STUDIES ON THE ECOPHYSIOLOGY OF PERIPHYTIC ALGAE IN COCHIN ESTUARY

THESIS SUBMITTED TO

THE COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE

DOCTOR OF PHILOSOPHY

IN

THE FACULTY OF MARINE SCIENCES

BY

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DECEMBER 1996

DEDICATED TO

BHARAT AND ARUNDHATI

CERTIFICATE

This is to certify that the thesis is an authentic record of the research carried out by **Sri. R. Sreekumar, M.Sc.,** under my supervision and guidance in the Marine Biology , Microbiology and Biochemistry Division, School of Marine Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Ph.D degree of Cochin University of Science and Technology and no part thereof has been presented before for any degree in any university.

Kochi
December, 1996.

Dr. K. J. Joseph
(Supervising Teacher)

DECLARATION

I hereby declare that the thesis entitled **"STUDIES ON THE ECOPHYSIOLOGY OF PERIPHYTIC ALGAE IN COCHIN ESTUARY"** is an authentic record of research carried out by me under the supervision and guidance of Dr.K.J.Joseph, Reader, Marine Biology Division, School of Marine Sciences, Cochin University of Science and Technology and that no part of it has previously formed the basis for the award of any degree, diploma or associateship in any University.

Kochi
December, 1996

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ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude to my supervising teacher, Dr. K.J. Joseph, Reader, Marine Biology Division, School of Marine Sciences, Cochin University of Science and Technology for suggesting the research problem, for inspiring guidance and constant encouragement throughout the course of this investigation.

I am very much obliged to Prof. (Dr.) N. R. Menon, Director, School of Marine Sciences, Cochin University of Science and Technology, who was kind enough to provide me the necessary facilities and constant encouragement for the study. Prof. (Dr.) R. Damodaran, Marine Biology Division has rendered useful suggestions and discussions during the investigation. I am much grateful to him.

My unfeigned thanks to the staff members of School of Marine Sciences, Cochin University of Science and Technology for their encouragement at various stages of my work.

I thank Prof. (Dr.) Jacob Chacko, Head, Chemical Oceanography Division and Dr. A. Mohandas, Director, School of Environmental Studies for providing me the infrastructural facilities at their respective departments for the completion of the work.

I express my sincere gratitude to Sri. K.K. Sivadasan, Sri. Joseph George and Miss. Newby Joseph, research fellows of the Marine Biology Division for their invaluable assistance rendered during the study.

My thanks are also due to the authorities of Cochin University of Science and Technology for providing me with all the facilities for my work.

I express my sincere gratitude to all my colleagues in the Department of Botany , Maharaja's College, Ernakulam for their wholehearted cooperation and encouragement. I am thankful to Dr. U.S. Sarma ,Director (Research), Central Coir Research Institute, Kalavoor for his valuable suggestions.

Last but not the least I would like to thank my wife Anita Sreekumar, who has been a source of inspiration at all times.

CONTENTS

1

GENERAL INTRODUCTION

Introduction

Primary producers in aquatic ecosystem assume unique significance beacause of their contribution to the total organic production generating the fishery resources. They transform the solar energy into potential food energy which is utilized by several consumers and finally made available as fish. Algae, the major primary producers in the aquatic environment comprise a large and heterogenous assemblage of relatively simple plants such as phytoplankton, periphyton (haptobenthos) and herpobenthos. Among these, the role of algal plankters have been discussed extensively with respect to different aquatic environments. Major part of the published data on organic production pertains to this particular group. Efforts are now on to assess the specific role of other groups in primary organic production.

The flora on the sub-aquatic surfaces has been subjected to very few systematic studies. Little is known of their geographical distribution, of seasonal cycles, relation to flow and water chemistry. The quantitative studies on this flora are scarce presumably due to the difficulties involved in the separation of algal cells from substrata. The attached algal flora is as highly developed in running (lotic) as well as in standing waters (lentic) and form an important community of all water bodies.

The flora forms an extremely heterogenous and complex association due to variability and distribution of natural substrata. The terminology applied to the various algae in individual habitats is almost as varied as the number of investigations (Sladeckova, 1962; Wetzel, 1964). The assemblage of organisms living on the bottom of freshwater or brackish ponds, lakes, rivers and the sea bed are termed benthic (from Greek Bevoo = bottom). Microorganisms growing on sticks, aquatic macrophytes and submerged surfaces are designated as periphyton (APHA, 1992). Organisms included in this group are the zoogleal and filamentous bacteria, attached protozoa, rotifers, algae and the free living microorganisms that swim, creep or lodge among the attached forms. The photosynthetic components include a diverse assemblage of algal forms that colonize nearly every conceivable type of substrata available in the aquatic system. A uniform system of terminology is recommended whereby the term periphyton includes all of the plant organisms, excluding rooted macrophytes, growing on submerged materials in water (Wetzel and Westlake, 1974). The term periphyton has also been used for the growth on artificial substrata such as glass slides (Sladeckova, 1960). In restricted studies of organisms on specific type of material such as rocks, macrophytes, usage of the general term periphyton is modified by an appropriate adjective such as epilithic or epiphytic periphyton.

In general two distinict types of benthic algal associations are logically reasonable. The haptobenthos grows on a solid substratum, which is usually either rock or part of an aquatic plant, though sometimes wood, animal surfaces or remains of a man-made object, metallic, ceramic, plastic or whatever. The herpobenthos grows in or on mud which it can easily penetrate. The term periphyton, as now used in a wide sense is synonymous with haptobenthos (Sladeckova, 1962). The plant components of the aquatic system can thus be classified in to well defined groups such as phytoplankton, periphyton, herpobenthos and macrophytes. The present study is on the ecophysiology of periphytic algae in Cochin estuary.

Scope of the Study

The estuaries are highly productive ecosystems and characteristically are more productive than the adjacent river or sea. Estuarine producers which include planktonic algae, periphyton, herpobenthos as well as macrophytes are capable of nearly year round photosynthesis. Productivity of an environment is mainly the contribution of various groups of autotrophic flora. Any quantitative estimation excluding any one of these would be an underestimation. Periphyton plays a very important role in the productivity of estuarine and coastal waters. It has been reported that periphytic algae attain high biomass (Moss, 1968; Hansson, 1988a) and may contribute up to 80% of the primary production (Persson et al., 1977). Considerable amount of work has been done on the productivity in Cochin backwaters by different investigators (Qasim, 1973, 1979; Nair et al., 1975; Gopinathan et al., 1984). All of them have estimated the primary production based only on phytoplankton of the estuary. Considering the contribution of other autotrophic components of the estuary such as periphyton (haptobenthos), sediment flora (herpobenthos) and macropytes, the productivity estimated by earlier authors were essentially underestimations. The present work is an attempt inter alia to assess the contribution of periphytic flora towards the total organic production in the estuary.

Practically no work has been done on the taxonomy, seasonal and spatial variation of periphytic algae of the ecosystem. An understanding of the species composition and distribution of periphyton would give more information regarding the richness of biodiversity of this tropical estuary. Quantitative estimation of this plant community would also highlight its probable contribution to the total organic production.

As the substrata which support periphyton are generally stationary , these organisms are reliable indicators of environmental fluctuations. The composition and abundance of periphyton at a given location are governed by the water quality at that point. Observations on periphytic growth generally are thus useful for evaluation of water quality. The autrophic index (AI) is a means of determining the trophic nature of the periphyton community. Normal AI values range from 50 to 200 (APHA, 1992). Larger values indicate heterotrophic associations or poor water quality. Efforts are made to find out the usefulness of autotrophic index (AI) as a means of describing changes in periphyton community between sampling stations. No such studies have been carried out in Cochin estuary earlier.

Review of Literature

Several studies have described the algal growth of periphytic communities both in flowing and standing waters in spite of the difficulty in the quantitative assesment of the standing crop. The study of periphyton is often hindered by the lack of suitable natural substrata at the desired sampling station. Furthermore, it often is difficult to collect quantitative samples from their irregular surfaces. To circumvent these problems artificial substrata have been used to provide, a uniform surface type, area and orientation.In the majority of periphyton studies artificial substrata have been used. (Sladeckova, 1962, 1972; Dumont, 1969; Rosemarin and Gelin, 1978; Loeb, 1981). The sampling of periphyton communities on artificial substratum is well established and a variety of sampling devices have been employed (Sladeckova, 1962; Austin et al., 1981). Recent studies have indicated that no single substratum (whether artificial or natural) could fully represent the variety present in a stream (Siver, 1977; Lowe and Gale, 1980; Eloranta, 1982). The use of artificial substrata however simplifies the sampling and improves replicability. But natural periphyton communities on aquatic macrophytes, rocks and other permanent structures quite often are collected for qualitative studies. Community structure and seasonal abundance of the periphyton of different aquatic systems of India using artificial and natural substrata have been studied, (Jha et al., 1981; Datta et al., 1987; Pal et al., 1988; Negi,1990; Tiwari,1990; Muthukumar et al., 1991).

Factors influencing periphyton growth

The relationship between periphytic algal growth rates and in situ chemical or physical parameters was evaluated in different ecosystems. Several studies on agricultural streams have found a lack of correlation between periphyton standing crop and increase in either nitrate (NO_3-N) or phosphate (PO_4 - P) (Kilkus et al., 1975 ; Moore, 1977). However, Cuker (1983) had observed that addition of limiting nutrients to periphyton increases algal biomass. Fairchild and Lowe (1984) observed that nutrient enhancement can accelerate the successional process effecting a more rapid replacement of species. Nutrient diffusing substrata have been used in lentic (Fairchild and Lowe, 1984; Lowe et al., 1986; Pringle et al., 1986; Pringle, 1987) environments, to examine the role of various nutrients, with apparent success. Cattaneo (1987) had observed that high nutrient levels can cause a shift from communities dominated by diatoms to communities dominated by green filaments. Physiognomy of the community often changes from being dominated by prostrate forms to dominance by large filaments. Sediment dwelling algae are known to take up nutrients not only from water but also from the sediment (Carlton and Wetzel, 1988; Hansson, 1988 a, 1989) which implies less sensitivity than algal plankton. Bushong and Bachmann (1989) also observed that benthic algal communities were seldom limited by nitrogen and phosphorus. Factors limiting periphyton accrual in east-central Illinois agricultural streams were investigated by Munn et al., (1989). The investigations revealed that variance in the rate of chlorophyll a accrual on substrata was explained through water temperature and turbidity whereas, stream nitrate and phosphate concentrations accounted for no significant portion of the variance.

Kilkus et al., (1975) reported that water temperature was a major driving variable for periphyton in agricultural streams in Iowa. Bushong and Bachmann (1989) also demonstrated that water temperature as an important factor in controllong periphyton growth rates.

Periphyton accumulation on artificial substrata was fastest near the water surface and decreased repidly with increasing depth (Eloranta, 1982). Hoagland et al., (1982) suggested that vertical gradients exist within a periphyton community for factors such as light and nutrients. The role of storm events in disrupting periphyton community development has also been discussed (Fisher et al., 1982).

Grazing can substantially reduce periphyton biomass (Dickman, 1968; Kehde and Wilhm, 1972). Grazed communities are often dominated by either prostrate species, which adhere tightly to the substrate or by small understorey species, which can avoid being grazed by virtue of their size (Hunter, 1980; Sumner and Mc Intire, 1982; Hunter and Russel-Hunter, 1983). The independent and interactive effects of nutrient enrichment and snail grazing on structuring periphyton communities in a northern temperate lake was investigated by Marks and Lowe (1989). Grazing had a more pronounced effect on altering community composition on the nutrient enriched substrata than on unenriched substrata. Grazing caused a decrease in diversity and increase in dominance by green algae on the nutrient enriched substrata. According to Hansson (1992), a great deal of the variation in periphyton biomass is due to variation in light and nutrient availability.

Periphyton and nutrient removal

Many lakes and streams show signs of excessive fertilization due to the input of aquatic plant nutrients from man-related sources (Lee, 1973). Eutrophication of lakes and drinking water reservoirs has considerable detrimental effects on the quality of water. Several studies have been made in which algal growth was used either to assist in the stabilization of untreated sewage or for the removal of nutrients (Neel et al., 1961; Hemens and Stander, 1970; Pano and Middlebrooks, 1982). A solution to the problem of separation of algae from purified water is the use of periphytic algal communities on rotating discs (Hemens and Stander, 1970) or in special streams or troughs (Skadovskij, 1961; Sladeckova et al., 1983). Experiments confirming that periphyton communities are useful means of nutrient removal from polluted streams were conducted by different workers (Bothwell and Jasper, 1983; Bothwell, 1983; Horner et al., 1983; Meier and Dilks, 1984; Vymazal, 1988).

Periphyton and fouling

The term fouling is commonly employed to distinguish the assemblage of animals and plants which grow on artificial or man made structures, such as wood, steel, aluminium, fibre glass when exposed to seawater. Though algae constitute important members of marine fouling community only very little has been done on the specific role of diatoms in fouling. Hendey (1951), Round (1971), Munteanu and Maly (1981) and Huang and Boney (1983) have studied various aspects of fouling by diatoms. Slime films on paints are dominated by diatoms intermixed with bacteria, blue-green algae and dinoflagellates. All these have the ability to produce mucilage resulting in a semi rigid jelly like matrix in which the component organisms are embedded. The diatom Achnanthes is frequently the dominant member of slime occurring on antifouling surface which prevents attachment of larger algae such as Enteromorpha (Callow et al., 1976). Hardy (1981) has reported the possibility of corosion caused by various extracellular products which come in contact with the surfaces of structures.While describing the composition of primary film in the tropical marine waters of Madras, Daniel (1955) identified spores belonging to 14 different algal species as components of primary film in addition to diatoms.Kelkar (1989) studied the fouling diatoms from Bombay offshore and Marmagoa.

Periphyton and pollution monitoring

Periphyton has long been associated with studies of aquatic pollution (Fjerdingstad, 1964) and a variety of studies have appeared concerning the structure (Cooper and Wilhm, 1975; Hein and Koppen, 1979; Tuchman and Blinn, 1979; Eloranta, 1982) or function (Orhon, 1975; Marcus, 1980; Eloranta, 1982) of periphyton in polluted environments. Effects of chemicals on periphyton structure and function also have been investigated using experimental ecosystems (Grolle and Kuiper, 1980; Muller, 1980) to which pollutants were added. Species diversity of periphyton as an index of pollution of River Ganga was reported by Laal *et al.* (1982). Gaur and Kumar (1985) described algal community structure in effluent holding and treatment ponds of five oil refineries. Singh and Gaur (1989) studied the changes in epilithic algal communities on introduced substrata in a stream polluted with oil refinery effluent at Digboi (Assam, India). The study showed that the number of algal taxa was less except blue green algae. Epilithic biomass (as chlorophyll *a*) also found to be considerably less at polluted stations. The algal community of the upstream station was markedly different from the community occurring just after the confluence of effluents ; however, the differences were gradually reduced downstream, indicating improvement in water quality. Effect of certain organic wastes on periphyton levels of the treated waters was studied by Kapur (1987). The importance of benthic algae growing on natural substrata and their role in river monitoring and pollution control was reported by Venkateswaralu et al. (1990).

Periphyton and primary production

Members of periphyton communities are the dominant primary producers in many lotic environments and contribute substantially to primary production in others (Wetzel, 1964.) Krock (1972) developed a test system making use of attached microbial communities established on artificial substratum in the San Francisco Bay. The communities were incubated in light/dark bottles and effects on photosynthesis and respiration of various added toxicants and stimulants were recorded. Orhon (1975) in a similar study, sampled attached microbial communities in a pollution gradient in Golden Horn estuary and measured the effects on photosynthesis and respiration. Persson et al. (1977) had observed that periphyton can contribute up to 80% of the primary production. Aquatic ecologists had thus became aware of the importance of periphyton as key primary producers in lakes (Kairesalo 1980; Loeb et al., 1983). Primary production in agricultural streams of central Illinois was found to be limited by temperature and light (Munn et al., 1989). Estimation of primary production with respect to periphyton was done in different ecosystems.In southern England streams, Marker (1976) reported primary production at the rate of 83.62 mg $C\ m^{-2}\ h^{-1}$. Wiley et al. (1987) had also reported very high production in prairie river systems and subarctic streams respectively.

Periphyton production in irrigation tanks with permanent turbid waters was studied by Krishna Rao (1990).

The present work embodies the result of an investigation of periphytic algae in Cochin estuary with special reference to its ecology and physiology. The scope of the study and a review of literature are given in **Chapter 1**. An account of the area of study and hydrological parameters that influence the growth and distribution of periphytic flora are described in **Chapter II** under the title The Environment. **Chapter III** deals with the periphyton colonization in Cochin estuary and factors influencing the same. Periphyton accumulation on various sub-strata is also discussed. **Chapter IV** is on the spatial and seasonal variation of the estuarine periphytic algae in Cochin estuary. Quantitative and qualitiative analyses of periphytic algae at 10 different stations are discussed. **Chapter V** desribes the community structure of periphytic algae in the ecosystem. **Chapter VI** is on the seasonal and spatial distribution of various photosynthetic pigments. **Chapter VII** deals with the role of periphytic algae in assessing the water quality of aquatic systems. **Chapter VIII** on the productivity of the estuary highlights the contribution of periphytic flora towards the total primary production. Main conclusions of the present work are presented in **Chapter 1X**.

2

THE ENVIRONMENT

Geographic Location

The locations of the present investigation includes the backwater system running almost parallel to the Arabian Sea (9^0 40' - 10^0 12'N, 76^0 15' - 76^0 25'E), with a total area of about 300 sq.km offers an ever fluctuating environment to the flora and fauna (Fig.1). On the northern half there are two permanent passages to the Arabian Sea, one at Cochin and the other at Azhicode. Several tributories of the Periyar river join the backwater at the northern half. On the southern half the river Pamba and Muvattupuzha join the system. All the rivers periodically enrich the area with nutrients and considerable quantity of silt by flood waters. The tidal effect reaches all along the lake upto the southern end.

Three distinct tidal seasons have been observed in this backwater, each of about four months duration. They are pre-monsoon (February to May), monsoon (June to September) and post-monsoon (October to January).

During the monsoon showers from June to September, the flood tides are more or less completely nullified by the freshets and there is a strong predominance of the ebb tides. From October to January, there is a decline in rainfall and the strength of flood tide over the ebb tide is minimum. During the hot dry months from February to May, the flood tide effects are considerably accentuated over the ebb tide. This brings about the changes in the salinity of the estuary. The backwater is subject to rapid changes by the incoming tides, which create turbulence in places where it opens to the sea. It is also polluted by industrial effluents and domestic sewage all along its banks in the industrial belt.

Hydrographic Parameters

Salinity

The temporal variations in salinity at 10 different stations in the estuary during the period of study are given in the Table 2.1. The monthly mean values of salinity varied from 0.3 $(x10^{-3})$ to 12.4 $(x10^{-3})$. The highest single value, 30.0 $(x10^{-3})$ was recorded from station 6 during January and the lowest, 0 , from stations 1 and 7 during November and April respectively. Salinity distribution in the estuary is the result of combined action of water movements induced by freshwater discharge, tidal variation and mixing process. In the estuarine system salinity plays a dominant role in the succession of algal flora. The effect of monsoon can be seen from decreasing salinity gradients in the entire backwater area during the period June to August and a gradual rise in salinity values was observed during the post - monsoon period. The maximum values were recorded during the pre-monsoon months. The salinity in the northern part of the estuary was of higher magnitude, due to the two natural openings to the Arabian Sea at Cochin and Azhicode.

Temperature

The water temperature values (Table 2.2) for entire period of observation are more or less in accordance with the climatic variations. Monthly mean values varied from 24.5 to 31.0 ^{0}C. There was a gradual increase in temperature from February to April followed by a fall during the monsoon. There was a slight increase in surface temperature in the entire ecosystem during the post-monsoon period. The decline in water temperature during the monsoon period is not only due to the influx of freshwater in the estuary but also the influx of cold water from the sea (Sankaranarayanan and Qasim, 1969).

Dissolved Oxygen

Seasonal variation in dissolved oxygen values at different stations are shown in Table 2.3. The monthly mean values varied from 4.60 to 6.01 ml/l. The highest single value, 7.43 ml/l, was recorded from station 3 during February and the lowest, 2.84 ml/l, from station 5 during August. The monsoon, post-monsoon and pre-monsoon values of dissolved oxygen were 4.90, 5.25 and 5.38 ml/l respectively. The seasonal values did not vary significantly though slightly higher values are recorded during post-monsoon and pre-monsoon periods.

Hydrogen Ion Concentration

The temporal variation in hydrogen ion concentration at different stations are given in Table 2.4. The monthly mean pH values of the estuary varied from 6.18 to 7.67 during the entire period of observation. The highest value, 8.70, was noted at station 10 during June and the lowest, 5.75, was recorded at station 8 during July. Average pH values for monsoon, post-monsoon and pre-monsoon were 6.71, 7.07 and 7.75 respectively. Hydrogen ion concentration of the ecosystem is influenced by tidal fluctuations.

Silicate

The seasonal variation in silicate values at 10 different stations is shown in the Table 2.5. The monthly mean values were in the range 3.65 - 25.51 mg/l during the period of study. The station 5 recorded the highest value, 57.27 mg/l, during September while the lowest, 0.85 mg/l, was obtained from station 9 during May. The monsoon, post-monsoon and pre-monsoon periods recorded 17.11, 15.54 and 6.8 mg/l respectively. Heavy inflow of water leached out through various rivers into the estuary must have contributed to the higher silicate values during the monsoon period.

Nitrite

Variation in nitrite nitrogen at different stations are presented in the Table 2.6. The monthly mean values of nitrite were in the range 0.31 - 2.93 µg at/l. The monsoon, post-monsoon and pre-monsoon values of nitrite were 0.46, 1.86 and 0.71 µg at/l. Post-monsoon period recorded comparatively higher concentration of nitrite nitrogen. Most of the values were within 1 µg at/l except at a few stations.

Phosphate

Table 2.7 shows the concentration of phosphate during different months at the stations studied. The monthly average values of phosphate phosphorus varied from 0.92 to 5.48 µg at/l during the period of observation. The station 8 recorded the highest value of 25.73 µg at/l, during May while the lowest, 0.10 µg at/l, from station 5 during February. In all, three phosphate concentration peaks were observed in the ecosystem, one towards September and October, another in January and a third appears in May and June. The monsoon, post-monsoon and pre-monsoon values of phosphate were 3.10, 2.84 and 2.42 µg at/l respectively.

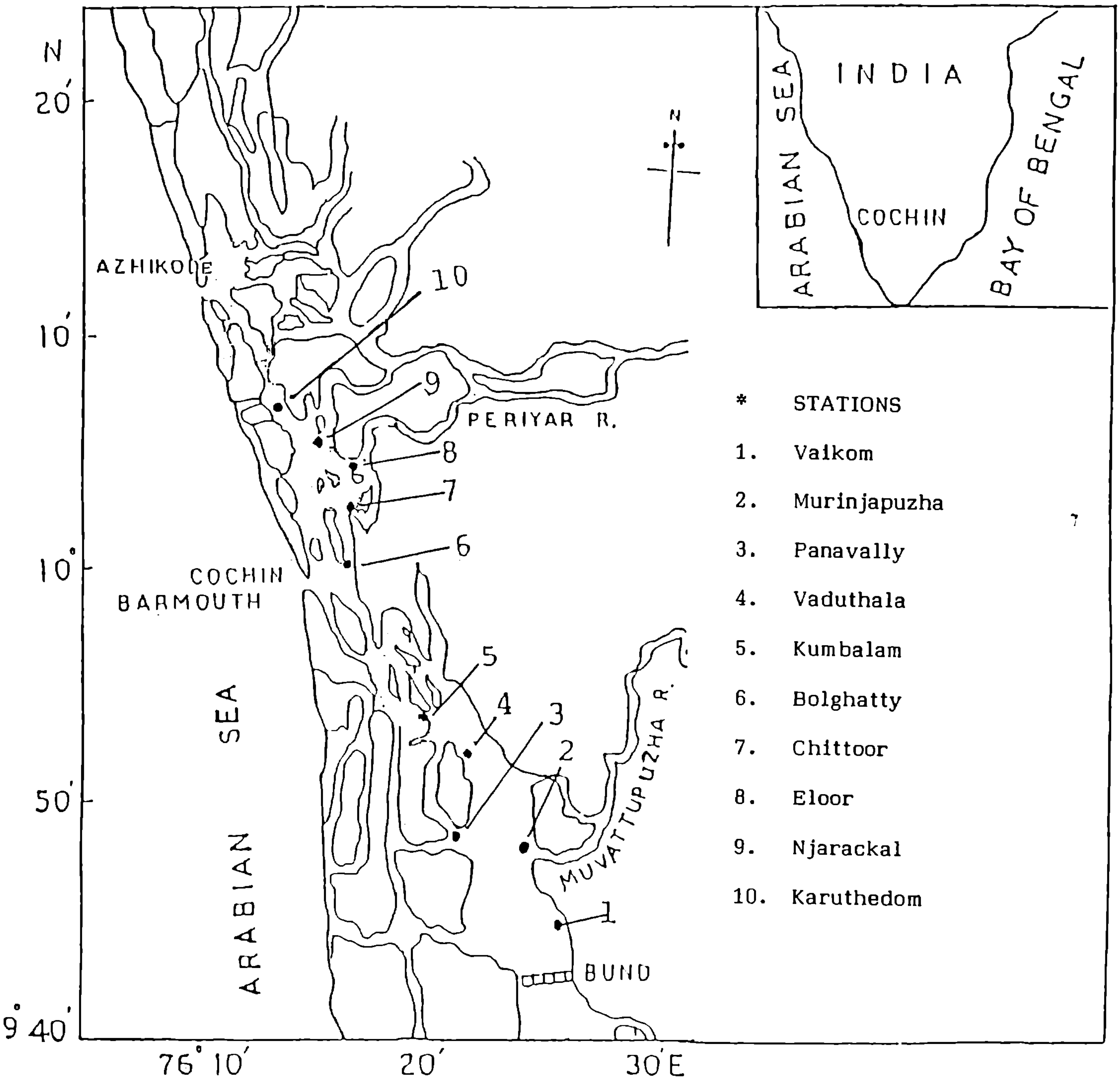


Fig. 1. Map showing the station locations

Table 2.1 Monthly mean values of salinity ($x10^{-3}$) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	0.32	0.04	0.09	0.20	0.06	0.02	2.50	4.00	9.00	10.00	6.00	8.00
2	0.25	0.02	0.05	0.20	0.03	0.04	2.00	0.12	0.25	2.00	0.69	0.69
3	0.16	0.16	0.06	0.19	0.06	0.02	3.00	10.00	5.00	10.00	11.00	6.00
4	0.48	0.03	0.12	0.30	0.09	0.12	3.50	15.00	10.00	13.00	13.00	6.00
5	0.25	0.04	0.15	0.38	0.09	0.30	6.00	25.00	23.00	22.00	20.00	12.00
6	0.32	0.52	0.25	2.20	1.50	0.60	27.00	30.00	28.00	22.00	14.00	15.00
7	0.05	0.31	0.06	0.20	0.06	0.01	3.00	5.00	5.00	3.00	0.00	1.00
8	0.05	0.02	0.20	0.20	0.20	0.02	5.00	0.25	2.00	2.50	0.24	0.34
9	0.32	0.08	6.90	0.60	0.03	0.30	16.00	12.00	17.00	17.50	14.00	10.00
10	0.81	0.26	7.20	2.30	0.90	0.29	10.00	15.00	20.00	22.00	22.29	14.29

Table 2.2 Monthly mean values of temperature (°C) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	26.9	27.0	28.0	27.5	29.5	29.7	30.0	29.0	31.0	30.5	30.5	29.5
2	27.0	27.5	27.5	27.0	27.5	28.0	29.0	27.0	30.0	30.0	30.0	29.0
3	26.4	27.0	28.0	28.0	29.0	29.0	29.5	27.0	30.2	29.0	29.0	29.5
4	26.4	26.5	28.0	27.5	28.0	29.0	29.0	27.5	29.2	29.0	29.0	28.5
5	27.0	28.0	28.0	28.0	28.0	29.0	29.0	26.0	29.2	28.5	28.5	28.5
6	25.9	26.5	27.0	27.0	28.0	28.0	27.0	27.5	29.5	29.9	29.5	29.0
7	26.0	25.0	26.5	26.5	27.5	28.0	28.0	27.5	30.5	29.2	29.2	29.5
8	25.0	24.5	27.0	27.0	26.5	28.7	28.5	28.0	30.5	29.0	29.0	29.5
9	25.5	26.0	28.0	29.5	27.0	30.0	29.0	29.0	31.0	30.0	30.0	30.0
10	27.1	27.0	28.5	30.0	27.5	29.0	29.5	29.5	30.5	30.5	30.5	30.0

Table 2.3 Monthly mean values of diss. oxygen ($ml.l^{-1}$) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	5.38	5.08	5.20	5.02	5.25	5.20	5.94	5.60	5.25	5.20	5.94	5.17
2	5.67	5.00	5.10	5.40	6.29	5.68	5.82	5.71	5.71	5.37	5.82	6.29
3	4.90	4.99	5.46	5.32	5.71	5.33	5.71	6.05	7.43	5.71	5.60	6.99
4	5.09	4.09	4.83	5.91	5.74	5.12	5.37	5.40	5.94	5.20	6.17	5.54
5	5.16	4.16	2.84	6.00	5.68	4.31	3.89	5.14	4.46	5.11	5.37	6.94
6	4.21	4.81	5.15	4.26	5.03	4.88	5.14	4.57	4.34	5.56	4.46	6.01
7	4.65	4.67	5.18	4.96	4.34	5.67	5.37	5.04	4.69	4.78	4.91	5.76
8	4.50	4.01	3.72	5.68	5.14	5.58	4.34	5.25	5.03	5.33	4.79	6.87
9	4.70	4.37	4.26	5.67	4.57	5.45	5.03	5.14	4.69	4.43	3.20	5.68
10	7.01	5.31	4.26	4.26	5.14	4.88	5.14	5.63	5.26	3.66	5.94	5.76

