Ecology of Algae in Two Forested Streams at Shillong (Meghalaya)

By

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THESIS SUBMITTED IN FULFILMENT OF THE DEGREE OF

Doctor of Philosophy

IN

Botany

NORTH-EASTERN HILL UNIVERSITY
SHILLONG

November, 1991

Dedicated
to
My Parents

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J. P. Gaur, Ph. D.
Reader

I certify that the thesis entitled **"Ecology of algae in two forested streams at Shillong (Meghalaya)"** submitted by Miss Jayashree Rout, M.Sc. for the Degree of **Doctor of Philosophy** of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. The work has not been submitted for any Degree of any other University.

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Forwarded
12.12.91

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Preface

The realization of significance of autotrophy in streams has led to a resurgence of interest on periphytic algal communities of these systems. Whereas the corpus of information on stream algae of North America and Europe appears to be quite impressive, similar details about tropical streams are still scanty. It is of particular concern that literature on stream algae of the entire Indian subcontinent is virtually non-existent. The generation of relevant information about algae of Indian streams becomes imperative in view of the ongoing rapid depletion of forest cover, and the necessity of evolving judicious strategies for the management of these endangered ecosystems.

The work presented in this thesis deals with the study of algal ecology of two pristine streams draining forested areas at Shillong. The thesis has been divided into eight chapters. The first chapter ('General Introduction') discusses the current status of the subject, and the reasons for taking up the present work. This is followed by a brief account of the study area in Chapter 2. The detailed studies of epilithic algae in relation to physico-chemical characteristics of stream water are given in Chapter 3. Similar studies for epipelic algal assemblages constitute the next chapter. Chapter 5 deals with laboratory bioassay for assessing the nutrient limitation in selected streams. Since light conditions are highly variable in forested streams, the influence of light on periphytic algae colonizing artificial substrata has also been studied (Chapter 6). Chapter 7 discusses preliminary survey of the ability of stream algae to tolerate desiccation. Each chapter includes 'Discussion'; however, a brief general discussion is also given (Chapter 8) to assimilate the information gathered in various chapters. This is followed by 'Summary' and 'Literature Cited'.

It gives me immense pleasure to place on record my profound sense of gratitude to my supervisor, Dr. J.P. Gaur, Reader, C.A.S. in Botany, Banaras Hindu University, for his invaluable guidance, sustained interest and constructive criticism in my Ph.D. research.

I would like to thank Professors R.S. Tripathi, R.R. Mishra and Y.S. Chauhan, who during their tenure as Head, Botany Department, NEHU, have kindly extended laboratory facilities. I am also thankful to the faculty members and non-teaching staff of Botany Department, NEHU, for their help during my research studies.

Mr. Ganesh Sharma has kindly helped me in field studies. I would like to appreciate the help of my lab colleagues Dr. A.K. Singh, Miss Mita Ghosh, Mr. Norbert Noraho and Mr. Nabendu Sengupta. I am thankful to my friends, Debjani, Raja, Bisnu, Arun, Jharna (Chakravorty), Beena, Sarfaraj, Saroj, Uttam and others who have helped me in all possible ways. I appreciate Dr. Surendra Singh and Dr. Girish Panda for their keen interest in my research work.

Mr. S.C. Pathak of GSI has been kind enough in advising me about the selection of sampling stations. Dr. B.K. Sharma, Zoology Department, NEHU, generously allowed me to use some instruments of his laboratory. I appreciate Dr. D.T. Khating, Head, RSIC, NEHU, for kindly allowing atomic absorption analysis and SEM of my samples. Dr. Sudip Dey and Mrs. Susmita Gupta of the Electron Microscope Laboratory, RSIC, NEHU, have kindly helped me in SEM studies. I also wish to thank Dr. S.N. Rai, Head, Computer Centre, NEHU, for his kind permission to use the computer facility for processing of my research data. Mr. Partha and Mr. Shome have rendered all possible help during the computational work.

I gratefully acknowledge the financial assistance from the Ministry of Environment, Govt. of India. A Senior Research Fellowship from CSIR enabled me to carry out the research work rather smoothly during the last phase of my Ph.D. work, and thesis writing.

I would like to thank Dr. Ashok Kumar, Reader, School of Biotechnology, Banaras Hindu University, for kindly extending necessary help during thesis writing. I am also grateful to Dr. Manju Pandey for kindly arranging my accommodation at BHU .Mr. R.P. Sinha, Research Fellow, Deptt. of Biotechnology, BHU has kindly corrected my typewritten manuscript and helped me in various other ways. Mr. J.K. Thakur, Dr. Nirupama Mallik and Miss Alka Dwivedi have also helped me in many ways. My sincere thanks are due to Mr. Rang Nath Singh who had kindly agreed to type out this thesis at a very short notice.

