REPORT OF THE INTERNSHIP TRAINING ON

STUDIES ON MICROBIO-CHEMICAL PRODUCTION AND CONSUMPTION OF OXYGEN IN THE ESTUARINE WATERS OF MANGALVANAM, COCHIN

AT

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE, COCHIN

UNDER THE GUIDANCE OF

SHRI G.S. DANIEL SELVARAJ

FOR THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE MASTER'S DEGREE IN ENVIRONMENT MANAGEMENT (MEM)

BY

NIRMALA, K.

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KOTTAYAM

MARCH 1999

Certificate

This is to certify that the work titled ***'Studies on microbio-chemical production and consumption of Oxygen in the estuarine waters of Mangalvanam'*** *submitted by* **Miss. Nirmala, K** *to the Mahatma Gandhi University in partial fulfilment of the requirement for the award of the Master's Degree in Environment Management is an authentic record of work carried out by her under the supervision of Shri G.S. Daniel Selvaraj at Central Marine Fisheries Research Institute during the period from September 1998- March 1999 and no part of this report has formed the basis for the award of any degree, diploma or other similar titles of any University.*

Place: Kottayam

Date: 12.04.99

Signature of Head of the school of Environmental Studies

Mahatma Gandhi University, Kottayam.

CERTIFICATE OF SUPERVISOR

This is to certify that the work titled ***'Studies on microbio-chemical production and consumption of Oxygen in the estuarine waters of Mangalvanam'*** *submitted by* ***Miss.Nirmala, K.*** *to the Mahatma Gandhi University in partial fulfilment of the requirement for the award of the Master's Degree in Environment Management is an authentic record of work carried out by her under my supervision at Central Marine Fisheries Research Institute during the period from September 1998 to March 1999 and no part of this report has formed the basis for the award of any other degree, diploma or other similar titles of any University. I further certify that* ***Miss. Nirmala, K.*** *has completed all the assigned work and duties to my satisfaction. She has impressed me with her dedication and hard work in the field collection, laboratory experiments, analyses and in the preparation of the report. Her conduct and character have been good during the course of study.*

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DECLARATION

*I, **Nirmala, K.** hereby certify that the report titled the **'Studies on microbio-chemical production and consumption of Oxygen in the estuarine waters of Mangalvanam', Cochin** submitted to the Mahatma Gandhi University, Kottayam in partial fulfilment of the requirement for the award of the Master's Degree in Environment Management (MEM) is bonafide record of the work done by me under the supervision of **Shri. G.S.Daniel Selvaraj,** Senior Scientist, CMFRI, Cochin during the period from September 1998 to March 1999 and no part of this has formed the basis for the award of any degree diploma or other similar titles of any other Universities.*

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BRIEF INFORMATION

1.	Name	-	Nirmala, K.
2.	Course	-	Master of Environment Management
3.	Academic year	-	1997-1999
4.	Name of the institution where internship training was completed	-	Central Marine Fisheries Research Institute (CMFRI), Cochin.
5.	Name and designation of the supervising officer	-	Shri G.S.Daniel Selvaraj, Senior Scientist, CMFRI, Cochin.
6.	Broad area of work	-	Estuarine Environment and Management
7.	Period of training	-	September 1998 - March 1999.
8.	Assessment of the work by the supervising officer.	-	Miss. Nirmala, K. has completed all the assigned work and duties to my satisfaction. She has impressed me with her dedication and hard work in the field collection, laboratory experiments and analyses.

CONTENTS

PREFACE

The present study is centered around aspects of microbio-chemical supply and consumption of Oxygen in the Mangalvanam waters in relation to associated environmental characteristics of the biotope located as part in the Cochin backwater system at Ernakulam (Kochi) during the southwest postmonsoon (September-December) period of 1998. Mangalvanam is one of the remnants of the past mangrove forest of the Cochin backwater system having connection with the Cochin backwater by way of a narrow feeder canal where water exchange takes place through tidal influence. The dredging operations and reclamation processes carried out by the Greater Cochin Development Authority during 1970-80 along the side of the Shanmugam road in the Cochin backwater resulted in heavy siltation and accumulation of sediments in the Mangalvanam water body which has reduced the average depth of the water body from three to one metre; and as such there is no specific map of the present Mangalvanam with its boundary demarcations although it is declared as the 'Bird Sanctuary' and steps have been taken to protect the sanctuary by the Kerala Forest Department.

This comprehensive study was planned since no works on these lines are available in literature from this water body.. The significance of the study, resume of relevant literature and scope of the study are given under the title 'Introduction'. The description of the mangrove environment, Cochin backwater and the study area (station positions), methodology in the collection of samples, laboratory experiments and analysis and treatment of data are included in 'Materials and methods'. The 'Results' and 'Discussion' embody sections relating to Environment, Photosynthesis, Algal respiration, other microbio-chemical (bacterial) production of Oxygen, Bacterial consumption of Oxygen, Net gain/loss of Oxygen per day (24 hrs) and Influence of tides and other related hydrographic parameters on the rate of bio-chemical production and consumption of Oxygen in the Mangalvanam waters. Salient features and findings of the present investigation are given in 'Summary' and the relevant literature cited in this report are included in 'References'.

I wish to express my deep sense of gratitude to my supervising teacher Mr.G.S.Daniel Selvaraj, Senior Scientist, CMFRI, Cochin for his constant advice, inspiring guidance and whole hearted support throughout the course of study and in the preparation of the manuscript. I express my sincere thanks to Dr.M.Devaraj, Director of C.M.F.R.I. for providing me the facilities to do my dissertation work in C.M.F.R.I, Cochin. I also express my sincere thanks to Dr. K.J.Mathew, Senior Scientist, C.M.F.R.I, Cochin for all the help and advice given to me during the period.

I express my thanks to Dr.C..P. Gopinathan, Senior Scientist, C.M.F.R.I. for providing me the facilities and to Miss. Renuka, T. R for rendering help to conduct experiments relating to algal respiration. I am thankful to Mr.L.R.Khambadkar for helping me in the analysis of plant nutrients. I also express my thanks to Mr.N.V. Thambi for helping me in the field to collect water samples.

I am also thankful to the Director and Co-ordinator of School of Environmental Studies for the guidance and suggestions given to me during the course of study.

INTRODUCTION

Estuaries occupy about thirteen percent of the global coastline. The Cochin backwater system is one of the fertile and largest estuarine systems along the Indian coast. This form the main source of estuarine waters to feed several hectares of potential aquaculture sites at high tide and to enrich the neighboring marine environment at low tide and during the southwest and northeast monsoon periods. The monsoonal effects result in wide fluctuations in the environmental parameters like light penetration, temperature, salinity, dissolved Oxygen, nutrients and in the species composition and succession of primary and secondary producers. Fishery resources of the coastal aquatic systems mainly depend on the magnitude of these primary and secondary producers, which in turn are influenced by various physical, chemical and biological factors. Among the southwest and northeast monsoons of the west coast, the southwest monsoon plays a vital role by the influx of nutrient-rich fresh water discharge from rivers and land drainage and by considerable admixture of nutrient rich saline water by the coastal upwelling process associated with this monsoon resulting in a highly complex dynamic environment within the backwater system. Such drastic changes in the environment influence considerably the organic production of the coastal ecosystems.

While organic production in the marine environment is chiefly contributed by phytoplankton through photosynthesis, that in the estuarine ecosystems is contributed by mangrove vegetation, aquatic weeds, other higher algae, phytoplankton and bacterial population which influence the dissolved Oxygen level significantly.

Among the estuarine systems, mangroves are highly productive ecosystems, which serve as reservoirs of organic matter and nutrients providing nursery grounds for a wide variety of organisms. The mangroves are distributed along the coastal belt from the highest spring tide mark to almost near to the mean sea level and are called "the tropical tidal wet lands".

Among the flora of marine, estuarine and fresh water systems, mangroves are the only one group of vegetation characterised by storage of aerial biomass. The upper canopy supports a rich insect fauna together with a variety of birds and bats. Among the aquatic forms, varieties of crabs, molluscs and other invertebrates and certain estuarine fishes like mud skippers are permanent inhabitants while some species of prawns and fishes are semiresident and migratory populations present in the mangrove ecosystems.

'Mangalvanam' is one such mini-mangrove ecosystem located in the heart of Cochin City (Fig.1) adjacent to the Central Marine Fisheries Research Institute (C..M.F.R.I.),National Institute of Oceanography (N.I.O), Bharat Petroleum Company Ltd. and the Railway good shed (old) of Ernakulam (Fig.2). It is having a diversified terrestrial and aquatic flora and fauna including a variety of bats and more than fifty eight species of birds. Recently, this Mangalvanam has been declared as the 'Bird Sanctuary' and being protected by the Kerala Forest Department. This Mangalvanam is one of the remnant patches of the past mangrove forest of the Cochin backwater system having connection with the backwater through a narrow feeder canal. The word 'Mangalvanam' is derived from 'Mangal' which is the synonym of the mangrove vegetation. While the Indian coast has about sixty species of mangrove vegetation recorded, 'Mangalvanam' is constituted by less than ten species of vegetation of which species of *Avicennia, Rhizophora, Bruguira, Excoccaria* and *Acanthus* are some of the dominant halophytes.

Dissolved Oxygen plays a vital role on the healthy survival of organisms in aquatic ecosystems and is influenced by the physical, chemical and biological processes of the environment. Biochemical role involving photosynthesis, respiration and other oxidation-reduction processes such as degradation and decomposition of decaying organic matter and recycling of minerals influences the rate of consumption and production or release of Oxygen in shallow estuarine waters. Further, physical factors such as rainfall, temperature, freshwater supply, tidal rhythms and connected mixing processes and circulatory pattern govern the concentration and distribution of dissolved Oxygen within the estuarine system.

Photosynthesis is the chief biochemical mechanism by which oxygen is replenished in fertile coastal water bodies by sea weeds, phytoplankton and certain benthic microflora. Besides these, certain autotrophic bacteria such as Cyanobacteria are also capable of oxygenic photosynthesis. Autotrophic bacteria are divided in to photosynthetic and chemosynthetic groups. While photosynthetic bacteria derive energy from sunlight, chemosynthetic bacteria such as nitrifying bacteria obtain energy from special chemical processes involving oxidation of organic compounds other than sugar. In both cases, the energy released is used for the synthesis of organic compounds.

A particularly important group of chemosynthetic microbes are the nitrifying bacteria found in the soil and in the overlying water body with high load of suspended organic matter. Some of these bacteria specifically *Nitrosomonas* and *Nitrococcus* obtain energy by oxidising ammonia (formed by the breakdown of animal and plant proteins during decay by the activities of saprophytic bacteria and fungi) to nitrites involving several steps such as formation of ammonium carbonate, nitrous acid and then nitrites of calcium or Magnesium. Another group of nitrifying bacteria known as *Nitrobacter* oxidizes nitrites to nitrates consuming Oxygen present in the water thereby reduces the Oxygen level in water.

There are certain bacteria, which convert nitrates into nitrites, ammonia and even nitrogen known as denitrifying bacteria releasing oxygen into the aquatic environment. These bacteria tend to live in conditions of oxygen shortage and to correct the deficiency of oxygen. They reduce nitrates to nitrites and ammonia thereby liberate Oxygen. This Oxygen released is then used (under anaerobic conditions) for aerobic breakdown of decaying organic matter and the energy released is used for the synthesis of organic compounds.

Apart from the consumption of Oxygen by the microorganisms by way of respiration and other biochemical oxidation processes, it is to add here that human interference have great impact both directly and indirectly on the depletion of dissolved Oxygen in the shallow

estuarine water bodies. In recent years, several ecological changes have taken place in the Cochin backwater as well as in the Mangalvanam biotope as a result of human interference such as deforestation, reclamation processes, dredging operations and release of chemical pollutants and sewage with high organic load resulting in accumulation of sediments and organic pollutants especially in the shallow pockets of the estuarine biotopes which has reduced the average depth, tidal influence and dissolved Oxygen concentration in water considerably.

The Mangalvanam is one of such affected mangrove biotopes in the Cochin backwater system with accumulation of decaying organic matter and pollutants in sediments as well as in the overlying water body which receives tide-influenced water from the backwater (Fig. 1) during high tide and releases it out during low tide, resulting in reduction of tidal prism and tidal influence within the biotope as compared to that of the Cochin backwater.

Relevant studies on the physico-chemical features of the Cochin backwater were those of Ramamirtham and Jayaraman (1963), Sankaranarayanan and Qasim (1969) and pillai *et. al.* (1975). Phytoplankton and productivity studies of the Cochin backwater were pertaining to plant pigments (Qasim and Reddy,1967; Preetha Paul 1990), seasonal abundance of phytoplankton (Gopinathan, 1972)and primary productivity (Pillai *et. al.*1975; Preetha Paul, 1990). Studies relating to bacteria of Cochin backwater were limited to those of Chandrika (1976),Promod and Dhevendran (1987) and Chandrika and Nair (1994).

Perusal of literature reveals that very little work has been done on the hydrography, primary productivity and bacterial studies of the Cochin backwater and associated biotopes (nil at Mangalvanam) during the past fifteen years. Studies relating to the role of bacteria on these estuarine biotopes are rare in general, because of the fact that the estimation of these bacterial biomass or number for regular samples is difficult, expensive, time consuming and cumbersome since these analyses require more time, energy, manpower and good laboratory facilities and limited samples alone can be analysed.

Regarding primary productivity studies of phytoplankton, although there are several methods such as cell counts, chlorophyll estimation, ^{14}C technique and Light and Dark bottle (Oxygen) technique to assess the photosynthetic production in water, every method has its own merits and demerits. Moreover, the methods adopted in the open sea, such as L&D bottle oxygen technique are so long being applied directly in the shallow estuarine and backwater systems neglecting the role of bacteria in the production and consumption of Oxygen which hamper the productivity results very much especially when the shallow estuarine waters are rich with organic pollutants and bacterial load.

In view of the above facts, a short term research project was selected to study the microbio-chemical production and consumption of oxygen in the estuarine waters of Mangalvanam during the southwest postmonsoon period from September to December 1998. The objectives of the present study are to conduct a preliminary survey of this mangrove biotope; to prepare a map of the present Mangalvanam (which is lacking);to fix two stations for regular sampling; and to study the diurnal and month to month variation in the rate of microbio-chemical production and consumption of Oxygen by photosynthesis, algal respiration and other sources of (bacterial) biochemical oxidation and reduction processes in relation to other associated hydrographic parameters such as rainfall, nutrients and tides to ascertain whether the Mangalvanam, biotope provides a self replenishing environment or to what extent the aquatic environment is in the oxidising or reducing state; and to understand the fertility of high and low tide waters in different months during the southwest postmonsoon period of 1998.

MATERIALS AND METHODS

Study Area

The present study was conducted in the 'Mangalvanam' waters located adjacent to the Central Marine Fisheries Research Institute,Cochin (Fig.1). It is a mangrove biotope comprising 3.1 hectares of area which is connected with the Cochin backwater system through a feeder canal. This mangrove area is fed by the tidal water through this canal. Two station were fixed, one inside and the other in the feeder canal (Fig.2) and the study was conducted during the southwest post monsoon period (September-December) of 1998.

Collection of water samples

Regular sampling was done in the morning between 09.00 and 10.00 hours as far as possible daily (excluding the holidays). Water temperature and tidal height were recorded in the field itself. Surface water samples for the analyses of salinity, dissolved oxygen and plant nutrients were collected regularly from these two stations and from the Cochin backwater (control). Water samples for productivity experiments were filtered gently through the zooplankton filter (0.4mm mesh) fixed in the bucket. The water samples were analysed for salinity, dissolved oxygen, phosphate, nitrite and nitrate following standard methods (Strickland and Parsons, 1972). Rainfall data were also collected from the 'Daily Weather Chart.'

Productivity Experiments

Filtered water samples collected in three 125 ml *B.O.D* bottles from each station were set for incubation experiments atleast 30 minutes after sampling but not later than one hour, to bring the microorganisms physiologically stabilised. Simulated incubation experiments were conducted in the laboratory adopting Light and Dark bottle Oxygen technique as in the case of primary productivity experiments giving uniformly 2.5 hours of incubation in each experiment for the light bottle in light and dark bottle in darkness. Dissolved oxygen values

Fig. 1. Map showing the study Area.