Table 2.4 Monthly mean values of pH at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	6.51	6.63	6.50	7.10	6.50	6.60	7.20	7.10	7.00	7.10	7.3	7.20
2	7.01	6.91	6.20	6.60	6.40	6.30	6.80	6.90	7.20	7.20	7.60	7.70
3	6.90	7.35	6.20	7.00	6.50	6.66	7.20	7.20	8.30	7.25	7.50	7.30
4	6.92	7.08	6.10	7.00	6.70	7.20	7.40	7.40	7.30	7.00	7.80	7.65
5	7.01	7.43	6.21	7.21	6.90	7.10	7.75	7.90	8.00	7.50	8.10	7.60
6	7.20	7.07	6.00	7.25	7.20	7.90	7.90	8.00	8.10	8.20	7.60	8.00
7	6.81	6.10	6.30	6.50	6.60	6.30	6.80	7.10	7.00	7.40	7.30	7.85
8	6.40	5.75	6.10	5.80	6.50	6.50	6.60	6.80	7.10	7.40	6.90	7.90
9	6.90	6 96	`6.40	7.15	7.10	7.10	7. 75	7.50	7.70	7.60	7.50	7.65
10	8.70	7.14	5.81	7.25	7.40	7.00	7.50	7.75	7.90	8.10	7.80	7.90

Table 2.5 Monthly mean values of SiO_3 ($mg.l^{-1}$) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	11.60	12.41	17.04	23.91	6.97	13.87	4.40	25.68	9.60	6.20	7.20	4.50
2	5.62	8.21	26.08	22.22	16.43	14.31	3.00	25.38	18.40	14.60	12.30	11.10
3	7.65	16.35	18.18	15.02	16.68	20.83	6.90	25.76	10.20	7.30	6.50	5.50
4	9.63	22.01	18.85	7.78	11.93	22.84	6.30	26.76	16.50	12.10	11.70	1.00
5	4.45	6.50	13.85	57.27	15.94	16.80	3.05	25.32	7.10	4.80	3.90	1.02
6	14.46	9.08	14.49	36.14	22.16	11.93	12.78	25.35	2.20	6.50	7.50	2.10
7	16.81	14.27	23.22	19.60	13.45	14.10	4.62	25.40	2.30	2.10	2.01	8.50
8	8.24	6.64	3.22	14.30	9.46	11.84	10.29	24.95	14.11	10.40	7.70	0.95
9	6.81	11.35	25.25	38.12	13.94	14.63	8.75	24.46	6.80	8.30	7.90	0.85
10	8.42	17.56	40.25	32.10	18.40	15.88	4.45	26.12	1.20	4.70	3.40	1.02

Table 2.6 Monthly mean values of NO_2-N (μg at l^{-1}) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	1.10	0.22	0.29	0.38	0.34	0.29	0.18	0.18	0.27	0.22	0.44	0.52
2	0.40	0.21	0.26	0.18	0.37	0.36	0.26	0.02	0.16	0.29	0.22	0.31
3	0.54	0.83	0.15	0.21	0.33	0.28	0.29	0.19	0.28	0.36	1.12	1.46
4.	0.47	0.26	0.27	0.22	0.35	0.26	0.76	5.50	0.12	0.57	0.76	0.92
5	0.36	0.13	0.29	0,29	0.42	0.19	5.21	0.21	0.14	0.15	0.48	0.81
6	1.41	0.25	0.52	0.13	1.52	0.98	1.49	0.16	1.22	2.30	2.12	2.21
7	0.96	0.12	0.31	0.12	1.73	0.19	5.10	10.60	0.64	0.16	0.18	2.46
8	1.23	0.28	0.15	0.46	1.02	9.80	8.21	10.50	0.62	0.27	0.32	0.52
9	1.41	0.61	0.49	082	0.51	0.46	2.51	0.71	1.01	0.42	0.35	1.42
10	0.52	0.44	0.63	0.28	0.46	0.28	0.98	1.20	0.62	0.31	0.91	0.52

Table 2.7 Monthly mean values of PO4-P (µg at l^{-1}) at different stations.

Stations	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	12.2	2.34	1.74	2.71	0.45	0.62	0.15	3.13	1.70	1.21	0.92	1.12
2	0.59	1.85	0.38	1.89	1.92	0.46	0.18	2.14	0.80	0.39	1.14	1.25
3	0.68	0.91	0.26	1.26	0.61	0.53	0.29	2.22	1.5	1.21	0.82	1.78
4	0.86	0.44	0.65	2.42	1.27	1.01	0.34	1.67	0.93	2.41	2.16	1.84
5	0.84	1.12	1.28	9.30	2.16	1.12	1.45	1.25	0.10	0.93	1.67	3.67
6	7.15	3.15	2.94	1.74	1.72	0.76	1.21	2.94	2.20	6.31	4.74	5.54
7	5.11	2.92	4.62	12.11	12.08	9.42	4.86	8.63	0.50	0.42	0.92	3.62
8	3.40	3.01	1.81	1.95	3.21	2.15	4.77	4.82	1.00	0.15	2.79	25.73
9	0.80	0.96	2.15	10.41	10.42	1.28	2.25	3.76	0.10	0.28	1.67	5.21
10	1.70	1.27	1.49	11.73	11.70	0.59	1.64	2.35	0.40	0.61	2.15	5.05

3

PERIPHYTON COLONIZATION

Introduction

Periphyton, organisms on sub-aquatic surfaces, forms an extremely heterogenous and complex association. The photosynthetic components of these include a diverse assemblage of algal forms that colonize nearly every conceivable type of substrate available. Aquatic biologists have become increasingly aware of the importance of periphyton as key primary producers (Wetzel, 1964; Persson et al., 1977; Loeb et al., 1983), pollution indicators of water quality (Singh and Gaur, 1989; APHA, 1992. Jayaprada and Raman , 1996) and nutrient removers from nutrient loaded water reservoirs (Vymazal, 1988). However, study of periphyton is often hindered by lack of retrievable natural substrata at the desired sampling station.Furthermore, it often is difficult to collect quantitative samples from these surfaces. Hence, artifical substrata have been used to provide a uniform surface type, area and orientation. The primary objective of the present study was to explain periphytic algal growth *in situ* on selected artificial substrata.

Material and Methods

Periphyton accrual *in situ* was studied on various substrata such as clay tiles, rocks, wood, metal sheets, shells of bivalves, plastic, painted surfaces and glass slides at a selected station in Cochin estuary. Thirty sets of test coupons of the above substrata in triplicate were suspended 30 cm below water surface by means of wooden floats. Daily each set of the coupons was pulled out with minimum disturbance and the associated periphyton was carefully separated with knives or scrapers and collected with the help of a camel hair brush in millipore filtered water. After preliminary observation and identification of the live materials, samples were transferred to polythene bottles and preserved in Lugol's solution. the surface area of the test coupons covered by periphyton was also noted. Quantitative analysis of the periphyton was carried out using a Sedgwick-Rafter cell and haemocytometer. The standing crop of periphyton was expressed in cell no./cm^2 of the substratum. Water samples were analysed for hydrological properties.

Salinity was estimated by Mohr-Knudsen method as described by Strickland and Parsons (1972). A SYSTRONICS-335 digital pH meter accurate to 0.01 pH unit was used to measure pH. Dissolved oxygen was estimated by Winkler method (Strickland and Parsons, 1972).Nitrite was estimated by the method described by Strickland and Parsons (1972).Reactive phsophate estimation was made by the method of Murphy and Riley (1962) where the extinction was measured in Spectrophotometer (HITACHI 150-20) at 885 nm. Multiple regression model and Pearson's coefficient of correlation (Snedecor and Cochran, 1968) was employed to find out the effect of hydrological parameters on the colonization of periphyton on different substrata. The variation in periphyton accumulation with respect to different substrata was studied using one-way ANOVA technique (Snedecor and Cochran, 1968).

Results and Discussion

Periphyton Accrual

The quantitative study of periphyton colonization on different substrata like wood, glass, plastic, metal sheets, painted surfaces, clay tiles, granite rocks and bivalve shells reveals (Table 3.1) that the colonization on these proceeds initially at an exponential rate for about two weeks. On clay tiles, after 24 h exposure, periphytic deposit of 0.03×10^3 cells/cm^2 was recorded. The colonization progressed steadily reaching the maximum on the 13^{th} day. Subsequently there was an immediate fall in cell concentration and remained more or less same. On rocky substrata the periphyton accumulation on the first day was 0.04×10^3 cells/cm^2 and recorded the maximum on the 10^{th} day. The first day accrual of periphytic algae on wooden sbustrata was 0.006×10^3 0.06×10^3 cells/cm^2 and proceeded at an exponential rate reaching a peak on the 13^{th} day. Plastic materials, glass slides, shells of bivalves, metal and painted surfaces also exhibited a similar trend. The periphytic algal biomass attained the maximum on these substrata between the 10^{th} and 14^{th} day followed by a decline and remained more or less same.Plastic material showed the maximum periphyton concentration of 12.6×10^3 cells/cm^2 on the 14^{th} day. Glass material, clay tile, and wood accumulated about 30.2×10^3, 19.9×10^3 and 23.7×10^3 cells/cm^2 respectively on the 13^{th} day. Rocks, metal and painted surfaces showed their highest standing crop of 17.7×10^3, 12.2×10^3 and 14.5×10^3 cells/cm^2 respectively on the 10^{th}

day. Shells recorded their highest periphyton concentration of about 21.2×10^3 cells/cm^2 on the 12^{th} day. The substrata like glass, wood, clay tiles and shells gathered comparatively more periphytic algae than others.

In all the substrata studied, periphyton colonization showed minor peaks without affecting the general trend . Within two weeks all the different substrata showed their maximum periphytic growth. The standing crop declined with siltation and infestation with Balanus sp. Since all the substrata were exposed to identical hydrographic conditions at a particular station, the fall in cell concentration in all of them must be due to sloughing, invertebrate infestation and grazing. The dominance of filamentous forms such as Mougeotia and Oscillatoria on substrata, after prolonged exposure, may be due to the fact that they are poorly grazed.

The periphyton concentration varied with substrata. This may be due to the difference in their texture. Smooth textured surface accumulate less silt and harbour less grazers than rough surfaced ones. The occurrence of greater periphyton concentration on glass slides may be due to this factor. Light is important factor limiting the periphyton colonization (Mc lntire et al., 1964; Gregory, 1980; Lowe et al., 1986, Nair et al., 1987). The exposure of substrata for less than two weeks may result in very sparse collection and more than this period may result in loss of materials due to sloughing. Hence the optimum period of accrual maxima on all substrata is between 10-14 days. The variation recorded in the rate of colonization of periphytic algae on the substrata studied is in agreement with the earlier observation that distribution of periphyton is extremely heterogenous on different substrata (Cooke, 1956).

Floral Composition

Periphytic algae recorded from the different artificial substrata during the experiment are given in the Table 3.2. Most of them get dispersed in the medium due to turbulence and remain as apparent plankton. They represent a `transitional flora' which on the availability of substrata transform to periphyton. Although pennate diatoms are more prone to periphytic nature, centric diatoms like Coscinodiscus radiatus, Skeletonema costatum and Thalassiosira subtilis are also found on the substrata whenever they are abundant in the estuary. The pioneer species such as Navicula gracilis and Amphora angusta were present throughout the period of observation on all the substrata indicating their greater adherence capcity, tolerance and adaptability. Their concentration has a direct influence on the standing crop of any substratum studied. The species composition of periphyton of a given substratum often changes with the exposure period. Certain algae recorded on a substratum disappear at a later stage. This may either be due to grazing effect or due to changes in the hydrographic parameters. Grazing causes decrease in species diversity (Lubchenco, 1978). The presence of dominant species such as Navicula gracilis, Amphora angusta, A. coffeaeformis, Gyrosigma scalproides, G. spencerii, Nitzschia closterium, N. seriata, Pleurosigma angulatum, P. aestuarii, Surirella fastuosa of Bacillariophyceae, Mougeotia of Chlorophyceae and Oscillatoria spp. of Cyanophyceae on all the substrata shows that there is no substratum specificity for them. The species composition of periphyton on the substrata studied is more or less similar as observed by Sladeckova (1962). However the occurrence of species such as Diploneis bombus, Pleurosigma naviculaceum, Biddulphia heteroceros, Gyrosigma fasciola, Licmophora californica, Melosira nummuloides, M. sulcata and Mastogloia braunii on some test coupons only may be due to the chance association resulting from their smaller number. Hydrographic parameters observed at the site during the study are shown in the Table 3.3.

Periphyton and Hydrography

Correlation of periphyton with the parameters (Table 3.4) such as salinity,pH, temperature, dissolved oxygen and nutrients was investigated by working out the product moment correlation coefficient, (r). The correlation coefficients were computed both for the original and log transformed values of periphyton concentration. The original values were found to show better relationship on the parameters. The periphyton values on `tile' was not found to be significantly correlated with any of the parameters. So also the values on `plastic'. Significant negative correlations were observed with salinity for the periphyton values on rock, wood, metal, painted area, shell and glass. The values on rock showed significant positive correlation with temperature also. Only the values on shell showed a significant correlation with pH (negative, in this case). The influence of temperature on painted area cannot be ruled out, though not significant. It can be seen that salinity is the most important parameter which influences, the periphyton values in the estuary.

Significant relationships are presented as scatter plots with the trend lines in Figs. 3.1 to 3.4.

From the multiple r square value (0.5117) of periphyton values on rock on temperature and salinity, it can be seen that about 51% of the variation in the periphyton values on rock are explained by the variations in temperature and salinity. Similarly, about 52% of the variations in the periphyton values on shell are explained by pH and salinity, the multiple r square value being 0.5202.

The variation observed in the periphyton concentration on different artificial substrata was analysed using one-way ANOVA technique (Table 3.5). The calculated F value (0.709) is less than the critical value for $V_1 = 7$ and $V_2 = 104$ and hence the difference in the periphyton concentration on different substrata was not significant (ANOVA ; $P < 0.01$).

The study shows the suitability of different substrata and the period of exposure required to get optimum periphytic growth. The magnitude of standing crop of periphyton on various substrata is indicative of their contribution to the total primary production of the estuarine ecosystem.

Summary

Colonization of periphytic algae on eight different substrata was studied for a period of one month. For the first two weeks, the rate of colonization of periphyton was found to be exponential on all the substrata and thereafter showed a conspicuous decrease. Substrata like wood, glass and bivalve shell showed comparatively higher rate of periphyton colonization. Various species of algae recorded from the different substrata consist mainly of pennate diatoms such as *Navicula gracilis*, *Amphora angusta*, *Nitzschia closterium*, *Gyrosigma spencerii*, *G. scalproides* and filamentous forms such as *Mougeotia adnata* of Chlorophyceae and *Oscillatoria* spp. of Cyanophyceae. No substratum specificity was noted among these algae. Utility of the different substrata and duration of exposure for the colonization of periphyton are discussed.

Table 3.1 Periphyton colonization on different substrata (No. X10^3 cm^{-2})

Day	Tile	Rock	Wood	Metal	Shell	Plastic	Painted Area	Glass
1.	0.03	0.04	0.06	0.11	0.20	0.04	0.12	0.01
2.	0.23	0.26	0.10	0.08	0.31	0.36	0.15	0.07
3.	0.66	0.20	0.03	0.11	0.08	0.09	0.10	0.15
4.	1.75	1.27	1.60	0.62	1.12	0.51	0.70	0.51
5.	1.54	2.90	0.84	0.32	1.93	0.75	0.88	0.38
6.	6.51	2.29	9.48	1.03	2.99	0.49	4.07	0.77
7.	13.79	4.12	8.00	3.86	7.06	7.38	1.54	2.05
8.	2.02	2.73	7.88	2.28	4.06	1.94	1.03	2.48
9.	1.56	0.96	7.21	0.35	0.54	0.30	0.33	3.58
10.	4.83	17.76	7.04	12.25	3.20	3.66	14.53	5.92
11.	2.81	1.12	4.92	7.82	9.79	0.85	6.65	6.88
12.	5.81	1.21	5.88	0.85	21.18	0.73	2.67	3.11
13.	19.90	4.95	23.77	9.27	7.35	9.30	8.13	30.19
14.	13.39	5.48	5.11	1.38	7.24	12.57	2.51	12.46
15.	10.46	1.62	11.15	3.03	6.65	1.10	1.56	6.44
16.	6.57	0.12	5.87	4.03	2.94	2.80	1.67	3.60
17.	0.26	0.76	0.56	0.53	0.31	0.37	0.60	0.75
18.	3.80	0.84	2.78	1.10	0.44	0.74	0.48	1.33
19.	2.80	0.96	1.33	0.31	0.92	0.39	0.35	1.48
20.	2.00	1.30	9.41	0.20	0.40	0.84	0.56	3.18
21.	2.12	2.17	1.39	0.65	1.46	3.80	0.70	2.86
22.	3.60	3.59	4.51	0.47	2.27	3.80	1.13	2.11
23.	2.09	7.71	5.40	0.54	3.52	3.99	1.47	1.67
24.	1.78	1.05	0.87	0.69	0.51	0.66	0.56	0.21
25.	2.24	5.10	2.80	3.33	1.80	1.77	1.35	9.78
26.	3.52	4.07	2.51	2.75	2.36	1.57	1.23	6.22
27.	6.83	1.34	2.42	1.54	3.22	1.12	1.42	2.91
28.	8.61	0.36	2.20	0.74	4.16	0.45	1.58	0.98
29.	2.75	6.88	4.77	3.62	6.27	2.57	3.88	7.11

Table 3.2 - Periphytic algae observed on different substrata

Algal forms	Substrata W	M	S	P	G	GR	T	PA
Amphora angusta Greg.	+	+	+	+	+	+	+	+
A. coffeaeformis Kutz.	+	+	+	+	+	+	+	+
Biddulphia pulchella Gray.	-	-	-	-	-	-	+	-
B. laevis Ehr.	+	-	-	+	-	+	+	+
B. rhombus W.Sm.	-	-	-	+	-	-	+	+
Coscinodiscus radiatus Ehr.	+	+	+	+	+	+	+	+
Diploneis bombus Ehr.	-	-	-	-	+	-	-	-
D. elliptica (Kutz) Cleve.	+	-	-	-	+	-	-	-
Fragilaria oceanica Cleve.	+	-	+	+	+	-	-	-
Gyrosigma balticum (Ehr.) Cleve.	-	+	-	+	-	+	-	-
G. fasciola Ehr.	-	-	-	+	+	+	+	+
G. scalproides Rab.	+	+	+	+	+	+	+	+
C. spencerii W. Sm.	+	+	+	+	+	+	+	+
Licmophora flabellata	-	-	-	+	-	-	-	-
Agardh Mastogloia braunii Grun.	-	-	-	-	-	+	-	+
Melosira nummuloides Agardh.	-	+	+	-	-	-	-	-
Navicula gracilis Ehr.	+	+	+	+	+	+	+	+
N. notabilis Grev.	-	-	+	-	-	+	-	-
Nitzschia closterium	+	+	+	+	+	+	+	+
W. Sm. N. longissima (Breb) Ralfs.	+	-	-	-	-	+	-	-
N. obtusa W. Sm.	-	+	-	-	+	-	-	-
N. panduriformis Greg.	+	-	+	-	-	+	+	-
N. seriata Cleve.	+	+	+	+	+	+	+	+
N. sigma W.Sm.	+	+	+	+	+	+	+	+
Pleurosigma angulatum	+	+	+	+	+	+	+	+
W.Sm. P. acuminatum Gran.	-	+	+	+	+	+	+	-
P. aestuarii W.Sm.	+	-	+	-	-	+	+	-
P. falx Mann.	-	-	+	+	+	+	-	+
P. naviculaceum Breb.	-	-	+	-	+	-	-	-
Skeletonema costatum	+	+	+	+	-	+	+	-
Surirella fastuosa Ehr.	-	+	-	+	-	-	-	+
Thalassiosira subtilis Gran.	+	+	+	+	+	+	+	+
Triceratium reticulatum Ehr.	-	+	+	+	-	-	-	-
Tropidoneis lepidoptera Cleve.	+	-	+	+	+	+	+	+
Mougeotia adnata Iyengar.	-	-	-	-	-	-	+	-
Oscillatoria spp.	+	+	+	+	+	+	+	+

(W - Wood, M - Metal, S - Shell, P - Plastic, G - Glass, GR - Granite, T - Tile, PA - Painted surface, `+' - Present , `-' - Absent)

Table 3.3 - Hydrographic parameters

Day	Salinity (‰)	pH	Do (ml/l)	Nitrite µg at/l	Phosphate µg at/l	Temp. (°C)
1	27.5	7.86	4.76	2.01	9.16	30.5
2	24.0	7.95	5.57	12.02	9.04	31.5
3	27.0	7.84	4.76	4.12	6.12	31.0
4	24.5	7.76	4.08	2.04	3.24	31.0
5	26.5	7.88	3.80	3.23	2.57	31.0
6	27.0	7.87	3.94	3.01	7.08	31.0
7	25.0	7.67	5.26	2.14	8.11	31.5
8	24.0	7.83	3.86	4.28	6.07	31.0
9	22.5	7.97	4.76	3.26	9.42	31.5
10	17.5	7.86	4.08	2.02	11.64	32.0
11	21.5	7.56	6.12	3.00	8.29	31.2
12	21.0	7.65	3.40	2.31	11.20	30.5
13	17.5	7.81	3.91	2.12	6.10	30.1
14	25.8	7.82	4.09	3.20	4.02	30.0
15	21.5	7.52	4.27	2.20	3.18	30.0
16	15.5	7.46	6.12	1.02	4.22	29.5
17	15.0	7.51	4.21	1.28	3.04	29.0
18	12.8	7.41	5.71	5.08	2.67	29.2
19	13.5	7.39	6.12	5.22	4.24	29.5
20	12.0	7.36	6.23	1.08	11.56	30.2
21	17.5	7.56	5.90	2.15	5.70	30.0
22	15.2	7.50	3.86	3.26	4.64	30.5
23	12.4	7.49	6.70	4.40	6.04	30.5
24	12.8	7.51	5.90	1.48	2.14	30.9
25	11.5	7.47	4.91	2.07	2.20	30.5
26	18.6	7.67	5.22	3.12	4.16	30.2
27	24.3	7.82	4.60	3.07	3.87	30.5
28	33.3	8.03	5.81	5.28	3.01	30.5
29	14.7	7.56	6.21	5.02	5.26	30.8

Table 3.4 Correlation matrix of periphyton *vs* hydrological parameters

	Tile	Rock	Wood	Metal	Shell	Plastic	Paint area	Glass	Plankton	NO_2	PO_4	Temp	Diss.O_2	pH	Sal.
Tile	1.00000														
Rock	.31365	1.00000													
Wood	.78374	.29286	1.00000												
Metal	.43743	.75556	.57797	1.00000											
Shell	.42747	.03510	.31569	.17365	1.00000										
Plastic	.88303	.40415	.54178	.37315	.25980	1.00000									
Paint area	.36392	.84127	.50335	.93442	.20381	.29496	1.00000								
Glass	.78450	.28345	.84330	.58634	.27700	.70694	.49609	1.00000							
Plankton	.41097	.03993	.09034	.04077	.09759	.32479	-.13176	-.11424	1.00000						
NO_2	-.24446	-.18920	-.26942	-.20292	-.22403	-.17376	-.20562	-.17227	-.07941	1.00000					
PO_4	-.02576	.00278	.29397	.28736	.11828	-.24610	.22790	.03002	.09592	.14484	1.00000				
Temp.	-.27468	.61551	-.11935	.48784	-.31329	-.27003	.50785	-.28113	.16148	.16196	.20788	1.00000			
Diss.O_2	-.20786	-.26361	-.27641	.07736	-.29696	-.14572	-.10772	-.17151	.27989	.41636	.32666	.20124	1.00000		
pH	-.25366	.06977	-.08460	-.29397	-.66699	-.12761	-.17852	-.09129	-.33954	.35195	-.04734	.10014	-.19630	1.00000	
Sal.	-.36278	-.57044	-.62485	-.80800	-.39807	-.24297	-.76984	-.62155	.14661	.02930	-.31807	-.37867	.09456	.19312	1.00000

(N=14, $r = \pm 0.53$, $P < 0.05$)

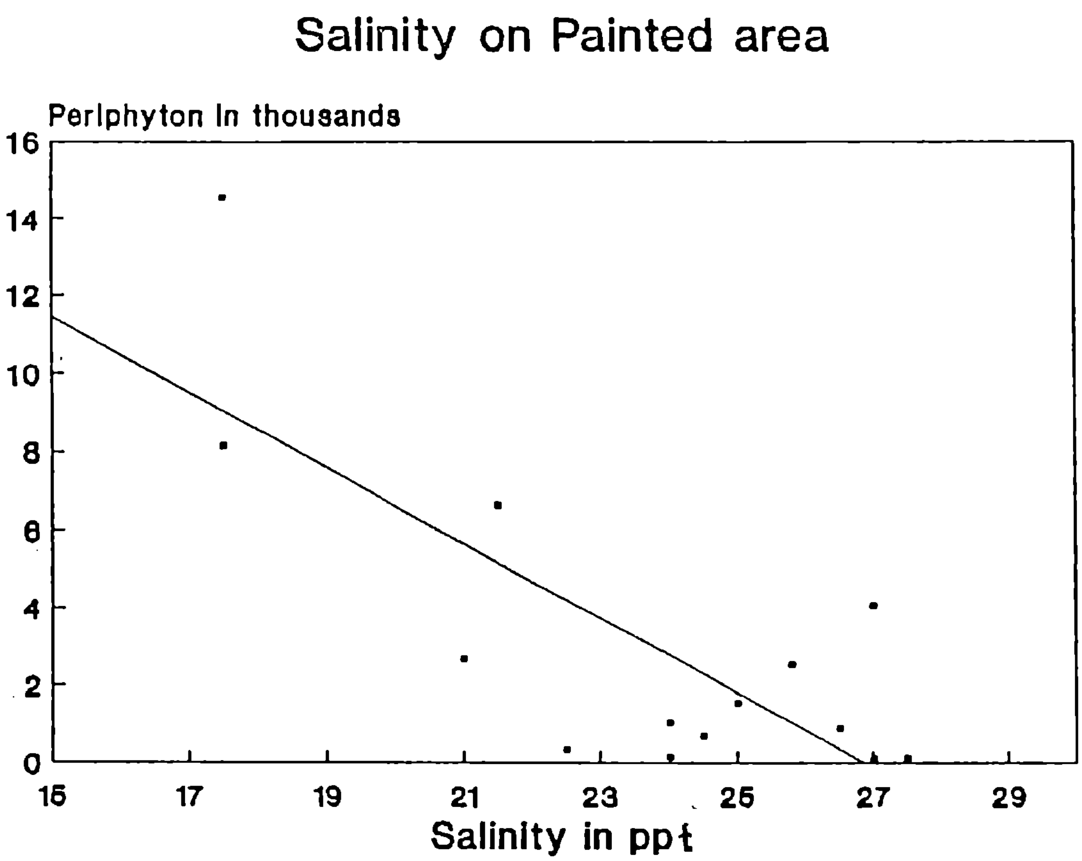
Table 3.5 - **ANOVA of periphyton concentration on different substrata**

Source	SS	DF	MS	F ratio
Bet. samples	149525536.00	7	21360790.00	0.709
Within samples	3134668544.00	104	30141044.00	
Total	3284194048.00	111		