Insufficient though, it is with deep sense of gratitude that I express my great indebtedness to my revered parents, sister, brother, brother-in-law, and other members of the family for their blessings, keen interest, inspiration and constant encouragement in my research pursuits.

28.11.91

(JAYASHREE ROUT)

Chapter 1 GENERAL INTRODUCTION

Streams and rivers constitute one of the major features of most landscapes, although their total area is about one-thousandth of that of the land surface (Hynes 1970). In spite of representing a small fraction of the total global area under water, the significance of streams is enormous. Streams are the most convenient and cheap source of water for domestic and industrial requirements particularly in the hilly regions. Irrigation and artificial impoundment of streams have aided in increasing local water supplies. The sound land-use practices trap stream water at or near its source for maximum usefulness to plants, animals, and man. Hydroelectric power generation is advancing day by day by damming the large streams and rivers. In addition, streams, serve as a repository of waste materials in many parts of the world. Another extremely important role of streams lie in the hydrologic cycle.

All rivers essentially originate as streams which, in turn, receive water from various sources. Streams may depend on glacial melting, which is not, as a rule, a common source of water for streams. During rainy seasons the surface runoff contributes substantially to total volume of stream water. The perennial streams mostly originate from springs. Ground water is the major source of water for such streams. In springs, physico-chemical characteristics of water do not fluctuate much, whereas variations are tremendous in case of ponds, lakes, rivers and coastal waters. The cold water springs usually maintain a temperature ranging from 9° to 18°C, while hot springs characterised by extremely high temperature (up to 90°C, Castenholtz & Wickstrom 1975) are mostly volcanic in origin and provide a steady state microcosm of extreme conditions. They have a high concentration of dissolved salts (Hynes 1970). In contrast, most cold water springs have high concentrations of Ca^{++} and HCO_3^- ions (Whitton 1975). Whatever may be the source of water in streams, they find their way to major rivers which, in turn, lead ultimately to the sea. Estuary is a good example of a coupled system between freshwater of the river and saltwater of the sea that achieves a good balance between physical and biotic components, and thereby a high rate of biological productivity which is undoubtedly unique.

Lotic systems, including streams, have several characteristic features that distinguish them from lakes and other standing bodies of water. The differences are due mainly to the following : (i) water current is much more of a major controlling and limiting factor in rivers and streams and the velocity of current varies depending on the steepness of the surface gradient, the roughness of the stream or river bed and the depth and width; (ii) in smaller streams, water is subjected to a greater variety of movements and to a more thorough mixing than the standing bodies of water; (iii) streams are more apt to be highly turbid than lentic systems at least seasonally; (iv) oxygen content in unpolluted streams is usually higher than in lentic waterbodies; (v) there is little or no thermal or chemical stratification in streams and other lotic systems, and (vi) lotic systems exhibit a great variety of physical, chemical and biological conditions as these systems are greatly influenced by the landscape through which they traverse. Owing to these characteristics, especially the land-water interlinkage, a stream or a river is said to constitute an open ecosystem in contrast to standing bodies of water. In lotic systems the prominent zonation is longitudinal, whereas in lakes and ponds it is horizontal. Moreover, the communities show older stages from source to mouth in lotic systems, while successive zones from middle to shore are characteristic of standing waters. The physico-chemical environment of streams differ from rivers in two main respects; the former habitats are shallower with much faster flow rates in comparison to the latter.

Streams may be conveniently viewed as the processors of natural organic matter which for small, shaded, cool headwater streams (in the range of first to third order) is derived from the watershed. Recent years have witnessed another very significant change in perspective from that of viewing streams, or different stretches within a stream, as individual entities to that of an integrated view popularly called as the "River Continuum Concept (RCC)" (Vannote et al. 1980, Newbold et al. 1982, Minshall et al. 1985). This concept provides a framework for integrating predictable and observable biological features of lotic systems. A critical reassessment of the concept has been made recently by Bott et al. (1985) in their investigation addressed at evaluation of the chemical, geomorphological, physical and biotic factors that are most strongly related to benthic community metabolism in temperate stream systems. Yet another significant feature in stream ecology is the critical linkage between stream and its landscape characteristics, and the importance in terrestrically derived organic matter on stream dynamics (Hynes 1963). The permeability of soil, slope of valley and precipitation characteristics are found to greatly influence the pattern of flow, dissolved organic matter and the concentration of nutrients in stream ecosystems. The term "Nutrient Spiralling" (Webster 1975), characteristic of running waters refers to the joint processes of transport and cycling of nutrients. The inefficiency of storage and processing of organic matter provides energy and inorganic nutrients for downstream communities. Vannote et al. (1930) have suggested that downstream communities are structured to capitalize on these inefficiencies of upstream processing. In every reach some material is processed, some stored, and some released. The amount released in this fashion has been used in calculating stream efficiency (Fisher 1977). It is extremely significant to note that biogeochemical cycle is an important phenomenon operative in lotic ecosystems with streams being no exception. Based on biological productivity streams are broadly classified into oligotrophic, mesotrophic and eutrophic categories. Oligotrophic streams are characterised by low nutrient supply in relation to the volume of water they contain. Eutrophic streams lie at the other end of the spectrum with high nutrient supply. Mesotrophic streams occupy an intermediate position between these two extremes with respect to nutrient supply, depth, biological productivity, water clarity and oxygen depletion. The eutrophic streams and rivers have high nutrient supply resulting in a high production at all levels of food chain, shallow depth and low transparency due to excessive plant growth.