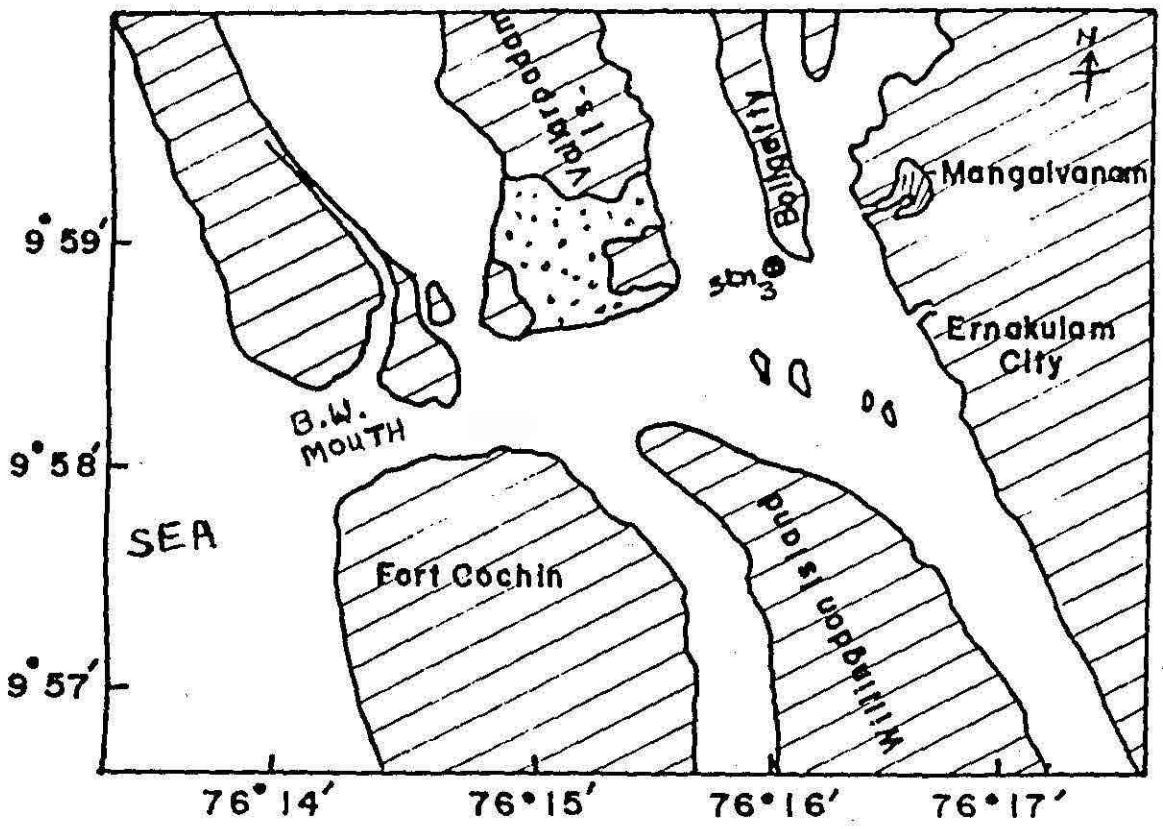
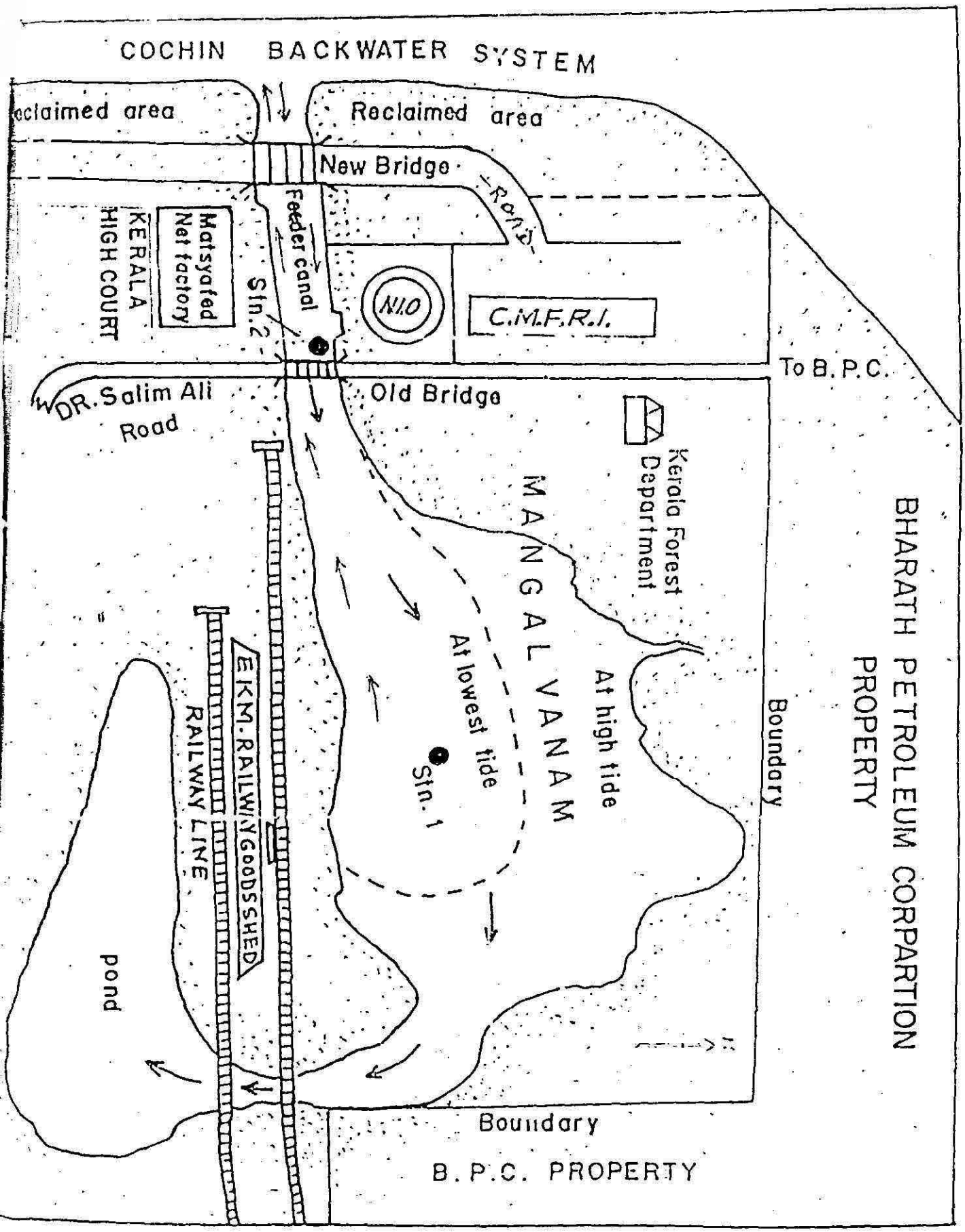


Fig.2 MAP SHOWING THE SAMPLING STATIONS IN MANGALVANAM



were estimated in the Initial ('I'), dark ('D') and light ('L') bottle samples using Winkler's method; and a modified formula of Light and Dark bottle Oxygen technique (Selvaraj,1997; 1999) was adopted to determine algal respiration, net photosynthetic production and other biochemical (bacterial) sources of production and consumption of oxygen in the water samples in which the Oxygen values obtained for L-D, L-I, I-D, I-L and D-I during 2.5 hours were extrapolated for 12 hours of the day.

Positive values of L-I thus obtained for 12 hours were considered for the net biochemical production of Oxygen during day time (12 light hours) and the negative values of the same, or (I-L values) if any were considered for the net rate of Oxygen consumption by microorganisms during 12 light hours of the day.

Positive values of D-I obtained for 12 hours were considered as the net rate of biochemical production of Oxygen during night time (12 darks hours); and the negative values of D-I i.e., I-D values were considered as the net rate of Oxygen consumption by the microbes for the 12 dark (night) hours of the day.

(L-D) values obtained for 12 hours were considered for the gross photosynthetic production of Oxygen per day. The average respiratory loss of Oxygen by photosynthetic organisms was considered as 20% of the gross phtosynthetic production of Oxygen (Selvaraj, 1999) based on the laboratory experiments conducted using the isolated cultured phytoplankton groups grown in sterilised (bacteria free) sea water using sterilised glass wares and essential nutrients (Gopinathan, 1982) as given below:

Reagents used in Walne's Medium.

Stock 'A' solution

KNO_3	100.00g
Na_2HPO_4	20g

NaEDTA	45g
H_3BO_3	33.4g
$FeCl_3$	1.3 g
$MnCl_2$	0.36g
Distilled water	1 litre

Stock 'B' solutions

Trace Elements

$ZnCl_2$	4.2 g
$CuSO_4$	4.0 g
$COCl_2$	4.0 g
Ammonium Molybdate	1.8 g
Distilled water	1 litre

Stock 'C' solution

Vit. B_1	200 mg/100ml Distilled water
Vit .B_{12}	10 mg/100ml Distilled water

One ml of Stock 'A', 0.5ml of 'B' and 0.1 ml of 'C' were made up to 1 litre using filtered and sterilised Sea water.

Experiment to determine algal respiration

Pure cultures of *Isochrysis galvana, Tetracelvis gracilis, Nanochloropsis salina* and *Chaetoceros calcitrans* were inoculated in a series of one litre sterilised flasks containing sterilised sea water (added with essential nutrients) and were allowed to grow. Primary productivity experiments (by Light and Dark bottle incubation method) were conducted on these water samples at intervals (after 6, 7, 10, 11 and 20 days) and the net primary production (L-I) and the respiratory loss of Oxygen (I-D) were determined (Selvaraj,1999).

In bacteria free sea water,micro-algal respiration per 12 hours = (L-D) per 12 hrs - (L-I) per 12 hrs) = (I-D) per12 hrs. and that for 24 hours of the day would be (I-D) values extrapolated for 24 hours.

$$\text{Rate of respiration (\%)} = \frac{(I-D)}{(L-D)} \times 100 \text{ per unit time}$$

From these experiments (Table-1), the average respiration value works out to 15% of gross primary production of Oxygen per 12 photosynthetic hours of the day. Considering the influence of environmental stress on the changes in photosynthetic species composition and their physiological state, Selvaraj (1999a) has considered 20% as the average respiratory loss of Oxygen during 12 photosynthetic hours of the day which would work out to 40% of L-D value for 24 hours of the day, and the same has been adopted in the present study also assuming that the respiratory loss doesn't vary much between light and dark hours of the day.

a. Photosynthetic production of Oxygen

Since photosynthetic activity is meant for the 12 light hours of the day, L-D value per 12 hours would be the same for 24 hours of the day also to indicate the gross photosynthetic production (G.P.P.) of Oxygen. While considering 20% of the gross photosynthetic production of Oxygen as the respiratory loss by the photosynthetic organisms in water for the 12 light hours of the day (photosynthetic period), 80% of gross photosynthetic production i.e., 0.8 (L-D) per 12 hours would give the net photosynthetic (primary) production (N.P.P) of Oxygen rather than the (L-I) values for 12 hours which might include bacterial consumption and production of Oxygen also in the shallow estuarine waters (Selvaraj, 1999a). While deducting 40% of gross primary production of Oxygen as the respiratory loss in 24 hours of the day from the gross production, the net photosynthetic production of Oxygen during 24 hours of the day works out of 60% of the L-D value in ml Oxygen per litre.

b. Other biochemical production of Oxygen in water

(Hereinafter referred as the bacterial production of Oxygen)

For the assessment of bacterial production of Oxygen during day time (12 light hours), positive values of L-I per 12 hours minus N.P.P. value i.e., 0.8(L-D) per 12 hours were considered. For the production rate of Oxygen at night (12 dark hours), positive values of D-I per 12 hours plus loss by algal respiration per 12 hrs. i.e, 0.2 (L-D) per 12 hours or the values obtained for 12 light hours, whichever was more was considered (Selvaraj, 1999a). Computation of day and night values of Oxygen thus obtained would give the bacterial production value of oxygen (ml/l) per 24 hours of the day.

c. Other biochemical consumption of Oxygen in water

(Hereinafter referred as the bacterial consumption of Oxygen)

Bacterial consumption of Oxygen at night (12 dark hours) could be assessed using the formula (I-D) value per 12 hours minus algal respiratory loss, i.e, 0.2 (L-D) per 12 hours. Consumption of Oxygen at day time (12 light hours) could be estimated by the formula (I-D) - 0.2 (L-D) per 12 hours plus positive values, if any, obtained from [(I-L)-(I-D)] per 12 hours. Computation of these values obtained for this 12 light and 12 dark hours of the day would give the bacterial consumption value of Oxygen in 24 hours of the day close to the reality (Selvaraj, 1999a).

This could be summarised as follows:

{2[(I-D)-0.2 (L-D)] per 12 hours + [(I-L)-(I-D)] per 12 hours} (If any).

d. Net bacterial production/consumption of Oxygen per day

Computation of the Oxygen values thus obtained from the estimated production and consumption of Oxygen by bacterial action per day would give the net bacterial production (+ value) or consumption (-value) of Oxygen per 24 hours of the day.

e. Net gain/loss of oxygen by Photosynthetic and Bacterial action together per day

Computation of the values obtained from items 'a' and 'd' would give the net gain (+value) or loss (-value) of Oxygen in the biotope per 24 hours of the day, which would be equal to

[(L-I)+(D-I)] - [(I-L) + (I-D)] per 12 hours

Based on the above calculation, the following 12 parameters were designed (Selvaraj, 1999 a) and the same has been applied in the present investigation on microbio-chemical production and consumption of Oxygen in the estuarine water body of Mangalvanam (Cochin) based on the results of 93 incubation experiments (17,25,26 and 25 for September, October, November and December respectively in 1998) obtained at each station. These include three diurnal observations (at Stations 1 and 2) also made between 0630 and 1830 hours at bihourly intervals during the last week of October, November and December 1998 to study the influence of tides and fertility of high and low tide waters. High and low tides were determined based on the 'tide water level' as proposed by Selvaraj (1999 b).

Treatment of Data

1. Gross Photosynthetic Production	:	$(L\text{-}D)_{12\ hrs} = (L\text{-}D)_{24\ hrs}$
2. Net Photosynthetic Production	:	$0.8\ (L\text{-}D)_{12\ hrs}$
3. Micro-algal respiration	:	(a) $0.2(L\text{-}D)_{12\ hrs}$ = (b) $0.4(L\text{-}D)_{24\ hrs}$.
4. Bacterial production of O_2 at day hrs	:	$(L\text{-}I)_{12\ hrs} - 0.8\ (L\text{-}D)_{12\ hrs}$.
5. Bacterial production of O_2 at night hrs:		(a) $(D\text{-}I)_{12\ hrs} + 0.2\ (L\text{-}D)_{12\ hrs}$ if (D-I) is +ve (b) $(L\text{-}I)_{12\ hrs} - 0.8\ (L\text{-}D)_{12\ hrs}$ if (D-I) is -ve (c) $[0.2\ (L\text{-}D)]_{12\ hrs}$ if (D-I) is Zero
6. Bacterial production of O_2 in 24 hrs	:	Items (4) + (5)
7. Bacterial consumption of O_2 in day hrs:		(a) $[0.8\ (L\text{-}D)_{12\ hrs} - (L\text{-}I)]_{12\ hrs}$ if (L-I) is +ve (b) $[0.8(L\text{-}D)_{12\ hrs} + (I\text{-}L)_{12\ hrs}]$ if (L-I) is -ve or, $[(I\text{-}D)_{12\ hrs} - 0.2\ (L\text{-}D)_{12\ hrs}] + [(I\text{-}L)_{12\ hrs} - (I\text{-}D)_{12\ hrs}]$
8. Bacterial consumption of O_2 at night hrs	:	$[(I\text{-}D) - 0.2\ (L\text{-}D)]_{12\ hrs}$.
9. Bacterial consumption O_2 in 24 hrs	:	Items (7) + (8) or, $2[(I\text{-}D) - 0.2\ (L\text{-}D)]_{12\ hrs} + [(I\text{-}L) - (I\text{-}D)]_{12\ hrs}$ (if any)
10. Net bacterial Production/Consumption of O_2 in 24 hrs	:	Items (6) - (9) (+ = prod ;- =cons.)
11. Net Photsynthetic Production of O_2 in 24hrs	:	Items (1) - (3)b
12. Net gain/loss of O_2 by Photosynthesis, respiration and bacterial action in 24 hours of the day	:	Items (10) + (11) or, $[(L\text{-}I)_{12\ hrs} + (D\text{-}I)_{12\ hrs}] - [(I\text{-}L)_{12\ hrs} + (I\text{-}D)_{12\ hrs}]$ (+ = gain/prod.; - = loss/cons.)

Table 1. Experimental results to determine respiration rate (ml O_2/l) in primary productivity experiments using isolated phytoplankton culture in sterilised seawater (incubation: 3 hours)

Date of expt.	'I' value	'D' value	'L'value	G.P.P (L-D) per 12 hrs. (ml O_2/l)	Respiration (I-D) per 12 hrs.	
					(mlO_2/l)	% of G.P.P
10.12.98 (after 6 days)	3.252	2.944	6.070	12.504	1.232	9.85
"	3.298	2.827	5.807	11.920	1.884	15.80
"	4.023	3.751	5.640	7.556	1.088	14.40
"	4.050	3.805	5.314	6.036	0.980	16.24
"	4.023	3.805	5.273	5.872	0.872	14.85
"	4.240	3.995	5.463	5.872	0.980	16.69
"	4.240	3.995	5.409	5.656	0.980	17.33
11.12.98 (after7 days)	2.419	2.337	2.935	2.392	0.328	13.71
"	2.365	2.283	3.044	3.044	0.328	10.77
"	2.446	2.365	2.935	2.280	0.324	14.21
"	2.392	2.310	3.071	3.044	0.328	10.77
14.12.98 (after 10 days)	5.028	4.621	7.148	10.108	1.628	16.11
"	5.055	4.566	7.230	10.656	1.956	18.36
15.12.98 (after 11days)	4.230	3.716	7.058	13.368	2.056	15.38
24.12.98 (after 20 days)	2.717	2.079	5.821	14.968	2.552	17.05
Average						*15%*

RESULTS

1. The Environment (general information)

Tidal variation was found to be one of the major factors influencing the ecological characteristics of the Mangalvanam environment. Accordingly the depth of the water body ranged from 15 to 75 cm and the maximum tidal amplitude recorded inside Mangalvanam was 60 cm during September- December 1998 while it was 90 cm in the adjacent Cochin backwater.