SS - Some of Squares

MS - Mean Square

DF - Degree of Freedom



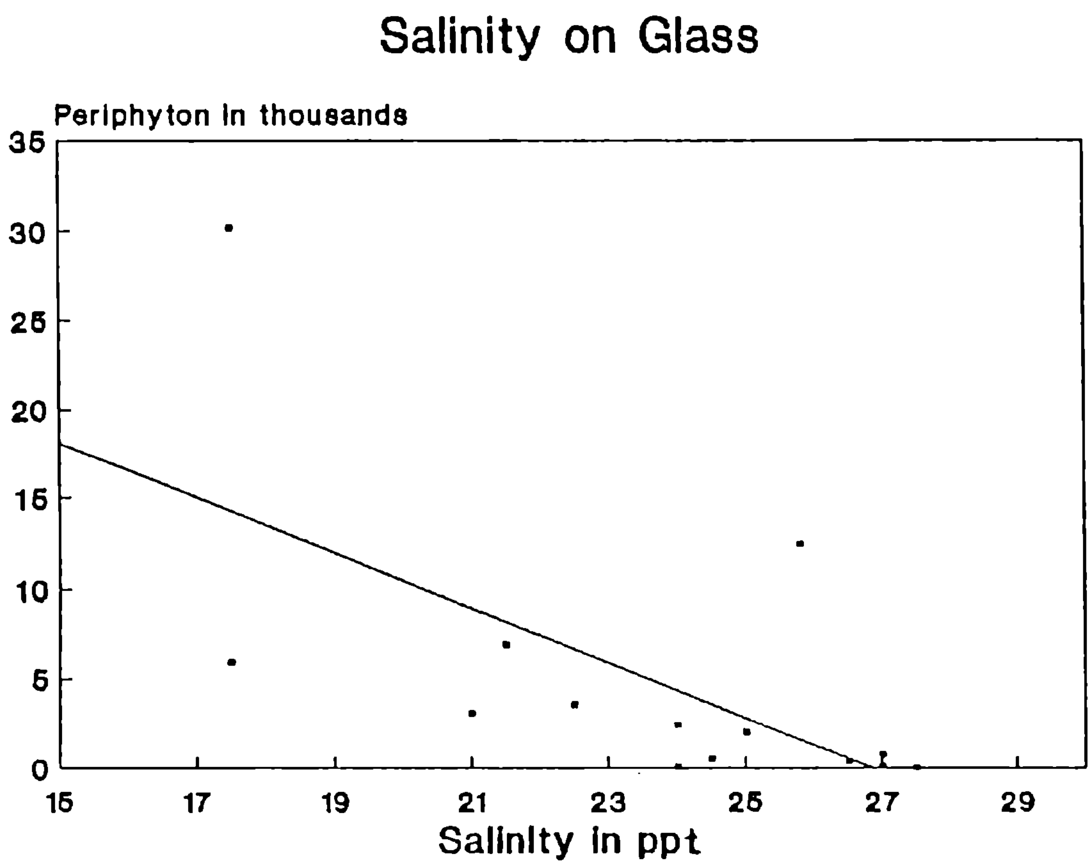


Fig. 3.1 Scatter plots with the trend lines

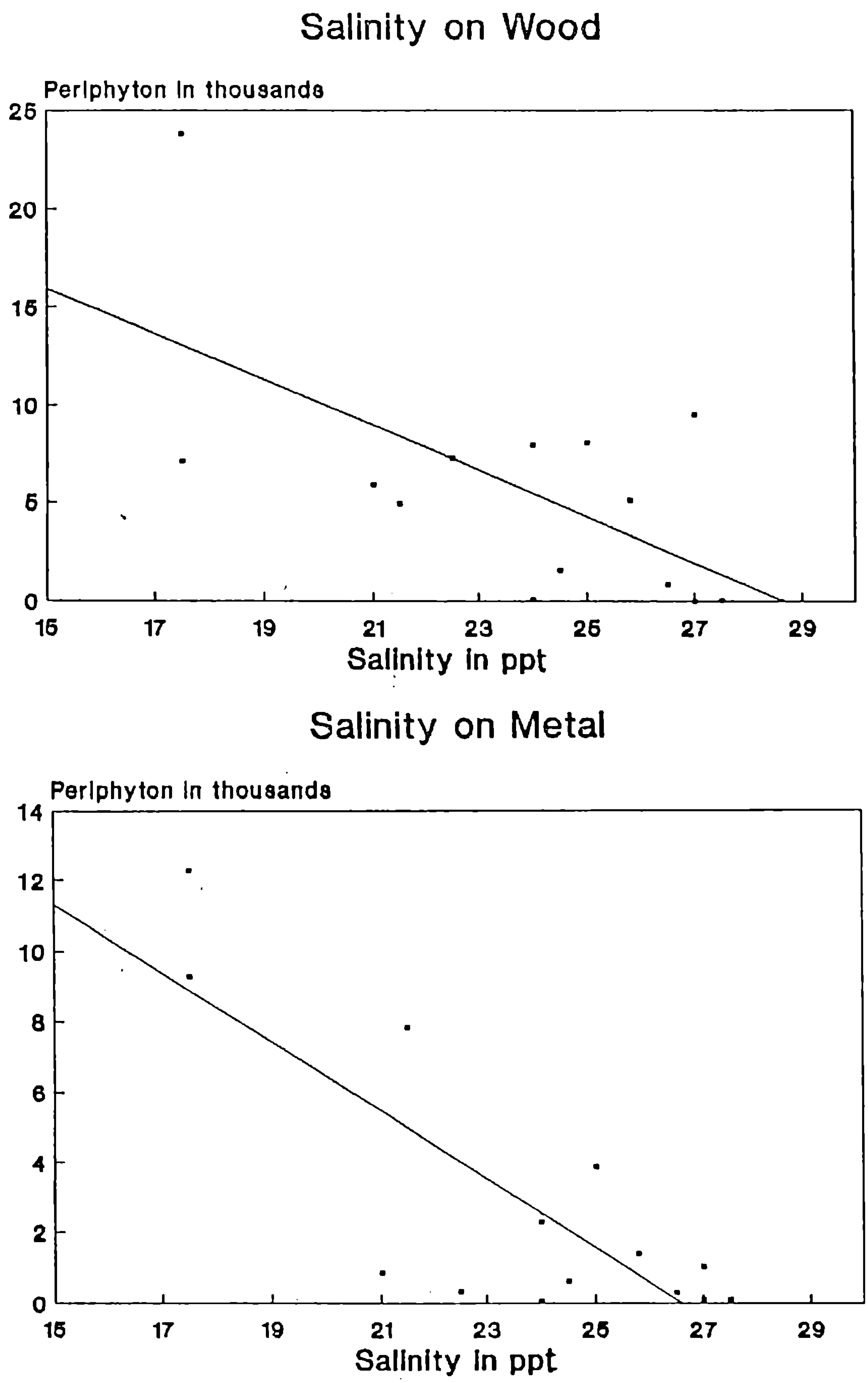
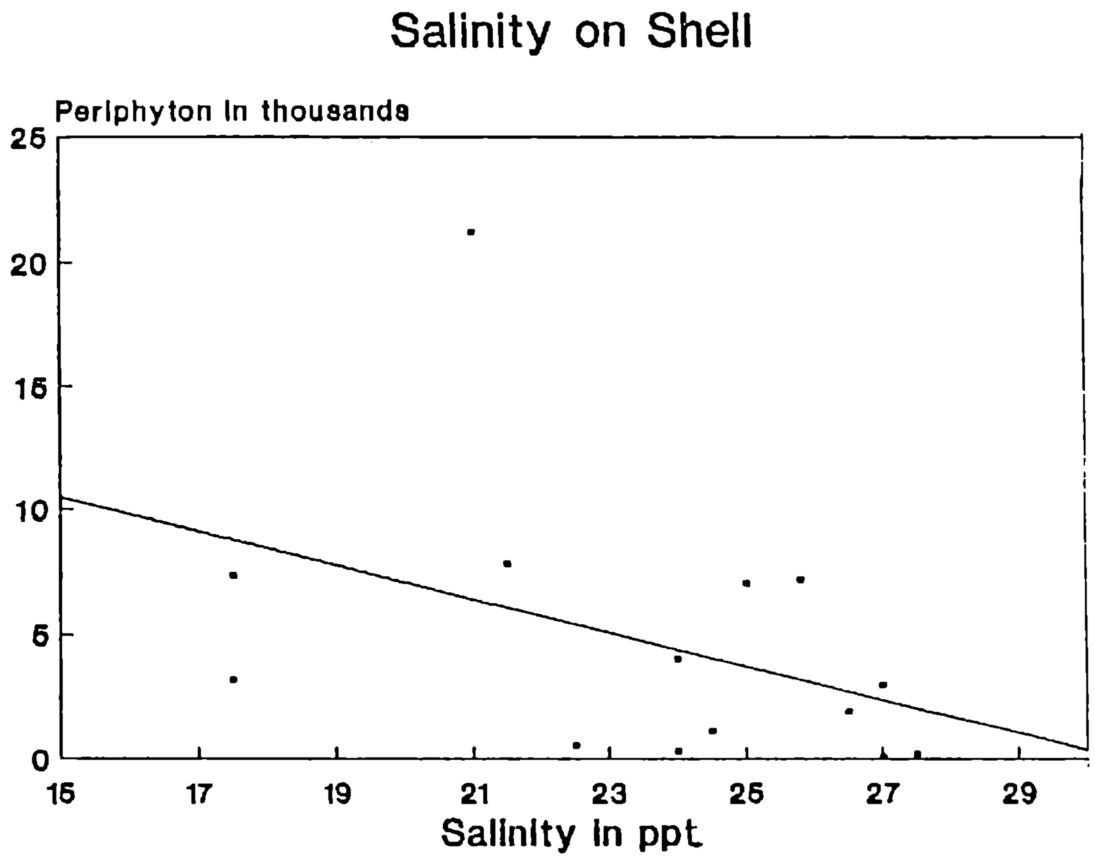


Fig. 3.2 Scatter plots with the trend lines



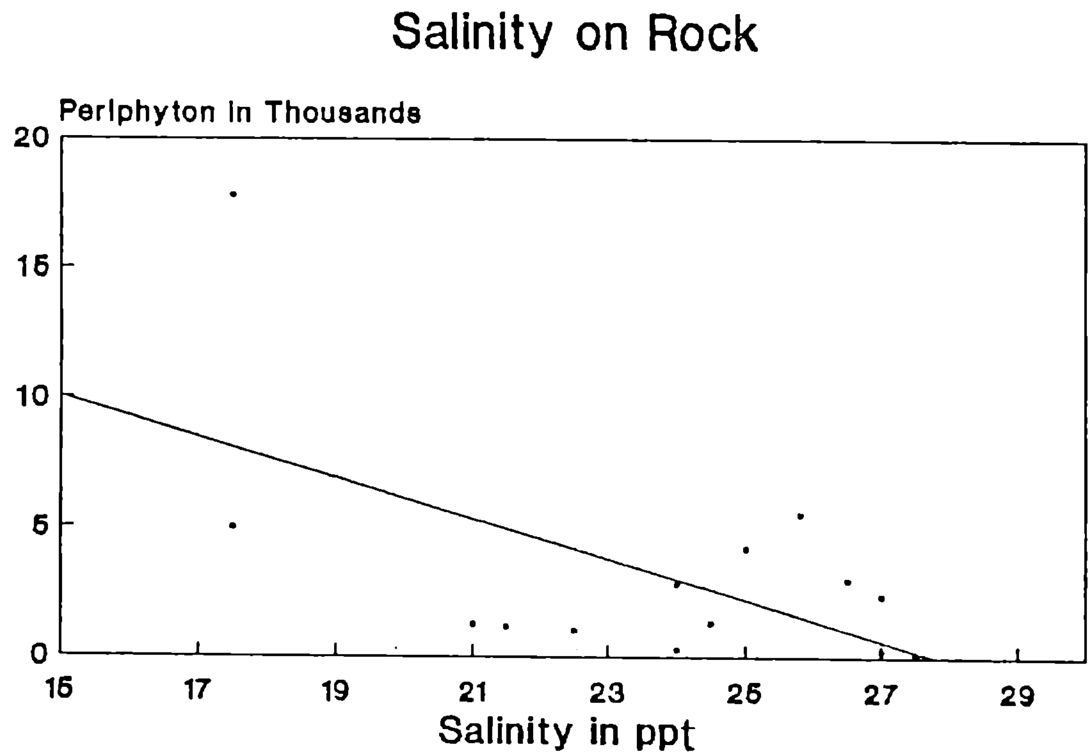
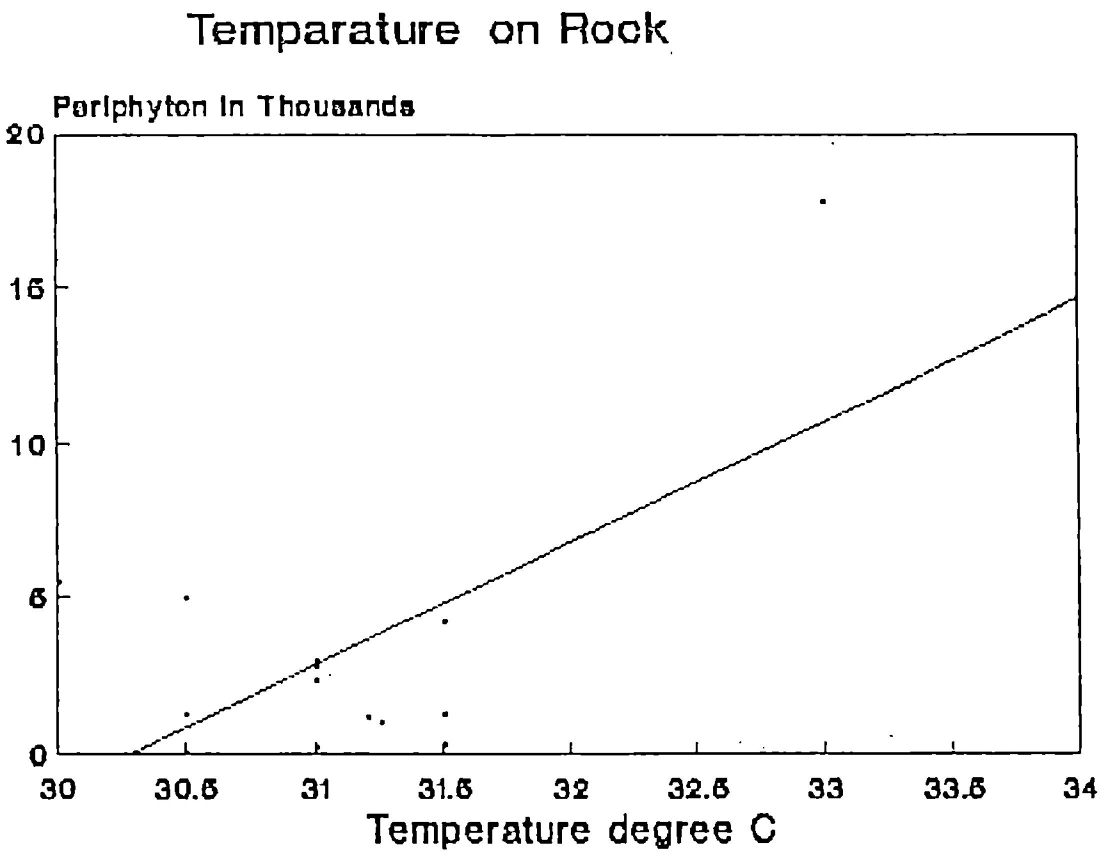


Fig. 3.3 Scatter plots with the trend lines



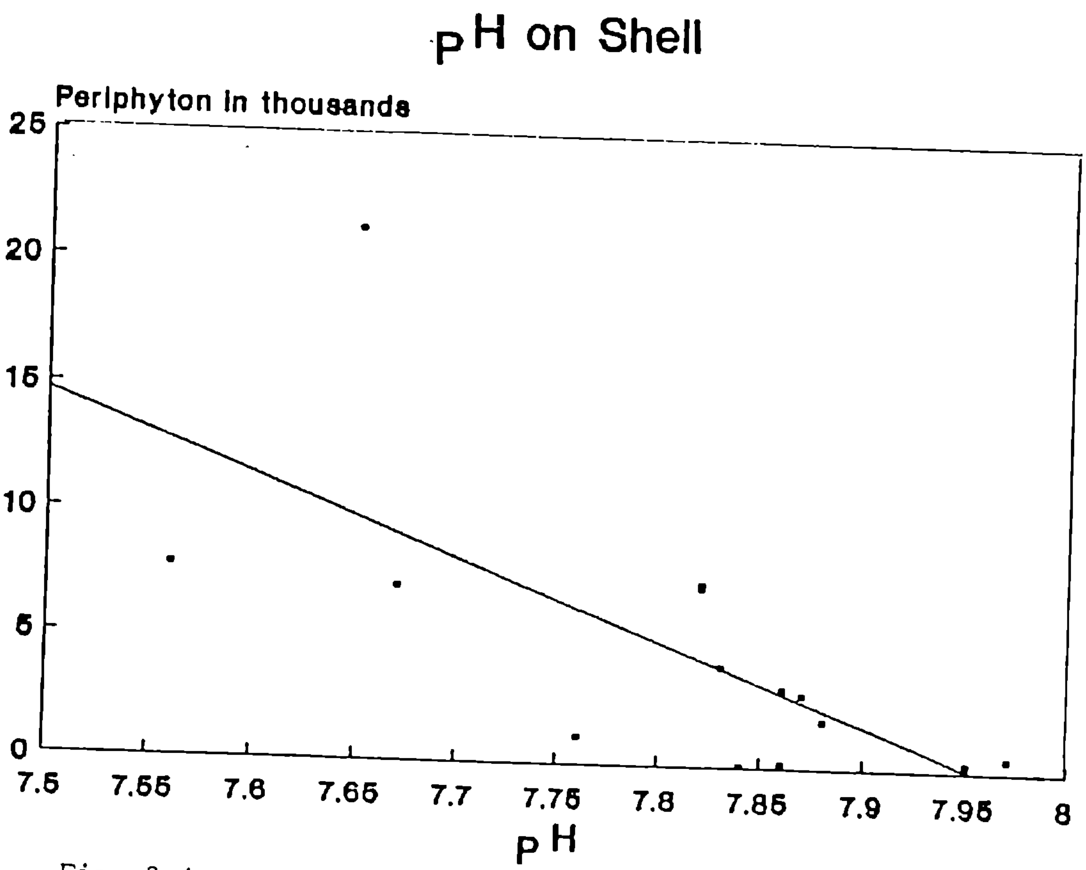


Fig. 3.4 Scatter plots with the trend lines

4

SEASONAL AND SPATIAL VARIATION

Introduction

Periphytic algae growing on stones, aquatic macrophytes and other submerged objects are useful in assessing the role of pollutants in the ecology of lakes, streams and estuaries (Sladeckova, 1962). They also effectively influence the productivity of any aquatic environment. In shallow waters the major groups of autotrophs are algal plankton, periphyton, sediment microflora and macrophytes.Although information on various aspects of algal plankton and their role in the productivity of Cochin estuary is available (George, 1958; Qasim et al., 1969, 1972; Gopinathan, 1972; Joseph and Pillai, 1975), information on periphytic algae and other autotrophs from Cochin backwater is wanting. Present study was undertaken to gather information on the qualitative and quantitative distribution of periphytic flora of the ecosystem.

Material and Methods

Ten locations (1-5, south of Cochin barmouth, 6-10 north of Cochin barmouth) from the backwater were surveyed for qualitative and quantitative distribution of periphytic algae during 1993-94. Periphytic algae from these locations were collected by using plain 25 by 75 mm glass slides (APHA, 1992).

At least three replicate slides mounted on wooden floats were suspended 30 cm below the water surface. Samples were collected fortnightly by pulling out the slides causing minimum disturbance. The associated periphyton was carefully scraped using scalpel and camel hair brush in millipore filtered water. After preliminary observations and identification of the live material, samples were transferred to polythene bottles and preserved in Lugol's solution. The algal forms were identified by consulting the standard and recent publications (Subramanyan, 1946; Desikachary, 1959; Randhawa, 1959; Hendey, 1964; Philipose, 1967; Gonzalves, 1981; Gopinathan, 1975, 1984; Jin Dexiang et al., 1985).

Scrapings from the slides were dispersed in suitable volume of preservative with vigorous shaking. Quantitative estimation of periphyton was done using a Sedgwick-Rafter cell. Periphyton concentration was expressed as number of cells per square centimeter of substrate area, calculated as follows:

$$\text{Cells/cm}^2 \text{ slide surface} = \frac{\text{Cells/ml suspended scrapings} \times \text{total volume of scrapings}}{\text{area of slide, cm}^2}$$

Results and Discussion

The periphytic flora of Cochin backwater comprised 66 species of diatoms, 8 of Chlorophyceae and 2 of Cyanophyceae (Table 4.1). Nearly 86% of periphytic algae belonged to Bacillariophyceae. Out of these, 7 genera and 9 species belonged to centrales and 24 genera and 57 species to pennales. The dominant species among the centrales were Melosira nummuloides, Biddulphia laevis and Thalassiosira subtilis and pennales were Navicula gracilis, Amphora angusta, A. coffeaeformis pleurosigma acuminatum, P. aestuarii, Gyrosigma spencerii, G. scalproides, Nitzschia closterium, N. obtusa and Achnanthes brevipes. Species of Navicula and Pleurosigma were recorded from almost all the stations studied. The Chlorophyceae comprised of 8 species consisting about 11% of the periphytic flora. The dominant among them were Mougeotia adnata and Spirogyra jogensis. Blue green algae were represented only by two genera ie. Oscillatoria and Merismopedia. The former being recorded from all the locations surveyed.

Qualitative Distribution

Among the 29 species of periphytic algae reported from station 1, 21 species were observed in monsoon, 17 in post-monsoon and 13 in pre-monsoon. Navicula gracilis, N. notabilis, Gyrosigma spencerii, Pinnularia interrupta and Mougeotia adnata dominated during monsoon Gyrosigma spencerii, Navicula gracilis and Oscillatoria spp. were present in greater numbers during the post-monsoon while Navicula gracilis, Nitzschia obtusa and N. seriata dominated during pre-monsoon. At stn.2 twenty seven species were observed during the period of study. Of these Navicula gracilis, Climacosphenia moniligera, Gomphonema lanceolatum, Nitzschia obtusa, N. sigmoidea and Oscillatoria spp. were observed in all seasons. The total number of species recorded at stns. 3, 4 and 5 were 30, 34 and 32 respectively.

Navicula gracilis, Pleurosigma aestuarii, Thalassiosira subtilis, Oscillatoria spp. were the dominant forms found in these stations. Stns. 6 and 7 recorded 34 species each. Navicula gracilis and Oscillatoria spp. were very common in both the stations. In addition to these, species such as Amphora angusta, Pleurosigma aestuarii and Nitzschia closterium were also present in large numbers. The lowest number of species was reported at stn.8. Out of the 25 species observed, Navicula gracilis, Amphora coffeaeformis, Achnanthes brevipes, Eunatogramma sp. and Navicula bicapitata were present throughout the period of study. The green alga, Stigeoclonium flagelliferum, was reported only from this station. The number of species observed at stns. 9 and 10 were 26 and 32 respectively. Navicula gracilis, Gyrosigma spencerii and Mougeotia adnata were commonly distributed in these stations. Navicula capitata was observed in significant numbers throughout the period at stn.10.

Analysis of algal species observed at different stations during monsoon, post-monsoon and pre-monsoon revealed that some are found only during monsoon and a few in pre-monsoon. 30 species were observed throughout the year irrespective of the seasonal changes in the estuary. These were Achnanthes brevipes, Amphora angusta, A.coffeaeformis Climacosphenia moniligera, Diploneis elliptica, D.subovalis, Eunatogramma sp, Gomphonema lanceolatum, Gyrosigma scalproides, Gyrosigma spencerii, Navicula bicapitata, N.capitata, N.gracilis, N.hasta, Nitzschia closterium, N.obtusa, N. seriata, N.sigma, N.sigmoidea, Pinnularia interrupta, P.braunii, Pleurosigma acuminatum, P. aestuarii, P. naviculaceum, Surirella fastuosa, Synedra ulna, Terpsinae musica, Thalassiosira subtilis, Mougeotia adnata and Oscillatoria spp. 15 species, Amphora ostrearea Biddulphia laevis, B. rhombus, Caloneis brevis, Campylodiscus echeneis, Gomphonema sphaerophorum, Navicula plicata, Nitzschia longissima, Mastogloia braunii, Surirella tenera, Closterium acerosum, Cosmarium contractum, C. pyramidatum, Spirogyra jogensis and Stigeoclonium flagelliferum were reported at different stations only during monsoon period. Achnanthes coarctata, Coscinodiscus radiatus, Gyrosigma balticum, G. macrum, Hantzschia amphioxys, Nitzschia vermicularis, Triceratium reticulatum were reported only during the pre-monsoon period in different parts of the backwater.

Owing to the mixing of waters in the Cochin backwater from the major rivers and to the banking of water during flood tides from the Arabian Sea, the periphytic algae was found to be composite in character. There was continuous fluctuation in turbidity, salinity and temperature of water in the ecosystem throughout the year. Periphyton at all the stations consisted mainly of diatoms. Next to diatoms, green algae were the dominant flora during certain seasons especially at stations 1,2,7 and 8. The blue-green algae, though present at all stations were not so conspicuous as the diatoms and green algae. Oscillatoria was the only genus of this group in almost all the stations surveyed. In Table 4.2-11, averages of the relative abundance of total periphyton and its component groups of algae, viz. the diatoms, the green and the blue green algae at different stations during monsoon, post- monsoon and pre-monsoon for one year are given. Forms observed at stations 1 and 2 were more or less of the same quality, though differing in quantity. The two stations being away from the opening to the sea , the periphytic algae consisted mainly of freshwater and euryhaline forms. At stations 5, 6, 9 and 10, which are near to the mouth of the estuary marine and brackishwater forms predominated. A few freshwater forms were also observed in these stations but during monsoon season only.

The Bacillariophyceae were the major component in the periphytic algae at all times in the estuary. The percentage composition of species representing Bacillariophyceae, Chlorophyceae and Cyanophyceae were 86%, 11% and 3% respectively. Most of the green-algal members of periphyton flora were observed during monsoon, their standing crop being comparatively less in other seasons. This clearly shows that they are recruited to the backwater through the major rivers discharging freshwater into the ecosystem. However, Mougeotia adnata was present in most of the stations and throughout the period of study indicating its typical estuarine adaptability. Oscillatoria among Cyanophyceae is the only genus widely distributed throughout the year in the estuary as periphyton. Though relatively less in number and species composition than the diatoms and green algae, this group was present at all stations.

Quantitative Distribution

The monthly mean values of periphyton cell concentration at 10 different stations are shown in the Table 4.12. The highest value of 31576 cells/cm^2 was reported from stn. 4 during February while the lowest 1430 cells/cm^2 from Njarackal during December. Monthly average cell concentration for the estuary varied from 9817 cells/cm^2 in October to 16288 cells/cm^2 in January. The annual mean periphytic algal cell concentration of different stations showed that it varied from 9625 cells/cm^2 to 18907 cells/cm^2. Stn.1 recorded the maximum annual mean cell concentration while stn. 8 recorded the lowest. Southern stations of the estuary in general recorded higher cell concentration than northern stations. Seasonal variation in the standing crop (Table 4.13) showed that the post-monsoon had higher cell concentration. The seasonal mean values of satanding crop for monsoon, post-monsoon and pre-monsoon periods were 13454, 13576 and 13229 cells/cm^2 respectively. Comparatively lower values of standing crop were recorded from Stations 2 and 8. Turbulence of water at stn. 2 due to the confluence of one of the tributories of Muvattupuzha River with the backwater may be responsible for the low periphyton standing crop. The toxic component of industrial effluents from factories such as FACT, TCC and Cominco Binani were discharged into one of the tributories of Periyar River. Stn. 8 is located near its confluence with the backwater on the northern side. Incidently the lowest annual mean value of standing crop was recorded from this station.

Temporal and spatial variation in periphytic algal cell concentration was analysed (Table 4.14) using a 2-way ANOVA. A significant variation in standing crop occurred among the different stations (ANOVA; $P < 0.05$) in the estuary. A significant difference was observed in the monthly values of standing crop in all the stations (ANOVA; $P < 0.05$).

The seasonal averages of periphpyton concentration showed that post-monsoon season had a greater cell concentration than monsoon or pre-monsoon. During south west monsoon (June-September) freshwater forms were recruited into the estuary. Stns. 1 and 2 showed dominance of these forms especially during monsoon. The post-monsoon flora comprised mainly of euryhaline species. Stations located near the barmouth showed the presence of many stenohaline forms especially during pre-monsoon. The study revealed remarkable species diversity in the periphytic flora of Cochin backwater which formed a significant autotrophic component of the ecosystem . The mangnitude of standing crop (Table 4.12) is indicative of their contribution to the total primary production.

Summary

The floral composition of periphyton in Cochin backwater from June 1993 to May 1994 were studied using artificial substrata. The floral composition depends on the recruitment of freshwater forms through the rivers and marine forms through the flood tides of Arabian Sea. Periphytic flora

in Cochin backwater comprised 66 species of Bacillariophyceae, 8 of Chlorophyceae and 2 of Cyanophyceae.

A significant variation was observed in the spatial and temporal distribution of standing crop of periphytic algae, the range being 5.9×10^{3} to 1.8×10^{4} cells $/cm^{2}$. The monthly mean values for the estuary varied from 9.8×10^{3} to 1.6×10^{4} cells / cm^{2}.

The magnitude of standing crop observed at various stations is indicative of its role in the primary productivity of the estuary.

Table 4.1 Periphytic flora in Cochin estuary

Bacillariophyceae

Achnanthes brevipes Agardh.
A. coarctata Berb.
Amphora angusta Greg.
A. coffeaeformis Kutz.
A. ostrearea Breb.
Biddulphia pulchella Gray.
B. laevis Ehr.
B. rhombus (Ehr.) W. Sm.
Caloneis brevis Ehr.
C. permagna (Bail.) Cleve
Campylodiscus echeneis Ehr.
Coscinodiscus nitidus Greg.
C. radiatus Ehr.
Climacosphenia moniligera Ehr.
Cymbella marina Castracane
Diploneis bombus Ehr.
D. elliptica (Kutz) Cleve.
D. subovalis Cleve.
Eunatogramma sp.
Eunotia diodon Ehr.
Fragilaria oceanica Cleve.
Gomphonema lanceolatum Kutz.
G. sphaerophorum Ehr.
Grammatophora marina (Lyngb.) Kutz.
Gyrosigma balticum (Ehr.) Cleve.
G. fasciola Ehr.
G. macrum W. Sm.
G. scalproides Rab.
G. spencerii W. Sm.
Hantzschia amphioxys (Ehr.)
Licmophora flabellata (Grev.) Agardh.
Mastogloia braunii Grun.
Melosira nummuloides (Bory) Agardh.
Navicula bicapitata Lagerstedt.
N. capitata Ehr.
N. gracilis Ehr.
N. hasta Pantocsek.
N. hennedyei Cleve.
N. notabilis Grev.
N. plicata Donk.
N. pusilla W. Sm.
Nitzschia closterium (Ehr) W. Sm.
N. longissima (Breb.) Ralfs
N. obtusa W. Sm.
N. panduriformis Greg.
N. seriata Cleve.
N. sigma W. Sm.
N. sigmoidea (Ehr.) W. Sm.
N. vermicularis (Kutz.) Hantzsch.
Okedenia inflexa Breb.
Pinnularia braunii (Grun.) Cleve.
P. interrupta W. Sm.
Pleurosigma acuminatum (Kutz) Grun.
P. angulatum W. Sm.
P. distortum W. Sm.
P. aestuarii W. Sm.
P. falx Mann.
P. naviculaceum Breb.
Striatella unipunctata Agardh.
Surirella fastuosa Ehr.
S. tenera Greg.
Synedra ulna Ehr.
Terpsinae musica Ehr.
Thalassiosira sublilis (Oslenfeld) Gran.
Triceratium reticulatum Ehr.
Tropidoneis lepidoptera (Greg.) Clev.

