	0.28	3.08	0.26	0.31	4.03	0.25	0.44	0.14	2.80	3.39
January	0.22	0.16	0.57	0.88	1.77	3.76	0.18	0.34	0.51	1.55	1.04
February	0.24	0.50	1.74	8.76	3.12	13.15	0.48	0.24	5.52	4.88	1.79
March	0.41	1.29	0.56	6.99	0.24	0.62	1.38	0.38	0.63	1.49	1.51
April	0.13	0.38	0.44	0.94	1.60	1.32	0.13	0.36	1.10	2.76	0.80
May	0.43	0.19	0.74	0.14	22.26	1.18	0.88	0.58	13.95	3.92	1.58

APPENDIX XXIII

CHLOROPHYLL (mg m^{-3})

STATION 2												MEAN	SD
Surface													
1.71	1.81	1.82	4.52	4.59	4.54	6.81	6.90	6.86	4.15	3.99	5.48		
4.98	5.91	6.66	2.31	2.35	2.33	1.41	1.50	1.47	4.35	3.99	4.59		
2.31	2.15	2.38	3.91	3.98	4.63	1.86	1.84	1.82	1.65	1.58	1.66	3.47	1.77
Bottom													
1.56	1.71	1.50	6.00	6.12	6.06	7.61	7.71	7.69	2.51	2.63	2.45		
7.20	7.28	7.27	0.90	1.00	1.04	1.09	1.21	1.03	3.09	3.18	3.06		
1.68	1.81	1.82	2.39	2.51	2.27	1.48	1.54	1.54	1.51	1.79	1.23	3.12	2.33
STATION 3													
4.00	3.98	4.05	6.51	7.01	6.19	3.70	3.98	3.51	4.10	3.80	5.00		
7.00	6.98	7.38	1.69	2.31	1.85	1.14	1.25	1.09	5.32	6.10	4.57		
2.53	2.68	2.44	2.71	2.82	2.78	2.06	2.06	2.06	4.81	5.11	4.99	3.88	1.82
2.41	2.12	2.64	3.76	2.99	4.41	4.47	5.10	3.90	7.18	7.31	7.26		
9.91	9.99	9.98	2.50	2.61	2.51	1.40	1.45	1.38	4.18	4.13	4.17		
2.57	2.51	2.51	2.67	2.77	2.78	2.00	2.10	2.08	2.00	1.67	3.00	3.79	2.40
STATION 4													
4.93	7.13	7.47	65.13	69.24	67.41	51.40	55.31	51.46	2.91	4.16	4.03		
0.65	0.71	0.71	1.98	3.00	1.83	1.00	1.53	1.43	2.50	3.16	1.94		
2.00	3.00	2.17	2.20	2.46	2.27	1.31	1.68	1.69	1.41	1.78	1.61	12.07	21.70
3.81	5.68	3.38	5.58	7.00	7.46	3.98	5.61	4.72	34.91	38.18	36.80		
87.70	91.38	91.59	1.00	1.81	1.72	1.38	1.51	1.52	3.00	3.80	2.68		
2.00	2.47	2.34	1.52	1.91	1.76	2.00	2.06	2.03	2.38	3.00	2.09	13.10	25.08

STATION 5												MEAN	SD
11.36	14.71	10.77	31.14	33.21	33.21	5.91	7.61	6.67	10.46	12.70	12.42		
102.50	101.78	102.44	2.39	2.19	2.23	1.76	1.45	1.71	6.43	6.84	6.62		
1.58	1.91	1.76	2.21	2.61	2.20	4.75	6.71	6.24	5.89	7.61	5.43	16.04	27.24
9.77	10.91	11.93	31.47	34.54	34.46	10.87	11.00	10.86	37.85	40.12	41.58		
37.25	39.14	38.39	1.61	1.92	1.90	1.90	1.99	1.87	5.46	5.12	5.74		
2.17	2.37	2.27	3.89	2.97	3.07	10.71	11.00	11.02	7.76	6.97	8.22	13.89	13.94
STATION 6													
25.71	29.00	30.82	87.60	90.50	90.22	10.86	12.01	11.06	12.75	14.13	13.02		
5.51	6.92	7.70	6.89	8.11	7.32	4.00	5.10	4.37	22.00	23.00	23.19		
2.71	4.00	4.99	4.69	6.00	6.04	29.16	32.13	33.57	29.76	32.13	32.88	21.38	22.96
7.80	7.40	7.60	12.11	14.12	13.58	10.76	12.10	11.16	11.61	10.00	8.90		
5.99	7.20	6.52	4.50	5.40	6.18	8.72	9.73	9.21	16.50	18.30	17.04		
5.10	4.10	4.21	5.91	6.50	6.34	21.69	23.00	22.36	23.00	23.20	23.00	11.41*	6.15

* t value significant at 5% level.