The water body of Mangalvanam was found to be turbid during September-October. High tide flow brought in heavy mats of *Salvinia* weeds to Mangalvanam during September-October which covered the entire water surface. The same was found decaying and sinking during November - December.

1.1. Rainfall

The Cochin backwater and Mangalvanam had a local rainfall of 1311 mm during September -December 1998. The rainfall data showed a declining trend from September to December. . The monthly rainfall recorded for September - December was 648,486,121 and 56mm respectively. The decreasing trend in rainfall is depicted in Fig. 3.

1.2 . Water Temperature

At station- 1 surface water temperature ranged from 26.0-28.8^{0}C in September, 25.0-29.0^{0}C in October, 27.0 - 29.5^{0}C in November and 28.0 - 31.0^{0}C during December. The monthly mean values were 27.1, 27.4, 29.5 and 30.0^{0}C respectively. At station 2, surface water temperature varied from 27.0 - 29.2^{0}C in September, 25.0 - 29.0^{0}C in October, 28.0 - 29.5^{0}C in November and 28.0 - 31.0^{0}C in December with their mean values recorded as 27.7,

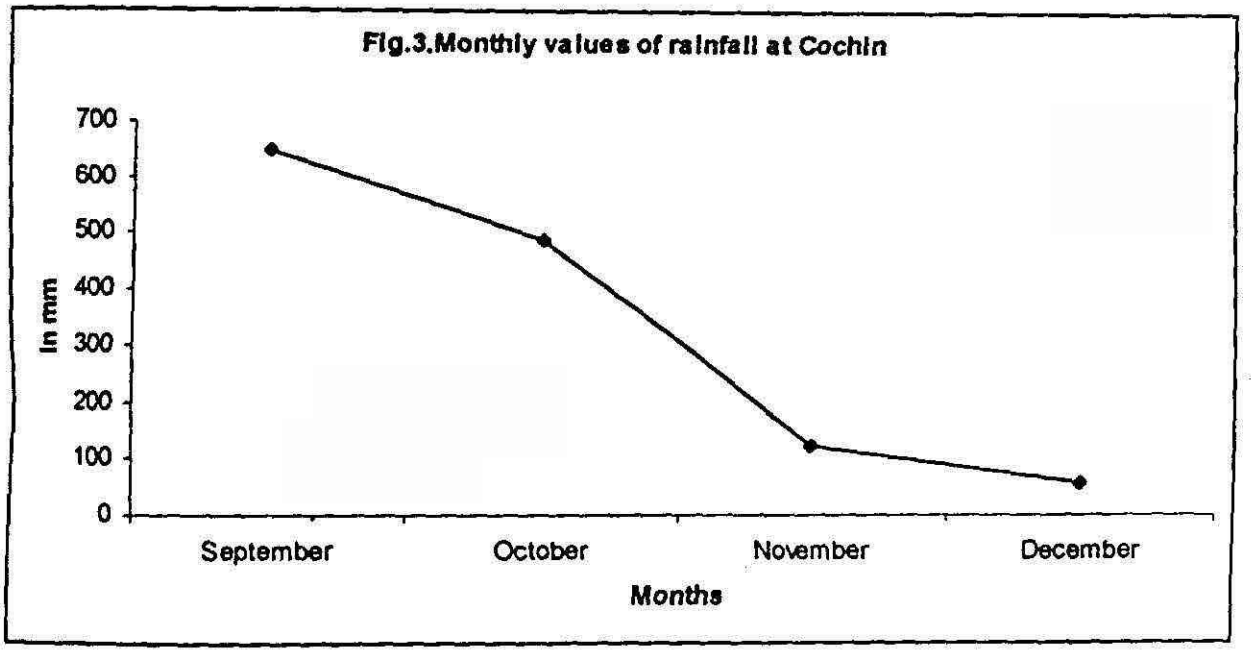
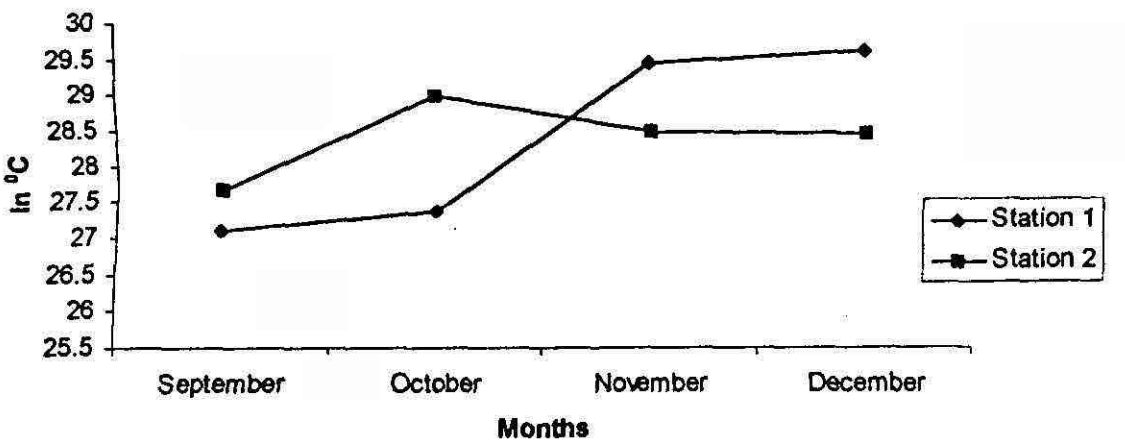


Fig.3.Monthly values of rainfall at Cochin
700
600
500
400
300
200
100
0
In mm
September
October
November
December
Months

Fig. 4 Monthly mean value of surface water temperature at stations 1&2



29.0, 28.5 and 29.8°C respectively. The increasing trends in water temperature for station-1 and 2 from September to December are illustrated in Fig.4. In Cochin backwater (control station), the monthly average surface values for September - December were 29.3, 29.5, 29.8 and 29.2°C respectively (Table-2).

Table-2. Monthly Average Values of Environmental Parameters in the Cochin Backwater

Parameters	September	October	November	December
Rainfall (mm)	648	486	121	55.8
Water temperature(°C)	29.3	29.5	29.8	29.2
Salinity (ppt)	1.36	5.05	6.58	15.75
Dissolved Oxygen(ml/l)	3.29	3.73	3.61	3.20
Phosphate (µg at/l)	3.82	4.20	0.53	3.06
Nitrite (µg at/l)	6.25	0.67	0.26	0.93
Nitrate (µg at/l)	15.15	3.89	0.10	0.10

1.3. Salinity

At Station-1, salinity values of surface water ranged from 0.17 - 0.25 ppt in September, 0.17 - 1.9 ppt in October, 1.12 - 13.85 ppt in November and 8.89 - 18.34 ppt in December with the mean values of 0.22, 0.80, 6.98 and 12.27 ppt for September, October, November and December respectively. At station 2, salinity values ranged from 0.25 - 0.42 ppt in September, 0.34 - 1.97 ppt in October, 1.59 -15.35 ppt in November and 9.64 - 20.68 ppt in December, when the mean values of the four months were 0.36, 1.29, 7.85 and 15.81 ppt respectively. The increasing trends in salinity values for station-1 and 2 are shown in Fig.5. In Cochin backwater monthly average salinity values for September - December were 1.36, 5.05, 6.58 and 15.75 ppt respectively (Table-2).

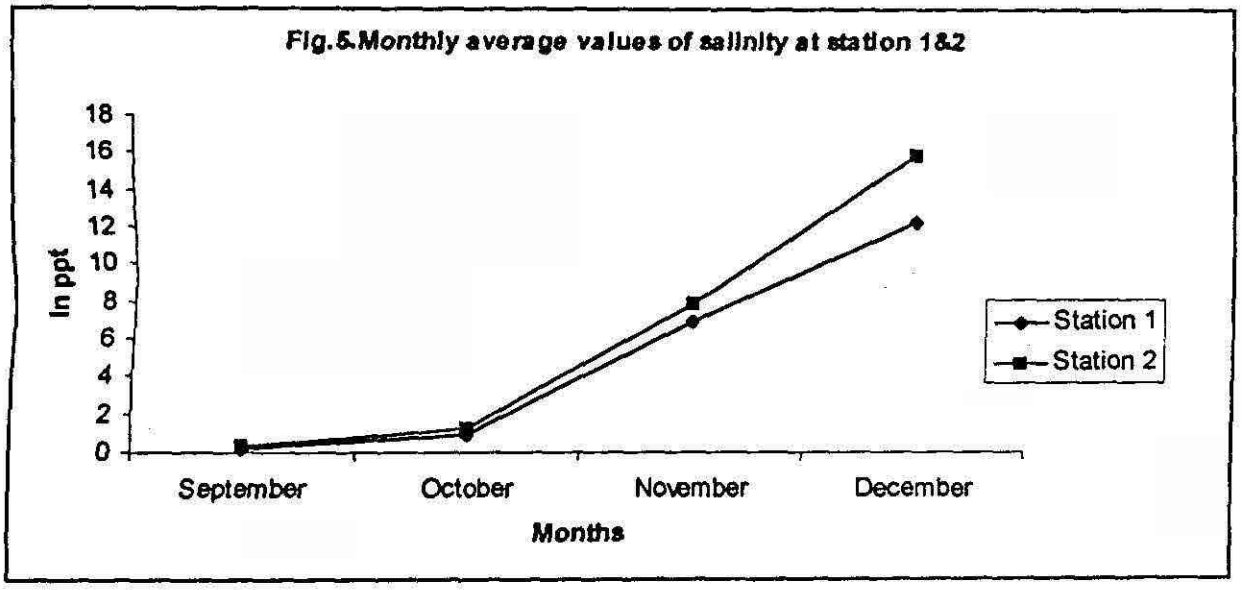


Fig.5.Monthly average values of salinity at station 1&2
18
16
14
12
10
8
6
4
2
0
In ppt
September
October
November
December
Months
Station 1
Station 2

Table-3. Monthly Average Values of Environmental Parameters in Mangalvanam (Average of Stations-1 & 2)

Parameters	September	October	November	December
Water Temperature (°C)	27.4	28.2	29.1	29.9
Salinity (ppt)	0.29	1.09	7.4	14.0
Dissolved Oxygen(ml/l)	1.91	1.91	1.77	1.79
Phosphate (µg at/l)	8.8	10.7	13.28	17.10
Nitrite (µg at/l)	3.69	1.96	5.49	6.35
Nitrate (µg at/l)	16.81	11.37	14.73	5.73

1.4 . Dissolved Oxygen

During the period of investigation, dissolved Oxygen level of the surface water varied from 0.50 - 4.05 ml/l. Higher values were observed during high tide flow. Among the two stations, higher values of dissolved Oxygen were generally noticed at station-2. At station-1, surface waters had dissolved Oxygen concentration ranging from 0.87 - 2.58 ml/l during September, 0.59 -3.67 ml/l during October, 0.83 - 3.94 ml/l during November and 0.56 - 3.05 ml/l during December with the mean values of 1.45, 1.82, 1.55 and 1.67 ml/l respectively. At station-2, dissolved Oxygen concentration varied from 1.02 - 3.64 , 0.78 - 3.84, 1.13 - 4.04, and 0.50 - 3.13 ml/l during September, October, November and December and their mean values were 2.36, 2,00, 1.99 and 1.91 ml/l respectively. At both stations, dissolved Oxygen values showed decreasing trend from September to December (Fig.6).In Cochin backwater, the average values for the four months were 3.29, 3.73, 3.61 and 3.20 ml/l respectively (Table-2).

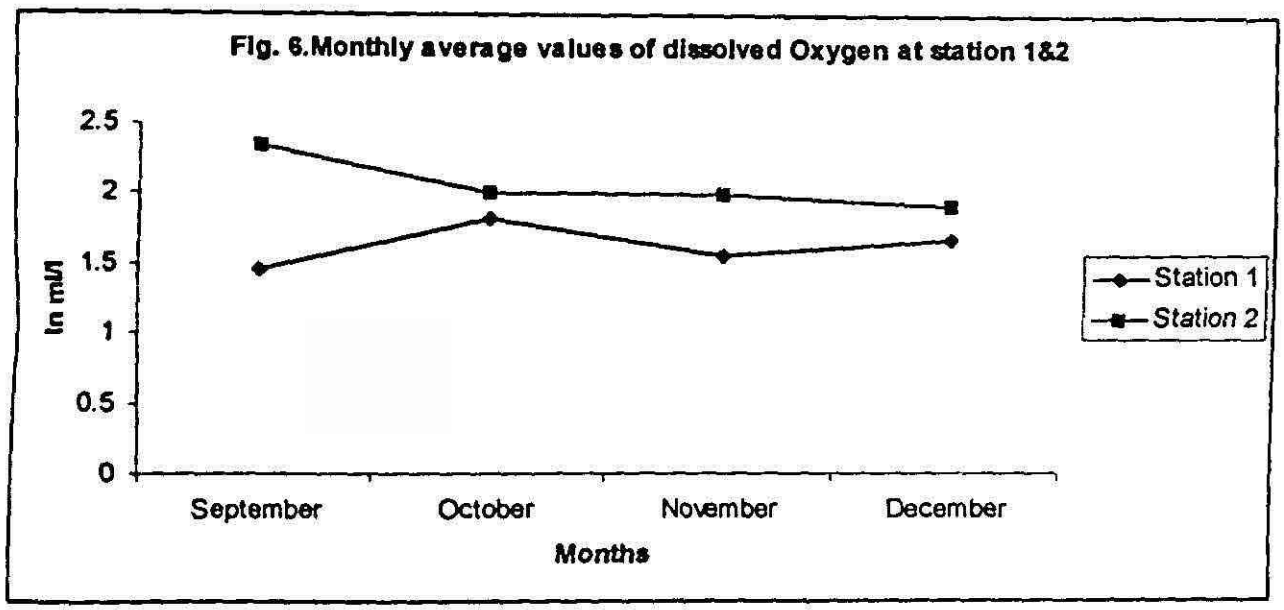


Fig. 6.Monthly average values of dissolved Oxygen at station 1&2
2.5
2
1.5
1
0.5
0
In ml/l
September
October
November
December
Months
Station 1
Station 2

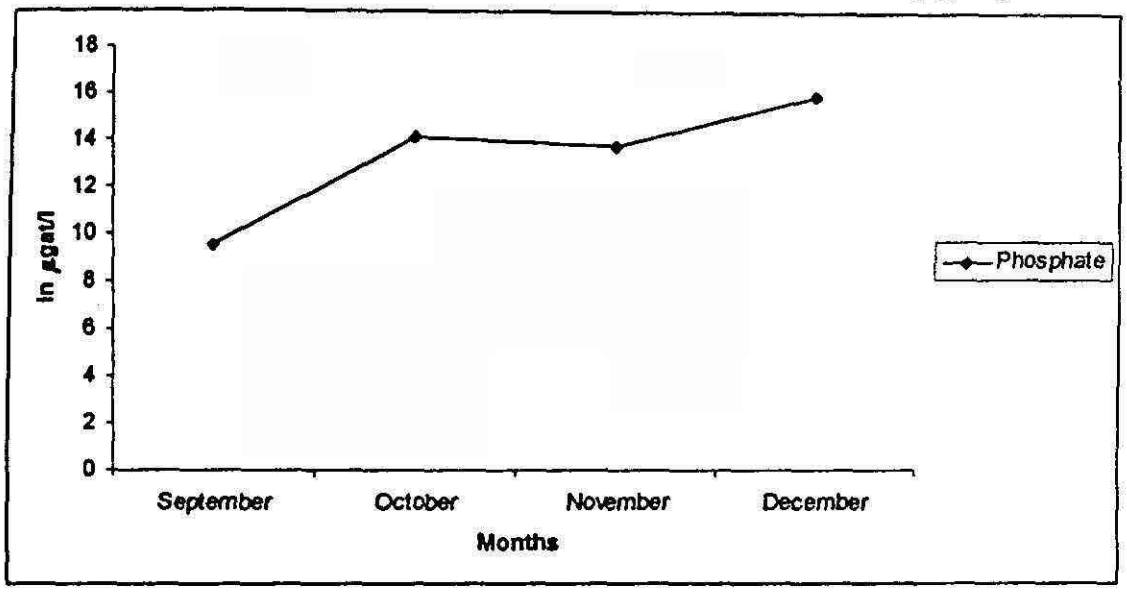
Table-4. Comparison of Environmental Parameters in Mangalvanam and Cochin backwaters