Chlorophyceae

Chlorella conglomerata (Olt.)
Closterium acerosum Ehr.
Cosmarium contractum Kutz.
C. pyramidatum Greg.
Mougeotia adnata Iyengar.
Oedogonium rufescens Wittrock.
Spirogyra jogensis Iyengar.
Stigeoclonium flagelliferum Kutz.

Cyanophyceae

Merismopedia elegans A. Braun.
Oscillatoria spp.

Table 4.2 Seasonal variation of periphytic flora at stn.1

Sl. No.	Algal forms	Monsoon	Post-monsoon	Pre-monsoon
1.	Achnanthes brevipes	*215	----	----
2.	Amphora angusta	282	458	1962
3.	Bidulphia laevis	150	----	----
4.	Climacosphenia moniligera	----	1261	----
5.	Coscinodiscus nitidus	----	----	39
6.	Gomphonema sphaerophorum	569	----	----
7.	Gyrosigma balticum	69	----	34
8.	G.macrum	----	----	39
9.	G.scalpriodes	561	219	----
10.	G.spencerii	2119	2482	----
11.	Navicula bicapitata	----	509	----
12.	N. capitata	465	----	----
13.	N. gracilis	3110	1989	6105
14.	N. notabilis	2852	247	----
15.	Nitzschia longissima	420	----	----
16.	N. obtusa	----	857	4750
17.	N.seriata	----	734	----
18.	N.sigma	1518	292	3418
19.	Pinnularia interrupta	3239	----	----
20.	Pleurosigma acuminatum	447	466	34
21.	P.aestuarii	596	78	1099
22.	Striatella unipunctata	66	----	103
23.	Synedra ulna	----	76	1099
24.	Thalassiosira subtilis	1499	659	40
25.	Closterium acerosum	363	----	----
26.	Cosmarium pyramidatum	69	----	---
27.	Mougeotia adnata	1993	1059	----
28.	Spirogyra jogensis	734	368	----
29.	Oscillatoria sp.	----	435	555
	Total	21336	16108	19227

*Cell numbers per cm^2

Table 4.4 Seasonal variation of periphytic flora at stn. 3

Sl. No.	Algal forms	Monsoon	Post-monsoon	Pre-Monsoon
1.	Achnanthes brevipes	----	----	*2798
2.	Amphora angusta	----	100	200
3.	A. coffeaeformis	150	160	150
4.	Biddulphia laevis	68	----	600
5.	Caloneis brevis	----	48	269
6.	Campylodiscus echeneis	----	----	53
7.	Climacosphenia moniligera	940	4317	----
8.	Eunatogramma sp.	----	50	----
9.	Eunotia diodon	----	275	----
10.	Gomphonema sphaerophorum	----	1136	----
11.	Grammatophora marina	443	----	----
12.	Melosira nummuloides	----	----	1160
13.	Navicula capitata	----	412	60
14.	N.gracilis	533	2556	3657
15.	Nitzschia closterium	----	----	1976
16.	N.obtusa	645	517	916
17.	N.sigma	430	67	390
18.	N.sigmoidea	----	288	433
19.	N.vermicularis	----	----	63
20.	Pinnularia braunii	----	45	----
21.	P.interrupta	1050	604	----
22.	Pleurosigma acuminatum	150	----	125
23.	P.aestuarii	----	53	400
24.	Surirella fastuosa	165	----	----
25.	Synedra ulna	----	99	195
26.	Terpsinae musica	----	622	616
27.	Thalassiosira subtilis	745	140	465
28.	Mougeotia adnata	350	----	----
29.	Spirogyra jogensis	425	5167	----
30.	Oscillatoria sp.	----	125	6021
	TOTAL	6094	16781	20547

*Cell numbers per cm^2

Table 4.5 - Seasonal variation of peripytic flora at stn. 4

Sl. No.	Algal forms	Monsoon	Pre-monsoon	Post-monsoon
1.	Achnanthes brevipes	*18	2218	409
2.	Amphora angusta	218	230	222
3.	A.coffeaeformis	----	----	254
4.	Biddulphia laevis	333	----	----
5.	Caloneis brevis	300	----	----
6.	Climacosphenia moniligera	----	1566	2015
7.	Diploneis bombus	----	45	----
8.	D.elliptica	18	120	158
9.	Gomphonema sphaerophorum	----	43	----
10.	Gyrosigma balticum	----	884	872
11.	G.macrum	----	320	247
12.	G.scalproides	738	590	867
13.	G.spencerii	304	1083	2904
14.	Melosira nummuloides	----	----	245
15.	Navicula capitata	37	----	80
16.	N.gracilis	3897	2541	2028
17.	Nitzschia obtusa	1470	960	----
18.	N.seriata	1726	132	----
19.	N.sigma	368	----	317
20.	N. sigmoidea	170	----	----
21.	Pinnularia braunii	----	120	----
22.	Pleurosigma acuminatum	37	318	----
23.	P. angulatum	----	----	575
24.	P. aestuarii	870	322	515
25.	P.naviculaceum	230	400	165
26.	Striatella unipunctata	----	50	----
27.	Surirella fastuosa	248	600	447
28.	Synedra ulna	205	----	----
29.	Terpsinae musica	1287	435	156
30.	Thalassiosira subtilis	2100	305	245
31.	Closterium acerosum	----	58	----
32.	Mougeotia adnata	2373	950	----
33.	Spirogyra jogensis	1706	----	----
34.	Oscillatoria sp.	3043	856	1383
	Total	21696	15146	14104

*Cell numbers per cm^2

Table 4.6 - Seasonal variation of periphytic flora at stn. 5

Sl. No.	Algal forms	Monsoon	Post-Monsoon	Pre-Monsoon
1.	Achnanthes brevipes	210	1020	----
2.	Amphora angusta	----	290	450
3.	A. ostrearea	----	1421	----
4.	Caloneis brevis	38	----	165
5.	Coscinodiscus radiatus	----	----	170
6.	Climacosphenia moniligera	68	720	----
7.	Cymbella marina	----	540	----
8.	Fragilaria oceanica	325	130	----
9.	Gomphonema sphaerophorum	315	93	----
10.	Gyrosigma macrum	----	----	300
11.	G. scalproides	327	----	325
12.	G. spencerii	2400	----	1208
13.	Navicula gracilis	2040	3902	600
14.	N. hasta	----	397	----
15.	N. hennedyei	----	617	85
16.	N. plicata	255	----	----
17.	Nitzschia closterium	917	----	220
18.	N. obstusa	----	580	255
19.	N. seriata	1945	----	----
20.	Pinnularia interrupta	640	----	----
21.	Pleurosigma acuminatum	1005	----	508
22.	P. aestuarii	300	1875	800
23.	P. naviculaceum	----	----	650
24.	Striatella unipunctata	----	360	----
25.	Surirella fastuosa	625	----	171
26.	S. tenera	937	----	----
27.	Synedra ulna	793	305	188
28.	Thalassiosira subtilis	505	220	612
29.	Triceratium reticulatum	----	----	905
30	Mougeotia adnata	----	----	300
31.	Spirogyra jogensis	82	455	----
32.	Oscillatoria sp.	2190	2203	1045
	Total	15917	15128	8957

Cell numbers per cm^2

Table 4.7 - Seasonal variation of periphytic flora at stan. 6

Sl. No.	Algal forms	Monsoon	Post monsoon	Pre monsoon
1.	Achnanthes brevipes	----	621	200
2.	A. coarctata	----	----	288
3.	Amphora angusta	390	720	1321
4.	A. coffeaeformis	----	117	355
5.	Biddulphia laevis	90	----	----
6.	Caloneis brevis	----	158	----
7.	Diploneis subovalis	-----	1093	----
8.	Eunatogramma sp.	45	----	----
9.	Fragilaria oceanica	----	825	----
10.	Gomphonema sphaerophorum	248	541	----
11.	Gyrosigma scalproides	----	133	----
12.	G. spencerii	1395	1000	----
13.	Hantzschia amphioxys	----	----	400
14.	Licmophora flabellata	----	400	1060
15.	Melosira nummuloides	567	----	----
16.	Naviecula gracilis	2404	1950	4568
17.	N. hasta	275	450	160
18.	Nitzschia closterium	108	188	1314
19.	N. obtusa	1005	657	----
20.	N. seriata	200	----	----
21.	N. sigma	2050	----	200
22.	Okedenia inflexa	300	----	----
23.	Pinnularia braunii	----	105	----
24.	Pleurosigma acuminatum	----	240	700
25.	P. angulatum	----	815	----
26.	P. aestuarii	950	170	160
27.	P naviculaceum	----	----	210
28.	Surirella fastuosa	395	----	----
29.	S. tenera	----	365	----
30	Terpsinae musica	----	390	325
31.	Thalassiosira subtilis	70	1073	190
32.	Cosmarium pyramidatum	1000	140	----
33.	Mougeotia adnata	1300	685	----
34.	Oscillatoria sp.	550	895	600
	Total	12042	13731	12051

Cell numbers per cm^2

Table 4.8 - Seasonal variation of periphytic flora at stn. 7

Sl. No.	Algal forms	Monsoon	Post monsoon	Pre monsoon
1.	Achnanthes brevipes	----	692	2475
2.	Amphora angusta	150	----	----
3.	A. coffeaeformis	----	1066	----
4.	A. ostrearea	779	----	----
5.	Caloneis brevis	----	-----	205
6.	Diploneis subovalis	120	420	120
7.	Eunatogramma sp.	96	----	200
8.	Eunotia diodon	----	31	----
9.	Gomphonema lanceolatum	1500	----	----
10.	G. sphaerophorum	30	----	----
11.	Gyrosigma scalpriodes	220	220	750
12.	G. spencerii	685	617	890
13.	Melosira nummuloides	----	350	----
14.	Navicula bicapitata	475	221	----
15.	N. gracilis	5129	1189	1773
16.	N. hennedyei	----	1656	-----
17.	Nitzshcia closterium	----	-----	50
18.	N. longissima	80	----	----
19.	N. obtusa	398	346	550
20.	N. panduriformis	----	350	----
21.	N. seriata	694	700	215
22.	Okedenia inflexa	1210	215	----
23.	Pinnularia braunii	1010	330	1150
24.	P. interrupta	1224	320	230
25.	Pleurosigma acuminatum	----	212	----
26.	Thalassiosira subtilis	189	1525	----
27.	Chlorella conglomerata	----	----	2230
28.	Closterium acerosum	55	68	----
29.	Cosmarium contractum	106	----	----
30.	C. pyramidatum	30	----	----
31.	Mougeotia adnata	----	151	2758
32.	Oedogonium rufescens	----	716	29
33.	Spirogyra jogensis	----	106	----
34.	Oscillatoria sp.	1050	235	245
	Total	15230	11736	13870

Cell numbers per cm^2

Table 4.9 - Seasonal variation of periphytic flora at stn. 8

Sl. No.	Algal forms	Monsoon	Post-monsoon	Pre-monsoon
1.	Achnanthes brevipes	----	----	38
2.	Amphora angusta	----	468	----
3.	A. coffeaeformis	20	94	325
4.	Biddulphia rhombus	160	----	----
5.	Cymbella marina	----	30	----
6.	Diploneis subovalis	80	----	----
7.	Eunatogramma sp.	1244	247	1395
8.	Eunotia diodon	----	32	----
9.	Gomphonema lanceolatum	610	----	255
10.	Gyrosigma scalproides	----	185	----
11.	Navicula bicapitata	240	50	595
12.	N. gracilis	700	1000	958
13.	N. hasta	----	717	----
14.	Nitzschia longissima	505	40	----
15.	N. seriata	----	765	19
16.	N. sigmoidea	----	----	275
17.	Pnnularia interrupta	----	50	190
18.	Synedra ulna	----	117	115
19.	Tropidoneis lepidoptera	----	795	245
20.	Chlorella conglomerata	-----	-----	377
21.	Cosmarium contractum	-----	-----	240
22.	Mougeotia adnata	-----	188	-----
23.	Oedogonium rufescens	-----	2858	162
24.	Stigeoclonium flagelliferum	595	----	----
25.	Oscillatoria sp.	439	351	118
	Total	4593	7987	5307

Cell numbers per cm^2

Table 4.10 - Seasonal variation of periphytic flora at stn. 9

Sl. No.	Algal forms	Monsoon	Post monsoon	Pre monsoon
1.	Achnathes brevipes	1714	----	250
2.	A. coarctata	----	1120	955
3.	Amphora angusta	----	708	320
4.	A. coffeaeformis	1053	240	180
5.	Diploneis subovalis	----	130	----
6.	Eunatogramma sp	312	----	----
7.	Fragilaria oceanica	----	170	----
8.	Gomphonema sphaeorphorum	440	577	----
9.	Gyrosigma scalproides	244	82	----
10.	G. spencerii	2916	143	415
11.	Melosira nummuloides	-----	----	745
12.	Navicula gracilis	190	3260	1646
13.	N. hasta	----	160	205
14.	Nitzschia closterium	----	----	185
15.	N. obtusa	2293	1015	----
16.	N. seriata	----	92	340
17.	Pleurosigma acuminatum	1528	----	----
18.	P. angulatum	----	----	420
19.	P. falx	----	55	56
20.	Surirella fastuosa	----	60	56
21.	Synedra ulna	22	249	----
22.	Thalassiosira subtilis	25	145	----
23.	Chlorella conglomerata	----	170	525
24.	Cosmarium pyramidatum	----	105	----
25.	Mougeotia adnata	1447	31	1163
26.	Osicllatoria sp.	----	350	370
	Total	12184	8862	7831

Cell numbers per cm^2

Table 4.11 - Seasonal variation of periphytic flora at stn 10.

Sl. No.	Algal forms	Monsoon	Post monsoon	Pre monsoon
1.	Achnanthes brevipes	750	1519	1517
2.	A. coaretata	----	----	995
3.	Amphora angusta	----	----	412
4.	A. coffeaformis	130	----	220
5.	Biddulphia pulchella	----	255	----
6.	Campylodiscus echeneis	290	----	----
7.	Diploneis subovalis	832	208	----
8.	Eunatogramma sp.	----	----	----
9.	Fragilaria oceanica	----	370	----
10.	Gomphonema lanceolatum	118	180	----
11.	Gyrosigma scalproides	----	392	----
12.	G. spencerii	533	480	1430
13.	Mastogloia braunii	250	----	----
14.	Melosira nummuloides	----	1365	790
15.	Navicula bicapitata	475	----	----
16.	N. capitata	2756	700	668
17.	N. gracilis	863	720	1317
18.	N. hasta	----	300	950
19.	N. notabilis	----	467	----
20.	N. plicata	----	120	205
21.	Nitzschia longissima	68	95	----
22.	N. obtusa	1575	625	----
23.	N. seriata	1705	1170	----
24.	N sigma	----	1125	115
25.	N. sigmoidea	----	----	647
26.	Pinnularia interrupta	----	----	1550
27.	Pleurosigma acuminatum	75	370	----
28.	P. aestuarii	70	130	525
29.	P. angulatum	----	220	375
30.	Thalassiosira subtilis	----	----	925
31.	Mougeotia adnata	500	875	2000
32.	Osicillatoria sp.	2287	713	1293
	Total	13227	12399	15990

Cell numbers per cm^2

Table 4.12 - Monthly mean values of periphytic algal cell numbers at stations 1-10

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1.	20160	16230	19037	29897	11806	12933	24694	14984	22998	18416	16416	15240
2.	12540	4010	15380	16760	13360	10728	18838	28597	20890	15930	9162	11447
3.	3622	3750	4040	12960	2848	8798	27259	28209	8305	20065	24376	29439
4.	21824	16085	27023	21830	8872	20700	16330	14672	31576	14090	2910	7834
5.	21226	4768	21020	16650	14790	23418	13650	8653	7580	6880	12047	9320
6.	8380	12990	14670	12126	11492	16370	9260	17793	12000	10125	18357	7720
7.	18749	20750	12322	9095	13437	10847	6620	16043	18934	10000	2644	23900
8.	6013	1740	2700	7920	5904	14742	3800	7501	5920	2510	4920	7875
9.	11994	9142	13540	14060	10668	8958	1430	14390	3984	5660	2391	19290
10.	18100	17852	8143	9000	5000	10107	22448	12040	17540	14410	17000	15010
Avg	14260	10731	13787	15029	9817	13760	14432	16288	14972	11808	11022	14707

Values per cm^2

Table 4.13 - Periphytic algal cell numbers (Seasonal Average) in the Cochin backwater

Stations	Monsoon	Post-monsoon	Pre-monsoon
1. Vaikom	21336	16108	19277
2. Murinjapuzha	12174	17886	14361
3. Panavally	6094	16781	20547
4. Vaduthala	21696	15146	14104
5. Kumbalam	15917	15128	8957
6. Bolghatty	12042	13731	12051
7. Chitoor	15230	11736	13870
8. Eloor	4593	7987	5307
9. Narackal	12184	8862	7831
10. Karuthedom	13277	12399	15990
Average	13454	13576	13229

Values per cm^2

Table 4.14 - Analysis of variance of standing crop (temporal and spatial)

Source	SS	DF	MS	F
Bet.Cols.	519598912.00	11	47236264.00	1.141
Bet.Rows.	1557626880.00	9	173069648.00	4.179
Error.	4100001024.00	99	41414152.00	
Total	6177226752.00	119		

5

COMMUNITY STRUCTURE

Introduction

Investigations on periphytic algae in Cochin estuary (Sreekumar and Joseph, 1995a, 1995b, 1996) have gathered information regarding the floral composition, seasonal and spatial variation, and factors influencing periphytic growth. A variety of studies have appeared concerning the structure (Cooper and Wilhm, 1975; Hein and Koppen, 1979; Eloranta, 1982) or function (Orhon, 1975; Marcus, 1980) of periphytons in different ecosystems. Efforts were also made to relate the changes in the periphyton community structure with the level of pollutants using introduced substrata (Cooper and Wilhm, 1975; Singh and Gaur, 1989). Various diversity indices, similarity index and biomass of periphytic algal community are often used for monitoring pollution levels. Richness, evenness, diversity and similarity indices, which are essential for understanding community structure are dealt with reference to the periphytic algae in Cochin backwater.

Material and Methods

Periphyton samples for the qualitative and quantitative study were collected from 10 different locations (Fig.1) in Cochin estuary. Detailed method of collection (APHA, 1992) and identification were described in chapter IV. Hydrographical parameters such as salinity, dissolved oxygen and nutrients such as nitrite, phosphate and silicate were determined following the standard methods (Strickland and Parsons, 1972)

Diversity Indices:-

Species diversity may be thought of as being composed of two components (Ludwig and Reynolds, 1988). The first is the number of species in the community, which the ecologists refer to as **species richness.** The second component is **species evenness** or equitability. Eveness refers how the species abundances (number of individuals, biomass cover etc.) are distributed among the species. Diversity indices incorporate both species richness and evenness into a single value. The same diversity index value can be obtained for a community with low richness and high evenness as for a community of high richness and low evenness.

Richness Index

Species richness was calculated according to Margalef's (1958) formula.

$$R = \frac{S-1}{\ln(n)}$$

where R = Species richness

S = Total number of species in the community

n = Total number of individuals in the community

Evenness Index

Species evenness was worked out according to Sheldon (1969)

$$E = \frac{e^{H'}}{S}$$

where E = Evenness index

eH' = Hill's diversity no.

S = Total number of species in the community.

Diversity Index

Diversity indices incorporate both species richness and evenness into a single value. Computation of species diversity in periphytic algae was made using Shannon-Weaver index (Pielou, 1975)

$$H' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$$

where H' = Diversity index

n = Total number of individuals in the community

ni = Total number of individuals in a species

Similarity Index

Similarity index is a simple and elegant measure of comparing stations for obtaining an integrated picture of the biotopes and calculated using Sorensen's (1948) equation :

$$S = \frac{2c}{a + b} \times 100$$

where 'c' = The number of species common at both stations and 'a' is the number of species at one station and 'b' is the species at the other station. S = index of similarity.

Results and Discussion

Environmental Factors

Environmental parameters such as salinity, temp., pH and dissolved oxygen and nutrients such as silicate, nitrite and phosphate were studied (Table 5.1). Water temperature ranged from 26.3 to 30.1 ^{0}C. Monthly variation in salinity was in the range from 0.12 to 14.07 x 10^{-3}. Generally salinity showed a decreasing trend from barmouth (station 6) to station 1, towards south and station 8, towards north ($1 < 2 < 3 < 4 < 5 < 6 > 7 > 8$). Salinity at stations 9 and 10 were similar to that of station 6 because of their proximity to the second permanent opening of the backwater into the sea. A decline in salinity at all stations was noticed during south-west monsoon (June - September). A steady increase in salinity was found during post-monsoon (October - January) and the highest being recorded during pre-monsoon (February - May) period. Dissolved oxygen concentration of water ranged from 4.63 to 5.85 ml. l^{-1}. The pH of water ranged from 6.24 to 7.73. The lowest monthly mean value of silicate (3.01 mg.l^{-1}) was noted in May and the highest (27.37 mg.l^{-1}) in September. The mean values of nitrite and phosphate ranged between 0.34 and 2.25 ug at. l^{-1} and 0.93 and 6.23 ug at.l^{-1} respectively.

Species Richness, Diversity, Evenness and Hill's Diversity Number-

The pattern of diversity (Table 5.2) indices showed varying trends at different stations studied. In general diversity indices showed comparatively higher values during monsoon and post-monsoon periods than those in pre-monsoon. The maximum R (Margalef, 1958) value (2.38) was at station 4 during post-monsoon and the minimum (1.06) at station 8 during post-monsoon. The maximum H'(Shannon-Weaver index) value (2.88) was at station 6 during post-monsoon and the minimum (1.76) at station 1 in the pre-monsoon period. Similarly the maximum N (Hill's diversity number) value (17.93) was recorded during pre-monsoon period at station 6 while the minimum (5.84) during pre-monsoon period at station 1. These clearly show the abundance and high diversity of species during monsoon and post-monsoon periods. No significant seasonal variation was observed in the case of E (eveness or equitability) values.

Floral Similarity

Floral similarity was measured using `trellis diagram' by pooling the total number of species over a period of one year at one station with another (Fig. 5.1). The abundance of Achnanthes brevipes, Amphora angusta, A. coffeaeformis, Gyrosigma scalproides, G. spencerii, Navicula gracilis, Nitzschia obtusa, N.seriata, N. closterium, N. sigma, Pleurosigma aestuarii, P. accuminatum, Surirella fastuosa, Synedra ulna and Thalassiosira subtilis at the stations studied accounted for the similarity between stations.

Species Composition

Periphytic flora of Cochin backwater comprised 66 species of Bacillariophyceae, 8 of Chlorophyceae and 2 of

Cyanophyceae (Table 5.3). The number of species recorded at 10 stations varied from 25-34. The maximum number of species (34) was reported at stations 4,6 and 7 while the minimum (25) was noted at stn.8.

Population Density

Monthly occurrence and abundance of periphyton standing crop at 10 stations are given in Fig 5.2. The average periphyton cell numbers in the estuary varied from 9.8×10^{3} to 1.6×10^{4} cells/cm^{2}. The highest standing crop (4.1×10^{4}) was reported from station 4 during February and the lowest (1.4×10^{3} cells/cm^{2}) from station 9 during December.

Correlation of periphytic algal biomass with the envrionmental parameters such as salinity, dissolved oxygen, temperature, pH, silicate, nitrite and phosphate was investigated by working out the correlation coefficient (r) (Table 5.4). Though salinity is one of the most fluctuating factors, no significant relationship with periphyton standing crop was observed except in station 3 . In general, though there was no significant correlation between periphyton and dissolved oxygen, significant positive correlation was observed at station 8. This station is apparently polluted due to its proximity to effluents from the nearby industrial concerns. Freshwater influx during monsoon removes toxic materials and increases the concentration of the dissolved oxygen. This facilitated the higher periphyton accrual during monsoon at this station. Temperature showed a significant positive correlation at station 3 while pH values showed a negative correlation with perihyton at station 5. These results are in agreement with the earlier studies (Sreekumar and Joseph,1995a) in the ecosystem. Though significant correlation between periphyton and nitrite was not observed in general, at station 8 a significant positive correlation was observed. Phosphate values did not seem to act as limiting factor for periphyton in this estuary.

Several studies on agricultural streams have found lack of positive correlation between periphyton biomass and either nitrate or phosphate (Kilkus et al., 1975; Moore, 1977). Similar results were obtained in this study also.Periphytic algae are known to take up nutrients from both water and sediment which got adhered to the substrata (Carlton and Wetzel, 1988; Hansson, 1988a). Hence they are not as sensitive as phytoplankton to nutrients in water. Moreover different seasons of the estuary are characterised by typical flora , response of which varies with species. The monsoon season is dominated by freshwater forms whereas premonsoon is dominated by stenohaline species. It is during the post-monsoon season, that the typical estuarine flora (euryhaline) flourish well. Incidently higher periphytic biomass was recorded during the post-monsoon season. The average periphyton cell numbers for monsoon, post-monsoon and pre-monsoon were 1.34×10^{4} , 1.35×10^{4} cm and 1.32×10^{4} cm^{-2} respectively. It is the qualitative variation induced by recruitment of riverine and marine flora that render the standing crop more or less uniform.

In Cochin backwater, the species diversity of periphytic algae was comparatively low. In Vellar estuary (south-east coast of India), Rajan <u>et al.</u> (1987) had reported higher values of species diversity index (3.37-4.73) of benthic diatoms. Similarly, a higher species diversity index ranging from 3.35 to 4.26 was reported in Mississipi salt marsh (Sullivan, 1978). However, diversity index values reported (Joseph and Sreekumar, 1993) for the phytoplankters of the estuary during pre-monsoon, monsoon and post-monsoon were 2.6, 2.1 and 2.2 respectively. Periphytic alage in most of the stations showed slightly higher values of diversity index than phytoplankton except for the pre-monsoon season.

Earlier studies (Boesch, 1972; Rajan <u>et al.</u>, 1987) for benthic diatoms had shown that the maximum H'value coincided with the occurrence of the maximum number of benthic diatom species. Stations 6 and 10 that showed higher values of H' during post-monsoon season recorded abundance of benthic diatoms (30 species) also.

There was considerable variation in the values of evenness index (E) at different stations during the period of study. The lowest value (0.38) was at station 3 during the post-monsoon and the highest value (0.82) was observed at station 8 during the monsoooon. Wide variation in the evenness index must be due to the impact of ever fluctuating estuarine environment on periphyton distribution. However, the mean values of evenness index for the pre-monsoon, monsoon and post-monsoon periods were

0.60, 0.67 and 0.61 respectively. Evenness index (E) is the result of competiton under optimum conditions or may be a response to unfavourable conditions (Patrick, 1971). Both these factors appear to hold good in this case. Monsoonal flushing into the estuary causes nutrient enrichment and depletion of nutrients occur as the rains subside in the succeeding months.

It is to be noted that Amphora angusta, Gyrosigma spencerii, Navicula gracilis, Nitzschia obtusa, Pleurosigma aestuarii, Thalassiosira subtilis, Mougeotia adnata, Oscillatoria spp. were dominant throughout the year in most of the stations studied. Despite the variations in different parts of the estuary, the common occurrence of these species throughout indicates that they are the typical euryhaline species of this tropical estuary.

Composition of the periphytic flora in Cochin estuary (Table 4.1) shows that out of 40 genera present, 31 belong to Bacillariophyceae while Chlorophyceae is represented by 7 genera and Cyanophyceae by two genera. Sixty six species of diatoms belonging to 31 genera form the dominant group of periphytic algae in the estuary. Among the 66 species, pennate diatoms are represented by 57 species and centric by 9 species. Species such as Gomphonema lanceolatum, G.sphaerophorum, Nitzschia sigmoidea, Pinnularia interrupta, P.braunii, Spirogyra jogensis, Cosmarium contractum, C. pyramidatum, Closterium acerosum, Oedogonium rufescens showed their highest standing crop during the monsoon period and at freshwater stations. The fact that these species decreased in number during the post-monsoon period indicated that they are freshwater froms and their tolerance to salinity is limited.

Although information on periphytic algae is meagre, the available data on Indian waters and that of elsewhere in the world indicate that diatoms form the dominant autotrophic component. The present study is also in agreement with the general trend. The fact that the diatoms form the dominant group of periphytic algae in the estuary shows that they are well adapted for this particular estuarine environment. Compared to centric diatoms, pennate diatoms which have mucilage pads for attachment are more in number in periphyton samples. Among the green and blue-green algae those having mucilage sheaths and rhizoidal cells occur as periphyton. The coexistence of various diatoms in the periphyton community is made possible owing to the adaptability and euryhalinity of species, while the essential requirements are not limited in the estuarine envrionment. However, grazing does occur but it is offset by the faster rate of multiplication among diatoms. All these favour diatoms to be the dominant periphytic algae. Moreover, unlike the filamentous or more elaborate green and blue-green algae, smaller size of diatoms offer less resistance to water currents in the estuarine system.