APPENDIX XXIV

Chlorophyll a (mg m^{-3})

Lorezen's Method

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.80	1.34	0.54	1.34	1.34	4.54	0.18	1.61	0.54	0.80	2.86
July	1.07	0.54	0.38	0.54	0.62	2.41	0.19	0.54	0.48	0.52	3.73
August	1.34	1.34	1.60	1.14	2.67	9.89	0.80	1.34	1.07	1.60	9.90
September	0.53	1.34	1.87	0.80	0.92	0.80	0.80	1.07	1.05	0.53	2.95
October	0.52	0.80	0.54	0.54	0.80	1.60	0.54	1.06	0.54	0.27	2.14
November	0.27	1.35	0.80	0.32	1.07	2.67	0.53	1.60	0.54	0.80	14.27
December	0.54	0.27	0.80	0.80	3.20	15.74	0.76	0.94	1.59	5.88	13.31
January	0.81	1.07	2.15	3.20	4.82	10.16	1.60	1.60	1.60	5.61	2.42
February	1.24	2.40	2.69	40.72	20.07	43.95	2.60	1.64	0.48	17.66	6.15
March	1.76	2.69	1.24	26.12	1.93	6.15	1.08	21.14	2.14	5.79	5.33
April	0.40	1.38	0.68	2.49	6.02	6.79	1.31	4.08	22.73	23.18	5.84
May	1.34	4.01	1.42	0.54	56.75	3.49	3.49	5.90	3.74	17.34	3.66

APPENDIX XXV

Chlorophyll a (mg m^{-3})

STATION 1												MEAN	SD
Lorenzen Method													
0.80	1.07	1.34	0.53	0.52	0.27	0.54	0.81	1.24	1.76	0.40	1.34	0.89	0.44
Jeffrey and Humphrey Method													
0.70	0.63	1.62	1.30	0.97	1.00	0.73	1.08	1.79	1.97	0.44	1.11	1.11	0.46
STATION 2													
1.34	0.54	1.34	0.53	0.52	0.27	0.54	0.81	1.24	1.76	0.40	1.34	1.54	0.99
1.21	0.54	2.03	1.66	1.71	1.09	1.07	1.30	2.62	3.69	2.28	3.73	1.91	0.98
STATION 3													
0.54	0.38	1.60	1.87	0.54	0.80	0.80	2.15	2.69	1.24	0.68	1.42	1.23	0.70
0.87	0.46	2.29	1.53	1.20	1.45	1.44	2.36	3.79	2.08	1.43	2.52	1.79	0.85
STATION 4													
1.34	0.54	1.14	0.80	0.54	0.32	0.80	3.20	40.72	26.12	2.49	0.54	6.55	12.41
1.31	0.52	1.16	1.06	0.94	1.00	1.12	3.81	42.35	30.82	1.74	0.32	7.18	13.39
STATION 5													
1.34	0.62	2.67	0.92	0.80	1.07	3.20	4.82	20.07	1.93	6.02	56.75	8.35	15.47
1.31	0.59	3.68	0.95	1.17	4.22	4.07	6.75	22.48	2.16	6.56	54.48	9.04	14.83
STATION 6													
4.54	2.41	9.89	0.80	1.60	2.67	15.74	10.16	43.95	6.15	6.79	3.49	9.02	11.32
4.63	2.31	11.17	2.40	2.10	21.01	21.56	16.76	52.30	7.50	7.88	3.73	12.78	13.71

APPENDIX XXVI

Pheopigments (mg m^{-3})

Sampling Period	Surface						Bottom				
	STATIONS										
	1	2	3	4	5	6	2	3	4	5	6
June	0.26	1.38	0.59	0.86	1.30	0.13	1.28	2.36	0.59	1.76	2.25
July	0.17	0.03	0.76	0.20	0.15	0.21	1.36	0.15	0.15	0.16	3.56
August	0.53	1.34	1.39	2.06	1.81	3.21	1.44	1.28	1.18	2.14	6.26
September	0.15	0.35	0.98	0.32	2.64	0.94	0.51	2.41	0.36	1.34	0.10
October	1.68	1.63	0.78	0.78	0.70	1.02	1.15	1.87	0.96	2.54	0.48
November	1.23	1.24	1.07	1.23	5.30	30.63	0.59	0.11	1.15	11.36	26.68
December	0.40	1.41	1.07	0.51	1.47	9.30	2.14	2.06	0.18	4.04	6.28
January	1.87	0.80	1.79	2.41	1.55	2.75	0.79	1.95	2.14	3.48	1.71
February	0.96	1.01	1.38	6.82	1.26	22.37	1.40	0.78	2.08	12.13	1.20
March	1.20	1.32	1.52	3.54	0.64	3.16	0.88	1.64	1.64	2.65	0.95
April.	0.24	0.96	0.98	1.02	0.46	2.64	1.14	1.08	3.40	15.12	1.68
May	0.38	1.46	2.57	0.24	0.82	0.45	1.20	1.04	54.13	11.63	0.88