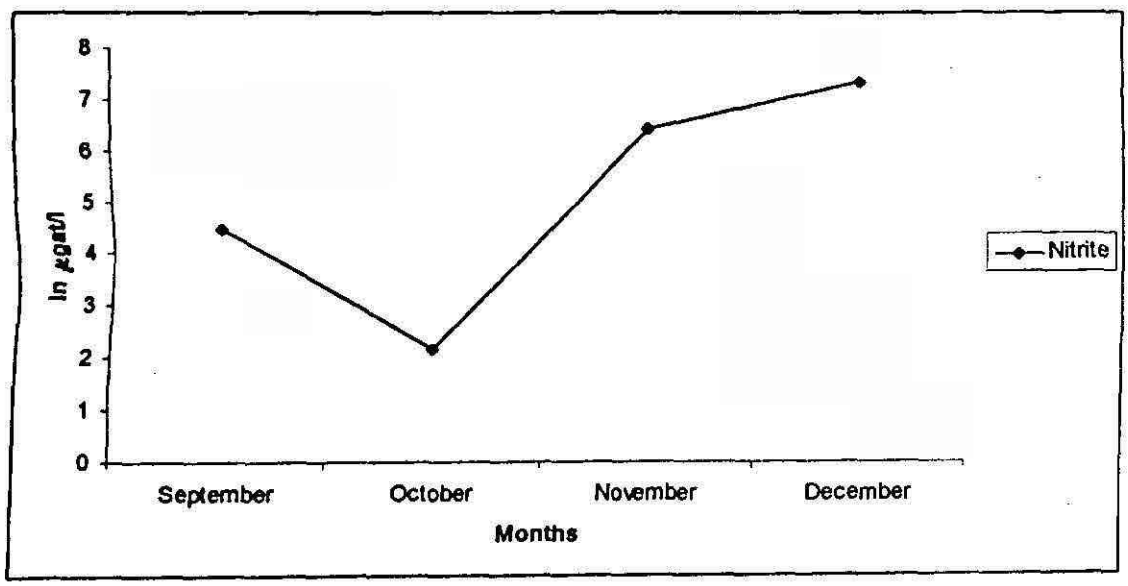
Parameters	September		October		November		December	
	Mangal	B.W	Mangal	B.W	Mangal	B.W	Mangal	B.W.
Water temp.(°C)	27.4	29.3	28.2	29.8	29.1	29.5	29.9	29.2
Surface Salinity(ppt)	0.29	1.36	1.09	5.05	7.40	6.58	14.00	15.75
Dissolved Oxygen(ml/l)	1.91	3.29	1.91	3.73	1.77	3.61	1.79	3.20
Phosphate (µg at/l)	8.80	3.82	10.70	4.20	13.28	0.53	17.10	3.06
Nitrite(µg at/l)	3.69	6.25	1.96	0.67	5.49	0.26	6.35	0.93
Nitrate(µg at/l)	16.81	15.15	11.37	3.89	14.73	0.10	5.73	0.10

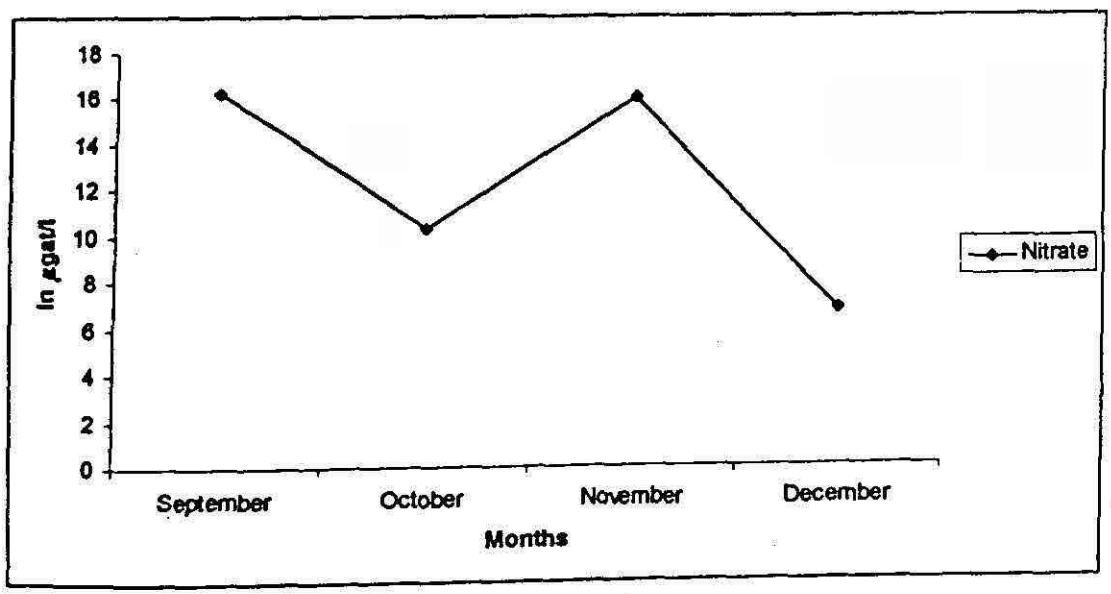
1.5 Reactive Phosphate (PO_4-P)

In Mangalvanam waters, phosphate-P values ranged from 2.12 - 23.83 µg at/l during September- December 1998. Phosphate concentration was found to be changing from hour to hour in both the stations (Table 4). At station-1, phosphate values ranged from 6.16 - 13.68 µg al/l in September, 3.53 - 18.53 µg at/l in October, 2.48 - 23.11 µg at/l in November and 2.12 - 22.20 µg at/l in December with the mean values of 9.69, 14.14, 13.79 and 15.89 µg at/l respectively. The increasing trend of phosphate concentrations observed during September-December is shown in Fig. 7. At station-2, phosphate concentration varied from 6.02 -12.71µg at/l in September,4.44 - 12.46 µg at/l in October, 2.24 - 22.82 µg at/l in November and 9.26 - 23.83 µg at/l in December, while the mean values recorded were 7.95, 7.25, 12.76 and 18.30 µg at/l during September-December respectively. The increasing trend in the concentration of phosphates observed at station-2 during September - December is shown in Fig. 8. In Cochin

Fig 7. Monthly mean values of Phosphate, Nitrite and Nitrate (µgat/l) at stn.1







backwater, the monthly average values obtained during September - December were 3.82, 4.20, 0.53 and 3.06 µg at/l respectively (Table-2).

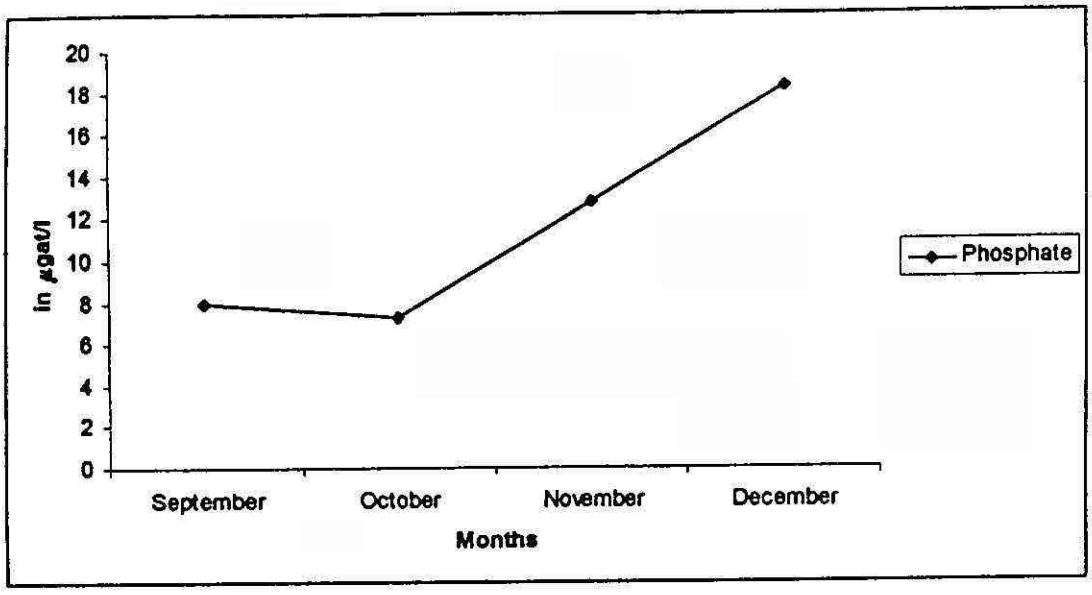
Table-5.Mean Values of Environmental Parameters in the Mangalvanam water body during High and Low tides

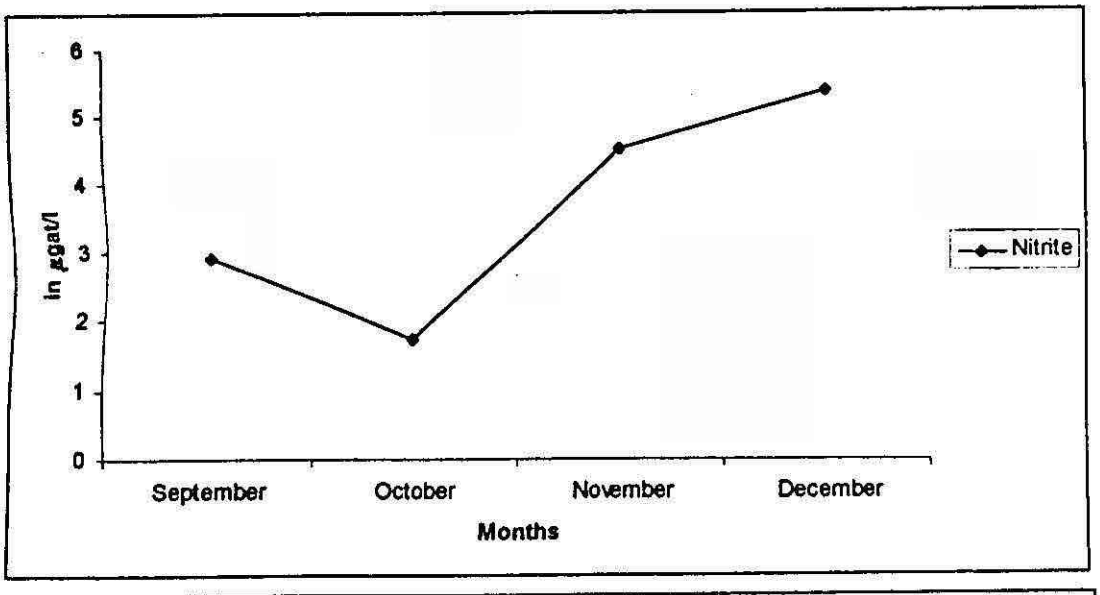
Parameters	October		November		December	
	H	L	H	L	H	L
Water temp.(°C)	29.0	28.5	29.5	28.6	29.7	28.0
Salinity (ppt)	1.65	1.50	11.45	7.6	18.56	15.33
Dissolved Oxygen (ml/l)	1.77	0.84	3.25	1.10	2.78	1.32
Phosphate(µg at/l)	4.37	9.87	3.60	19.97	9.8	22.5
Nitrite (µ g at/l)	12.23	13.34	4.75	6.7	1.65	2.93
Nitrate((µ g at/l)	1.53	1.83	4.4	12.93	2.05	2.80

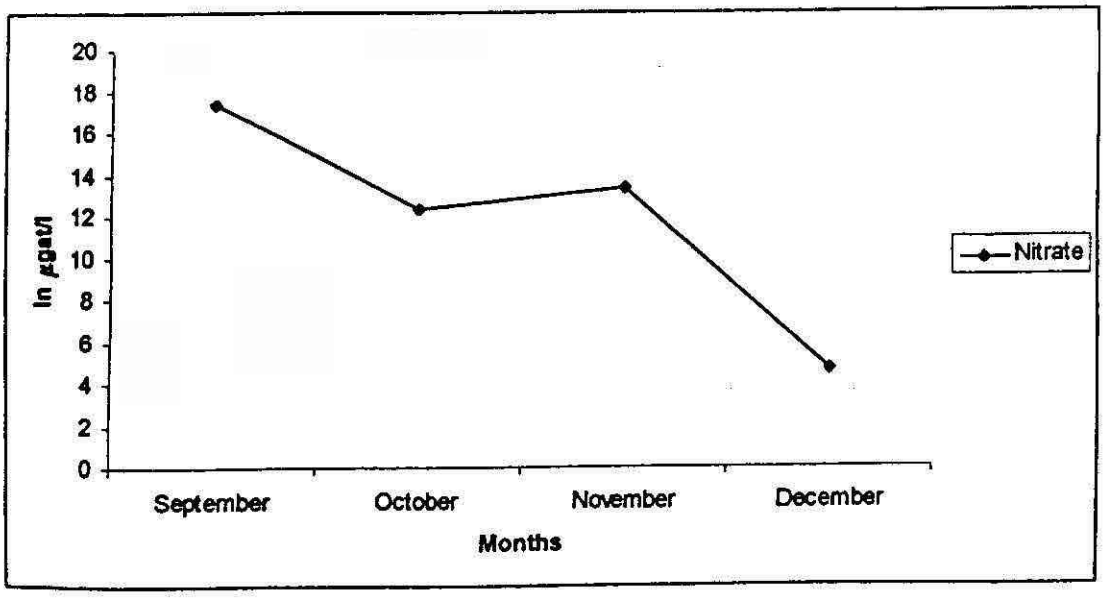
1.6 Nitrite (No_2 - N)

In the surface waters, nitrite - N values ranged from 0.89 - 19.18 µg at/l during September-December at Mangalvanam. At station-1, nitrite-N values ranged from 1.39 - 9.0 µg at/l in September, 1.47 - 3.43 µg at/l in October 1.41 - 10.02 µg at/l in November and 1.13 - 18.47 µg at/l in December with their mean values recorded as 4.48, 2.18, 6.44 and 7.33 µg at/l respectively. The increasing trend during September - December is shown in Fig. 7. At station-2, No_2-N values ranged from 1.08 - 4.09 µg at/l in September, 1.13 - 2.12 µg at/l during October, 1.03 - 7.89 µg at/l in November and 0.89 - 19.18 µg at/l in December with their mean values recorded as 2.90, 1.74, 4.53 and 5.37 µg at/l respectively. The increase in the trend of phosphate concentration is shown in Fig.8. In Cochin backwater, the monthly averages obtained for nitrites were 6.25, 0.67,0.26 and 0.93 µg at/l in September, October, November and December respectively (Table-2).

Fig. 8 Monthly mean values of Phosphate, Nitrite, Nitrate (µgat/l)at stn.2







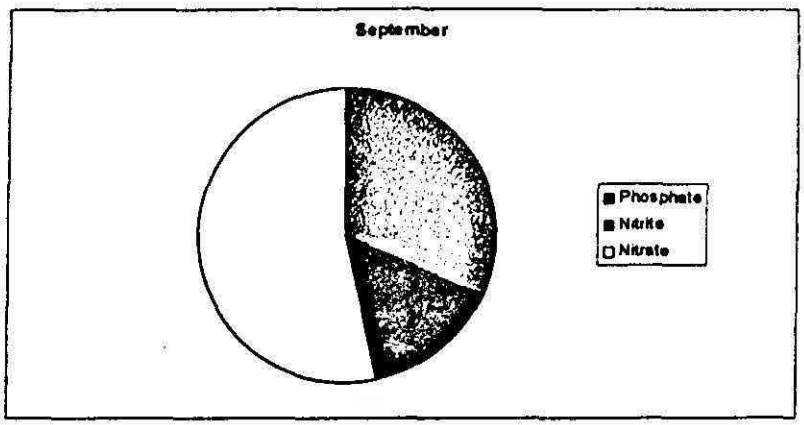
1.7 Nitrate (No_3-N)

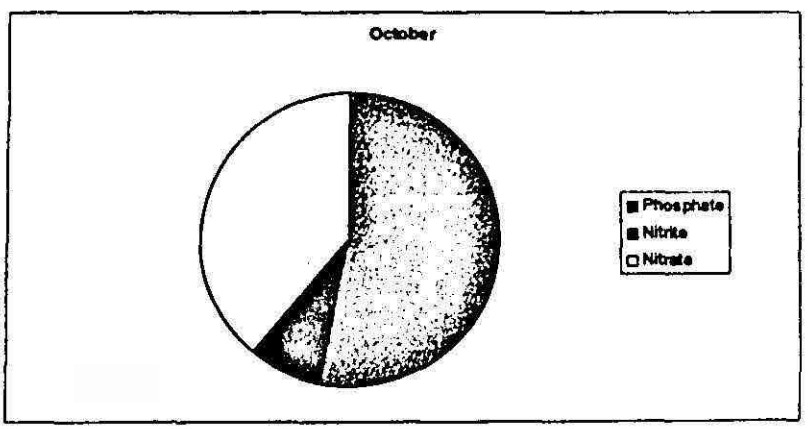
The nitrate values of Mangalvanam waters showed wide fluctuation from 0.65 - 34.95 µg at/l during September - December with the influence of tides. At station -1, nitrate concentration fluctuated from 8.37 - 22.64 µg at/l during September, 8.67 - 11.4 µg at/l during October, 4.7 - 32.36 µg at/l during November and 1.29 - 19.93 µg at/l during December with their mean values recorded 16.26, 10.35, 16.07 and 6.79 µg at/l respectively showing decline in December (Fig. 7). At station- 2, NO_3-N values showed a range of 10.93 - 28.16 µg at/l in September, 10.93 - 28.16 µg at/l in October, 3.34 - 34.95 µg at/l in November and 0.55 - 12.24 µg at/l in December with their monthly average values of 17.35, 12.38, 13.38 and 4.67 µg at/l respectively (Fig. 8). In Cochin backwater, the average values obtained for nitrates were 15.15, 3.89. 0.10 and 0.10 µg at/l during September, October, November and December 1998 respectively (Table- 2).