Summary

The average periphyton cell numbers for monsoon, post-monsoon and pre-monsoon were 1.34×10^{4}, 1.35×10^{4} and 1.32×10^{4} per cm^{2} respectively. Though the standing crop at different stations exhibited considerable variation with salinity ,this is not reflected in the average values of the estuary as a whole.But the individual values of standing crops varied from 9.8×10^{3} to 1.6×10^{4} cells / cm^{2}.

At stn.3, the standing crop showed significant positive correlation with salinity, one of the most fluctuating hydrographic parameters. At other locations the correlation between standing crop and salinity was not significant. The variation in the relationship can be attributed to the type of flora characteristic of space or seasons. Different parts of the estuary showed the dominance of freshwater, euryhaline or stenohaline forms depending on their proximity to river mouth or sea. Among the 40 genera and 76 species of periphytic algae, the diatoms comprise 31 genera and 66 species. The number of species recorded at different stations varied from 25-34. Diversity index of periphytic algae was slightly higher than that of planktonic algae of the backwater. Similarity indices of periphytic flora at majority of stations studied were generally < 60 indicating the extent of its diversity.

Table 5.1 Monthly mean values of environmental parameters

Month	salinity ($\times 10^{-3}$)	Diss.oxygen ($ml.l^{-1}$)	Temp. (^{o}C)	pH	Silicate ($mg.l^{-1}$)	NO_2-N ($\mu g\ at.l^{-1}$)	PO_4-P ($\mu g\ at.l^{-1}$)
June	0.35	5.10	26.4	7.20	10.59	0.74	3.02
July	0.12	5.07	26.3	6.87	11.54	0.34	2.26
Aug.	1.61	4.63	27.4	6.24	19.97	0.51	2.23
Sep.	0.58	5.30	27.8	6.94	27.37	0.74	6.23
Oct.	0.38	5.08	28.0	6.83	14.03	1.03	6.01
Nov.	0.21	5.07	28.8	6.95	15.16	1.17	1.61
Dec.	8.78	5.06	28.6	7.43	5.77	2.21	1.67
Jan.	13.47	5.15	28.0	7.39	25.40	2.25	5.89
Feb.	13.80	5.06	30.10	7.55	8.46	0.54	0.93
Mar.	14.07	4.85	29.5	7.48	7.51	0.71	1.70
Apr.	11.84	5.05	29.6	7.47	7.09	0.87	2.43
May	9.11	5.85	29.3	7.73	3.01	1.18	5.96

Table 5.2 Diversity indices of species richness (R), diversity (H), evenness (E) and Hill's Diversity number (N).

Stn. Nos.	Pre-monsoon				Monsoon				Post-monsoon			
	R	H'	E	N	R	H'	E	N	R	H'	E	N
1	1.21	1.76	0.44	5.84	2.00	2.57	0.62	13.11	1.65	2.35	0.61	10.50
2	1.56	2.32	0.64	10.27	1.38	2.40	0.79	11.09	2.14	2.72	0.69	15.22
3	1.91	2.25	0.47	9.52	1.37	2.35	0.81	10.54	1.95	2.02	0.38	7.60
4	1.88	2.34	0.52	10.48	2.10	2.51	0.56	12.36	2.38	2.71	0.62	15.03
5	1.97	2.72	0.80	15.24	1.96	2.59	0.66	13.38	1.66	2.38	0.64	10.90
6	1.59	2.16	0.54	8.75	1.70	2.39	0.64	10.99	2.30	2.88	0.77	17.93
7	1.57	2.25	0.59	9.52	2.07	2.33	0.49	10.33	2.34	2.79	0.71	16.44
8	1.63	2.29	0.66	9.91	1.06	2.00	0.74	7.42	1.66	2.01	0.46	7.51
9	1.53	2.16	0.54	8.67	1.16	2.03	0.63	7.67	2.09	2.23	0.46	9.30
10	1.75	2.69	0.82	14.87	1.68	2.262	0.81	13.78	2.22	2.83	0.77	17.09

Table 5.3 List of periphytic algae occurring in Cochin estuary

Algal genera	Number of species Stations									
	1	2	3	4	5	6	7	8	9	10
Bacillariophyceae										
Achnanthes	1	-	1	1	1	2	1	1	2	2
Amphora	1	3	2	2	2	2	3	2	2	2
Biddulphia	1	1	1	1	-	1	-	1	-	1
Caloneis	-	-	1	1	1	1	1	-	-	-
Campylodiscus	-	-	1	-	-	-	-	-	-	1
Coscinodiscus	1	-	-	-	1	-	-	-	-	-
Climacosphenia	1	1	1	1	1	-	-	-	-	-
Cymbella	-	-	-	-	1	-	-	1	-	-
Diploneis	-	1	-	2	-	1	1	1	1	1
Eunatogramma	-	-	1	-	-	1	1	1	1	1
Eunotia	-	-	1	-	-	-	1	1	-	-
Fragilaria	-	-	-	-	1	1	-	-	1	1
Gomphonema	2	2	1	1	1	1	2	1	1	1
Grammatophora	-	-	1	-	-	-	-	-	-	-
Gyrosigma	4	1	-	4	3	2	2	1	2	2
Hantzschia	-	-	-	-	-	1	-	-	-	-
Licmophora	-	-	-	-	-	1	-	-	-	-
Mastogloia	-	-	-	-	-	-	-	-	-	1
Melosira	-	1	1	1	-	1	1	-	1	1
Navicula	4	3	2	2	4	2	3	3	2	6
Nitzschia	4	3	5	4	3	4	5	3	3	5
Okedenia	-	-	-	-	-	1	1	-	-	-
Pinnularia	1	1	2	1	1	1	2	1	-	1
Pleurosigma	2	2	2	4	3	4	1	-	3	3
Striatella	1	-	-	1	1	-	-	-	-	-
Surirella	-	1	1	1	2	2	-	-	1	-
Synedra	1	1	1	1	1	-	-	1	1	-
Terpsinae	-	-	1	1	1	1	-	-	-	-
Thalassiosira	1	1	1	1	-	1	1	-	1	1
Triceratium	-	-	-	-	1	-	-	-	-	-
Tropidoneis	-	-	-	-	-	-	-	1	-	-
Chlorophyceae										
Chlorella	-	-	-	-	-	-	1	1	1	-
Closterium	1	-	-	1	-	-	1	-	-	-
Cosmarium	1	-	-	-	-	1	2	1	1	-
Mougeotia	1	1	1	1	1	1	1	1	1	1
Oedogonium	-	1	-	-	-	-	1	1	-	-
Spirogyra	1	1	1	1	1	-	1	-	-	-
Stigeoclonium	-	-	-	-	-	-	-	1	-	-
Cyanophyceae										
Merismopedia	-	1	-	-	-	-	-	-	-	-
Oscillatoria	-	1	1	1	1	1	2	1	1	1
	29	27	30	34	32	34	34	25	26	32

Table 5.4 Correlation coefficient (r value) between periphytic algae and environmental parameters

Station	Salanity	Dissolved oxygen	Temperature	pH	Silicate	NO_2-N	PO_4-P
1	0.2600	0.0294	-0.1695	0.3544	0.1253	0.0201	0.1692
2	0.3701	0.2801	0.475	-0.1059	0.2981	-0.4685	-0.2000
3	**0.7893	0.4312	*0.6614	0.4932	-0.3990	0.1699	0.3936
4	0.1637	-0.0564	0.1990	-0.1884	0.0876	-0.4711	-0.0855
5	-0.3645	-0.1762	-0.1500	-0.5962	0.3008	0.2817	0.2844
6	-0.0657	-0.3733	0.1452	-0.1044	0.2501	-0.4230	-0.3151
7	-0.0859	-0.0564	-0.2263	-0.0837	0.4526	0.2544	0.1757
8	-0.1897	*0.6785	0.3900	0.2214	0.1501	*0.5779	0.3559
9	0.1845	0.0126	0.5167	0.0965	-0.0775	-0.5431	0.1151
10	0.2855	0.3700	0.2247	0.4841	-0.6006	0.3622	-0.5190

* Significant at 5% level ($P < 0.05$)

** Significant at 1% leve ($P < 0.01$)

Degree of freedom = 11

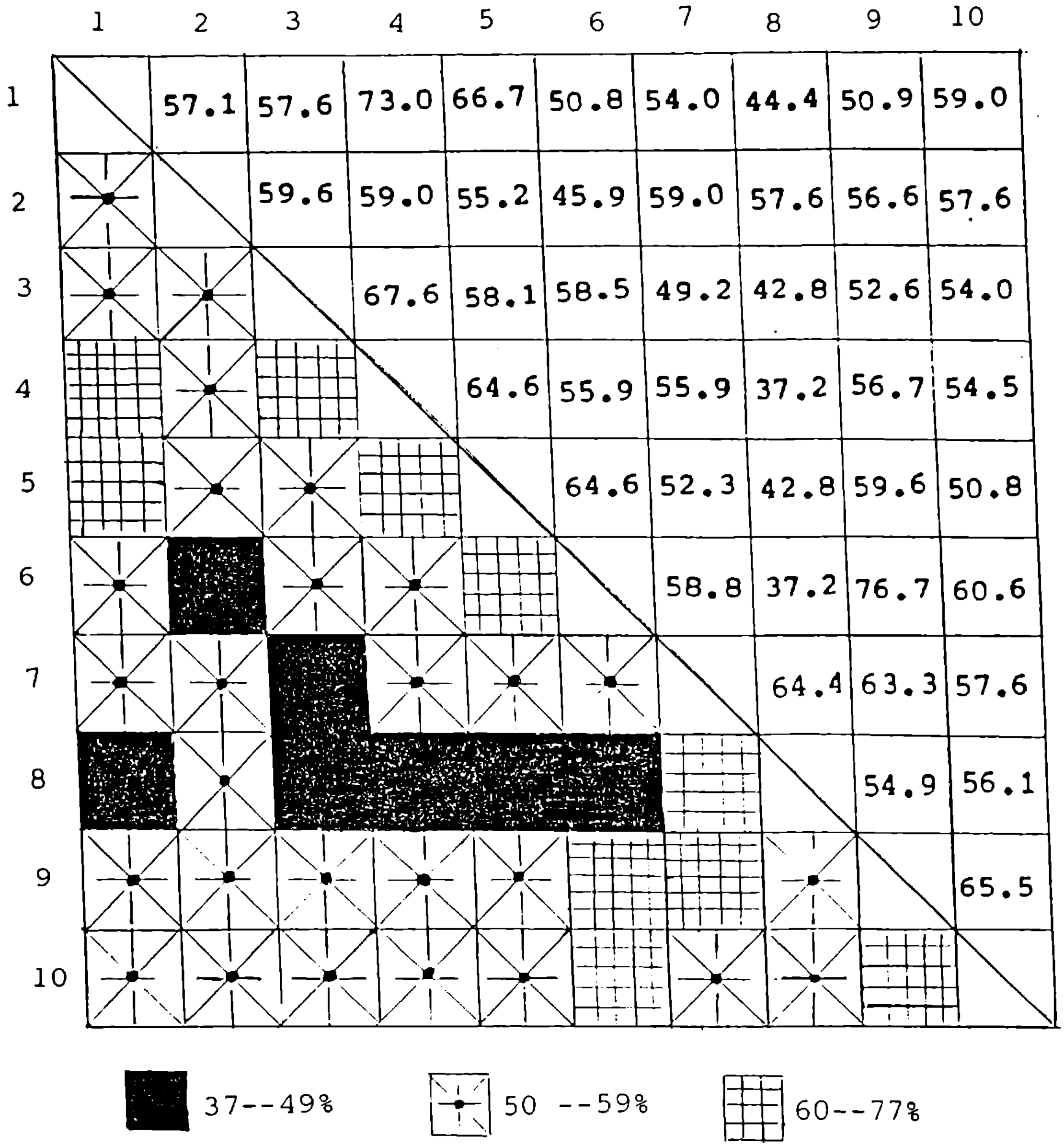


Fig. 5.1 Trellis diagram showing floral similarity at 10 stations.

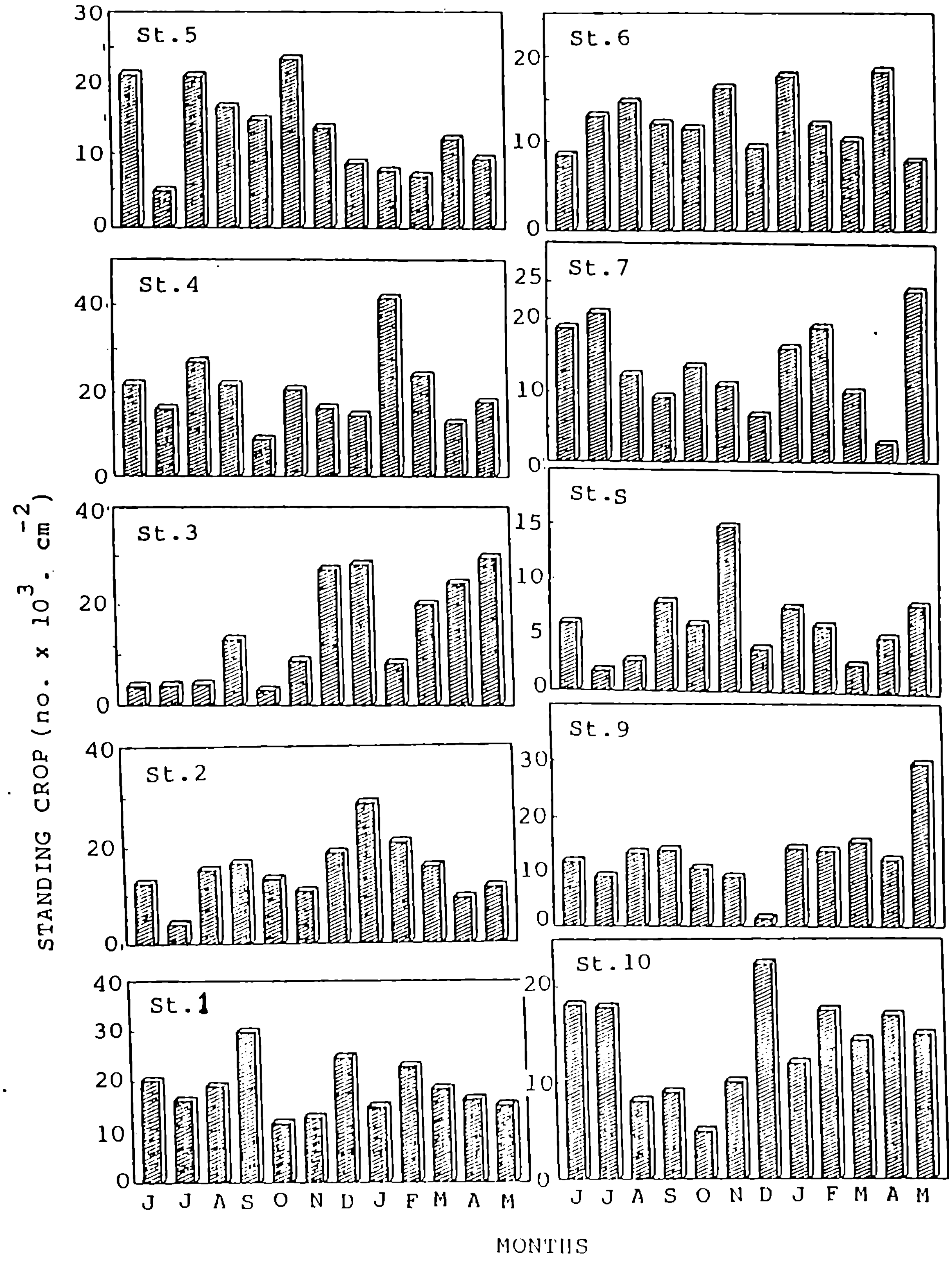


Fig.5.2 Monthly mean values of periphyton standing crop at stations 1-

6

PIGMENT COMPOSITION

Introduction

Cochin backwater has been studied extensively with regard to the various groups of planktonic algae (George, 1958; Qasim et al., 1969, 1972; Gopinathan, 1972; Gopinathan et al., 1984; Nair et al., 1975; Joseph and Sreekumar, 1993). However, information on periphytic algae, growing on stones, aquatic macrophytes and other submerged objects is scanty. Periphyton colonization on different substrata, floral composition of the periphyton community, its spatial and temporal variation in the estuary have been studied (Sreekumar and Joseph, 1995 a, 1995 b). Periphyton has a significant role in the primary production and influence the ecology of water bodies. Seasonal and spatial variations in pigment composition of periphytic algae in the estuarine complex are presented in view of their importance in primary production.

Material and Methods

Quantitative determination of the pigments was done using periphyton growth on glass slides of 25/75 mm size kept submerged at different stations (APHA, 1992). Pigments were extracted with aqueous acetone and OD measured with a spectrophotometer (Hitachi 150-20). Individual glass slides retrieved from different stations were placed directly into 100 ml of a mixture of 90% aqueous acetone and 10% saturated $MgCO_3$

solution. The samples were frozen in the field and kept steeped in acetone for 24 h in the dark at or near $4^{0}C$. 3 ml of clarified extract was transferred to a 1 cm cuvette and absorbance read at 750, 665, 645, 630, 510 & 480 nm. The concentration of chlorophyll `a', `b', `c' and carotenoids were calculated using the equations given in Strickland and Parsons (1972).

$$C_b = \text{Chlorophyll } \underline{b} = 20.7\, E_{6450} - 4.34\, E_{6650} - 4.42\, E_{6300}$$

$$C_c = \text{Chlorophyll } \underline{c} = 55\, E_{6300} - 4.64\, E_{6650} - 16.3\, E_{6450}$$

$$C_p = \text{Carotenoids} = 7.6\, (E_{4800} - 1.49\, E_{5100})$$

Where E is the absorbance at the respective wave lengths. Each extinction was corrected for a small turbidity blank by subtracting the 750 nm reading.

The chlorophylls and carotenoids were estimated in mg/m^2 using the formula (APHA, 1992) :

$$= \frac{C \times \text{volume of extract, L}}{\text{area of substrate, } m^2}$$

where C_b, and C_c and C_p are respective C values of chl.b, chl.c and carotenoids.For the estimation of active chlorophyll a and pheophytin a, the procedure was similar to that of chlorophylls as given above. The extinction of the extract was measured at 665 and 750 nm. Each 750 nm reading was subtracted from the corresponding 665 nm extinction and using the corrected values chlorophyll a and pheophytin a concentration per unit surface area of sample was calculated as follows:

$$\text{Chlorophyll } \underline{a}, \text{mg/m}^2 = \frac{26.7\,(665_b - 665_a) \times v}{\text{area of substrate, m}^2}$$

$$\text{pheophytin a, mg/m}^2 = \frac{26.7\{1.7(665_a) - 665_b\} \times v}{\text{area of substrate, m}^2}$$

Where: 665_b = extinction at 665 nm before acidification

665_a = extinction at 665 nm after acidification

v = volume of extract, L,

The value 26.7 is the absorbance correction and 1.7 is the absorption-peak-ratio.

Results and Discussion

Chlorophyll a

The seasonal and spatial variations of chl.a are shown in Table 6.1. The annual mean concentration of chl.a in the estuary was 50.80 mg/m^2. During monsoon period the mean chl.a value was 58.14 mg/m^2 whereas pre-monsoon and post-monsoon values were 47.49 and 46.77 mg/m^2 respectively. The highest concentration of chl.a (214.20 mg/m^2) in the estuary was recorded at Panavally in September whereas the lowest (10.26 mg/m^2) from Murinjapuzha during July. Chl.a values are generally taken as a measure of standing crop in any ecosystem. The concentration of chl.a at different stations highlighted the magnitude of periphyton biomass and its role in the ecosystem. The seasonal variation in the chl.a values indicated that monsoon period was more suitable for periphytic growth in the estuary than either premonsoon or post-monsoon. The lowering of salinity due to heavy rains and inflow of freshwater from various rivers into the estuary might have facilitated the growth of both freshwater and euryhaline forms.

Singh and Gaur (1989) reported chl.a concentrations of 53.08, 34.58 and 49.34 mg/m^2 for periphyton in a stream polluted with oil refinery effluent at Digboi (Assam, India) in April, 1986, September, 1986 and January, 1987 respectively. However, Hansson (1992) had reported 30-270 mg/m^2 in Swedish Lakes and 20-400 mg/m^2 in Antarctic Lakes. Joseph and Pillai (1975) reported seasonal and spatial variation in chl.a values for the planktonic algae in Cochin estuary. For the plankton, chl.a values were the lowest during monsoon and highest during post-monsoon. The annual contribution of chl.a by the sediment microflora of the estuary is estimated to be 70.35 mg/m^2 with the incidence of higher values during both pre-monsoon and monsoon (Sivadasan and Joseph, 1995). But periphytic chl.a showed the maximum concentration during monsoon season.

Seasonal and spatial variations in the concentration of chl.a were examined using a two way ANOVA (Table 6.2). Significant difference in chl.a values was observed between different stations as well as months. (ANOVA; P<0.01). Correlation between the monthly mean values of chl.a and hydrological parameters such as salinity, temperature, dissolved oxygen, pH, silicate, nitrite and phosphate of the estuary was analysed (Table 6.3). No significant correlation between chlorophyll a and hydrological parameters was observed. However, correlation analysis at different stations revealed that there is negative correlation between chl.a and salinity in locations near river mouths and positive correlation in stations with saline conditions. Hence salinity could be one of the factors influencing its distribution in the estuary.

Productivity of an ecosystem is a function of the standing crop which is often expressed as chl.a concentration. The richness of chl.a of the periphytic flora indicated the extent to which this autotrophic component influenced productivity of the estuary. The annual mean value of primary production estimated based on phytoplankton alone was clearly an underestimation.Thus the necessity of a correction factor for periphyton production is imperative for a more realistic estimation of primary productivity.

Chl.b concentration showed wide variations from station to station (Table 6.4). It varied from zero at a few stations during pre-monsoon to 51.98 mg/m^2 at Vaikom during September. The mean values of chl.b in the estuary during monsoon, post-monsoon and pre-monsoon were 11.08, 4.54 and 3.54 mg/m^2 respectively while the annual mean concentration was 6.36

mg/m^2. The concentration of chl.b being directly related to the green algal biomass, comparatively higher values of it during monsoon season indicated its luxuriant growth during the period. Heavy rains during monsoon lowered the salinity in the estuary favouring the growth of freshwater green algae such as Mougeotia, Spirogyra, Closterium, Oedogonium and Stigeoclonium. The southern stations of the estuary showed higher values of chl.b than the northern stations. Incidentally southern region received more freshwater from rivers in addition to the usual monsoon precipitation.

Vaikom, the southernmost station studied recorded the maximum concentration of chl.b during monsoon season. Salinity here was very low ($< 1 \times 10^{-3}$) throughout the year. Compared to the values of chl.a, chl.b values were very low except in a few stations during monsoon months. During the monsoon season, the backwater maintained more or less freshwater conditions but salinity increased gradually through the post-monsoon and reaching the maximum during pre-monsoon. However, the chl.b values were maximum during monsoon and gradually decreased during the post-monsoon and reaching the lowest during pre-monsoon. An inverse relationship between chl.b and salinity values was evident in the estuary.

The ratio of chl.b to chl.a (Table 6.5) showed temporal variation from 0.03 (March) to 0.21 (September). Values are comparatively low to that reported for phytoplankton in Vellar estuary (0.54) by Vijayalakshmy in 1986. Chl.b/chl.a ratios for monsoon, post-monsoon and pre-monsoon wer 0.19, 0.11 and 0.07 respectively. The annual mean value was 0.12 whereas the same for chl.c was 0.25 indicating the dominance of diatoms among the periphytic flora (Table 4.1).

Monthly mean values of chl.c (Table 6.6) showed an irregular pattern of distribution with an annual mean value of 12.59 mg/m^2 in the estuary. The lowest value recorded in the ecosystem was 1.24 mg/m^2 at Vaduthala during October and the highest (60.55 mg/m^2) also at the same place in September. The monsoon, post-monsoon and pre-monsoon values of chl.c were 12.66, 9.13 and 15.98 mg/m^2 respectively. Unlike chl.a and chl.b, the maximum concentration of chl.c was observed during pre-monsoon season. With the increasing salinity in the estuary, there was a corresponding increase in the diatom standing crop as indicated by the higher values of chl.c during pre-monsoon. The ratio of chl.c to chl.a (Table 6.5) in the estuary was fluctuating and was less than unity throughout the year. This ratio showed the physiological state of the standing crop (Bhargava and Dwivedi, 1976) and for a healthy crop it is less than unity. Qasim and Reddy (1967) observed a similar fluctuation in the chl.c to chl.a ratio for phytoplankton population of the same ecosystem.

Total Chlorophyll

Distribution of total chlorophyll (a+b+c) was similar to chl.a the both being maximum in September and minimum in October in most of the stations (Fig. 6.1). Annual mean value of total chl. was 69.75 mg/m^2 with monsoon, post-monsoon and pre-monsoon showing 81.88, 60.44 and 66.93 mg/m^2 respectively. The concentration of chlorophyll is indicative of the floral composition (Gopinathan et al., 1984). The estuary recorded an annual mean of 50.80 mg/m^2 of chl.a during the period of study indicating the presence of a fairly good quantity of periphyton standing crop throughout the year. Chl.b and chl.c are characteristic of green algae and diatoms respectively. The annual mean concentration of chl.b was 6.36 mg/m^2 and that of chl.c was 12.59 mg/m^2. This comparatively higher value of chl.c showed that the dominant periphytic flora of the estuary comprised mainly of diatoms . This was evident from the floral composition of the estuary (Table 4.1). Diatoms formed 86.9% where as green algae and blue green algae comprised 10.5% and 2.6% respectively. Thus the pigment concentration agree well with the composition of periphytic flora.

Carotenoids

Monthly variation of carotenoids are given in Table 6.7.The maximum concentration of carotenoids was recorded in September as in the case of chl.a, chl.b and chl.c. The values were, in general, higher during the monsoon period and decreased gradually during the post-monsoon and pre-monsoon periods. Annual mean values of carotenoids for different stations such as Vaikom, Murinjapuzha, Panavally, Vaduthala, Kumbalam, Bolghatty, Chittoor, Eloor, Njarackal and Karuthedom were 21.76, 8.44, 26.47, 12.29, 6.50, 13.92, 17.00, 25.03, 15.23 and 16.17 mg/m^2

respectively.Eloor station recorded the highest value (80.39 mg/m^2) in November. Stations which recorded higher values of chl.a showed higher values of carotenoids also. The carotenoid values of periphytic flora were relatively low when compared to the sediment flora (microbenthos) in this estuarine system (Sivadasan & Joseph, 1995). The ratio of caroteniods to chl.a (Table 6.5) was also fluctuating and were always less than unity throughout the year.

Pheophytin

Pheophytin concentration of periphyton in the estuary (Table 6.8) was the highest (16.04 mg/m^2) during monsoon followed by a gradual decrease during post-monsoon (11.97 mg/m^2) and pre-monsoon (8.78 mg/m^2). The incidence of high pheophytin must be due to the high turbidity of the estuarine water resulting from the greater inflow of freshwater from various rivers in the ecosystem. Turbidity affected light penetration which led to a faster rate of conversion of chlorophyll to pheophytin. This was evident from the higher values of pheophytin at stations located at river mouths. Eloor (10.28 mg/m^2) Chittoor (9.85 mg/m^2) and Njarackal (11.89 mg/m^2) are located near confluence of Periyar river and the estuary while Murinjapuzha (10.34 mg/m^2) and Panavally (23.98 mg/m^2) are situated near the Muvattupuzha river mouth. The upstream station, Vaikom (20.24 mg/m^2), is situated near the Thanneermukkam barrage opening. The ratio of pheophytin to chl.a (Table 6.5) varied from 0.16 to 0.33 with 0.28, 0.27 and

0.19 for the monsoon, post-monsoon and pre-monsoon periods respectively.

Summary

The annual mean chl.a content of periphyton estimated for the estuary is 50.80 mg/m^2. The very high values of chl.a recorded from different stations signify the role of periphytons in the ecology of Cochin backwaters. The seasonal averages of chlorophyll concentration show that the pigment production is slightly more during the monsoon (58.14 mg/m^2). Monthly values (mean) of chlorophyll at different stations revealed that there is significant spatial and temporal variation in its distribution (2 way ANOVA:P <0.01). The annual mean values of chl.b and chl.c concentration were 6.36 and 12.59 mg/m^2 respectively. These values confirm the floral composition of periphytic algae described in chapter V.

The annual mean corotenoid content of periphyton estimated to be 16.28 mg/m^2. The ratio of chl.b chl c and carotene to chl a was always less than unity. Pheophytin a concentration for the monsoon, post-monsoon and pre-monsoon periods were 16.14, 119.97 and 8.78 mg/m^2 respectively. There was a gradual decrease in pheophytin a concentration during the post-monsoon period. Increased turbulence and low light penetration during the monsoon may be responsible for the higher pheophytin a concentration during the post-monsoon period. Increased turbulence and low light penetration during the monsoon may be responsible for the higher pheophytin a concentration.

Table 6.1. Seasonal variation of chlorophyll a content of periphyton at different stations in Cochin estuary.