Many headwater streams are strongly influenced by the riparian vegetation which reduces autotrophic production by shading and contributes large amounts of allochthonous detritus. As the stream size increases, the reduced importance of terrestrial organic input coincides with enhanced significance of autochthonous primary production and organic transport from upstream. In this way stream metabolism shifts from heterotrophy to autotrophy with increased P/R ratio. The zone through which this shift occurs is primarily dependent upon the degree of shading (Minshall 1978). In deciduous forests and some coniferous forests, the transition probably occurs at order 3. At higher elevations and latitudes, and in xeric regions where riparian vegetation is restricted, the transition to autotrophy may be at order 1. Deeply incised streams, even with sparse riparian vegetation, may be heterotrophic due to side slope ("canyon") shading.

Autotrophy plays a major part in the trophic economy of a wide variety of streams, and large rivers which are not disturbed by man (Minshall 1973). Total gross primary production here exceeds community respiration on an annual basis and accretion (storage of excess photosynthate) and/or export (transportation of biomass out of the system) occurs.

Algae are the main autotrophs in stream ecosystems. Bacteria and aquatic fungi also seem to be of significance in performing the vital role of transforming organic matter to inorganic form which may then be used again by the producers. Different types of invertebrates including molluscs, aquatic insects, annelids, rotifers, protozoans, helminths, and fishes are important biotic components of stream systems. Stream algae mainly provide the complex organic molecules for the vast range of animals. In addition, some 50-90% of oxygen in streams is estimated to come from algal growth (Cloud 1968). Stream algae may be used as ecological indicators. They are now being increasingly used in field bioassays with a view to gain relevant information about the availability of nutrients and other chemicals to algae and their different stimulatory and inhibitory effects and pollution in streams (Squires et al. 1979 b, Economou-Amilli 1980, Lampkin & Sommerfeld 1982, Heinonen 1984, Stevenson 1984 a, Leland & Carter 1985, Deniseyer et al. 1986, Beamish et al. 1987, Singh & Gaur 1989).

Although phytoplanktonic assemblages are often found in slow flowing rivers, they are generally absent in streams. If present, they occur in pools along the bank of streams. Due to maintenance of high flow rate, streams favour those algae which are capable of attaching themselves to substrata. For algae forming a slimy layer on various substrata, the terms "periphyton" and "Aufwuchs" have been frequently used (see Otten & Willemse 1988). Some workers even use the term "benthic" for such assemblages (Keithan et al. 1988, Stevenson et al. 1991). The periphytic algal communities encountered in streams, are the epilithon (algae attached to stones, pebbles, and large rocks), the epipelon (algae lying freely in sediment), the epipsammon (algae attached to sand grains), the epiphyton (algae attached to plant surfaces), and the epizoon (algae on the surfaces of animals). The macroalgae of streams include the members of Rhodophyta, Phaeophyta, Chlorophyta and Cyanophyta, whereas the diatoms and coccoid algae mainly constitute the microalgal component of streams.

Algal flora attached to sand grains is fairly extensive in streams, but has as yet been studied less than any other algal community. Small coccoid Cyanophyta and Chlorophyta members often occupy the hollows of the grains but the most conspicuous components are often diatoms, either adnate to the surface or raised on very short mucilage stalks. Harper (1969) found that the epipsammic diatoms from a freshwater site showed very little movement, e.g., Amphora ovalis var. pedilulus moved on an average 1.7 $\mu m\ s^{-1}$, whilst the epipelic diatom Navicula oblonga averaged 11 $\mu m\ s^{-1}$. Harper & Harper (1967) surmised that it is essential for diatoms to attach to a surface even when moving. The minerology and microtopography of sand grains influence the epipsammic assemblage (Krejcki & Lowe 1936). These workers found stalked diatoms mainly on "hills" or exposed portions of sand particles. In contrast, motile prostrate diatoms were predominant in crevices and depressions. Miller et al. (1987) believe that the epipsammon represent a specialised community capable of existence in highly variable environments. According to them disturbance probably plays an important role in structuring this community and keeps it in a pioneering state. Krejci & Lowe (1987) studied temporal variations in epipsammic community of a brook. The persistence of common epipsammic algae in the assemblage led them to support the idea developed from the RCC that species comprising riverine benthic assemblages continually persist and rarely become completely absent.