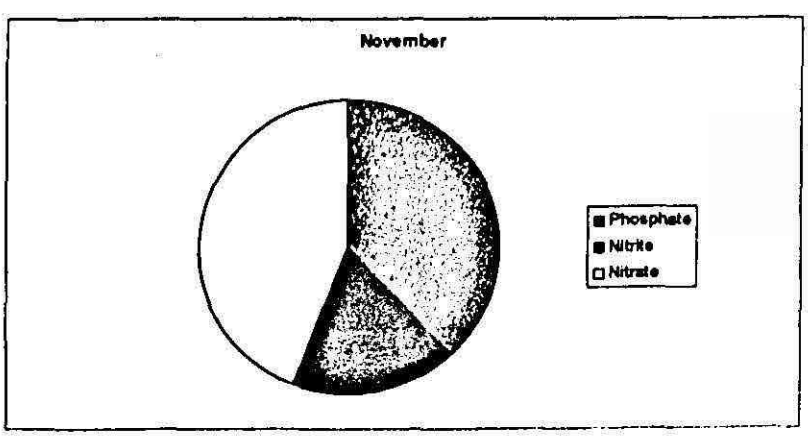
1.8 Diurnal studies on hydrographic parameters

During high tide surface water temperature varied from 29.0 - 29.5^{0}C in October, 29.0 - 30.0^{0}C in November and 27.0 - 31.0^{0}C in December while the low tide values were 29.0 - 29.5^{0}C, 28.0 - 29.5^{0}C and 27.5 - 31.0^{0}C respectively. Surface salinity values at high tide ranged from 1.5 - 2.0 ppt in October, 11.2 - 11.7 ppt in November and 17.5 - 19.5 ppt in December while the low tide values ranged from 1.3 - 1.7 ppt in October, 6.3 - 9.0 ppt in November and 13.8 - 17.7 ppt, in December. Dissolved Oxygen values at high tide ranged from 1.04 - 2.98 ml/l in October, 2.70 - 3.80 ml/l in November and 2.76 - 2.80 ml/l in December while the low tide values ranged from 1.04 - 2.48 ml/l in October, 0.90 - 1.20 ml/l in November and 0.54 - 2.69 ml/l in December. The mean values of surface water temperature, salinity and dissolved Oxygen obtained from the two stations at high and low tide periods are given in Table - 5.

Fig.9 Relative abundance of plant nutrients at station 1 during September -December 1998







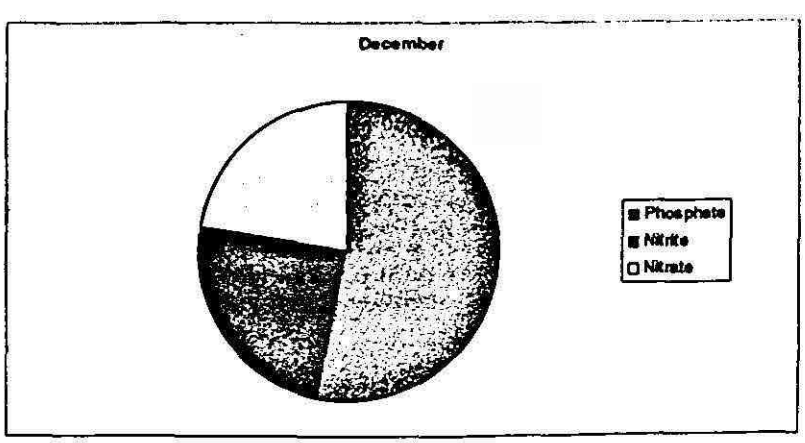
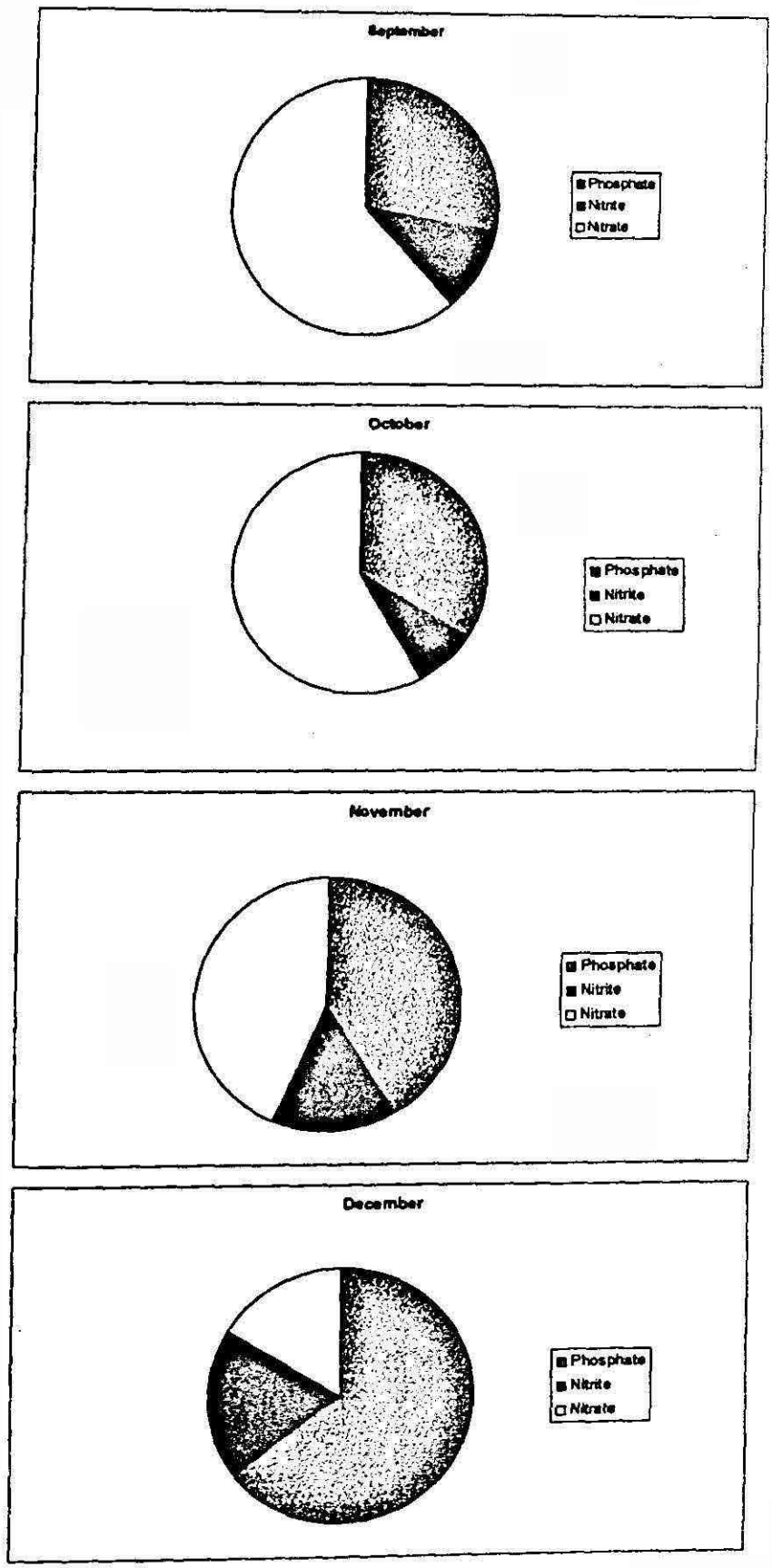


Fig.10 Relative abundance of plant nutrients at station 2 during September -December 1998



Phosphate - P values at high tide varied from 4.0 - 4.7 µg at/l in October, 2.4 - 4.8 µg at/l in November and 7.2 - 12.4 µg at/l in December while the low tide values were 7.0 - 12.5, 14.8 - 22.3 and 21.3 - 23.8 µg at/l in October, November and December respectively. Nitrite-N values at high tide varied from 1.3 - 1.7 µg at/l in October, 1.8 - 7.7 µg at/l in November and 7.2 - 12.4 µg at/l in December while low tide values ranged from 1.5 - 2.0 , 4.2 - 8.0 and 1.1 - 4.5 µg at/l during October, November and December respectively. Nitrate-N at high tide varied from 9.7 - 16.4 µg at/l in October, 4.3 - 4.5 µg at/l in November and 1.0 - 3.1 µg at/l in December while the low tide values ranged from 10.6 - 15.5, 11.9 - 13.8 and 0.8 - 4.4 µg at/l during October, November and December respectively. The mean values of phosphate-P, Nitrite-N and Nitrate-N obtained from the two stations at high and low tide periods are given in Table- 5.

1.9 Consolidated environmental data

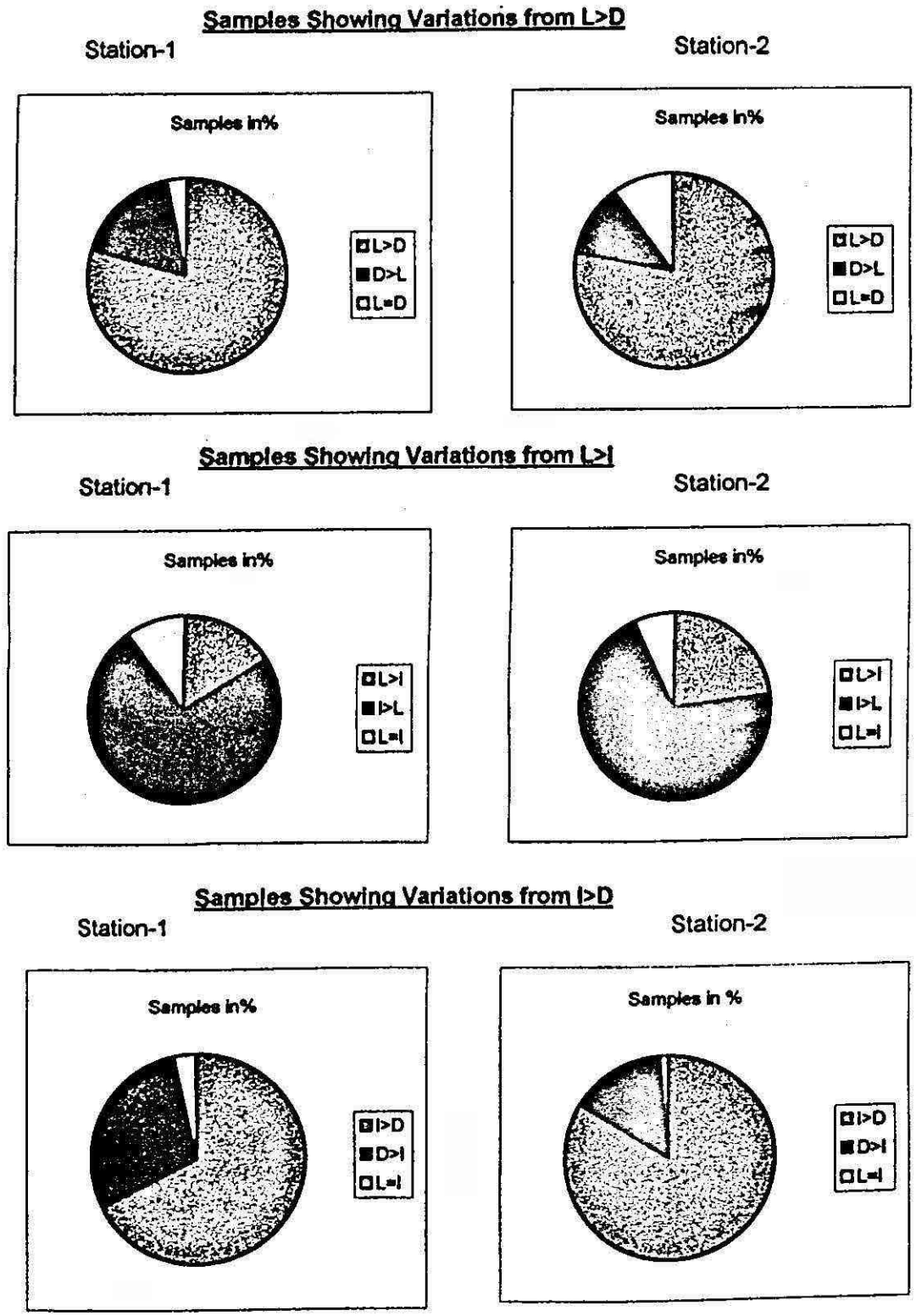
The consolidated monthly average values of stations 1 and 2 (Pooled together) with reference to surface water temperature, salinity, dissolved Oxygen and plant nutrients are given in Table- 3 and comparison of these data with those of the Cochin backwater pertaining to September - December 1998 is shown in Table- 4. The relative abundance of plant nutrients at station- 1 and station2 for the four months is illustrated in Figs. 9 & 10 respectively.

2. Photosynthesis

Analysis of water samples showed that *Coscinodiscus, Ceratium* and *Navicula* were common in September- October months while species of *Biddulphia, Chaetoceros, Fragilaria, Nitzschia* and *Pleurosigma* were common during November and December. In general their abundance was noticed in the high tide water in all the four months.

During September (out of 17 samples at each station), 76.5% at station -1 and 64.7% at station- 2 showed photosynthetic production of oxygen. In October, 64% of samples at both stations (out of 25 samples each) showed on photosynthetic production of Oxygen. During November, (out of 26 samples at each station), 80% at station-1 and 88.5% at station-2 showed

Fig. 11. Samples Showing Variation of I,D, & L Values From The Expected Ratio



gross photosynthetic production of Oxygen. In December, 88% of samples in both stations (out of 25 samples each) showed gross photosynthetic production of oxygen in the incubation experiments. The irregularities observed between L and D values, L and I values and I and D values in the incubation experiments due to interference of bacterial action during September - December period are depicted in Fig.11.

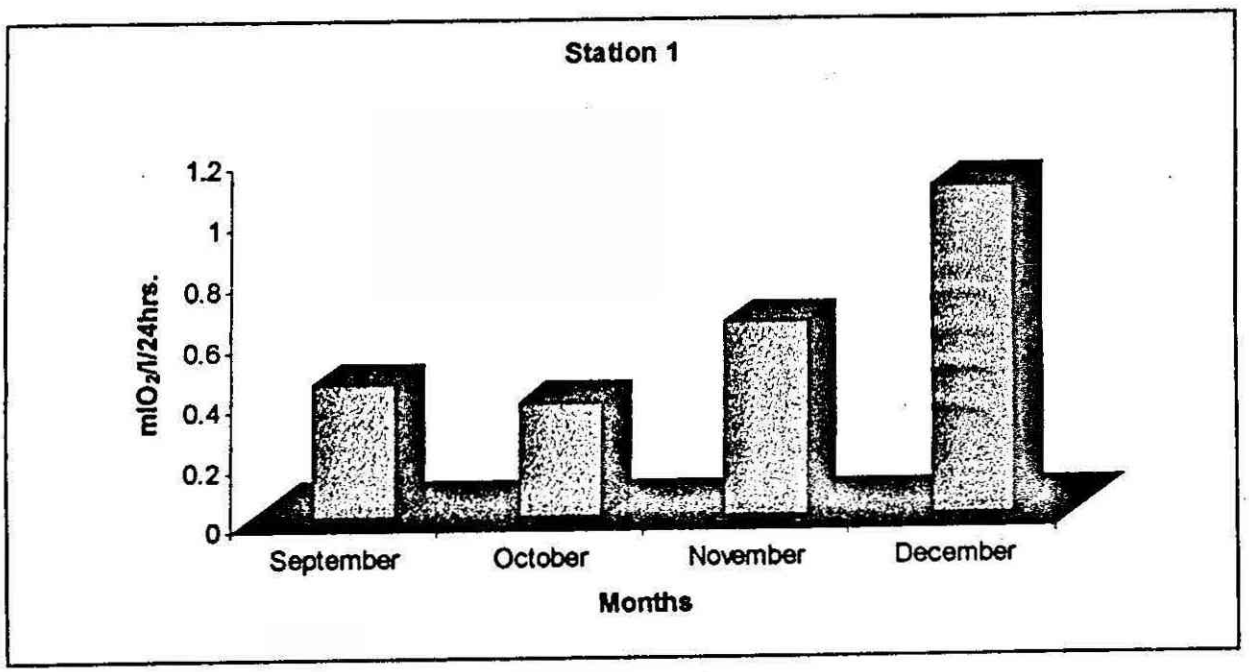
2.1 Gross photosynthetic production of Oxygen

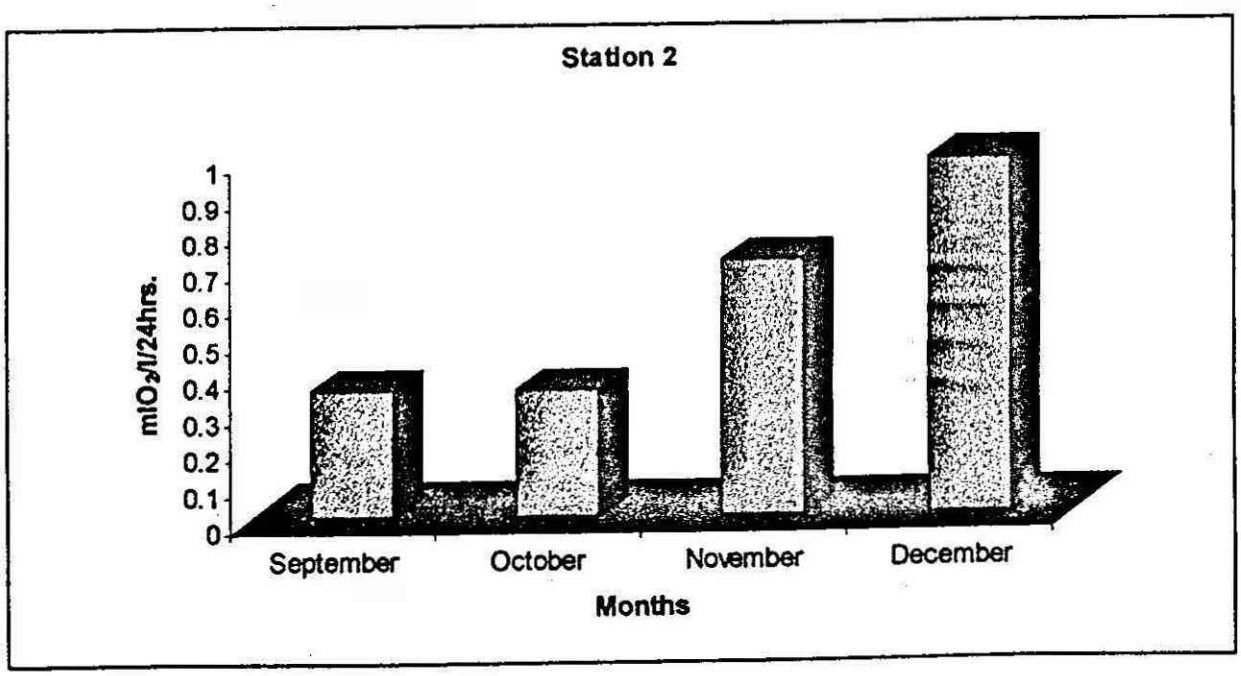
At station-1 the higher values of gross photosynthetic production of Oxygen obtained during october November and December were 0.131, 1.422, 1.331 and 4.083 ml O_2/l/d respectively. The mean values obtained in these months were 0.441, 0.379, 0.641 and 1.082 ml/l/d respectively. At station 2, the highest values of the gross photosynthetic production of Oxygen during the four months were 1.175, 1.480, 2.129 and 3.063 ml/l/d respectively and the monthly mean values obtained were 0.349, 0.350, 0.706 and 0.984 ml/l respectively (Table-6) The increasing trends observed in the monthly average values of gross photosynthetic production of Oxygen at stations 1 and 2 are shown in Fig. 12.