Stn.	Monsoon				Post-monsoon				Pre-monsoon			
No.	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.	93.98	86.60	77.72	91.43	62.58	69.42	84.90	62.53	68.46	66.76	65.78	65.11
2.	40.88	10.26	67.66	54.23	22.67	16.99	48.63	58.42	35.49	56.49	25.11	44.93
3.	83.29	91.57	113.85	214.20	48.04	35.60	74.03	110.64	38.12	52.92	68.32	64.08
4.	40.89	24.61	48.23	79.19	16.54	29.12	22.96	30.15	60.16	38.03	24.76	30.85
5.	61.64	19.27	59.01	45.94	29.42	68.76	55.21	40.47	32.08	28.57	48.88	37.52
6.	32.30	41.38	48.42	71.65	16.06	22.68	10.64	24.68	18.08	14.74	31.26	13.73
7.	43.45	66.83	59.20	78.95	50.25	57.77	24.45	71.17	35.46	72.98	52.81	85.39
8.	25.55	12.66	16.31	138.02	49.48	129.29	33.61	73.33	66.04	17.37	30.86	32.16
9.	22.65	16.92	43.01	51.46	22.52	52.35	20.80	48.46	39.20	52.01	69.15	70.49
10.	49.54	37.32	20.39	41.08	14.07	37.73	85.54	38.98	66.92	37.86	73.51	77.36
Avg.	49.54	40.64	55.38	86.62	33.16	51.97	46.08	55.88	46.00	43.77	49.04	51.16

Values in mg m^{-2}

Table 6.2. Summary of ANOVA of chlorophyll a at different stations.

Source	Sum of Sqaures	Degree of Freedom	Mean Square	F ratio
Between colums	18446.72	11	1676.97	2.988
Between rows	30602.58	9	3400.29	6.058
Residual	55568.04	99	561.29	
Total	104617.34	119		

Table 6.3 **Correlation matrix of chlorophyll *a* vs hydrological parameters**

	Chl. a	Sal.	Temp.	Diss. oxygen	pH	Silicate	Nitrite	Phosphate
Chl.	#1.0000							
Sal.	0.0329	#1.0000						
Temp.	-0.0396	#0.7303	#1.0000					
Diss. oxygen	0.1928	0.0833	0.1665	#1.0000				
pH	-0.0880	*0.6580	*0.5974	*0.5630	#1.0000			
Silicate	0.4104	-0.4345	-0.4730	-0.4276	-0.6591	#1.0000		
Nitrite	0.0702	0.3965	0.2863	0.3163	0.4143	-0.0920	#1.0000	
Phosphate	0.2670	-0.1536	-0.3097	0.5335	-0.0662	0.2442	0.3112	#1.0000

"*" ----- 5% Significance
"#" ----- 1% Significance
Degree of Freedom = 11

Table 6.4 Seasonal variation in chlorophyll b content of periphyton at different stations in Cochin backwaters.

Stn.	Monsoon				Post-monsoon				Pre-monsoon			
No.	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	8.06	16.13	30.04	51.98	6.82	4.54	2.56	0.96	2.96	0.00	0.00	0.42
2	31.81	0.52	4.65	2.03	0.68	0.47	1.02	0.04	6.12	0.24	1.47	21.54
3	3.18	38.08	16.90	48.62	14.67	5.36	9.54	20.72	6.71	4.04	1.21	0.59
4	1.96	0.86	1.14	2.27	0.57	0.97	0.14	0.38	2.24	0.98	0.36	0.00
5	12.52	2.09	6.17	4.56	2.90	6.00	4.93	3.06	1.58	0.92	2.82	1.56
6	5.66	6.23	0.83	1.26	0.92	0.34	1.12	1.48	0.76	1.31	4.71	2.39
7	1.74	2.95	19.21	6.13	2.63	7.63	0.49	4.14	4.67	2.27	6.77	8.04
8	1.63	3.93	1.94	40.60	28.28	17.04	1.61	1.94	4.32	0.93	2.14	1.04
9	16.37	3.94	8.16	20.80	1.77	10.41	0.89	0.80	1.43	1.67	10.41	2.52
10	6.32	4.71	1.49	5.58	1.78	2.16	8.08	1.63	1.13	2.46	12.48	10.69
Avg.	8.93	7.94	9.05	18.39	6.11	5.49	3.04	3.52	3.19	1.48	2.24	4.88

Values in mg/m^2

Table 6.5 Temporal variation in the ratio of different pigments to chlorophyll *a*

Pigments		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Chl.*b*	: Chl.*a*	0.18	0.20	0.16	0.21	0.18	0.11	0.07	0.06	0.07	0.03	0.09	0.10
Chl.*c*	: Chl. *a*	0.23	0.24	0.15	0.24	0.30	0.15	0.20	0.17	0.30	0.26	0.39	0.38
Carotenoids	: Chl.*a*	0.30	0.36	0.35	0.43	0.35	0.38	0.23	0.24	0.31	0.33	0.27	0.22
Phaeophytin *a*	: Chl.*a*	0.27	0.30	0.26	0.28	0.33	0.25	0.28	0.20	0.21	0.20	0.17	0.16

Table 6.6 Seasonal variation in chlorophyll c content of periphyton at different stations in Cochin backwaters

Stn.	Monsoon				Post-monsoon				Pre-monsoon			
No.	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	26.36	14.36	16.84	32.79	4.67	7.00	7.95	9.81	31.96	28.02	26.04	25.71
2	2.58	13.63	9.64	9.80	4.87	6.79	11.49	2.84	8.42	7.61	28.08	51.32
3	13.54	7.93	10.39	34.13	26.54	6.99	3.13	8.94	4.27	14.64	21.12	19.89
4	10.92	8.54	14.37	60.55	1.24	1.59	2.89	4.56	20.11	8.76	6.36	8.24
5	14.06	4.24	5.92	8.51	7.72	11.27	4.75	9.21	2.08	3.15	6.34	2.49
6	6.46	8.98	2.63	12.07	15.00	5.83	4.29	8.37	14.87	9.02	31.24	10.75
7	3.25	9.73	13.88	10.71	10.31	7.18	1.44	11.67	8.67	6.39	9.27	17.32
8	12.48	8.82	2.44	26.03	13.14	17.69	1.98	18.76	15.01	9.58	6.75	3.23
9	4.37	2.83	6.83	5.95	5.43	4.37	14.44	12.64	7.52	3.02	18.40	35.96
10	20.12	20.32	2.93	6.65	11.93	6.65	39.34	10.29	23.69	15.84	37.80	22.36
Avg.	11.41	9.94	8.58	20.72	10.09	7.54	9.17	9.71	13.66	11.40	19.14	19.72

Values in mg/m^2

Table 6.7 Seasonal variation in carotenoid content of periphyton at different stations in Cochin backwaters

Stn.	Monsoon				Post-monsoon				Pre-monsoon			
No.	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	32.11	36.48	17.87	52.41	12.31	19.90	10.23	12.50	24.09	16.29	14.61	12.27
2	3.51	2.75	20.06	8.23	3.22	12.95	11.46	7.40	9.02	11.52	9.08	2.09
3	21.41	57.78	55.21	77.63	14.61	8.75	2.23	26.54	14.27	18.54	6.92	13.70
4	16.25	9.28	19.73	33.16	4.79	5.02	2.48	11.40	17.94	6.28	12.44	8.71
5	4.57	2.59	11.42	12.01	7.08	4.50	10.29	1.30	12.87	6.39	4.12	0.89
6	18.01	10.31	16.50	59.98	7.62	9.48	2.51	9.37	11.88	4.50	11.70	5.27
7	24.5	6.82	17.10	19.34	17.36	29.02	11.08	18.35	6.59	31.64	18.18	4.02
8	12.76	5.59	8.95	72.94	37.91	80.39	9.21	16.48	9.29	14.74	16.80	15.32
9	9.51	7.40	3.35	22.37	5.57	17.30	16.95	18.59	16.76	20.12	24.85	20.48
10	7.64	5.95	21.71	18.01	6.31	12.50	32.08	11.00	20.10	14.28	15.51	28.98
Avg.	15.03	14.49	19.19	37.61	11.63	19.98	10.86	13.29	14.28	14.43	13.42	11.17

Values in $mg/^{2}$

Table 6.8 Seasonal variation in pheophytin a of periphyton at different stations in Cochin estuary.

Stn.	Monsoon				Post-monsoon				Pre-monsoon			
No.	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.	15.27	21.64	24.83	36.02	43.14	19.25	26.19	14.22	16.04	8.54	10.14	7.57
2.	10.98	4.26	22.51	26.82	6.52	8.47	4.82	10.33	8.13	5.92	3.14	12.15
3.	30.76	42.19	28.04	65.79	17.84	14.76	24.03	18.12	7.02	9.18	16.39	13.64
4.	12.20	6.73	14.16	18.39	3.69	6.74	10.01	4.50	25.64	6.27	3.96	5.23
5.	21.50	4.27	12.80	8.54	6.09	24.40	10.89	8.07	6.67	3.85	6.01	4.15
6.	6.07	5.21	9.46	20.34	4.98	6.57	2.98	6.05	6.00	2.00	7.83	3.76
7.	12.79	16.36	8.90	26.81	4.58	10.76	4.34	16.54	5.27	20.88	10.56	4.92
8.	11.03	10.92	4.96	12.16	12.07	10.35	22.70	18.64	6.92	4.78	2.96	5.89
9.	4.57	3.19	12.56	18.72	5.94	14.18	5.29	8.57	6.39	14.32	10.78	13.74
10.	7.11	8.93	4.58	9.12	2.98	16.41	18.02	4.86	8.85	10.86	12.64	12.38
Avg.	13.23	12.37	14.23	24.17	10.78	13.19	12.93	10.99	9.69	8.66	8.44	8.34

Values in mg m^{-2}

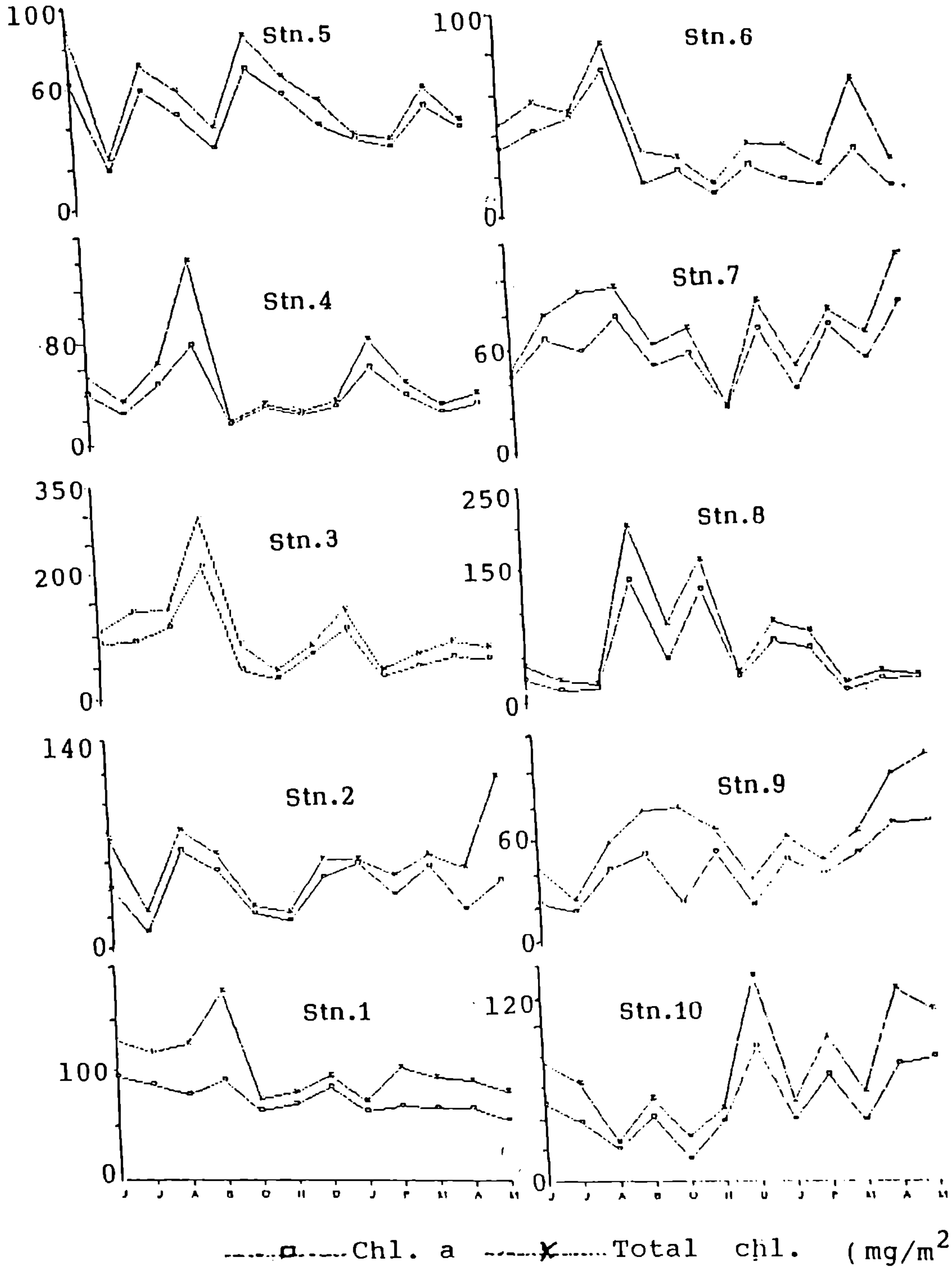


Fig. 6.1 Monthly variations of chl.a and total chl. at stations 1 - 10

7

AUTOTROPHIC INDEX

Introduction

Many studies have described the algal growth of periphytic communities in lentic and lotic waters. The majority of periphyton studies have used artificial substrata (Cooke, 1956; Sladeckova, 1962; Dillard, 1969; Dumont, 1969; Hynes, 1970; Patrick, 1973; Rosemarin and Gelin, 1978; Cattaneo and Kalff, 1979; Loeb, 1981). Periphytic growth on substrata and community structure are affected by a variety of factors such as hydrology, nutrients, grazing, period of exposure, temperature, depth and water currents. The conditions reported for the optimum periphytic growth by different investigators vary. This is due to various limiting factors of the ecosystem. However, the general trend in periphytic growth with regard to these factors have been established. Periphyton communities are sensitive to changes in water quality (Wuhrmann and Eichenberger, 1975) and responded to pollution by altering their structure (Patrick, 1973). Studies on periphytic algal community structure have been found to be useful for biomonitoring of water quality (Cooper and Wilhm, 1975; Bott et al., 1978; Rai et al., 1981; Gaur and Kumar, 1985). Singh and Gaur (1989) demonstrated the usefulness of periphytic algal criterion for monitoring oil pollution in running waters. Periphyton communities have recently been employed as biological indicators of acidification of lakes (Stevenson et al., 1985). The utility of autotrophic index (AI) of periphyton in the assessment of water quality has been discussed in APHA (1992). No such studies have been done on periphyton in

Cochin estuary. The only information available is regarding the distribution and factors influencing its colonization in the estuary (Sreekumar and Joseph, 1995a, 1995b, 1996). Hence the present study explores the utility of periphyton community in the water quality determination of Cochin estuary.

Material and methods

Ash-free Dry Weight (AFDW)

Periphyton samples on glass slides submerged at different stations were collected fortnightly over a period of one year. Dry and ash-free dry weight analysis (APHA, 1992) was done using the slides expressly designated for the purpose. The fortnightly values of ash-free dry weight were pooled for calculating the monthly mean values.

a. Procedure:

The sample air-dried in the field and protected from abrasion, moisture and dust were re-wet with distilled water. Glass slides were scraped with a razor and washed with distilled water in to separate prewashed, tared crucible to collect all materials that had accumulated on each substratum during the colonization. The material is air dried and then dried at 105 ^{0}C, allowed to cool for 12 h in a dessicator and weighed to the nearest 0.1 mg. The samples were then ashed in a muffle furnace at 500 ^{0}C for 1 h, cooled to room temperature, wetted with distilled water and dried again to constant weight at 105 ^{0}C (to correct for dehydration of clays).

b. Calculations :

Ash-free dry weight calculated as the weight of the ash subtracted from the dry weight, provided an estimate of the total biomass (autotrophic, heterotrophic and detrital) of the periphyton community. The mean weight from each slide was reported as dry weight and ash-free weight per square meter of exposed surface. if 25 by 75 mm slides are used, then

$$g/m^2 = \frac{g/slide\ (average)}{0.00375}$$

Autotrophic Index (AI)

The Autotrophic Index (AI) is a means of determining the trophic nature of the periphyton community. It is calculated as follows :

$$AI = \frac{\text{Biomass (ash-free weight of organic matter), } mg/m^2}{\text{Chlorophyll } \underline{a}\text{, } mg/m^2}$$

(APHA, 1992)

Results and Discussion

The monthly mean values of dry weight mass (DW) and ash-free dry weight mass (AFDW) of periphyton at 10 different stations in Cochin estuary for one year are given in the Tables 7.1. and 7.2. The DW values varied from 2.66 to 47.01 g/m^2. The annual mean values of DW at Vaikom, Murinjapuzha, Panavally, Vaduthala, Kumbalam, Bolghatty, Chittor, Eloor, Njarackal and

Karuthedom were 24.56, 15.88, 16.71, 10.66, 9.92, 8.81, 15.07, 13.60, 14.75, and 13.51 g/m^2 respectively. Monthly average AFDW for the estuary varied from 4.56 to 11.84 g/m^2 with monsoon, post-monsoon and pre-monsoon recording 7.84, 6.70 and 8.21 g/m^2 respectively. The annual mean value of AFDW was 7.58 ± 1.94 g/m^2 for the estuary. The highest single value of 19.00 g/m^2 was reported from Vaduthala in September while the lowest 1.21 g/m^2 from Eloor during July.

Spatial and temporal variations in AFDW in the estuary were analysed using a 2 - way ANOVA (Table 7.3). A significant variation occurred in the values of AFDW between different stations (ANOVA; $P < 0.05$). A significant difference in AFDW was also noted during different months in all the stations of the estuary (ANOVA; $P < 0.05$). Correlation of AFDW with chl. a revealed that there was significant correlation between AFDW and chl. a ($P < 0.05$). The relationship between AFDW and chl. a of periphytic matter was very similar to that found by Liaw and Mac Crimmon (1978) and Eloranta (1982).

Regression analysis of AFDW (X; mg/m^2) and chl.a (Y; mg/m^2) showed (Table 7.4) that up to 96% of the variation in chl.a can be explained on the basis of variation in AFDW. Highly significant correlation between chl.a and AFDW is shown in scatter plots (Fig. 7 .1-5).

The average organic content (%) of periphyton in the estuary was 55.60 ± 4.48. The percentage varied from 33.29 to

74.12 (Table 7.5) at 10 different stations. Monsoon season recorded the lowest percentage (48.49) of organic content. There was an increase of organic content during post-monsoon (57.48%) and the trend continued during pre-monsoon period (60.85%). Reduction in organic content of periphytic matter during the monsoon season (Table 7.6) in the estuary may be due to the turbidity resulting from freshwater inflow into the backwaters through various rivers. The lower percentage of periphytic organic matter recorded at Murinjapuzha and Eloor which are located near the confluence of Muvattupuzha and Periyar rivers respectively into the estuary confirms this. With the decline of monsoon, turbulence in the water body also decreases. The increase in organic content of periphytic matter during the post-monsoon is in agreement with the above concept.

Monthly mean values of chl.a at different stations are shown in Table 6.1. The values ranged between 10.26 and 214.20 mg m^2. The annual mean concentration of chl.a of periphytic algae was 50.80 ± 12.94 in the estuary. The average chl. a values in the estuary during different months vary from 33.16 to 86.62 mg/m^2.

Spatial and temporal values of autotrophic index (AI) worked out for the estuary are shown in the Table 7.7. Highest single value of 280 was recorded at Kumbalam during March and the lowest 66 from Panavally during May. As per the APHA (1992), normal AI values range from 50 to 200. The annual mean of AI of the estuary during the period of study was 154 ± 20 and lie well within the normal Al range. However, the annual mean values of 4 stations approach near the upper limit of normal AI range. Vaikom, Murinjapuzha, Bolghatty and Karuthedom recorded annual mean values of 194, 194, 179 and 163 respectively. Incidently these stations have recorded negative values of net daily metabolism (NDM) during different seasons in earlier studies. Vaikom and Bolghatty stations are known for their proximity to the collective efflux of domestic sewage from the adjacent towns. Non-viable organic materials in these stations also must have contributed to the higher AI values. Earlier studies (Crossey and La Point, 1988) had shown that AI could be a better indicator in the case where a pollutant such as sewage detritus caused a shift from an autotrophic to heterotrophic community. Moreover, isolated high AI values were noted even in stations where the annual mean was < 150. This clearly shows that the trophic status of the estuary is highly vulnerable. Significant variation in spatial and temporal AI values (2 way ANOVA; $P < 0.05$) also confirm this. Summary of ANOVA of AI values are shown in Table 7.8. Fairchild et al. (1989) had reported AI values ranging from 66 ± 4 to 242 ± 28 in Lake Lacawac, Pennsylvania.

Artificial substrata were retrieved from study sites after the optimum period of exposure. AI value is directly affected by changes in AFDW and chl. a. The AFDW values in turn are influenced by the nonliving organic matter (detrital) that may gather on the substrata. Nonetheless, continuous monitoring of different locations in a large water body such as Cochin backwaters with a standardized procedure for AFDW and chl. a determination can yield reliable data regarding the trophic status and water quality.

Summary

Using artificial substrata (25/75 mm glass slides) DW, AFDW and chl.a of periphyton were determined. There was sifnificant correlation between AFDW and chl.a. These parameters were employed for the calculation of AI.

The annual mean AI value for the estuary was found to be 154 ± 20 which is within the range of AI values for normal water conditions (APHA, 1992). Vaikom and Murinjapuzha stations recorded higher annual mean AI values near the upper limit of the normal range.

All the stations studied recorded occasional very high AI values, indicating low water quality. The study shows the utility of AI as a criterion for assessing water quality in the backwater.

Table 7.1 Monthly mean values of DW of periphyton at different stations in Cochin estuary

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	31638.1	27747.7	31978.9	37707.3	19129.5	19480.7	20618.8	27943.1	25633.1	18463.1	23312.0	11125.9
2	12667.8	3389.6	25998.1	19555.5	9501.2	5699.2	23317.5	20253.3	17191.6	23490.4	9135.1	20454.1
3	17507.3	24203.6	29255.0	47014.8	10961.3	6284.6	10690.7	17658.1	5471.1	10157.3	11365.2	10029.1
4	7156.1	4454.2	32512.1	29953.1	3022.4	5777.0	4342.3	6587.7	12543.7	7497.7	7612.6	6544.6
5	13528.8	4219.6	12594.7	14376.9	6789.2	14804.4	12986.7	7778.2	5615.4	11708.5	7662.4	7033.5
6	8972.6	9747.6	12702.9	24922.7	3607.9	5694.1	5491.0	9033.0	5625.3	5027.1	9599.9	5303.1
7	12782.5	14749.5	12999.4	19229.9	9660.3	11509.3	11659.3	14503.1	788.0	30912.7	19950.1	15041.6
8	4579.5	2656.9	5545.6	32230.4	16604.0	39445.2	6634.2	14590.2	22328.2	3355.2	9119.6	6157.8
9	5504.7	3592.8	13261.6	13247.7	4897.4	25361.8	4749.5	9732.4	12030.6	12891.2	30597.7	41170.1
10	10822.0	9406.9	5332.5	28929.0	6729.2	7594.9	16769.8	6948.8	20377.0	13993.0	16695.2	18589.8

Values in mg/m^2

Table 7.2 Monthly mean values of AFDW of periphyton at different stations in Cochin estuary

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.	16540.4	15538.7	12746.8	16274.8	11890.5	12204.1	15282.7	16257.3	16430.8	12084.8	16444.3	8486.9
2.	6132.5	1436.2	10825.6	7483.9	3830.9	2582.9	12593.8	11801.6	9582.6	14686.2	5875.7	8625.5
3.	8475.3	10255.1	12181.8	17992.6	4419.6	2848.2	5774.1	10289.4	3049.6	6350.4	7310.1	4249.3
4.	4170.6	2608.4	12660.2	19005.2	1670.5	3261.7	2709.2	3405.2	6256.8	4411.7	5001.5	3547.2
5.	7396.2	1973.1	6609.7	5374.1	3295.5	8182.4	6459.6	4532.4	3496.2	7998.1	5425.8	4277.8
6.	4199.2	5327.1	6585.2	9672.5	2055.8	2971.8	2660.4	5676.4	3724.0	3537.1	7002.2	2883.3
7.	5127.1	7351.2	7104.2	10026.5	5879.3	7163.4	5980.1	8255.2	3900.6	17150.4	12674.3	8880.6
8.	2350.2	1215.3	2071.3	14906.6	6432.4	17454.5	3663.4	7626.3	13274.1	1684.9	4968.4	3008.1
9.	2944.5	2047.2	5677.3	6586.8	2702.4	13520.4	2870.6	6057.5	7996.8	6709.9	16596.2	18901.2
10.	6142.6	4926.4	2589.5	11091.4	3446.7	4565.3	11120.1	4872.5	14722.4	7647.2	9703.3	9902.8

Values in mg/m^2

Table 7.3 ANOVA of AFDW of periphyton in Cochin estuary

Source	SS	DF	MS	F
Bet. Cols	380201792.00	11	34563800.00	2.322
Bet. Rows	742131008.00	9	82459000.00	5.539
Error	1473909632.00	99	14887976.00	
Total	2596242432.00	119		

Table 7.4 Linear correlation between AFDW (x; mg/m^2) and chl.a content (y; mg/m^2) at different stations in Cochin estuary.

Stn. No.	Regression equation	n	r
1.	$y = 2.7899\ x + 34.1961$	12	0.5746
2.	$y = 3.7466\ x + 10.3449$	12	0.8548
3.	$y = 0.010\ x + 0.7882$	12	0.9616
4.	$y = 3.0779\ x + 19.5035$	12	0.8690
5.	$y = 5.7393\ x + 12.7183$	12	0.7553
6.	$y = 0.0071\ x - 4.7926$	12	0.8992
7.	$y = 2.7142\ x + 75.7230$	12	0.5450
8.	$y = 7.1350\ x + 5.2916$	12	0.9433
9.	$y = 2.9116\ x + 19.9488$	12	0.8929
10.	$y = 4.7295\ x + 12.6007$	12	0.7793

Table 7.5 Monthly mean values of organic content of periphyton at different stations in Cochin estuary

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.	52.28	56.18	39.86	43.16	62.16	62.65	74.12	58.18	64.10	35.45	70.54	76.28
2.	48.41	42.37	41.64	38.27	40.32	45.32	54.01	58.27	55.74	62.52	64.32	42.17
3	55.37	51.45	33.29	58.74	68.48	64.38	72.27	80.63	69.82	54.70	72.50	84.05
4.	58.28	58.56	38.94	63.45	55.27	56.46	62.39	51.69	49.88	58.84	65.70	54.20
5.	54.67	46.76	52.48	37.38	48.54	55.27	49.74	58.27	62.26	68.31	70.81	60.82
6.	46.80	54.65	51.84	38.81	56.98	52.19	48.45	62.84	66.20	70.36	72.94	54.37
7.	40.11	49.84	54.65	52.14	60.86	62.24	51.29	56.92	49.50	55.48	63.53	59.04
8.	51.32	45.74	37.35	46.25	38.74	44.25	55.22	52.27	59.45	50.22	54.48	48.35
9.	53.49	56.98	42.81	49.72	55.18	53.31	60.44	62.24	66.47	52.05	54.24	45.91
10.	56.76	52.37	48.56	38.34	51.22	60.11	66.31	70.12	72.25	54.65	58.12	53.27

Values in % of DW

Table 7.6 Sesonal averages of organic content of periphyton at different stations in Cochin estuary.