✓The epipelon is another widespread community occurring in regions where sediment accumulate and on to which light penetrates. The species are almost all microscopic and the associations rich and widespread. They live on and in the surface layers of sediment and cannot withstand long periods of darkness and anaerobic conditions (Moss 1977). Many diatoms, coccoid green and blue-green algae and euglenoids are found in epipelic assemblages. In order to avoid burial in continuously depositing sediment, many epipelic algae are capable of movement (Harper 1977). This attribute enables them to regain to the surface layer for utilizing light energy. During dark period, these algae move in to the sediment once again. The epipelic algae derive their nutrients from water as well as the sediment (Round 1981).

In streams with moderate or low flow conditions several macrophytic species as also large filamentous algae occur abundantly. These serve as ideal hosts for many epiphytic algae. According to Round (1981) epiphytic algae prefer those host plants which do not produce mucilage, tannin and phenolic substances. The epiphytic communities are dominated by diatoms together with small filamentous algae. The exact nature of relationship between epiphytes and their hosts has remained a subject of great dispute. Cattaneo and Kalff (1977) found similar epiphyton densities on natural and artificial plants and concluded that macrophytes are neutral substrates for the epiphyton. This viewpoint was subsequently criticised by Gough & Gough (1981) who found differences in epiphyton composition on morphologically similar macrophytes. Recently, Blindow (1987) has made similar observations. Preliminary studies have shown the transfer of nutrients and photosynthetically fixed carbon from the epiphyton to host (see Darley 1982), although this aspect warrants more sincere researches.

The epilithon of running waters have received very little attention. Macroscopic growths of species such as *Cladophora glomerata*, *Lemanea fluviatilis*, *Batrachospermum boryanum*, *Chaetophora incrassata* and *Ulothrix* sp. are common on rocks in many fast flowing waters (Hynes 1970, Round 1981). Several microalgae, notably diatoms, also occur abundantly in epilithic assemblages. Slower flow tends to result in silt deposition on the stones and this hampers the growth of the epilithon. The pattern of algal colonization of rock surfaces varies depending on the microenvironmental situations. The pioneering algal species are mainly attached to the rock substrata in prostrate position. When the community matures, the late-comers organize themselves in erect position, an adaptation to probably avoid light and nutrient limitation (Hudon & Bourget 1981). The vertical overgrowth in advanced stages of colonization is suggestive of competition for space in the periphyton (Hoagland et al. 1982). Increase in thickness of periphytic biofilm is very likely to produce a gradient of growing conditions within the assemblage (Lock et al. 1984). If such is the case, the algae located within each of these strata may experience entirely different growing conditions. Cells in the lower strata may be exposed to low light and nutrient levels, whereas the cells in the upper strata are benefited by high light intensities and abundant supply of nutrients. Hudon et al. (1987) observed increased accessory pigment concentration in the lower strata and called it an adaptation to low light conditions. Paul & Duthie (1989) speculated that the overstory extracts nutrients from water, whereas the understory helps in recycling nutrients as organic complexes within the periphyton.

Scanning electron microscopy (SEM) has been used to more precisely describe the three dimensional organisation of microcommunities on the surfaces of aquatic macrophytes (Allanson 1973, Sieburth & Thomas 1973, Sieburth et al. 1974), wood discs (Cundell & Mitchell 1977), rocks (Perkins & Kalpan 1978), slate tiles (Dickman & Gochnauer 1978), plastic panels (Hudon & Bourget 1981), glass slides (Maszaleck et al. 1979, Hoagland et al. 1982) and fine plankton netting (Winterbourn 1990). A series of seral stages during the colonization were described by Hudon and Bourget (1981), Hoagland et al. (1982) and Korte and Blinn (1983). Jorgensen and Revsbech (1983) analysed the microzonation within the cyanobacterial mats using SEM and have also described a microelectrode for measuring photosynthetic rate of algal mats. The importance of mucilage secretion by long stalked diatoms (Cymbella affinis and Gomphonema olivaceum) has been explained in context of their autoecological role in the development of spatially complex periphyton communities (Roemer et al. 1984, Lock et al. 1984). On the other hand, the synecological observations (e.g., biofilm-substrate interfaces, spatial relationships, community sloughing) are used together with the autecological data to interpret the structural integrity of these microcommunities (Lock et al. 1984, Sinsabaugh et al. 1991). The spiralling concept of nutrient reutilization in running waters was assessed in view of the changing physiology of microorganisms comprising a developing biofilm (Paul & Duthie 1989). The immigration of algae on to the substratum is related to current velocity and the stage of assemblage development. The autogenic modification of substratum surface condition is related with immigration rates and current velocity in the later stages of the community development (Stevenson 1981). Temporal variations in immigration due to variability of algal drift have been observed (Müller-Haeckel & Håkansson 1978). Current velocity controls the rate of nutrient supply to cells. Stimulatory effects of water current on nutrient uptake, productivity and respiration have been observed by Whitford (1960), Whitford & Schumacher (1961 & 1964), Pfeifer & Mcdiffett (1975) and Lock & John (1979).