Table- 6. Monthly Average Values of Photosynthetic production of Oxygen and Micro-algal Respiration at Station- 1

Parameters	September	October	November	December
Gross photosysthetic production of Oxygen (ml/l/24hrs)	0.441	0.379	0.641	1.082
Micro-algal respiration (mlO_2/l/12 hrs.)	0.088	0.076	0.128	0.216
Micro-algal respiration(ml O_2/l/24 hrs.)	0.176	0.152	0.256	0.432
Net photosynthetic Production of oxygen (ml/l/24 hrs.)	0.264	0.228	0.385	0.649

Fig.12.Monthly average gross photosynthetic production of O_2 in 24 hrs. during September -December 1998





2.2 Algal respiration

At station-1, the maximum values obtained for algal respiration for the different months were 0.522, 0.569, 0.532 and 1.633 ml/l/24 hrs. with their mean values 0.176, 0.152, 0.256 and 0.432 ml/l/24 hrs. respectively. At station-2, the maximum values obtained were 0.420 ml/l/24 hrs. in September 0.592 ml/l/24 hrs., in October 0.852 ml/l/24 hrs in November and 1.441 ml/l/24 hrs in December with their mean values recorded as 0.140, 0.140, 0.282 and 0.394 ml/l/24 hrs respectively (Table-7).

Table-7. Monthly Average Values of Photosynthetic Production of Oxygen and Micro-algal Respiration at Station-2

Parameters	September	October	November	December
Gross photosynthetic Production of Oxygen (ml/l/24 hrs.)	0.349	0.350	0.706	0.984
Micro-algal respiration (mlO_2/l/12 hrs.	0.070	0.070	0.141	0.197
Micro-algal respiration (mlO_2/l/24 hrs)	0.140	0.140	0.282	0.394
Net photosynthetic production of Oxygen (ml/l/24 hrs)	0.209	0.210	0.424	0.590

2.3 Net photosynthetic production of Oxygen

The monthly mean values of Oxygen (per 24 hrs) were 0.264, 0.228, 0.385 and 0.649 ml/l/d at station-1 for September-December 1998 (Table-6) while those values at Station-2, were 0.209, 0.210, 0.424 and 0.590 ml/l/24 hrs. (Table-7).

Table-8. Monthly Average Values of Bacterial Production of Oxygen during day and night at Station-1

Parameters	September	October	November	December
Bacterial production of O_2 during day (ml/l/12hrs)	0.0016	0.021	0.008	0.004
Bacterial production of O_2 during night (ml O_2/l/12 hrs)	0.0016	0.089	0.008	0.004
Bacterial production of O_2 during day and night (ml O_2/l/24 hrs)	0.0032	0.110	0.016	0.008

3. Bacterial production of Oxygen

At station-1, the maximum values of production obtained were 0.0568, 1.167, 0.402 and 0.422 ml/l/24 hrs. respectively during September, October, November and December. The monthly average values obtained were 0.003, 0.110, 0.016 and 0.008 ml/l/24 hrs. during September - December respectively (Table-8). At station2, bacterial production was found only in September - which ranged from 0- 0.839 ml/l/24 hrs. with a mean value of 0.090 ml/l/24 hrs. (Table-9).

Table-9. Monthly Average Value of Bacterial production of Oxygen during day and night at Station 2

Parameters	Septermber	October	November	December
Bacterial production during day (ml/l/12 hrs)	0.045	-	-	-
Bacterial production during night(ml/l/12hrs)	0.045	-	-	-
Bacterial production during day & night (ml O_2/l/24 hrs.)	0.090	-	-	-

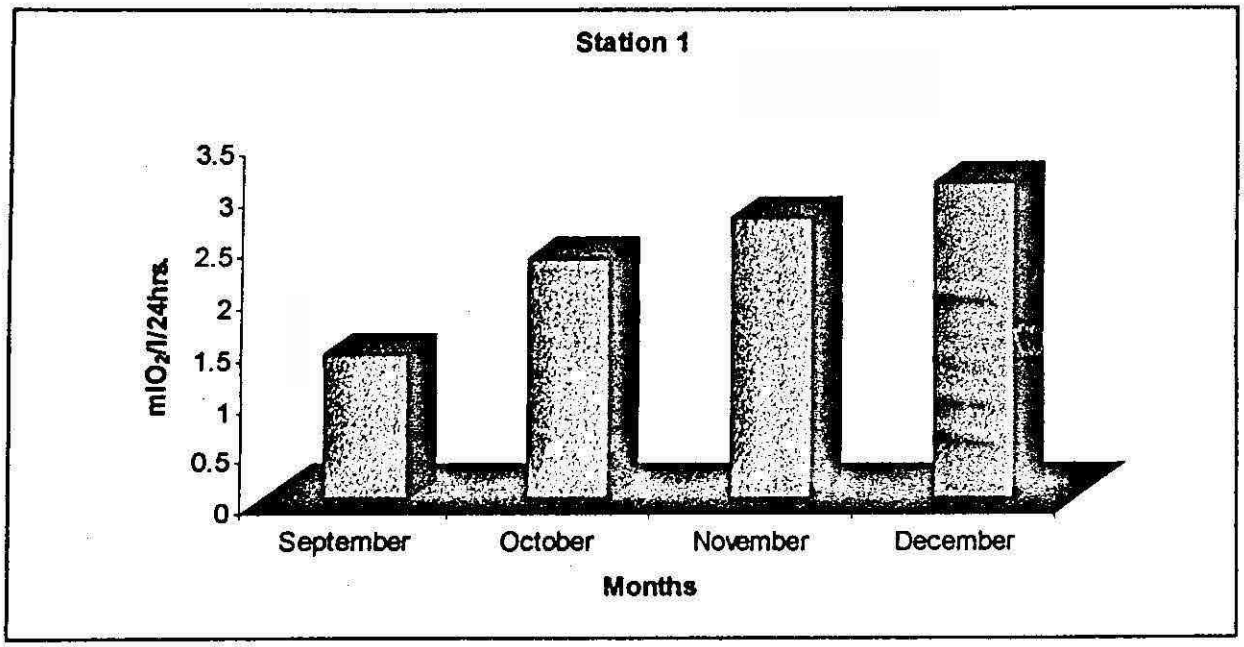
4. Bacterial consumption of Oxygen

At station-1, the highest values of bacterial consumption of Oxygen for the four months were 2.872 ml/ l/24 hrs in September, 7.217 ml/l/24 hrs. in October, 8.959 ml/l/24 hrs. in November and 5.669 ml/l/24 hrs in December with their mean values estimated as 1.417, 2.345,2.735 and 3.075 ml/l/24 hrs. respectively (Table-10). At station 2, the highest values of bacterial consumption of oxygen for September - December months were 6.528, 9.307, 4.734 and 6.259 ml/l/24 hrs. respectively (Table-11), while the mean values were 1.873, 2.201, 1.778 and 2.647 ml/l/24 hrs. respectively. The trends in the bacterial consumption rates for station 1 and 2 are illustrated in Fig. 13.

Table-10. Monthly Average Values of Bacterial consumption of Oxygen during day and night at Station-1

Parameters	September	October	November	December
Bacterial consumption of Oxygen during day (ml/l/12 hrs)	0.767	1.215	1.423	1.578
Bacterial consumption of Oxygen during night (ml/l/12 hrs)	0.703	1.130	1.312	1.497
Bacterial consumption of Oxygen during day & night(ml/l/24 hrs.)	1.417	2.345	2.735	3.075

Fig.13.Monthly average Bacterial consumption of O_2 in 24 hrs. during September -December 1998



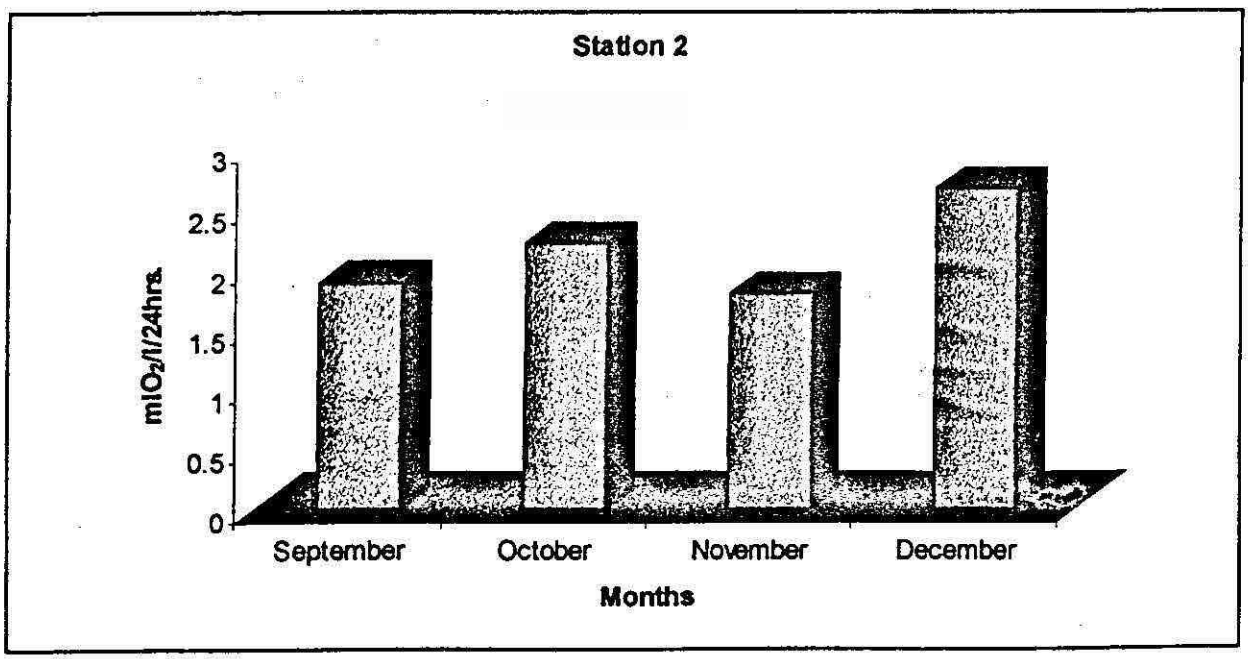


Table-11. Monthly Average Values of Bacterial consumption of Oxygen during day and night at Station-2

Parameters	September	October	November	December
Bacterial consumption of Oxygen during day (Ml/l/12 hrs)	0.951	1.128	0.899	1.328
Bacterial consumption of Oxygen during night (ml/l/12 hrs)	0.920	1.074	0.878	1.319
Bacterial consumption of Oxygen during day & night (ml/l/24 hrs)	1.873	2.201	1.778	2.647

5. Net gain/loss of Oxygen per day (By photosynthesis and bacterial action)

At station-1, maximum values of net gain of oxygen obtained were 0.559, 1.166, 0.659 and 0.449 ml O_2/l/24 hrs. during September, October, November and December while the maximum values of net loss of Oxygen were 2.872, 7.622, 7.774 and 4.642 ml O_2/l/24 hrs. respectively. The mean values of overall net loss of Oxygen were 1.203, 2.035, 2.335 and 2.418 ml O_2/l/24 hrs. respectively during September - December. At station-2, maximum net gain obtained during September - December period were 0.839, 0.247, 0.449 and 0.790 ml O_2/l/24 hrs while maximum rate of net losses were 6.528, 9.048, 3.557 and 5.809 ml/l/24 hrs. respectively. The monthly mean values of net loss of oxygen were 1.573, 1.991, 1.354 and 2.057 ml/l/24 hrs. during September - December months respectively. The increasing trends in the values towards December at stations-1 and 2 are given in Table-12 & 13 respectively.

Table 12. Monthly Average Values of Overall net Loss of Oxygen at Station 1

Parameters	September	October	November	December
Bacterial production of Oxygen(ml/l/24 hrs.)	0.003	0.109	0.017	0.007
Bacterial consumption of Oxygen (ml/l/24 hrs)	1.470	2.34	2.736	3.075
Net bacterial production/ consumption of Oxygen(ml/l/24 hrs) (+ve production ; -ve consumption)	-1.467	-2.263	-2.720	-3.077
Net photosynthetic production of Oxygen (ml/l/24 hrs)	0.264	0.228	0.385	0.649
Overall net loss of Oxygen by photosynthetic and bacterial action (ml/l/24 hrs)	1.203	2.035	2.335	2.418

Table 13. Monthly Average Values of net Loss of Oxygen at Station 2

Parameters	September	October	November	December
Bacterial production of Oxygen (ml/l/24 hrs)	0.091	-	-	-
Bacterial consumption of Oxygen (ml/l/24 hrs)	1.8731	2.2013	1.7776	2.6472
Net bacterial production /consumption of Oxygen (ml/l/24 hrs)	-1.782	-2.201	-1.778	-2.647
Net photosynthetic production of Oxygen (ml/l/24 hrs.)	0.209	0.210	0.424	0.590
Overall net loss of Oxygen by phytplanktonic and bacterial action (ml/l/24 hrs.)	1.573	1.991	1.354	2.0571

6. Diurnal studies on production and consumption of Oxygen

During high tide the highest values of gross photosynthetic production obtained were 1.480, 1.065 and 3.063 ml/l/d in October, November and December and those values at low tide were 0.987, 1.065 and 0.721 ml/l/d respectively. The mean values obtained at high and low tides are presented in table-14. The maximum values of bacterial consumption of Oxygen obtained during high tide were 2.60, 1.86, 3.41 ml/l/24 hrs. during October, November and December respectively with maximum values 2.65, 2.80, 3.28 ml/l/24 hrs. during low tide respectively. The mean values obtained during high and low tides are presented in Table-14.

The consolidated monthly average values from stations 1 and 2 (when pooled together irrespective of tides) for photosynthetic and bacterial production/consumption of oxygen during September - December 1998 are given in Table-15. The increasing trend in the bacterial consumption of Oxygen and decreasing order of dissolved O_2 values (ml/l) are illustrated in Fig. 14. The interrelationship among gross photosynthetic production of Oxygen and plant nutrients for September-December is shown in Fig.15 and among bacterial consumption of Oxygen, rainfall and plant nutrients for the four months are shown in Fig. 16.

Table-14. Influence of Tides on the Production and Consumption of Oxygen during October-December 1998 (Based on diurnal observation.)

Parameters	October		November		December	
	H	L	H	L	H	L
Gross photosynthetic production of oxygen (ml/l/d)	0.530	0.412	0.733	0.441	2.27	0.441
Algal respiration (mlO_2/l/d)	0.212	0.164	0.293	0.176	0.908	0.176
Bacterial consumption of oxygen(ml/l/24 hrs)	1.1856	1.9800	1.4040	1.6300	2.2700	2.8200

Fig. 14. Histogram showing Inter-relationship among Bacterial consumption of Oxygen, Bacterial production of Oxygen, Net primary production of Oxygen and Dissolved Oxygen in Mangalvanam waters.