APPENDIX XXVII

PHEOPIGMENTS (mg m^{-3})

STATION 2												MEAN	SD
Surface													
0.75	0.85	0.80	1.00	1.20	0.83	1.00	1.50	1.46	0.90	0.99	0.99		
1.40	1.50	1.48	1.30	1.40	1.44	0.03	0.03	0.03	1.30	1.50	1.22		
0.31	0.38	0.36	1.60	1.69	1.60	1.00	1.31	1.41	1.35	1.46	1.42	1.08	0.47
Bottom													
0.81	0.77	0.79	1.39	1.47	1.34	0.80	0.91	0.93	1.11	1.21	1.10		
1.15	1.22	1.23	1.21	1.31	1.32	1.30	1.40	1.38	1.40	1.50	1.42		
0.45	0.55	0.53	1.10	1.20	1.15	0.49	0.61	0.67	2.11	2.24	2.07	1.16	0.42
STATION 3													
1.70	1.85	1.82	1.31	1.43	1.40	1.48	1.55	1.53	0.95	1.10	0.89		
2.41	3.00	2.30	0.50	0.45	0.82	0.71	0.81	0.76	1.30	1.40	1.47		
0.89	1.00	1.05	0.75	0.81	0.78	1.00	1.10	1.11	1.10	1.00	1.11	1.25	0.53
1.90	1.89	2.06	0.82	0.75	0.77	1.60	1.70	1.62	1.20	1.01	1.03		
1.00	1.10	1.02	2.30	2.40	2.38	0.11	0.18	0.16	1.20	1.31	1.33		
2.35	2.48	2.40	1.75	2.10	1.76	0.09	0.15	0.09	2.01	2.10	2.07	1.39	0.76
STATION 4													
2.35	2.45	2.43	6.80	6.75	6.91	3.50	3.60	3.52	1.00	1.20	0.86		
0.20	0.28	0.24	0.80	0.90	0.88	0.18	0.22	0.20	2.00	2.10	2.02		
0.28	0.35	0.33	0.75	0.81	0.78	1.20	1.30	1.19	0.42	0.55	0.56	1.66	1.83
2.00	2.21	2.21	2.00	2.10	2.14	1.45	1.51	1.42	3.10	3.90	3.20		
54.00	55.00	53.39	0.49	0.61	0.67	0.12	0.18	0.15	1.00	1.22	1.32		
0.33	0.39	0.36	0.96	0.96	0.96	1.10	1.50	0.85	0.15	0.21	0.18	5.64	14.65

STATION 5												MEAN	SD
1.50	1.60	1.55	1.21	1.30	1.27	0.61	0.70	0.61	0.40	0.50	0.48		
0.78	0.86	0.82	1.00	1.50	1.40	0.15	0.15	0.15	1.75	1.90	1.78		
2.50	2.75	2.67	0.65	0.75	0.70	4.89	5.81	5.20	1.31	1.55	1.55	1.51*	1.32
3.10	3.50	3.84	12.00	13.00	11.39	2.50	3.00	2.45	15.00	15.30	15.06		
11.00	12.00	11.89	1.60	1.81	1.87	0.18	0.12	0.18	2.00	3.00	1.42		
1.00	2.00	1.02	3.00	2.00	2.62	11.08	11.00	12.00	4.00	4.20	3.92	5.70	5.03
STATION 6													
2.15	2.81	3.29	22.00	23.00	22.11	3.00	3.41	3.07	2.50	2.70	2.72		
0.40	0.50	0.45	0.10	0.16	0.13	0.18	0.24	0.21	0.30	3.40	3.23		
0.90	0.98	0.94	1.00	1.10	0.96	29.70	31.00	31.19	9.00	9.50	9.40	6.40	9.50
1.69	2.00	1.44	1.00	1.50	1.10	0.90	1.00	0.95	1.60	1.70	1.74		
0.85	0.90	0.89	2.00	2.50	2.25	3.31	3.80	3.57	6.00	7.00	5.78		
0.10	0.10	0.10	0.40	0.51	0.53	25.80	27.00	27.24	6.00	6.80	6.04	4.34	7.03

* t value significant at 5% level.