Researches on the structure and functioning of stream ecosystems with emphasis on origin of organic and inorganic resources escalated markedly in the last fifteen years or so. Much of these recent investigations focused on energy flow and carbon fluxes, being stimulated by the concept of streams as systems processing organic matter. The measurements of chlorophyll *a* content as an indicator of relative benthic primary producer biomass is an important parameter in stream ecology. Studies on chlorophyll *a* and periphytic metabolism in temperate, subarctic and antarctic streams have been described in detail (Stockner & Shortreed 1976, Pennak & Lavelle 1979, Sumner & Fisher 1979, Bott & Ritter 1981, Minshall et al. 1983, Keithan & Lowe 1985, Bott et al. 1985, Brown & King 1987, King & Cummins 1989 a, b, c, Howard-

Williams & Vincent 1989, LaPerriere et al. 1989). Various methods have been proposed by different workers for assessing the contribution of primary producers to stream ecosystem metabolism (Bott et al. 1978). Changes in dissolved oxygen levels over a 24 h cycle at two points along a stream (upstream-downstream method; e.g., Hall 1971), or in plexiglass chambers containing natural periphytic assemblage under in situ condition (Rodgers et al. 1978, Keithan & Lowe 1985, Mullholland et al. 1986) have been recommended. Tracer technique involving the use of ^{14}C is also available for measuring algal photosynthesis and primary production in closed chambers placed under in situ condition (Bott et al. 1978). Laboratory streams have been successfully employed by researchers particularly Max L. Bothwell and C. David McIntire to elucidate various ecological and physiological aspects of lotic algae. Bothwell (1985) and Freeman (1986) have carried out comprehensive sets of assays to isolate the limiting nutrient in continuous-flow troughs in lab channels and rivers, respectively, and Aizaki (1978), Aizaki & Sakamoto (1989) and Horner et al. (1983) have demonstrated correlations between dissolved inorganic phosphorus concentrations with algal biomass in both streams and laboratory channels. Recently, Bothwell (1989) has carried out continuous-flow trough experiments to demonstrate the different processes of nutrient saturation of periphytic growth rates and areal biomass.

Knowledge about stream algae has not advanced much due to methodological problems. Quantitative methods for studying algal periphyton of streams have been reviewed and discussed by several workers (Cooke 1956, Lund & Talling 1957, Blum 1960, Sládečkova

1962, Hynes 1970, Weitzel 1979, Aloi 1990). Algal distribution on natural substrata lying in the stream bed is extremely patchy due inter alia to variability in size, shape and nature of substratum, and the pattern of water flow around them (Round 1981). Recently, De Nicola and McIntire (1990) have suggested that in cobble riffle areas of natural streams, the interaction between current flow and substratum relief has the potential to create patches of algae which are different in biomass and taxonomic composition. Thus the study of stream algae by quantitative techniques offer formidable difficulties (Hynes 1970). The technical difficulties are mainly associated with accurate quantitative removal of algae from uneven and rough surfaces of natural substrata. This problem has prompted many workers to use artificial substrata (Cooke 1956, Blum 1960, Lund & Talling 1957, Sládečkova 1962). They believe that almost anything left for a while in a stream becomes covered with algae. The importance of substratum properties on periphyton formation has been discussed by Linskens (1963), Luther (1976), and Luning (1985), in case of natural substrata, and Hoagland et al. (1982), Hamilton (1985) and Edyvean et al. (1985) for artificial substrata. The materials used as artificial substrata are wood, slate, clay, concrete, asbestos, asbestos-cement, sheets of metals, celluloid, a great number of organic plastics and glass (Aloi 1990). Nevertheless, the glass slide method has been used successfully in various comparative studies (Sládeček & Sládečkova 1964, Stockner & Armstrong 1971, Weitzel 1979, Patrick & Roberts 1979, Hunter 1980, Marcus 1980, Munteanu & Maly 1981, Bamforth 1982, Oemke & Burton 1986). Although many investigators have assumed that algal communities on glass substrata are identical to the naturally occurring epilithic or epiphytic communities, few have verified this. Stockner & Armstrong (1971) found diatom communities on glass slides and rocks to have similar seasonal periodicity, but there were differences in species abundances and biomass. Korte & Blinn (1983) found plexiglass to be more suitable for microbial colonization than aluminium. Fairchild & Lowe (1984) and Fairchild et al. (1985) described a new method for in situ bioassay of nutrient limitation. This method involves the use of clay flower pots filled with agarized nutrient solution. Periphytic algae growing on the surface of such pots placed in situ respond to nutrients diffusing from tiny pores in the wall of the pots. A similar nutrient-diffusing substratum composed of agar-consolidated sand and nutrients in a petri dish is useful in sampling periphyton that grow on sandy bottoms (Pringle & Bowers 1984). Grimm & Fisher (1986), Pringle (1987) and Hill & Knight (1988) have used nutrient diffusing substrata to assess the response of periphytic algae to nutrient enrichment.