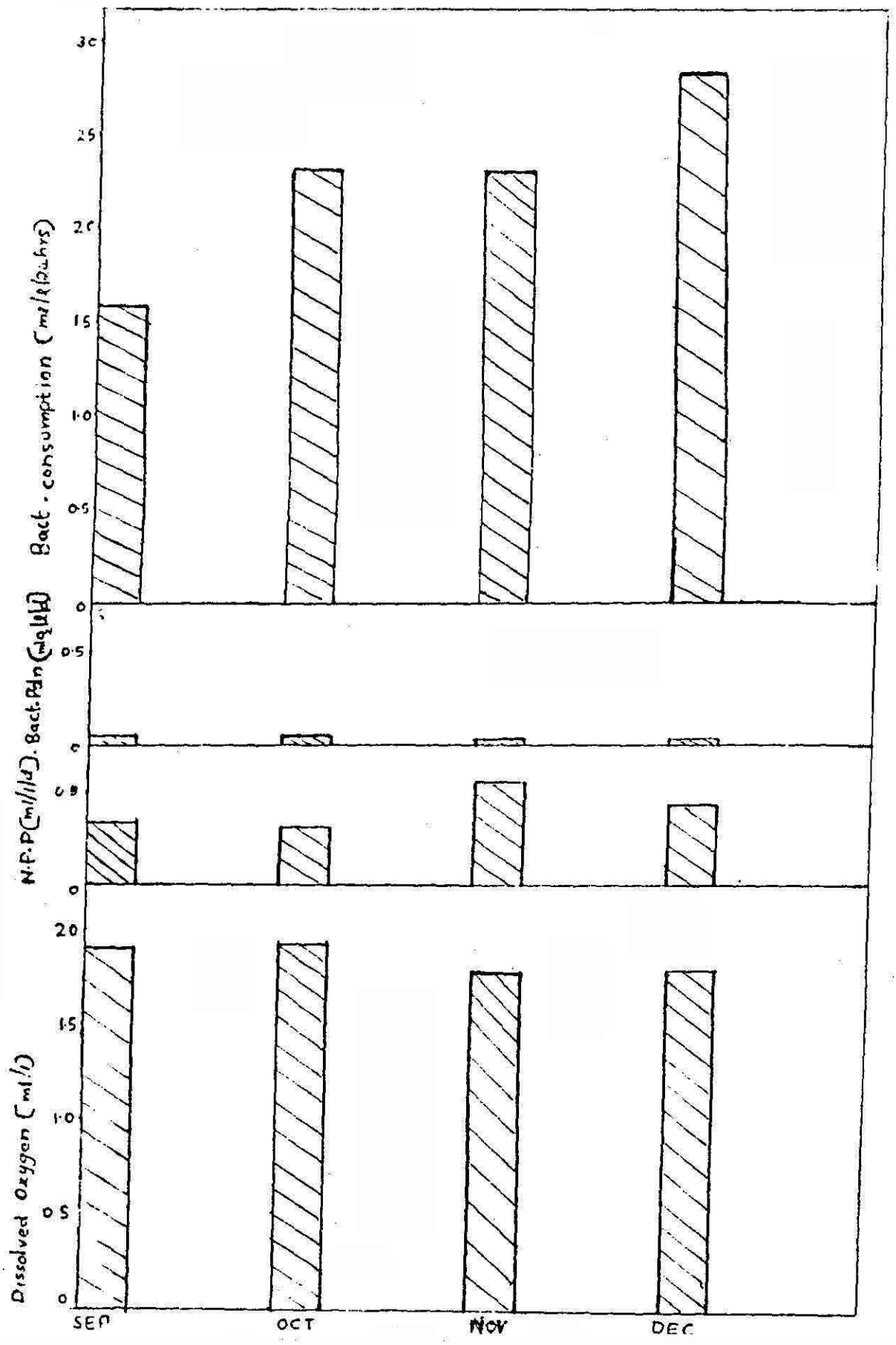


Fig. 15. Interrelationship among Gross Primary Production of Oxygen and Plant Nutrients.

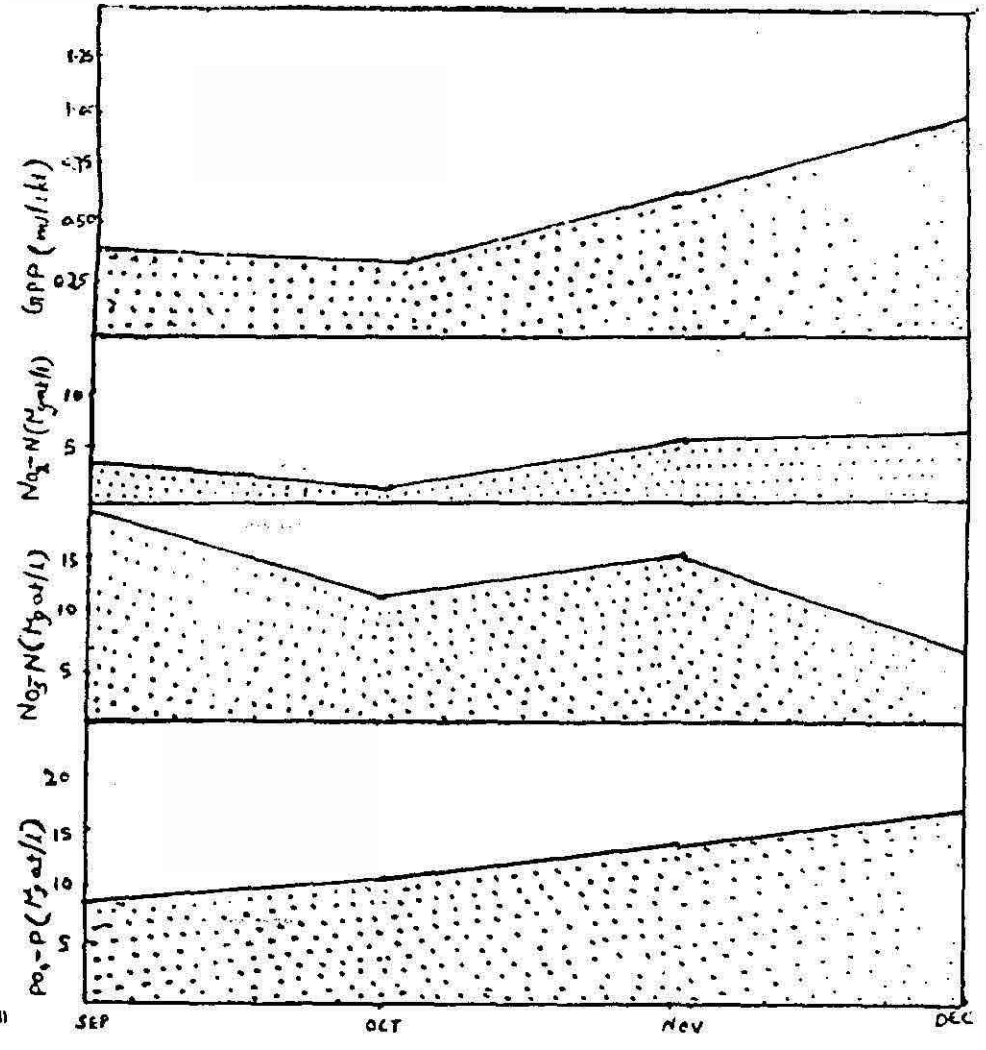


Fig. 16. Inter-relationship among Bacterial Consumption of Oxygen, Rainfall and Plant Nutrients.

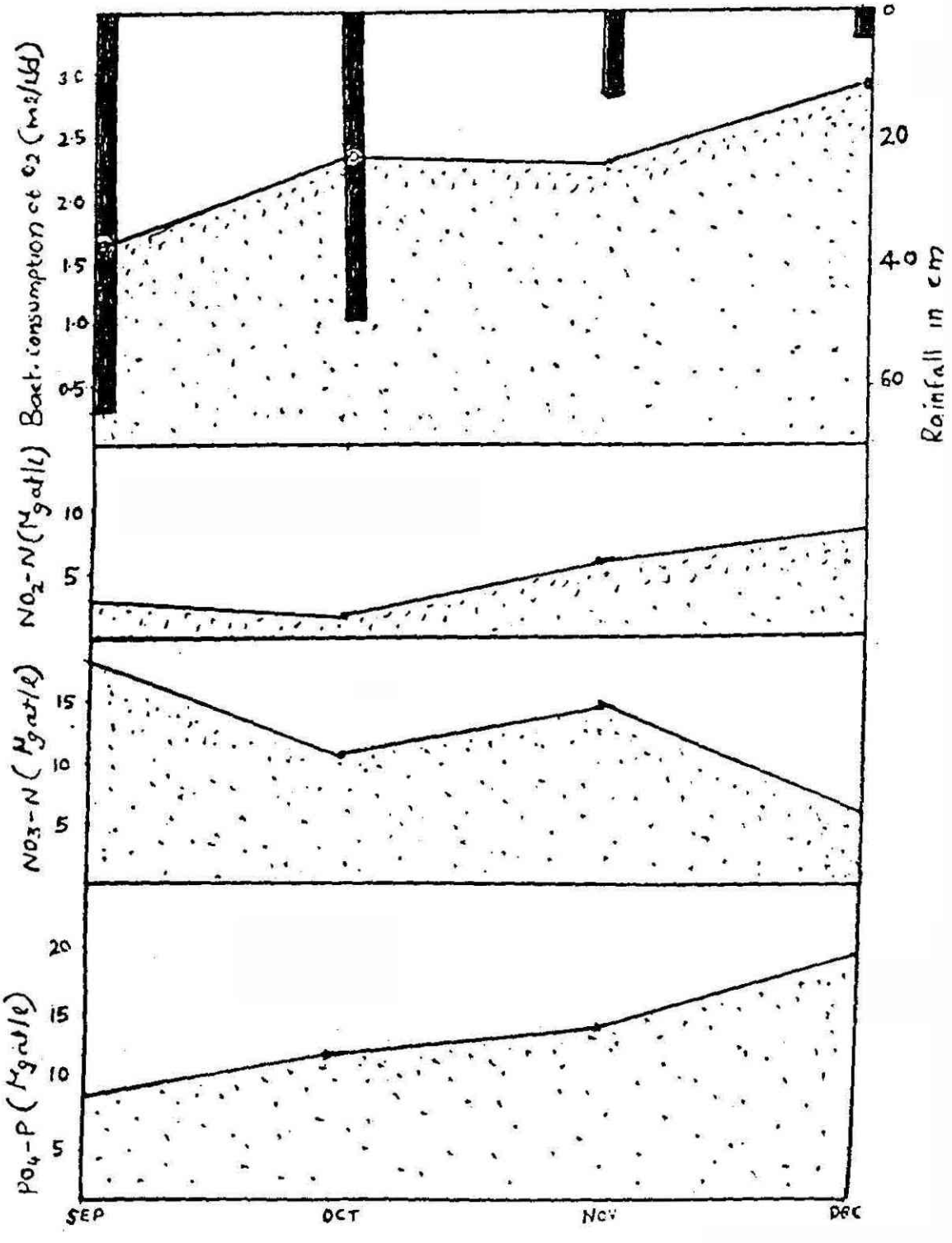


Table-15.Monthly Average Values of Photosynthetic production of Oxygen and Micro-algal respiration

Parameters	September	October	November	December
1.Gross Photosynthetic production of Oxygen (ml/l/ld)	0.395	0.364	0.673	1.033
2. Net Photosynthetic production of Oxygen(ml/l/ 24 hrs.)	0.316	0.291	0.538	0.826
3.Micro-algal respiration (ml O_2/l/12hrs)	0.079	0.073	0.135	0.661
3b. Micro-algal respiration (ml O_2/l/24hrs)	0.158	0.146	0.269	0.413
4. Bacterial production in day	0.023	0.010	0.004	0.002
5. Bacterial production in night	0.023	0.045	0.004	0.002
6. Bacterial production of Oxygen in 24 hrs	0.046	0.055	0.008	0.004
7. Bacterial consumption of Oxygen in day	0.859	1.171	1.161	1.453
8. Bacterial consumption of Oxygen during night	0.812	1.102	1.095	1.408
9. Bacterial consumption of Oxygen during 24 hrs	1.671	2.273	2.256	2.861
10. Net Bacterial Production/ consumption of Oxygen in 24 hrs (+ve production; -ve consumption)	-1.625	-2.218	-2.248	-2.857
11. Net photosynthetic Production of Oxygen in 24 hrs	0.237	0.218	0.404	0.620
12. Net gain/loss of Oxygen by phyto and bacterial action in 24 hrs. (ml/l/24hrs) (+ve production,-ve consumption)	-1.388	-2.000	-1.844	-2.237

DISCUSSION

The results of the present investigation showed wide fluctuation in the physico-chemical and biological properties which play important role in the production and utilisation of Oxygen in the estuarine water body of Mangalvanam which forms part of the Cochin backwater system. Along the south west coast of India, three seasons are recognized based on the south west monsoon viz. the stable pre-monsoon, unstable monsoon and relatively less stable postmonsoon seasons. The topographic features of the backwater system, tidal currents, fresh water discharge and associated circulation and mixing processes govern the distribution of temperature, salinity, dissolved Oxygen and other chemical components such as organic and inorganic nutrients in the estuary which show variation in space and time. Cyclic changes in the monsoon seasons and associated climatic changes, diurnal variation caused by tidal influence and human interference directly or indirectly influence the dissolved Oxygen concentration in the estuarine system.

The annual average rainfall is supposed to be 323 cm in the Cochin region (Daily Weather Chart). The local rainfall of 131.1 cm obtained during the September -December period of 1998 in the present study works out to 40% of the average annual rainfall of Cochin region, where as the rainfall for the corresponding period of 1996 and 1997 were 92.0cm and 123.4 cm respectively. This shows that there is 12% increase in the rainfall from 1996 to 1998 during the south west Post monsoon period around Cochin.

Among the hydrographic parameters, the results that indicated the surface water temperature values were less than 30°C in the Mangalvanam water body as well as in the Cochin backwater throughout the study period. Sankaranarayanan and Qasim (1969) have related this lower temperature with the monsoon effects on the water body. The monthly average salinity showed a decline in the Mangalvanam water body as compared to the Cochin backwaters and the feeder canal in all the four months (Table - 4). This indicates that the tidal influence is less inside Mangalvanam. The results also revealed that the monthly average

dissolved Oxygen values were less than 2.0ml/l in all the four months when it was above 3.0 ml/l in the Cochin backwater (Table - 4) .The low Oxygen values in water observed at Mangalvanam might be chiefly due to the bacterial consumption through biochemical processes. The presence of *Salvinia* weeds at the surface which prevent the air-water interaction and their decomposition with increase in salinity towards December (Table -4) might be another reason for depletion of Oxygen. This could be attributed to the observation and inference made by Kaviraj *et. al.* (1996) in the case of macrophyte *Pistia stratiotes.* The phosphate, nitrite and nitrate concentrations showed higher values in the Mangalvanam water body as compared tothe Cochin backwater in all the four months (Table -4) indicating that the bacterial mineralisation processes were also faster in the Mangalvanam waters. The higher values of nutrients observed inside Mangalvanam than in the feeder canal also could indicate the same. The highest value of phosphate recorded in the Mangalvanam waters was 23.83 µg at/l during December while Pillai *et. al.* (1975) have recorded the highest value of 32.0µg at/l in a shallow station of the Cochin backwater. The higher values of phosphate and nitrites recorded in November - December with very low rainfall as compared to September - October months suggest that this increase was not due to land drainage or fresh water supply (Fig.16).

The results of the diurnal studies for October, November and December also revealed that water temperature, salinity and dissolved Oxygen values were higher in the high tide water than in the low tide water while the phosphate, nitrite and nitrate values showed a reverse trend (Table - 5) which also indicated that the chief source of nutrients in November - December was through *in situ* production by biochemical mineralisation processes. The low dissolved Oxygen and high nutrient values noticed in the low tide water having less than 35 cm water column (Table - 5) during October, November and December in Mangalvanam also indicated high mineralisation processes and connected bacterial action related to phosphorous and nitrogen cycles going on in the sediments and in the overlying water body; while the water temperature and salinity values were influenced by the high tide water brought in from the Cochin backwater system.

The phytoplankton groups analysed in the present investigation revealed an increasing trend in their composition and number towards December. This could be related to the increase in salinity of waters during the later half of the post monsoon period. The species composition observed in the present study suits well with the observation made by Preetha Paul (1990). She has recorded *Coscinodiscus*, *Ceratium*, *Rhizosolenia* and *Navicula* in the Cochin backwater with salinity less than 4 ppt and *Chaetoceros*, *Fragilaria*, *Nitzschia* and *Pleurosigma* in the saline water ranging from 5-20 ppt. Qasim *et al.* (1972) have also reported that species of *Coscinodiscus* could survive in the very low saline condition in the backwater during southwest monsoon months. In the present observation their abundance in the high tide water showed higher rate of production in the primary productivity experiments than in the low tide water especially during December.

The results indicated that the monthly mean values of gross photosynthetic release of Oxygen at stations 1 and 2 were low in September and October (<0.5 ml/l/d) although the nutrients showed higher values. The low photosynthetic productivity observed during September - October months might be related to the prevailing fresh water influence and associated turbidity caused by the local rainfall and land drainage(Table 2, 6 &7) as also reported by Qasim *et. al* (1969). The availability of higher concentration of plant nutrients with low photosynthetic productivity in September - October revealed that the plant nutrients did not function as the limiting factor (Table - 3). The increasing trend in the gross photosynthetic production of Oxygen observed during November - December with reduction in rainfall and increase in salinity values (Table -3) could be attributed to the southwest postmonsoon effect creating a relatively favourable environment for the growth of phytoplankton in the estuarine system as also reported by Kumaran *et. al.* (1975). According to Roberts (1971), certain photosynthetic bacteria are also involved in the primary organic production through photosynthesis in such aquatic ecosystems.