Stn. No.	Monsoon	Post-monsoon	Pre-monsoon
1.	47.87	64.20	69.09
2.	42.67	49.48	56.18
3.	49.71	71.44	70.26
4.	54.80	56.45	57.15
5.	47.82	52.95	65.55
6.	48.02	55.11	65.96
7.	49.18	57.82	56.88
8.	45.16	47.62	53.25
9.	50.75	57.79	54.66
10.	49.00	61.94	59.57

Values in % of DW

Table 7.7 Monthly mean values of AI of periphyton at different stations in Cochin estuary

	Monsoon				Post-monsoon				Pre-monsoon			
Stn.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1.	176	180	164	178	190	177	180	260	240	181	250	154
2.	150	140	160	138	169	152	259	202	270	260	234	192
3.	96	112	107	84	92	80	78	93	80	120	107	66
4.	102	106	262	240	101	112	118	113	104	116	202	115
5.	120	108	112	117	112	119	117	112	109	280	111	114
6.	130	129	136	135	128	131	250	230	206	240	224	210
7.	118	110	120	127	117	124	245	116	110	235	240	104
8.	92	96	127	108	130	135	109	104	201	97	161	94
9.	130	121	132	128	120	258	138	125	204	129	240	268
10.	124	132	127	270	245	121	130	125	220	202	132	128

Table 7.8 ANOVA of AI of periphyton in Cochin estuary

Source	SS	DF	MS	F
Bet. Cols	51100.80	11	4736.44	2.334
Bet. Rows	117135.66	9	13015.07	6.414
Error	200872.53	99	2029.02	
Total	370109.00	119		

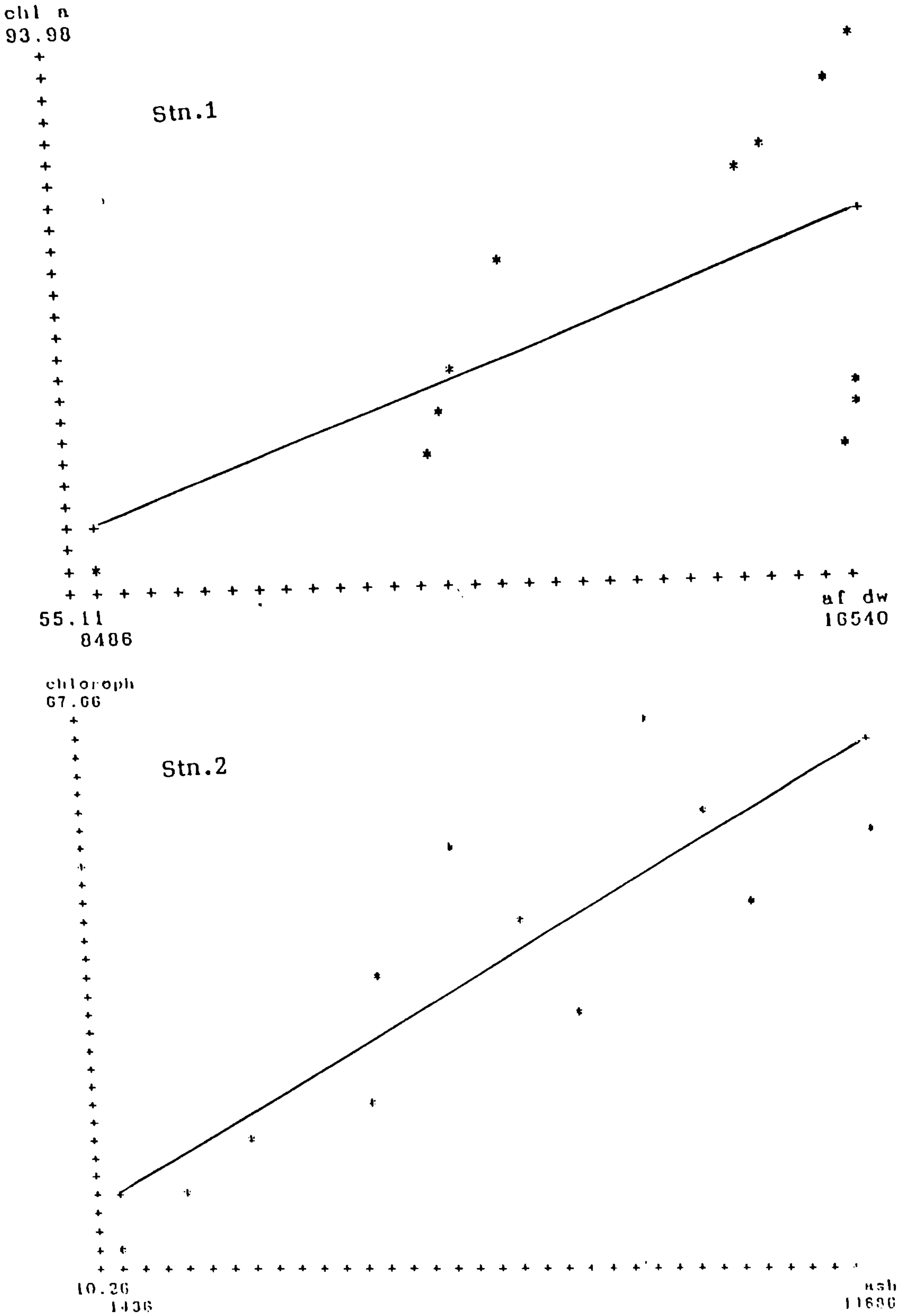


Fig. 7.1 Linear correlation between AFDW (x; mg/m^2) and chl.a content (y; mg/m^2) at stns. 1 & 2

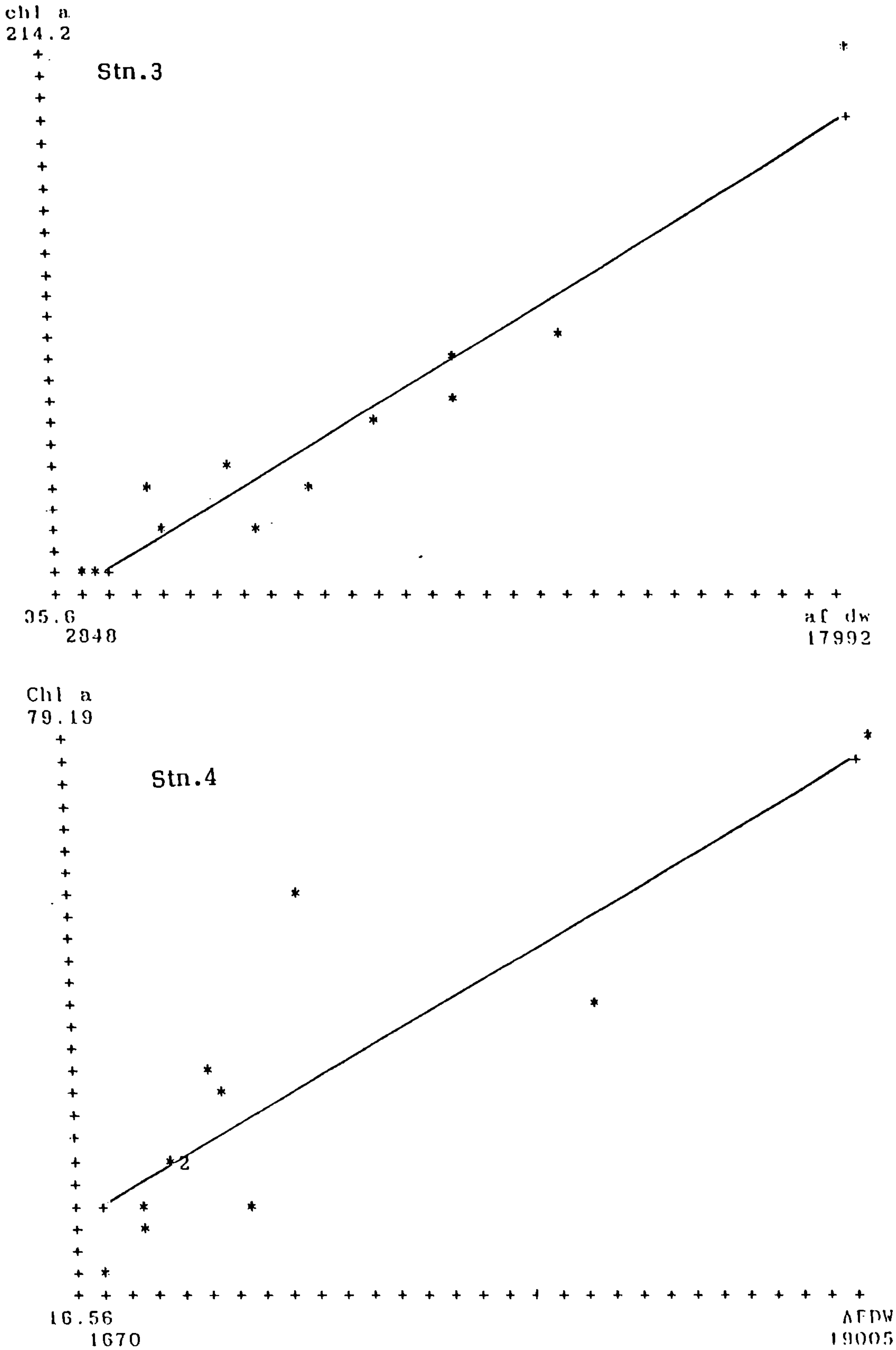


Fig. 7.2 Linear correlation between AFDW (x; mg/m^2) and chl.a content (y; mg/m^2) at stns. 3 & 4

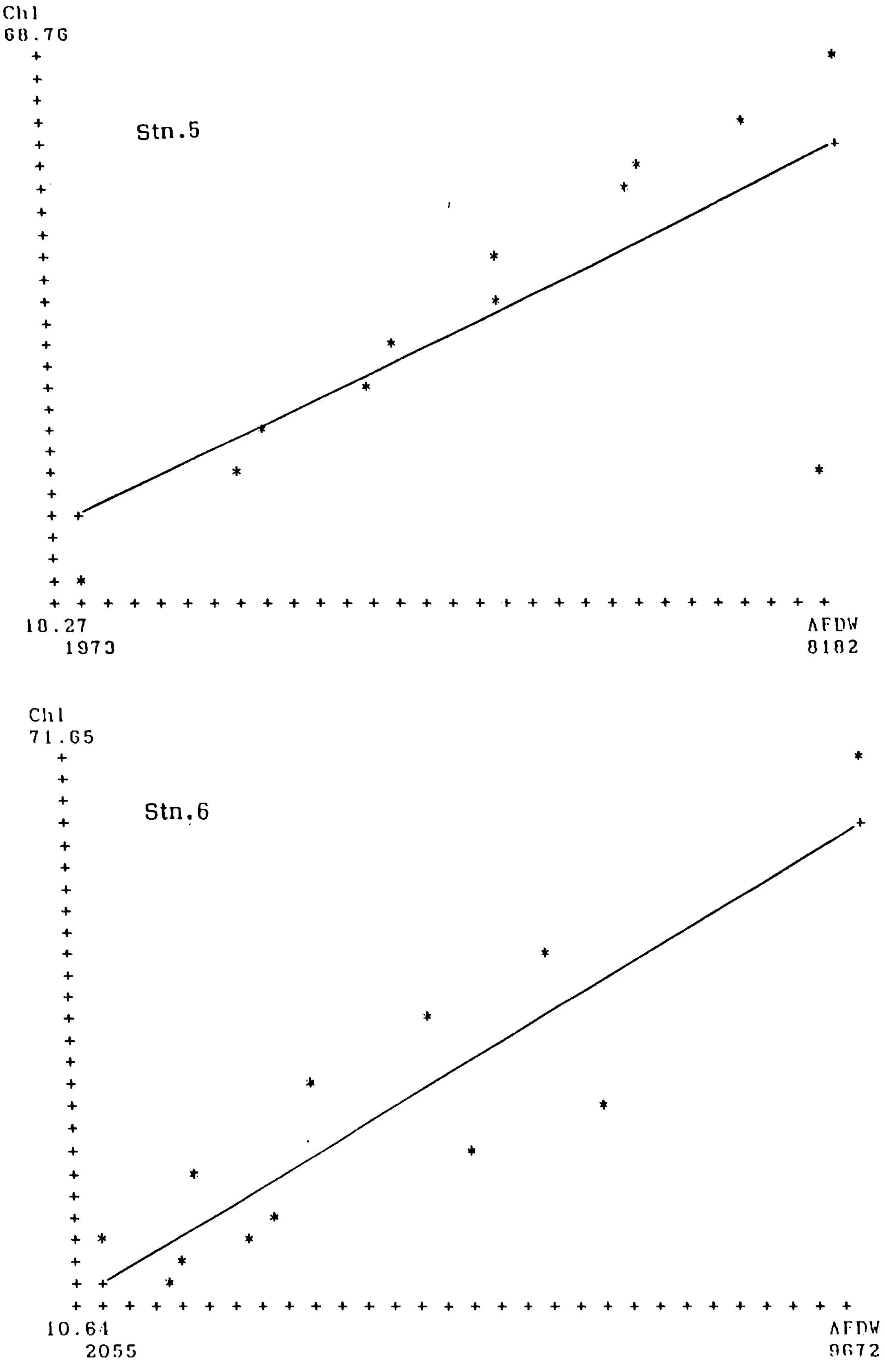


Fig. 7.3 Linear correlation between AFDW (x;mg/m^2) and chl.a content (y;mg/m^2) at stns. 5 & 6

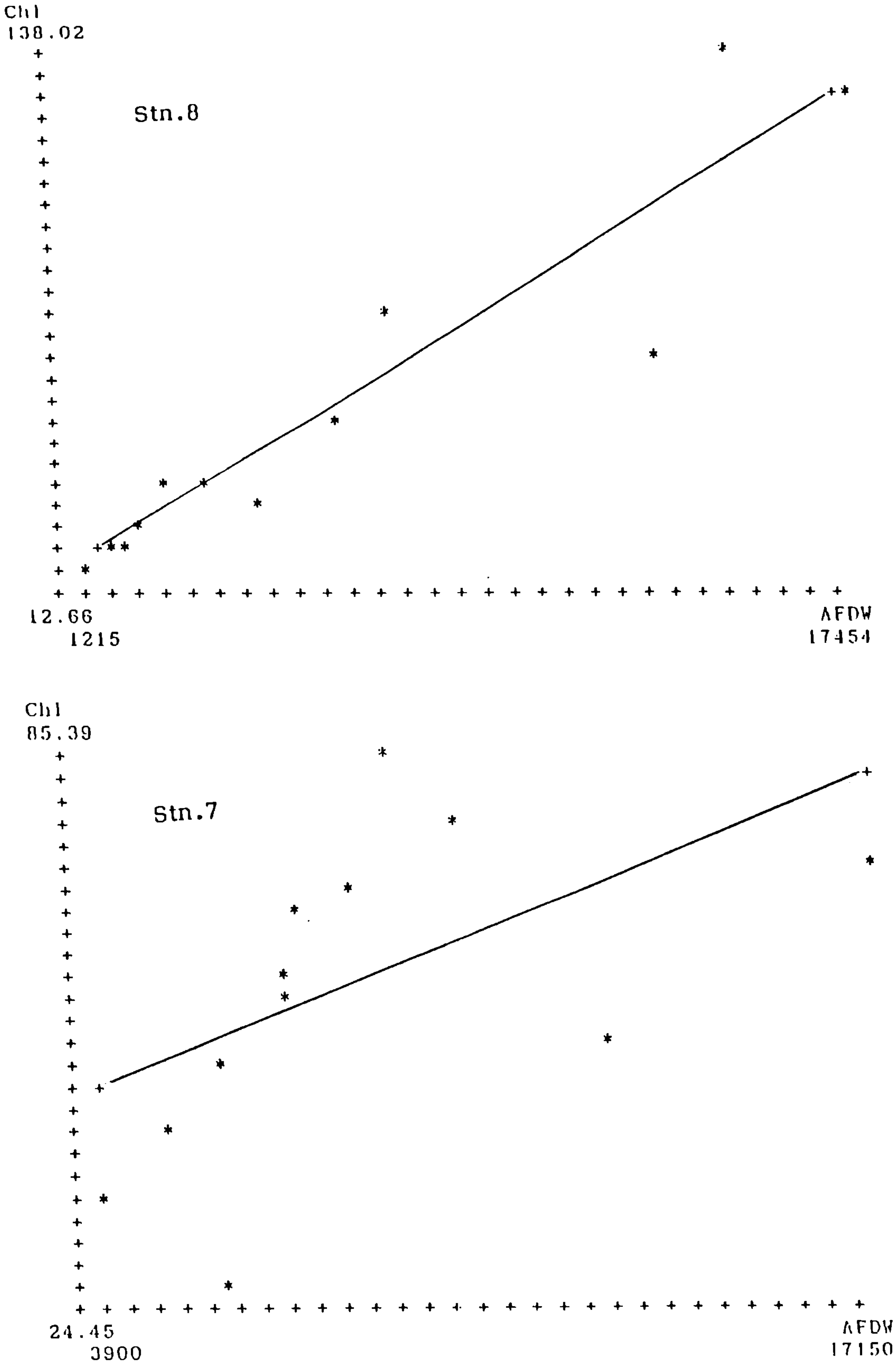
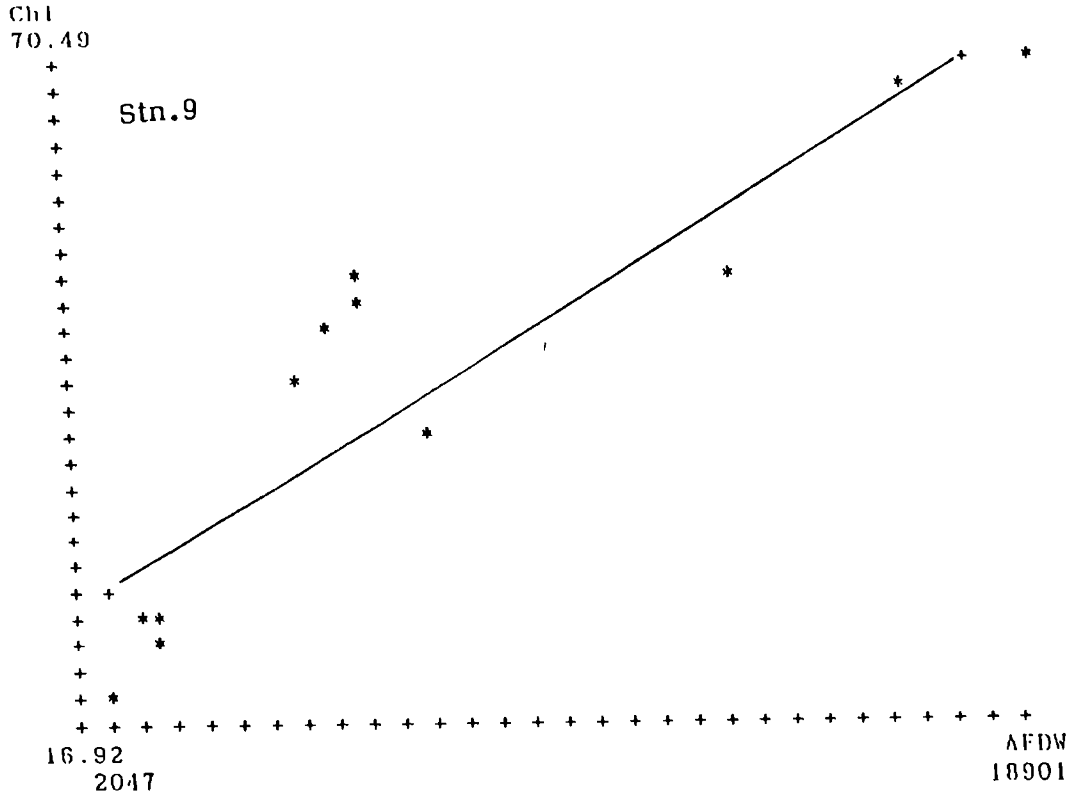


Fig. 7.4 Linear correlation between AFDW (x;mg/m^2) and chl.a content (y;mg/m^2) at stns. 7 & 8



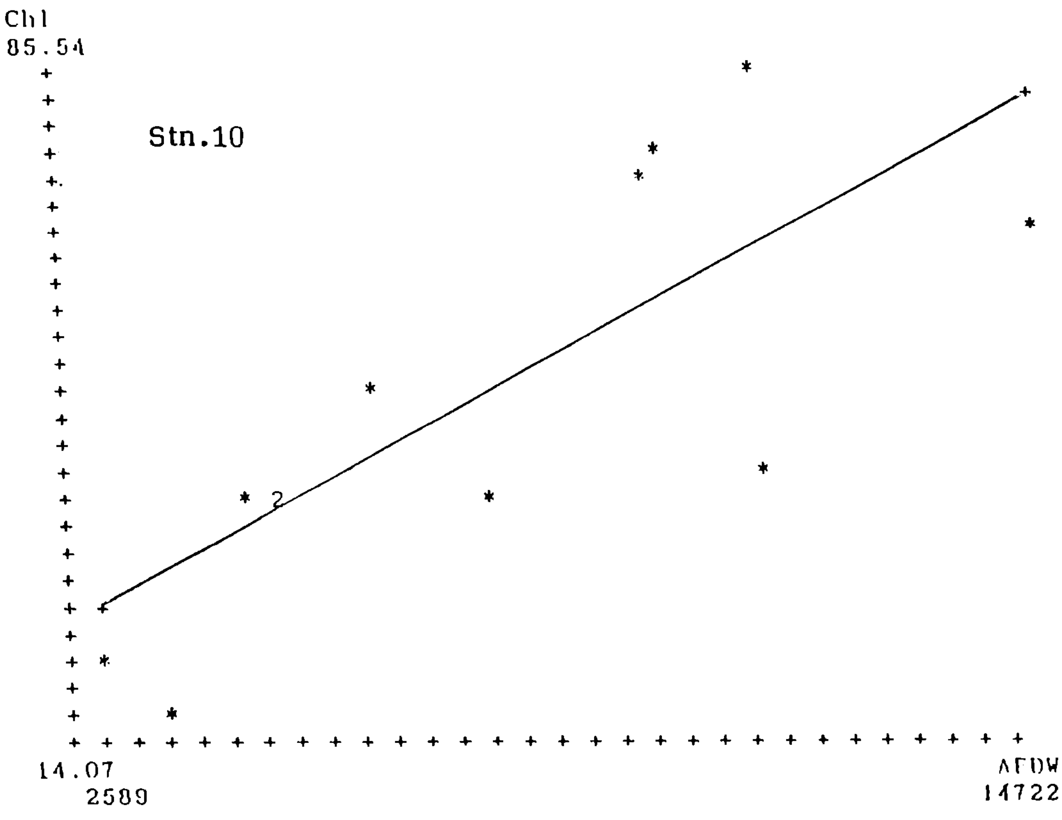


Fig. 7.5 Linear correlation between AFDW (x; mg/m^2) and chl.a content (y; mg/m^2) at stns. 9 & 10

8

PRIMARY PRODUCTION

Introduction

The total primary organic production in an aquatic ecosystem is very often used for the assessment of the fishery resources.Estimation of primary production is generally done with phytoplankton community, though other autotrophic gorups such as periphyton and macrophytes are present in varying quantities in different environments.In a shallow estuarine ecosystem periphtytic and sediment dwelling algae also contribute significantly to the total primary production in addition to phytoplankton. Several studies (Qasim et al., 1969,1974;Nair et al., 1975; Qasim, 1973,1979;Gopinathan et al., 1984) were made on the primary production in Cochin estuary. Qasim (1973) estimated the gross production in the estuary to be 0.35 to 1.5 gC $/m^2$/day.In the Vembanad lake adjacent to Cochin estuary , Nair et al.(1975) have recorded an average production rate of 1.2 gC $/m^2$/day.This may be an underestimation since the contribution to the total production by autotrophic groups such as periphytic algae, sediment microflora and macrophytes was not included while determining the production values.The quantitative estimation of production in any environment excluding periphytic and benthic algal communities where they are present in significant proportion, is far from the real value.The aim of the study is to assess the role of periphytic algae in the primary productivity of Cochin estuary.

Material and Methods

Measurements of primary productivity were made using Gaarder and Gran's light and dark bottle method as described by Strickland and Parsons (1972) and APHA (1992).The dissolved oxygen values for the initial,dark and light bottles were determined by Winkler method. The difference in oxygen concentration (ml/l) between light and dark bottles was converted into its carbon equivalent (mg C/l) for gross production and the difference between the light and initial values was converted into carbon equivalents for net production.

(a) **Sampling** : BOD bottles, 300 ml, clear and opaque borosilicate glass with ground glass stopper were used for sample incubation.The bottles were acid cleaned and rinsed thoroughly with distilled water. As a precaution the entire bottle (dark) was wrapped in aluminium foil or placed in light proof container during incubation.Small glass slides of known surface area were suspended 30 cm below water surface using a wooden float for simulated colonisation (2 weeks) of periphyton (Sreekumar and Joseph, 1995b).Periphyton community samples for productivity estimation were obtained by fortnightly collections from ten different locations in Cochin estuary.

(b) **Procedure** : At each station both the light and dark bottles were filled with water collected from the region, the periphyton samples were obtained.The bottles were thoroughly rinsed just before use, with water being tested.Productivity and respiration were determined by inserting small glass slides with periphytic growth into the bottles. The samples were incubated for a minimum period of 2 h. A set of Gaarder-Gran light and dark bottle productivity and respiration measurements were also made to obtain a correction for phytoplankton metabolism.

(c) **Calculations** : The gross and net primary production and respiration of periphyton community were calculated (APHA, 1992) as follows :-

$$P_G = \frac{V_{LB}(C_{LB} - C_{IB}) + V_{DB}(C_{DB} - C_{IB})}{t \times A}$$

where :

P_G = gross production, ml O_2 / m^2/h,

V_{LB} = Volume of light bottle , l,

C_{LB} = concentration of O_2 in the light bottle, ml/l, corrected for phytoplankton metabolism,

C_{IB} = concentration of O_2 in the initial bottle, ml/l,

V_{DB} = volume of dark bottle , l,

C_{DB} = concentration of O_2 in the dark bottle, ml/l, corrected for phytoplankton metabolism,

t = length of exposure, h, and

A = substrate area, m^2.

Periphyton community respiration was calculated by :

$$R = \frac{V_{DB} \; (C_{IB} - C_{DB})}{t \times A}$$

R = community respiration, ml $O_2/m^2/h$,

V_{DB} = volume of dark bottle , l,

C_{IB} = concentration of O_2 in the initial bottle, ml/l,

C_{DB} = concentration of O_2 in the dark bottle, ml/l,corrected for phytoplankton metabolism,

t =length of exposure,h, and

A = substrate area , m^2 .

The net periphyton community production (P_N) was determined as the difference :

$$P_N : P_G - R$$

Assimilation Number (AN): It is the amount of carbon assimilated divided by the amount of chl.a (mg C/mg chl.a/h).This ratio is an index of photosynthetic carbon production per unit chlorophyll (Raymont, 1980).Larger AN values indicate relatively more productive photosynthetic assemblages.

Production/Respiration Ratio (P/R): Calculated by dividing community production (GPP) by community respiration (CR_{24}).This ratio has been used to classify aquatic systems as autotrophic

(P/R > 1) or heterotrophic (P/R<1) (Odum ,1957, Vannote et al., 1980).

Net Daily Metabolism (NDM): It is calculated deducting daily community respiration (CR_{24})from daily gross primary production.This parameter is equivalent to Woodwell and Whittaker's (1968) net ecosystem productivity, Odum's (1971) net community productivity and Marker's (1976) net photosynthesis.NDM is positive during periods when photosynthesis is greater than respiration (ie., autotrophy predominates) and the system is accumulating organic matter.NDM is negative when the converse occurs and heterotrophy predominates with the net organic matter degradation.

Results and Discussion

Gross Primary Production

The monthly mean values of gross primary production at different stations in Cochin estuary are shown in the Table 8.1.The highest value of 296.66 mg C / m^2 /h was observed at Panavally station in September whereas the lowest 29.75 mg C/m^2 /h was reported from Eloor during July.The average production for the estuary during different months was in the range 87.86 to 181.56 mg/C/m^2 /h.The monsoon ,post- monsoon and pre-monsoon mean values of periphyton production were 131.36,109.03 and 118.78 mg C /m^2 /h respectively.The rate of production was found to be the highest during monsoon and lowest during post monsoon.The annual mean periphyton production calculated for the ecosystem was 119.77 mg C/m^2 /h.

Marker (1976) had reported 83.62 mg C $/m^2$/h periphyton primary production in southern England streams.Very litte data is available for comparison of production values of this ecosystem with that of other estuaries .Wiley et al. (1987) found that primary production in a prairie river system from below detection level to about 50g O_2/m^2/d.La Perriere et al. (1989) had reported 90.63 mg C $/m^2$/h and 87.5 mg C$/m^2$/h of gross primary production in high subarctic streams such as Chatanika river and Delta Clearwater Creek respectively.

The variation observed in regard to gross primary production both spatial and temporal were analysed (Table 8.2) using ANOVA.A significant variation in gross primary production occurred between different stations (ANOVA; $P<0.05$).Similarly there was a significant variation in primary production during different months of the year(ANOVA ;$P<0.05$).The incidence of three well marked seasons on account of the south west monsoon must be responsible for the temporal variation in primary production.The stations studied were located at places where some of the major rivers join the estuary or near big industrial concerns that discharge effluents into the ecosystems or near barmouth where comparatively higher salinity was observed.The changes in hydrographic parameters due to tidal waves also must have contributed to the variations in primary production spatially.

Correlation of periphyton production with biomass (chl.*a*), standing crop (cell count), hydrographic parameters such as salinity , temperature, dissolved oxygen, pH and nutrients such as nitrites, phosphates and silicates was studied by working out the correlation coefficient, r value (Table 8.3).There was no consistent correlation between primary production values and hydrographic parameters studied.However, production values showed significant positive correlation ($r= 0.7112, P<0.01$) with temperature at Njarackal and with NO_2-N ($r= 0.6032$, $P<0.05$) at Eloor.Correlation studies of periphyton biomass (chl.**a**) and hydrographic parameters made earlier also yielded similar results.There was significant positive correlation between standing crop (cell count) and production in most of the stations studied.Lack of correlation observed in some stations may be due to the characteristic floral composition of the site.In almost all the stations studied there was significant correlation between gross primary production values and chl.a ($P<0.01$).Significant correlations are shown in scatter plots (Figs.8.1- 8.3).