The position and exposure period are extremely important if artificial substrata are to be employed for different purposes. A horizontal position may be preferred when studying the influence of light on periphyton composition. For studying the effect of current velocity on periphyton colonisation all possible positions are preferred (Munteanu & Maly 1981, Stevenson 1984). In short-term experiments the rates of photosynthesis, respiration, nitrogen fixation and nutrient uptake can be measured for a period less than 24 h (Hansmann et al. 1971, Elwood & Nelson 1972, Bothwell 1988). Whereas, for long-term experiments the exposure period of 1 wk (Kesler 1981, Sumner & McIntire 1982), or 14 d (Patrick et al. 1954, Castenholtz1960), or even a month (Brown & Austin 1971, Lowe

& Gale 1980, Hunter 1980) have been recommended for sampling the equivalent of the "mature" community occurring on natural substrata in streams. The rock substrata permit the best growth of algae in general, whereas sandy bottoms are unfavourable for algal attachment, and sandy streams tend to be poor in epilithic algae. Owing to formidable difficulties in obtaining a representative sample of stream algae from natural substrata, limited success has been achieved in identifying the factors governing their ecology. Blum (1957) had for the first time applied the transect method of terrestrial plant ecologists to stream algae. Hynes (1970) has considered this method to be worthy of further use, and has advocated the need for refinements. Inspired by earlier works (Blum 1956, Descy 1973, Saunders & Eaton 1976), Holmes & Whitton (1981) have extensively used the line transect method to study the ecology of algae of Tees river in England. This method gave satisfactory results to Sheath & Burkholder (1985) and Sheath et al. (1986 b)also, but it is time consuming and difficult to apply in extensive sampling programmes.

As in other aquatic environments, stream algae are affected by an array of factors including current speed (McIntire 1966, Stevenson 1983, 1984 b, Keithan & Lowe 1985, Steinman & McIntire 1986, Biggs & Close 1989), pH (Hancock 1973, Van Dam et al. 1981, Maurice et al. 1987), light intensity (Brylinsky & Mann 1973, Busch 1978, Sumner & Fisher 1979, Gregory 1980, Keithan & Lowe 1985, Steinman & McIntire 1986), temperature (Patrick et al. 1969), nutrients (Stockner & Shortreed 1978, Crawford 1979, Marcus 1980, Peterson et al. 1983, Pringle & Bowers 1984, Grimm & Fisher 1986, Lowe et al. 1986), and dissolved and particulate organic inputs originating from riparian vegetation which may have a detrimental or benificial effect on stream algae (Larson 1978). Superimposed on these primary factors are intensity and periodicity of rainfall, which can cause scouring and rearrangement of stream surfaces, and the effects of herbivores which can influence algal biomass, rates of primary production, and community structure (Gregory 1983, Lamberti & Resh 1983, Mulholland et al. 1983). Physical parameters have commonly been shown to be the most important factors controlling algae of heavily shaded streams at both the structural and functional levels (Minshall 1978, Vannote et al. 1980). Typically light is the principal factor limiting algal productivity in streams with dense tree canopies (Hill & Knight 1988), or in streams traversing through deep canyons (Blinn et al. 1981). A number of studies discuss the importance of light energy on the growth of lotic algae (Minshall 1978, Eloranta & Kunnas 1979, Vannote et al. 1980, Homles & Whitton 1981, Sheath et al. 1986, Steinman & McIntire 1987). The effect of light intensity on algal production has been determined in several Oregon streams (Gregory 1980, Lyford & Gregory 1975, Murphy & Hall 1981). Sheath and Burkholder (1985) observed the fate of green algae in the Rhode Island streams subjected to dense riparian shading. Photoperiod, the length of time light reaches the primary producers per day, is important in periphyton productivity and abundance (Byers 1963, McIntire & Phinney 1965).