The irregularities observed in the hour to hour and day to day photosynthetic production values of the high tide water clearly indicated that photosynthetic organisms were not uniformly distributed in the Cochin backwater. The lower gross photosynthetic production of Oxygen observed in the low tide water than in the high tide water inside Mangalvanam (Table 14) revealed that there was heavy mortality of phytoplankton going on inside Mangalvanam in all the four months. The lower concentration of dissolved Oxygen and low rate of production of Oxygen confirmed that the Mangalvanam biotope did not provide a favourable environment for the healthy survival of aerobic organisms as compared to the adjacent Cochin backwater.

In most of the incubation experiments conducted at station - 1, the loss of Oxygen by other sources was found to be much higher than that by algal respiration. This indicates that the bacterial consumption of Oxygen by organic degradation, decomposition and mineralisation processes such as nitrification are faster in water body of Mangalvanam. According to Hall *et. al.* (1978) nitrification alone accounted for 25% of Oxygen consumption. Analysis of the data in high and lowtide waters also revealed that such consumption of Oxygen was much higher in the low tide water. This could be attributed to the shallowness (<35 cm depth) of the water column and its interaction with the bottom sediments.

Regarding the bacterial production of Oxygen in the Mangalvanam waters, less than 6% of the samples showed production values at station. 1 and 2, while in all other samples consumption values were much higher than the average algal respiration values. The bacterial production of Oxygen could be related to the denitrification and sulphate reduction processes involved in the nitrogen and sulphur cycles and other associated reduction processes. According to Jones and Simon (1980), denitrification accounted for 17% while the sulphate reduction accounted for 2% of Oxygen production. However, the very low values of bacterial production of Oxygen observed during September-December in the present study (fig. 14) revealed that such processes involving release of Oxygen other than photosynthesis were slow in the Mangalvanam waters during southwest postmonsoon months.

In the present investigation although the photosynthetic production of Oxygen showed positive correlation with the bacterial consumption of Oxygen in the Mangalvanam waters (Fig. 14), the photosynthetic production of Oxygen in the Mangalvanam waters was not found sufficient to compensate the biochemical loss of Oxygen occurring in water during September - December. The results indicated an increasing trend of bacterial consumption of Oxygen from September to December (Table- 10;Fig.13). This result goes well with the observation made by Selvaraj (1997) at the Moplah Bay of North Kerala coast where the highest consumption rate was recorded in December and the lowest in August. The consumption values in the present study showed negative correlation with the monthly average values of dissolved Oxygen concentration (Fig. 14) and also with the rainfall which showed decline from 65-6cm during September -December (Fig. 3). It appeared that the day to day variation in the rainfall and associated hydrographic parameters observed during September-November interfered much with the fluctuation in the bacterial consumption of Oxygen in water which might have masked the trend in the correlation during September -November months; while their correlation was found to be clear and effective in December when the rainfall was negligible (<6cm). This might be the reason that the correlation of bacterial consumption of Oxygen with the concentration of plant nutrients was also found to be significant in December rather than in the other three months. The progressive increase in nitrite values with reduction in nitrate values and increase in bacterial consumption of Oxygen with reduction in dissolved Oxygen values observed in December (Fig. 16) might indicate that the nitrifying bacteria responsible for converting ammonia to nitrites (*Nitrosomonas* and *Nitrococcus*) and their action were more than those bacteria which convert nitrites to nitrates (*Nitrobacter*) in the Mangalvanam biotope. These nitrifying bacteria do not exist in isolation, but form part of a natural system often found in bottom sediments and in the overlying shallow waters having more of suspended particles (Roberts, 1971). In the first phase of nitrification process (ammonia to nitrites), according to Roberts (1971), this conversion involves several steps: (i) the ammonia liberated from decaying organic matter by the activities of saprophytic bacteria combines with Carbon dioxide to form ammonium carbonate;

(ii) *Nitrosomonas* and *Nitrococcus* convert this ammonium carbonate to nitrous acid ; and (iii) this nitrous acid immediately combines with Calcium and Magnesium salts to form appropriate nitrites. In the second phase, the *Nitrobacter* oxidizes nitrites to nitrates consuming Oxygen from the aquatic environment.

The fall in nitrate values observed in December (Fig. 16) along with reduction in the average dissolved Oxygen values and low rate of bacterial production of Oxygen revealed that the reduction in nitrate values might not be due to denitrification process. The progressive increase in the photosynthetic production of Oxygen in December (Fig. 15) might suggest that the reduction in nitrates observed in December could be due to utilisation by phytoplankters present in the estuarine system and the adjoining water bodies. The role of Oxygen in phosphorus is not clearly understood although the phosphate values showed an increasing trend with increase in Oxygen consumption and reduction in dissolved Oxygen values during November-December than in September - October. (Figs. 15& 16) months as observed in the case of nitrites. However the phosphobacteria such as *Pseudomonas, Vibrio, Moraxella, Bacillus, Micrococcus* and *Corynebacterium* recorded in the Cochin backwater system (Promod and Dhevendran , 1987) might play significant role in the production and consumption of Oxygen through the phosphorus cycle. Detailed studies on the phosphorous cycle of this biotope would be desirable.

The reduction in rainfall subsequently would increase the salinity of water leading to sinking and decay of the *Salvinia* weeds in the waterbody of Mangalvanam resulting in the consumption of Oxygen for organic degradation and decomposition processes. Devol *et. al.* (1990) have also reported that mangroves are detritus based ecosystems and their high production coupled with frequent tidal inundation results in Oxygen depletion in the sediments and in the overlying shallow waters. Microbiological studies by Chandrika (1976) in the Cochin backwater revealed domination of aerobic bacterial genera such as *Alcaligenes, Vibrio, Pseudomonas, Aeromonas, Flavobacterium* and *Micrococcus which* might be

responsible for the consumption of dissolved Oxygen through the degradation of organic matter. According to Chandrika and Nair (1994), their maximum counts were recorded during the southwest post monsoon period. However, more information on these aspects would be desirable to derive at a definite conclusion.

The present study is the first of its kind to assess the rate of microbio-chemical production and consumption of Oxygen in the shallow estuarine waters. The present investigation concludes that the rate of photosynthetic production of Oxygen in the water body of Mangalvanam is not able to compensate the loss of oxygen in water caused by other biochemical processes. The low dissolved Oxygen concentration and higher rate of biochemical Oxygen consumption than its production in water inside Mangalvanam confirm that this Mangalvanam is not providing a self-replenishing favourable environment for the healthy survival of aerobic organisms during the southwest postmonsoon season. Similar studies for the pre-monsoon and southwest monsoon periods on these aspects would be desirable which would pave the way for the ecologists and microbiologists to identify the affected areas and also help them to understand to what extent the environment is in the oxidising or reducing state. Such studies would help the managers or the concerned government agencies for taking necessary steps to conserve the dying estuarine ecosystem. If proper steps such as deepening of the feeder canal, removal of sludges and aquatic weeds from the water body of Mangalvanam and rehabilitation of mangrove seedlings along the banks of the water body are taken up and implemented at the earliest by the concerned government agencies, there is a possibility of reviving this dying mangrove biotope again to the healthy condition.

SUMMARY

This dissertation presents an account of the study carried out at the Central Marine Fisheries Research Institute, Cochin during September - December 1998 on the microbio-chemical production and consumption of dissolved Oxygen in the shallow estuarine water body of 'Mangalvanam' in relation to associated environmental parameters.

The importance of dissolved Oxygen, resume of literature on related aspects and scope of the study are mentioned under 'Introduction'. The description of the study area, collection of data and methodology are included in 'Materials and methods'.

The methodology adopted for the assessment of the rate of microbio-chemical production and consumption of oxygen in water in the present study is based on primary productivity experiment by Light and Dark bottle incubation technique and B O D estimation as modified by Selvaraj (1997; 1999).

The difference in the Oxygen values between 'L' and 'I' bottles extrapolated for 12 hours was considered for the production/consumption during the 12 light hours of the day and that of 'D' and ''I' for the 12 dark (night) hours of the day.

During sampling, water samples were gently passed through zooplankton filters (0.4mm mesh) to eliminate the respiratory loss of oxygen by the zooplankters; and the water samples collected in 125 ml B O D bottles ('I','D' and 'L') were set for incubation experiments about 30 minutes after sampling to bring the microorganisms physiologically stabilised inside the B O D bottles. All the 'L' bottle samples in the incubation experiments were exposed to uniform light intensities for 2.5 hours in the laboratory and the 'D' bottle samples in darkness at room temperature throughout the course of the experiments (September to December).

Micro-algal respiratory loss of Oxygen was determined in the laboratory experiments using isolated phytoplankton culture media in sterilised (bacteria free) sea water; and 20% of the gross photosynthetic production of Oxygen (L-D) was considered as the micro algal respiratory loss for 12 photosynthetic hours of the day and 40% of the same for 24 hours of the day as adopted by Selvaraj (1999a). The micro-algal respiratory loss of Oxygen for the day and night hours were considered same in the present study.

The research findings on the environmental parameters and on the microbio-chemical production and utilisation of Oxygen in water are presented under 'Results' with Tables and Figures. The factors influencing fluctuation in values, their interrelationship and influence of local rainfall and tides are discussed under the title 'Discussion'; and this session concludes with the present status of the Mangalvanam with suggestions for improvement of this dying mangrove biotope.

The salient findings of the present study are as follows:

The local rainfall data of the Cochin Sector showed an increase of 12% from 1996 to 1998 during September-December period. The surface water temperature was less than 30°C in the Mangalvanam waters and it was almost similar to the room temperature in the respective months.

Relatively lower values of salinity and dissolved Oxygen recorded inside Mangalvanam than in the Cochin backwater during high and low tide periods in all the four months indicated relatively poor tidal influx inside Mangalvanam.

Apart from the respiratory loss by microorganisms, accumulation of Salvinia weeds inside Mangalvanam played significant role on the reduction of dissolved Oxygen in water preventing air-water diffusion and through their decomposition process.

Higher concentrations of phosphate, nitrite and nitrate in water recorded inside Mangalvanam than in the adjacent Cochin backwater in all the four months and relatively higher concentrations of these nutrients recorded in the low tide water coupled with relatively low dissolved Oxygen values and increased bacterial consumption of Oxygen especially during November - December period when the rainfall was negligible confirmed high rate of bacterial mineralisation processes such as nitrification inside Mangalvanam.

The rate of bacterial consumption of Oxygen was found to be much higher than the rate of micro-algal respiration in the water body of Mangalvanam.

Bacterial consumption of Oxygen in water showed an increasing trend from September to December, which showed negative correlation with the monthly average values of dissolved Oxygen concentration and also with the local monthly rainfall, which showed a decline from 65 to 5.6 cm during September-December.

The day to day variation and discontinuity in the rainfall observed within the months during September-November appeared to alter the values and interrupt the correlation among the hydrographic parameters and with the biochemical production and consumption of Oxygen in this estuarine environment. The correlation between bacterial consumption of Oxygen and plant nutrients was found to be significant in December when the rainfall was negligible (less than 6cm).

The progressive increase in nitrite values with reduction in nitrate values and increase in bacterial consumption of Oxygen with reduction in dissolved Oxygen concentration recorded in December might indicate that the nitrifying bacteria such as *Nitrosomonas* and *Nitrococcus* involved in the conversion of ammonia to nitrites were more in the shallow estuarine waters of Mangalvanam.

Since there was no significant increase in the average dissolved Oxygen concentration with reduction in nitrate values in December, it would be difficult to state at this stage whether the reduction in nitrate values was due to the bacterial denitrification process. However, the very low values of bacterial production of Oxygen recorded in all the four months would reveal that such bacterial biochemical reduction processes involving release of Oxygen were slow during September-December.

The progressive increase and higher values of photosynthetic production of Oxygen recorded in December with considerable reduction in nitrate values in the Mangalvanam and in the adjacent Cochin backwater could be related to the utilisation of nitrates by the photosynthetic organisms.

However, the record of higher concentrations of phosphate, nitrite and nitrate with relatively low photosynthetic production inside Mangalvanam than in the Cochin backwater indicated that these nutrients did not function as the limiting factors for primary production in the estuarine waters.

The irregularities observed in the hour to hour and day to day photosynthetic production values of the high tide water clearly indicated that photosynthetic organisms were not uniformly distributed in the Cochin backwater.

Lower gross photosynthetic production of Oxygen observed in the low tide water than in the high tide water inside Mangalvanam revealed that there was heavy mortality of phytoplankton going on inside Mangalvanam.

Although the monthly average photosynthetic production of Oxygen showed increasing trend and positive correlation with the bacterial consumption of Oxygen towards December, the rate of net photosynthetic production of Oxygen was not found to compensate the loss of Oxygen occurring through other microbio-chemical (bacterial) oxidation processes.

The present study confirmed that the water body inside Mangalvanam did not provide a self-replenishing favourable environment during the southwest postmonsoon months for the healthy survival of aerobic organisms.

The present study is the first of its kind to assess the rate of microbio-chemical production and consumption of Oxygen in the shallow estuarine waters and in the Mangalvanam biotope. Similar studies conducted for the other two seasons (premonsoon and southwest monsoon) would pave the way for the ecologists and microbiologists to identify the affected areas and also help them to understand to what extent the environment is in the oxidising or reducting state. Such studies would help the managers or the concerned government agencies for taking necessary steps to conserve the dying estuarine ecosystem.

If proper steps such as deepening of the feeder canal, removal of sludges from the water body of Mangalvanam and rehabilitation of mangrove seedlings along the banks of the water body are taken up and implemented at the earliest by the concerned government agencies, there is a possibility of reviving this dying mangrove biotope again to the healthy condition.

REFERENCES

CHANDRIKA,V . 1976. Indicators of bacterial pollution in Cochin backwater. *Sov Proc. Rec National Seminar on Environmental Pollution.* pp-290-294.

CHANDRIKA, V AND P.V. RAMACHANDRAN NAIR 1994. Seasonal variation of aerobic heterotrophic bacteria in Cochin backwater. *J. Mar. biol. Ass. India.*, 36 (1): 81-86.

DEVOL, A.H, ERIK KRISTENSEN, SAIYED. I. AHMED, MONAWWAR SALEEM AND NASREEN BANO 1990. Carbon Oxidation in the sediments of the mangrove ecosystem of the Indus river delta. 'The Arabian Sea' Living Marine Resources and the Environment. pp. 420-429.

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

GOPINATHAN. C.P. 1982. Methods of culturing phytoplankters. *C.M.F.R.I. Special Publication*, 8: 113-119.

HALL, G.H., V.G. COLLINS, J.G. JONES, AND R.W. HORSLEY 1978. The effect of sewage effluent on Grasmere (English Lake District) with particular reference to inorganic nitrogen transformation. *Freshwater Biology*, 19: 966-72.

JONES, J.G. AND B.M. SIMON. 1980. Decomposition processes in the profundal region of Blelham Tarn and the Lund Tubes. *J. Ecology.*, 68: 493-512.

KAVIRAJ, A., GHOSAL, T.K AND B.M.A. HASAN 1996. Nutrient enrichment of water by decaying and compost of aquatic macrophyte *Pistia stratiotes, J. Nature Conseve.*, 8(1): 159-164.

KUMARAN, S.A. AND T.S.S. RAO 1975. Phytoplankton distribution and abundance in Cochin backwater during 1971-1972 *Bull. Dept. Mar. Sci. Univ. Cochin.*, 7 (4): 791-799.

PILLAI, V.K., K.J. JOSEPH AND A.K. KESAVAN NAIR 1975. The plankton production in Vembanad Lake and adjacent waters in relation to environment parameters. *Bull. Dept. Mar. Sci. Univ. Cochin.*, 7 (1): 137-150.

PREETHA PAUL 1990. A study on phytoplankton pigments and primary productivity in the Cochin backwater during southwest monsoon. M.Sc. *Dissertation*, Cochin University, pp. 86.

PROMOD,K.C.AND K. DHEVENDRAN 1987. Studies on phosphobacteria in Cochin backwater. *J. Mar. biol. Ass. India.*, 29(1&2): 297-305.

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

QASIM, S.Z. AND C.K.GOPINATH 1969. Tidal cycle and the environmental features of Cochin backwater (a tropical estuary). *Proc. Indian Acad. Sci.*, 69-B (6): 336-348.

QASIM, S.Z. AND C.V.G. REDDY 1967. Estimation of plant pigments of Cochin backwater during monsoon months. *Bull. Dept. Mar. Sci. Univ. Cochin.*, 17 (1) : 95-110.

RAMAMIRTHAM, C.P. AND R. JAYARAMAN 1963. Some aspects of the hydrological condition of backwaters around Willingdon Island (Cochin). *J. Mar. biol. Ass. India.*, 5 (2): 170-177.

ROBERTS, M.B.V. 1971. Autotropic nutrition. In Biology-A Functional Approach. The English Language Book Society and Nelson , pp. 141-161.

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

SELVARAJ, G.S.D. 1997. A methodology to assess the biochemical Oxygen utilisation and production in estuarine ecosystems. *Proc. Nat. Sem. Water. Quality Issues in Aqu. Syst.* pp 139-146.

SELVARAJ, G.S.D. 1999 a. An approach to differentiate net photosynthetic and other biochemical production and consumption of Oxygen in estuarine water bodies and aquaculture systems. National Seminar on Development and Transfer of Fisheries Technology, Feb. 1999. *Abstracts*, p.35 (Paper in Press.).