Assimilation Number

The monthly mean values of assimilation ratio for the periphyton are given in Table 8.4.The highest value of 7.29 was observed in July at Murinjapuzha and the lowest 1.1 in January at Panavally.The monthly mean values of AN for the entire estuary varied from 2.21 to 3.05.The monsoon , post-monsoon and pre-monsoon values were 2.48,2.49 and 2.54 respectively.Curl and Small (1965) suggest that several factors may affect the assimilation number that it cannot be regarded as a constant.The assimilation number in the estuary, remains more or less the same during the monsoon and post monsoon.A slight increase in the value was noted during pre-monsoon period.This may be due to the extended period of sunshine and sufficient light penetration on account of less turbulence in water.Joint and Pomroy (1981) had suggested a higher rate of primary production when water is less turbid.The conditions are just the reverse during monsoon and post monsoon .The average value of assimilation number calculated for the periphyton of the estuary is 2.5 which is well within the range (2-6) suggested by Strickland (1965).There is no evidence for the influence of nutrient concentration on periphyton assimilation number in this estuary.Strickland's view that nutrient deficiency reduces the values of assimilation number is not supported by Steele and Baird (1961).The difference in assimlation number at different stations were analysed (Table 8.5) using ANOVA.There was no significant variation neither spatial nor temporal with regard to the assimilation ratio of periphytic algae in the estuary (ANOVA; $P < 0.05$).

Community Respiration

Monthly mean values of periphyton community respiration (Table 8.6) at different stations varied from 10.80 to 120.22 mg $C/m^2/h$.The highest monthly average value of 81.62 mg $C / m^2/h$ for the entire estuary was observed in September while the lowest rate of 39.30 mg $C /m^2/h$ was noted in October.The monsoon, post-monsoon and pre-monsoon values of community respiration rates were 57.71 ,55.05 and 58.22 mg $C/m^2/h$

respectively.Pre-monsoon recorded comparatively higher respiratory rates possibly due to the increased temperature conditions.The annual mean value of the respiratory rate for the estuary was 55.05 mg $C/m^2/h$.

Net Daily Metabolism (NDM)

Temporal variations in NDM at different stations are summarised in Table 8.7.During monsoon all the stations except Murinjapuzha (stn.2) Vaduthala (stn. 4) and Karuthedom (stn. 10) were dominated by photosynthetic assimilation.In September respiration was predominant at Murinjapuzha and Karuthedom whereas at Vaduthala respiratory activity dominated in August and September.In the post- monsoon, autotrophy again predominated at most of the stations.However, four stations viz. Vaikom , Murinjapuzha , Bolghatty and Chittoor showed dominance of respiration during December. During pre-monsoon, heterotrophy (observed as dominance in respiratory activity) dominated in most of the stations except at Panavally and Eloor.But photosynthesis was dominant during April and May at Karuthedom.Panavally and Eloor are two stations where autotrophy predominated throughout the year.Almost the same conditions were prevalent at Kumbalam except for March when respiration was dominant.Deviation of NDM from zero on either way can be explained by the dominance of autotrophy or heterotrophy.Results obtained during the study are explained on this basis.Negative NDM values at Vaikom and Bolghatty during post-monsoon and pre-monsoon resulted from the predominance of heterotrophic components of the periphyton community.These stations by their proximity to sewage discharges are highly polluted due to decomposing organic matters.The environment in these stations facilitates the dominance of heterotrophic component of the periphyton community.During monsoon , heavy freshwater flushing at these stations remove degrading organic matter and NDM will be on the positive side.Eloor station located near the discharge of toxic industrial effluent from FACT and Cominco Binani Ltd. showed positive NDM values throughout the year.This can be possibly due to the harmful effect of toxic material on the more sensitive heterotrophic components.The fact that the environment was not conducive for autotrophs was evidenced from the low incidence of periphyton standing crop as well as chl.a.Hornberger et al. (1977) devised a scheme for evaluating water quality on the basis of production and respiration since NDM is affected by a variety of factors influencing autotrophs and heterotrophs, its utility for the evaluation of water quality in the highly fluctuating estuarine environment is doubtful.However, continuous monitoring of specific locations with regard to metabolic activity wil reveal the trophic level changes taking place and its relation to the changing environment.

Production/ Respiration (P/R)

Monthly mean production / respiration ratio (Table 8.8) at different stations can also be conveniently used for determining the trophic level existing at different locations and periods.P/R value is > 1 when NDM is positive and is < 1 when NDM is negative. NDM value of zero is functionally equivalent to a GPP: R_{24} value of unity except that NDM is an absolute value whereas GPP : R_{24} is a relative assessment of system metabolism.

According to Nair et al. (1975) planktonic production is 1.2 g C/m^2/d and the total production estimated for the estuary and the adjacent backwaters is about 100,000 tonnes of carbon per year.Periphyton production observed during the present study is at the rate of 1.4 g C/m^2/d.The estuarine complex having 180 km boundary with an average 1 m depth can assimilate about 92000 tonnes of carbon per year.Periphyton production in the estuary is thus upto 92% of the planktonic production.The phytoplankton and the periphyton together contribute about 1,92,000 tonnes of carbon per year towards total primary production in the estuary.

Summary

The primary production of periphytic algae in Cochin estuary was investigated.Periphyton colonised on artificial substrata were incubated in light and dark bottles.Production was estimated by measuring the changes in dissolved oxygen.

Periphyton production did not show significant correlation with the hydrographic parameters studied.However there was significant positive correlation between gross primary production and biomass (Chl.a).

Significant variation (spatial and temporal) exists in the rate of primary production at different stations of the estuary.

The annual mean gross primry production of periphyton in the estuary was estimated as 119.77 mg C/m^2/h.Monsoon season was comparatively more productive than post-monsoon and pre-monsoon.The phytoplankton and periphyton together contribute about 1,92,000 tonnes of carbon per year towards total primary production in the estuary.

Table 8.1 Monthly mean values of gross primary production (periphyton) at different stations. (mg/C/m^2/h)

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	209.66	196.74	180.22	204.55	160.11	170.15	190.45	150.08	165.76	164.57	154.82	140.69
2	131.22	74.79	137.01	91.16	85.73	88.51	95.80	147.21	125.67	126.31	107.69	95.07
3	107.27	230.02	207.32	296.66	132.68	108.29	160.12	122.69	166.88	132.93	146.68	139.69
4	123.07	71.36	125.39	257.36	47.8	76.87	71.63	91.65	167.24	98.49	78.24	90.69
5	126.36	57.00	131.59	100.14	67.66	107.26	108.76	74.46	74.42	48.56	124.15	72.22
6	82.04	107.58	120.08	197.75	41.43	54.65	28.19	61.20	47.98	38.01	81.58	37.62
7	113.75	188.46	150.36	205.27	148.23	138.07	68.46	177.21	107.12	163.47	124.10	209.54
8	61.83	29.75	33.27	266.37	111.92	252.11	78.98	196.52	140.00	35.08	84.24	71.20
9	59.16	41.11	84.42	104.00	56.52	115.74	52.83	102.73	77.61	123.78	188.50	174.17
10	128.80	82.85	44.65	92.43	26.59	86.77	236.09	69.38	169.97	63.60	183.77	217.38

Table 8.2 Analysis of variance (ANOVA) for the periphyton primary production

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F ratio
Bet. Cols	111115.75	9	12346.19	5.250
Bet. Rows	56433.15	11	5130.29	2.182
Error	232811.34	99	2351.63	
Total	400360.24	119		

Table 8.3 Correlation coefficient (r value) between periphyton production and chl. a, standing crop and environmental parameters

Stn. No.	Chl. a	Standing Crop	Salinity	Temp.	DO	pH	SiO_3	NO_2-N	PO_4-P
1	**0.9898	0.0157	-0.5015	-0.6772	0.0204	-0.3338	0.1795	0.1795	0.2874
2	**0.6756	*0.6689	0.2942	0.0798	-0.1036	0.1227	0.3110	-0.4326	-0.2383
3	*0.7771	-0.1171	-0.1424	-0.0654	-0.1080	0.0466	0.1610	-0.1662	-0.0459
4	**0.9831	-0.2562	0.1142	-0.0472	0.2237	-0.1448	0.1423	0.2205	0.2639
5	**0.8761	**0.8094	-0.1618	-0.0717	-0.3197	-0.2956	0.1014	0.3844	0.1390
6	**0.9968	0.3796	-0.5696	-0.4514	-0.5548	-0.6417	-0.4589	-0.6828	0.0701
7	**0.9607	0.3666	-0.1445	-0.2438	0.0183	0.0307	0.4188	-0.2830	0.1857
8	**0.9833	0.8705	-0.0661	0.3351	0.5420	-0.0170	0.5041	*0.6032	0.1921
9	**0.9640	0.5427	0.5282	**0.7112	-0.0737	0.3297	-0.2919	-0.3298	-0.0859
10	**0.9854	**0.8312	0.3548	0.4449	0.4386	0.4291	-0.7237	0.3069	-0.2292

'*' -- Significant at 5% level ($P < 0.0.05$)

'**'-- Significant at 1% level ($P < 0.001$)
Degrees of freedom = 11

Table 8.4 Monthly variation in assimilation ratio of periphytic algae at different stations in Cochin estuary

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	2.23	2.27	2.31	2.23	2.55	2.45	2.24	2.40	2.42	2.46	2.35	2.55
2	3.21	7.29	2.02	1.68	3.78	5.21	1.97	2.52	3.54	2.23	4.28	2.11
3	1.21	2.51	1.82	1.38	2.76	3.04	2.16	1.10	4.37	2.51	2.14	2.18
4	3.01	2.98	2.60	3.25	2.89	2.64	3.12	3.04	2.78	2.59	3.16	2.94
5	2.05	3.12	2.23	2.18	2.30	1.56	1.97	1.84	2.32	1.70	2.54	1.92
6	2.54	2.60	2.48	2.76	2.58	2.41	2.65	2.48	2.65	2.71	2.61	2.74
7	2.61	2.82	2.54	2.60	2.95	2.39	2.80	2.49	3.02	2.24	2.35	2.45
8	2.42	2.35	2.04	1.93	2.26	1.95	2.35	2.68	2.12	2.02	2.73	2.21
9	2.61	2.43	1.96	2.02	2.51	2.21	2.54	2.12	1.98	2.38	2.72	2.47
10	2.60	2.22	2.19	2.25	1.89	2.30	2.76	1.78	2.54	1.68	2.50	2.81

Table 8.5 Analysis of variance (ANOVA) showing the significance of the assimilatory number of periphyton in different stations and months

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F ratio
Bet. Cols	14.30	9	1.59	4.167
Bet. Rows	7.56	11	0.69	1.803
Error	37.75	99	0.38	
Total	59.61	119		

Table 8.6 Monthly mean values of periphyton community respiration (mg $C/m^2/h$) at different stations

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	88.52	92.05	76.76	94.28	78.21	82.62	98.47	80.48	88.34	76.29	80.67	72.85
2	60.52	29.28	59.04	47.50	40.29	42.74	50.73	66.24	69.06	64.77	55.08	49.93
3	40.84	58.26	90.52	120.22	54.28	41.63	68.50	50.73	80.28	55.44	62.06	64.29
4	48.76	26.47	65.40	130.84	18.28	30.54	29.77	45.08	80.49	40.28	40.87	36.47
5	55.62	20.82	56.27	39.87	31.44	40.52	39.80	33.90	29.62	30.27	55.42	30.29
6	35.64	42.28	50.58	90.22	15.67	24.76	15.06	32.44	24.80	20.04	38.88	19.49
7	51.85	90.20	80.49	99.63	70.04	60.30	35.24	88.49	53.38	89.80	63.42	102.76
8	20.64	10.80	14.28	106.72	45.97	90.39	30.60	95.04	69.71	14.02	40.61	30.52
9	27.07	20.12	32.25	40.02	23.54	60.94	24.50	45.46	39.79	60.36	95.04	87.56
10	61.95	36.47	18.59	46.95	15.32	38.66	105.80	26.75	86.54	32.08	90.76	106.91

Table 8.7 Monthly mean values of net daily metabolism (NDM) of periphyton community at different stations (mg C/m^2/d)

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	391.44	151.68	320.40	191.88	44.28	58.92	-77.88	-130.56	-131.04	143.88	-78.24	-60.14
2	122.16	194.76	227.2	-46.08	61.80	36.36	-67.92	176.60	-149.40	-38.76	-29.64	-57.48
3	307.08	642.00	315.36	674.64	289.44	300.36	277.44	254.76	75.84	264.60	270.72	133.32
4	306.60	221.04	-64.92	-51.84	134.88	189.48	145.08	17.88	75.12	215.16	-42.00	213.01
5	181.44	234..4	228.60	244.80	57.36	314.64	349.92	79.42	182.16	-143.76	159.72	139.68
6	129.12	276.24	227.04	207.72	121.08	61.56	-23.16	-44.16	-79.16	-24.84	45.84	-16.32
7	120.60	96.72	127.44	72.12	97.80	185.64	-24.24	2.76	4.32	-193.56	-32.88	48.24
8	246.60	97.80	56.52	635.16	239.76	855.96	213.36	77.28	6.86	84.48	63.24	121.92
9	60.24	10.44	239.04	287.52	113.28	-73.68	45.96	141.72	-23.64	36.72	-18.96	-11.40
10	58.80	118.92	89.64	-17.60	-48.60	113.40	301.08	190.56	-37.58	-6.72	206.52	42.72

Table 8.8 Monthly mean values of P/R ratio of periphyton communicy

at different stations.

Stn. No.	Monsoon				Post-monsoon				Pre-monsoon			
	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	1.18	1.06	1.17	1.08	1.02	1.02	0.96	0.93	0.93	1.07	0.95	0.96
2	1.08	1.27	1.16	0.95	1.06	1.03	0.94	1.11	0.90	0.97	0.97	0.95
3	1.31	1.30	1.14	1.23	1.22	1.30	1.16	1.20	1.03	1.19	1.18	1.08
4	1.26	1.34	0.95	0.98	1.30	1.25	1.20	1.01	1.03	1.22	0.95	1.24
5	1.13	1.36	1.16	1.25	1.27	1.32	1.36	1.09	1.25	0.80	1.12	1.19
6	1.15	1.27	1.18	1.09	1.32	1.10	0.93	0.94	0.86	0.95	1.04	0.96
7	1.09	1.04	0.93	1.03	1.05	1.12	0.97	1.00	1.00	0.90	0.97	1.01
8	1.49	1.37	1.16	1.24	1.21	1.39	1.29	1.03	1.01	1.25	1.03	1.16
9	1.09	1.02	1.30	1.30	1.20	0.94	1.07	1.12	0.97	1.02	0.99	0.99
10	1.03	1.13	1.19	0.98	0.86	1.12	1.11	1.29	0.98	0.99	1.01	1.01

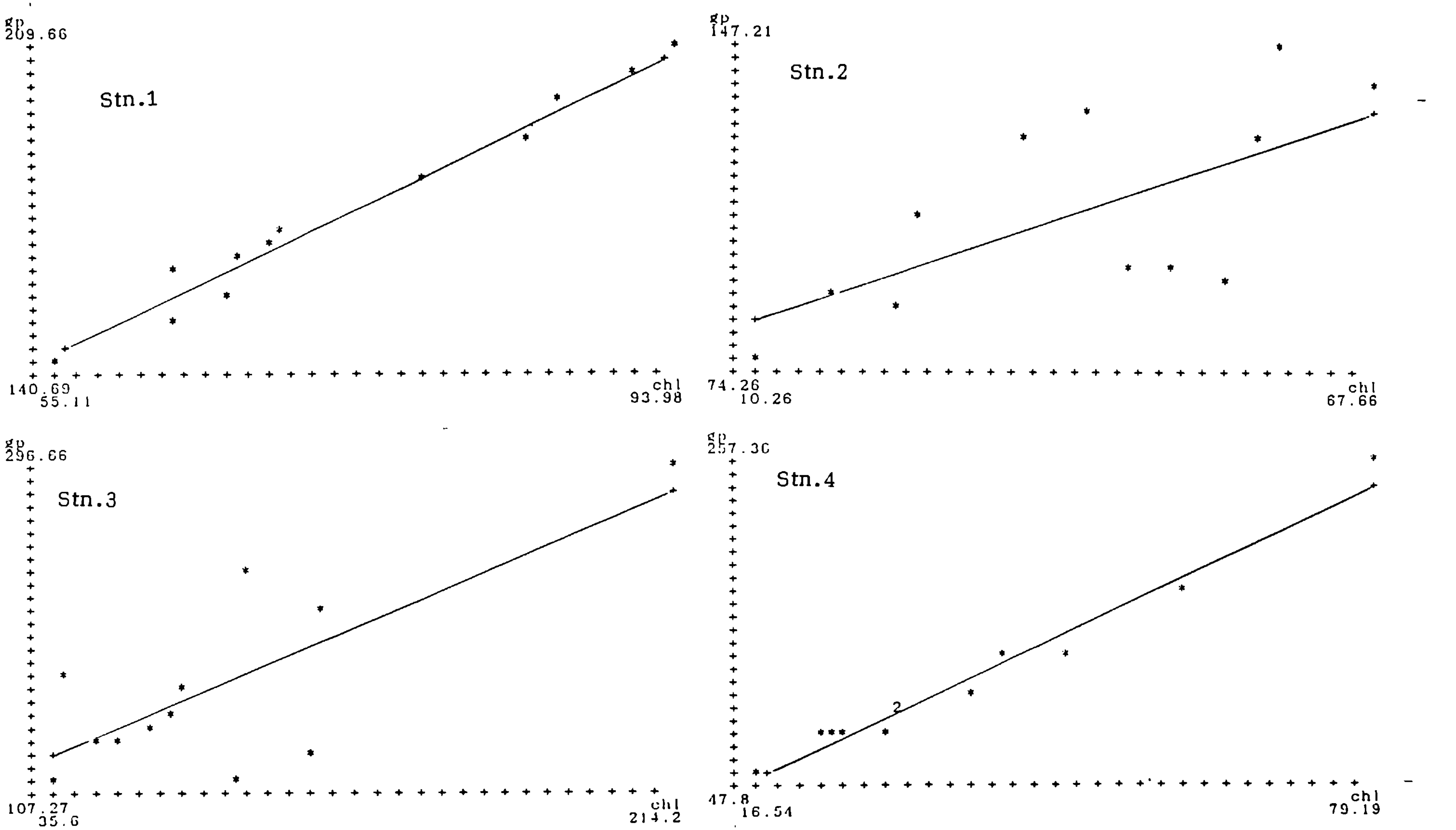


Fig.8.1 Linear correlation between chl. a (x;mg/m^2) and GPP (y;mg C/m^2/h) at stns. 1,2,3 & 4

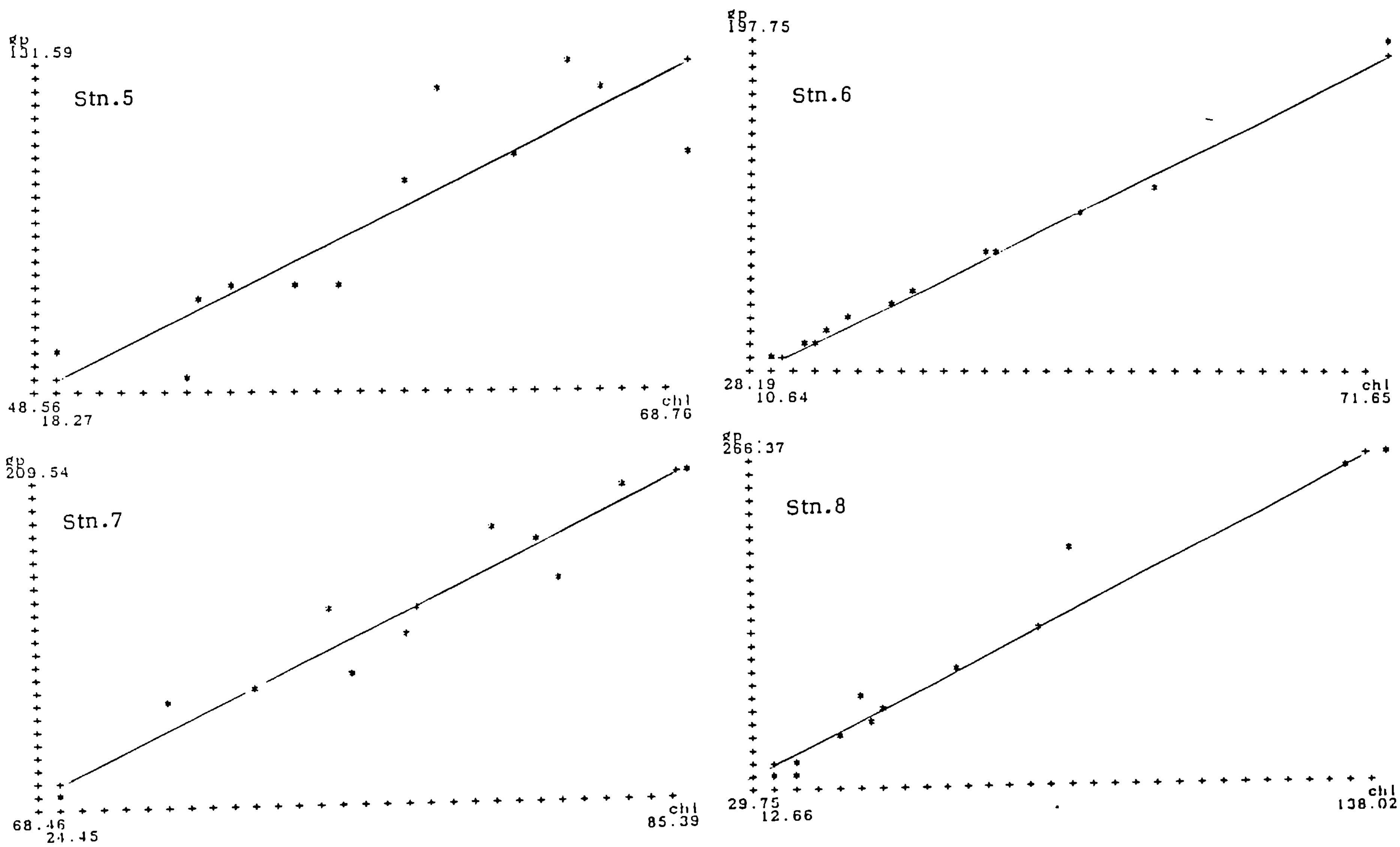


Fig.8.2 Linear correlation between chl.a (x; mg/m^2) and GPP (y; mg C/m^2/h) at stns. 5, 6, 7 & 8

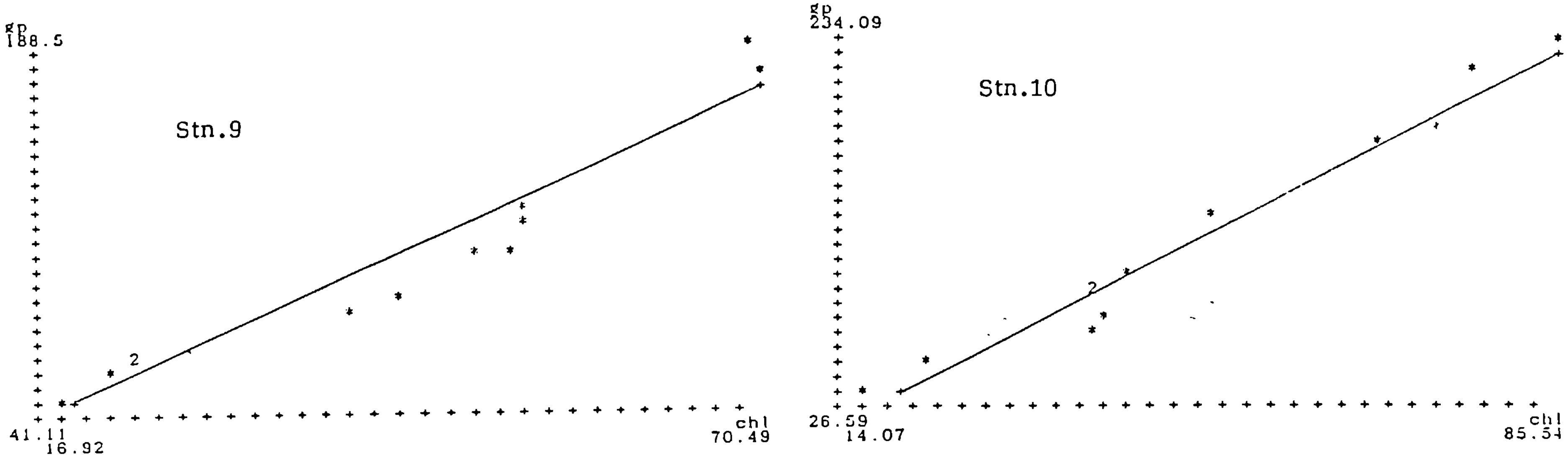


Fig.8.3 Linear correlation between chl. a (x;mg/m^2) and GPP (Y; $mgC/m^2/h$) at stns. 9 & 10.

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CONCLUSIONS

The photosynthetic component of periphyton, the microorganisms growing on submerged surfaces in water, includes a diverse assemblage of algal forms that contribute significantly to the total primary production of various aquatic ecosystems. Earlier investigations on these flora, which escaped our attention so far, reveal that they are very sensitive to water quality and hence serve as reliable indicators of pollution. The autotrophic index of periphyton is generally considered as a useful criterion for the assessment of water quality. Changes in the floral composition and community structure of periphyton are quite often interpreted in relation to the aquatic environment by several investigators. No such studies have been made from Cochin estuary. The ecophysiology of periphytic flora of Cochin estuary has been investigated in view of its importance in the above aspects.

Due to the lack of retrievable natural substrata at the desired sampling site, the suitability of different artificial substrata such as clay tile, wood, glass, metal, painted surface, bivalve shell, plastic and rock and the duration of their exposure for optimum periphytic accrual have been studied. For the first two weeks, the rate of colonisation was found to be exponential on all the substrata. Periphyton concentration varied with the texture of the substrata and those such as wood, glass and bivalve shells showing comparatively higher concentration of periphytic algae. However no preferential accrual was observed among the various species. The algae recorded from the different substrata were mainly of pennate diatoms.Of the hydrographic parameters studied, salinity was found to have profound influence on the periphyton standing crop.

Periphytic algae of Cochin backwater comprised of 40 genera and 76 species. Among these 31 genera belonged to Bacillariophyceae,seven genera to Chlorophyceae and 2 to Cyanophyceae.Out of the 31 genera of diatoms, 24 were pennales and 7 centrales.Irrespective of the conspicuous seasonal variations, 30 species such as Amphora angusta, Gyrosigma spencerii, Navicula gracilis, Nitzschia obtusa, Pleurosigma aesturaii, and Thalassiosira subtilis were found distributed throughout the year, exhibiting wide tolerance of salinity. About 15 species such as Gomphonema sphaerophorum, Nitzschia longissima, Closterium acerosum, Cosmarium contractum, C. pyramidatum, Spirogyra jogensis and Stigeoclonium flagelliferum were reported only during monsoon period.These are freshwater forms.Certain species such as Achnanthes coarctata, Coscinodiscus radiatus , Gyrosigma macrum, Hantszchia amphioxys and Triceratium reticulatum were reported only during premonsoon when the salinity of the estuary is higher.Thus periphytic flora is found to be composite in nature due to the fluctuating hydrography and recruitment of the flora from the sea and rivers into the ecosystem. The periphyton standing crop in the estuary varied from 9.8×10^3 to 1.6×10^4 cells $/cm^2$. Though salinity was one of the major factors influencing periphyton growth there was a lack of consistency in the correlation of this factor with its standing crop.This may be due to the variation in the floral composition of periphyton at different parts of the estuary.The diversity index <Shannon and Weaver> of periphyton was in general slightly higher than that of planktonic algae in the ecosystem.Similarity index of periphytic flora between majority of stations was <60 indicating the extent of variation.Diatoms form the dominant group of the periphytic algal community as in other ecosystems.The common occurrence of species such as *Amphora angusta*, *Gyrosigma spencerii*, *Navicula gracilis*, *Nitzschia obtusa*, *Pleurosigma estuarii*, *Thalassiosira subtilis*, *Mougeotia adnata* and *Oscillatoria* sp. throughout the year indicates that they are the typical euryhaline forms of this estuary. The annual mean value of chl. *a* of periphyton in the estuary has been estimated to be 50.84 mg/m^2 . This comparatively high magnitude of chl.*a* highlights the role of periphyton in the primary productivity of the estuary.The temporal and spatial variations in the distribution of chl.*a* were significant {ANOVA; $P<0.05$}. The annual mean values of chl. *b* and chl.*c* of periphyton were 6.36 and 12.57 mg/m^2 respectively.The ratio of chl.*a* : *b* being , <2:1 and comparatively higher value of chl.c indicate the dominance of diatoms in the periphyton of this ecosystem as also evidenced by the floral composition.

The autotrophic index of periphyton at different stations in the backwater varied from 66 to 280.The annual mean value of AI was estimated to be 154 ±20 which is well within the range {50 -200} prescribed for normal water quality {APHA,1992}. However the annual mean values of AI at stns. 1,2,6 and 10 were near to the upper limit of normal AI range. Isolated high AI values were also recorded even at stations where the annual mean was <150.The high values at different stations indicate occasional degeneration of water quality.AI is a useful criterion for monitoring the water quality of the estuary.

The periphyton productivity was estimated using artificial substrata kept submerged at different stations for simulated periphytic growth.Periphyton colonised on artificial substrata were incubated in light and dark bottles and production was estimated by measuring changes in the concentration of dissolved oxygen. The annual mean production has been estimated to be 1.4 g C/m^2 /d. The estuarine complex having 180 km boundary with an average 1m depth of periphytic growth assimilate about 92,000 tonnes of carbon per year which is almost of the same magnitude as that of planktonic production {100,000 tonnes of carbon} from the estuary and the adjacent waters reported by Nair et al.{1975}.Periphyton productivity in the backwater is thus estimated to be 92% of the planktonic production.The phytoplankton and periphyton together contribute about 192,000 tonnes of carbon per year towards total primary production.

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