The importance of immigration, growth and competition for nutrients and light in benthic diatom succession was studied in experimental channels of a low nutrient stream (Stevenson et al. 1991). Succession rates were greater in NP-enriched than control channels. The density-dependent decreases in nutrient availability in benthic mats were greater in NP-enriched than in control channels. They have found that shading during the later stages of community development reduced algal standing crop. A substantial proportion of benthic diatoms can detach from substrata and drift downstream (Stevenson 1990), which can be a response to unfavourable habitat conditions (Bothwell et al. 1989). According to Stevenson et al. (1991), the ability to detach from substratum and immigrate rapidly may be an important adaptation. Thus diatoms may escape from resource limited conditions deep inside a mat, drift downstream, and reattach to the surface of another mat, where they may again be exposed to nutrients in the water column.

Productivity of stream algae is influenced by several other physical factors: temperature (Dillard 1969, Kilkus et al. 1975, Darley 1982), current velocity (Whitford & Schumacher 1961, 1964, Munteanu & Maly 1981, Antoine & Benson-Evans 1982, Peterson 1987), substratum composition (Bott 1983) and disturbance (Fisher 1983). Patrick (1971), Tuchman & Blinn (1979) and Blinn et al. (1989) reported the relationship between water temperature and the structural composition of the diatom community. Deniseger et al. (1986) found that low temperature and high flow were limiting to algal biomass accrual. Many previous studies have shown that current velocity can influence the structure and dynamics of lotic algal asseblages (Whitford 1961, 1964, Munteanu & Maly 1981, Horner & Welch 1981, Antoine & Benson-Evans 1982, Stevenson 1983, Peterson 1986, 1987, Steinman & McIntire 1986, Peterson & Stevenson 1989). Floods have been shown to reduce species number and diversity of stream communities and these changes depend upon local flood frequency (Siegfried & Knight 1977, Gray & Fisher 1981, Fisher et al. 1982, Power & Stewart 1986). Fisher et al. (1982), Power & Stewart (1986) and Fisher & Grimm (1988) have described the alteration in algal assemblage structure and decrease in biomass following flash floods. Many of these workers relate reduction in algal biomass at high flows to scouring action of water current. The effect of drying has not received due attention of stream researchers, but disruption of the structure, function and dynamics of stream communities during drought condition have been reported (Fritsch 1944, Evans 1958, Hostetter & Hoshaw 1970, Peterson 1987).

Many researchers have emphasized that chemical factors are more important than physical variables in determining the structure and function of stream algal assemblages. Several studies on nutrient dynamics of stream ecosystems showed P and N to be the principal nutrients limiting algal growth (Sommerfeld et al. 1974, Gregory 1980, Grimm et al. 1981, Elwood et al. 1981, Peterson et al. 1983, Triska et al. 1983). Supplementation of these nutrients during in situ bioassays enhanced algal growth to a great extent (Wuhrmann & Eichenberger 1975, Fairchild et al. 1985, Pringle & Bowers 1987, Lowe et al. 1986, Pringle et al. 1986, Munn et al. 1989, Hart & Robinson 1990). Unforeseen natural events also influence significantly the chemical budget of streams (Martin 1979) and this, in turn, may adversely affect algae.

The pH exerts considerable influence on stream algae. Many genera like Lemanea, Batrachospermum and Stigeoclonium occur at wide range of pH, others however show preferences for a particular pH (Hynes 1970). Low pH has been found to reduce the diversity of periphytic diatom assemblages (Descy 1979, Maurice et al. 1987). It has been suggested that acidic conditions reduce the availability of nutrients to algae of various groups. The preference of blue-green algae for high pH is particularly marked (Brock 1973).

Seasonal variations in stream algal communities have been studied in Europe, Japan and North America, and long lists of the times of occurrence of various algal species have been published (e.g., Budde 1928, 1932, Wehrle 1942, Mack 1953, Gumtow 1955, Blum 1957, Koboyasi 1961, Bursche 1962). Johansson et al. (1977) gave a complete bibliography of algal studies in running waters. In temperate regions standing crop of periphyton exhibits systematic seasonal variations. Maximum biomass often occurs during the summer, whereas the minimum occurs during the winter (Flemer 1970, Lyford & Gregory 1975, Stockner & Shortreed 1976). The summer maxima is mainly associated with increase in temperature, light intensity and photoperiod and low flow, whereas the winter minima is due mainly to physical removal of periphyton, abrasion, increased grazing pressure, decreased temperature and light intensity and shorter photoperiod. Spring and summer maxima were reported by Sabater (1990) in a limestone stream in Spain. Reports of winter maxima (Tominaga & Ichimura 1966) and autumn maxima (Ertl et al. 1972) emphasize low flow during these periods. Growths of benthic diatoms are characteristic of chalk-streams during the spring (Westlake et al. 1972, Marker 1976). In chalk-streams, Casey et al. (1981) related the changes in silicon concentration to the seasonal cycle of diatoms. Seasonal succession of algae in a eutrophic stream in southern England was studied by Moore (1977 c). Similar studies have been made in temperate region by other workers (Douglas 1958, Marker 1976, Jones 1978, Wilhm et al. 1978, Anderson 1984, Holmes & Whitton 1981, Rounick & Gregory 1981, Wehr 1981, Lamberti & Resh 1987, Lay & Ward, 1987, Biggs & Close 1989, Sabater 1990).

1.1 Present Study

The present work has been guided by the consideration that the ecology of stream algae does not seem to have been studied properly in the entire Indian subcontinent, although efforts have been made to investigate the ecology of phytoplankton in Indian rivers (Iyengar & Venkataraman 1951, Roy 1965, Lakshminarayan 1965 a & b, Venkateswarlu 1969, 1976, 1983, Venkateswarlu et al. 1987 a & b, Reddy & Venkateswarlu 1987, Rai et al. 1987). Limited efforts have been made on floristics and other aspects of algae of thermal springs (Gonzalves 1947, Chatterjee & Guha 1964, Sarkar & Rai 1964, Thomas & Gonzalves 1965 a-g, Prasad & Srivastava 1965, Vasistha 1968, Jana 1973, 1978, Saha & Dutta 1983, Jha 1985, Singh 1991).

The data presented in this dissertation deal with a detailed study of algal communities in two pristine forested streams. Epilithic algal assemblages of the selected streams were studied with respect to biomass, species composition and diversity. Temporal variations in the structure of epilithic assamblages have been followed and their relationships with physico-chemical characteristics of the environment have been explored using canonical correspondence analysis. Likewise, the epipelic algal assemblages of the selected streams were also studied. Laboratory bioassay experiments were carried out to define the nutrients limiting algal growth in selected streams. Since shading often limits the growth of periphytic algae in streams, effect of different light conditions on periphytic assemblages was studied using glass slides as the artificial substrata. Some short-term experiments have also been carried out to understand the response of stream periphyton to desiccation, and changes in desiccated assemblages after rewetting.

Chapter 2 STUDY AREA

Two streams namely Wah Dienglieng and Wah Risa, draining forested catchments and located in the East Khasi Hills (Shillong, Meghalaya), were selected for the present study. Two stations one upstream and the other downstream, approximately 1 km apart, in each stream, were selected for regular sampling. The up- and downstream stations of Wah Dienglieng shall be hereafter referred to as St. 1 and 2, respectively. Similarly, St. 3 and 4 are the up- and downstream reaches of Wah Risa. Plate I and II show photographs of the four sampling stations. All the stations are of third-order according to Horton-Strahler method (Horton 1945, Strahler 1952). According to this method the first-order streams have no tributaries, when two first-order streams meet they become a second-order stream. Similarly, two second-order steams coalesce to form a third-order stream, and so on. Various important physiographic features of four stations are listed in Table 2.1.

Plate I Photographs of sampling stations of Wah Dienglieng stream: Left, St. 1; Right, St. 2.

Plate II Photographs of selected stations of Wah Risa stream: Left, St. 3; Right, St. 4.

Table 2.1 Important features of the selected streams at various stations.

Parameter	Wah Dienglieng		Wah Risa	
	St. 1	St. 2	St. 3	St. 4
Altitude (m)	1,615	1,520	1,605	1,525
Latitude	25°33'N	25°33'N	25°33'N	25°33'N
Longitude	91°53'E	91°53'E	91°52'E	91°53'E
Order (according to Horton-Strahler method)	3	3	3	3
Width (m)	0.3-3.5	1.5-4.0	1.5-4.5	1.0-5.0
Depth (cm)	3-42	8-37	10-45	7-43

The four stations selected for field study are accessible for sampling throughout the year. Moreover, these sites are not far away from the Botany Department of North-Eastern Hill University. The proximity of the selected streams was extremely useful as it facilitated quick transport of water and algal samples to the laboratory for subsequent analyses. The streams chosen for this work are not at all polluted as their drainage areas have been rendered full protection by the Forest Department, Government of Meghalaya. The catchments do not have any human settlement, and at places vulnerable to biotic interferences, a fence of barbed wire has been erected.

The region under study has a tropical monsoonic climate (Champion & Seth 1968). The places not far away from the study area like Cherrapunjee and Mawsynram, experience the highest rainfall in the world. The total annual rainfall was 3838 mm in 1988 and 2781 mm in 1989 during the course of the study (Fig.2.1). July was the peak time when highest rainfall occqurred in both the years. Rainfall may some time continue till October. Normally, winter and spring do not have any rainfall, and hence the streams remained at their base flows during these periods. Atmospheric temperature during summer was as high as 25°C, while the mean winter temperature was as low as 6°C. Winter is marked by the appearance of ground frost during night and early morning hours. Flashfloods and spates in the streams during the rainy season are quite frequent due to heavy rainfall.

Based on the rainfall and temperature regimes, each annual cycle can be divided into four seasons:

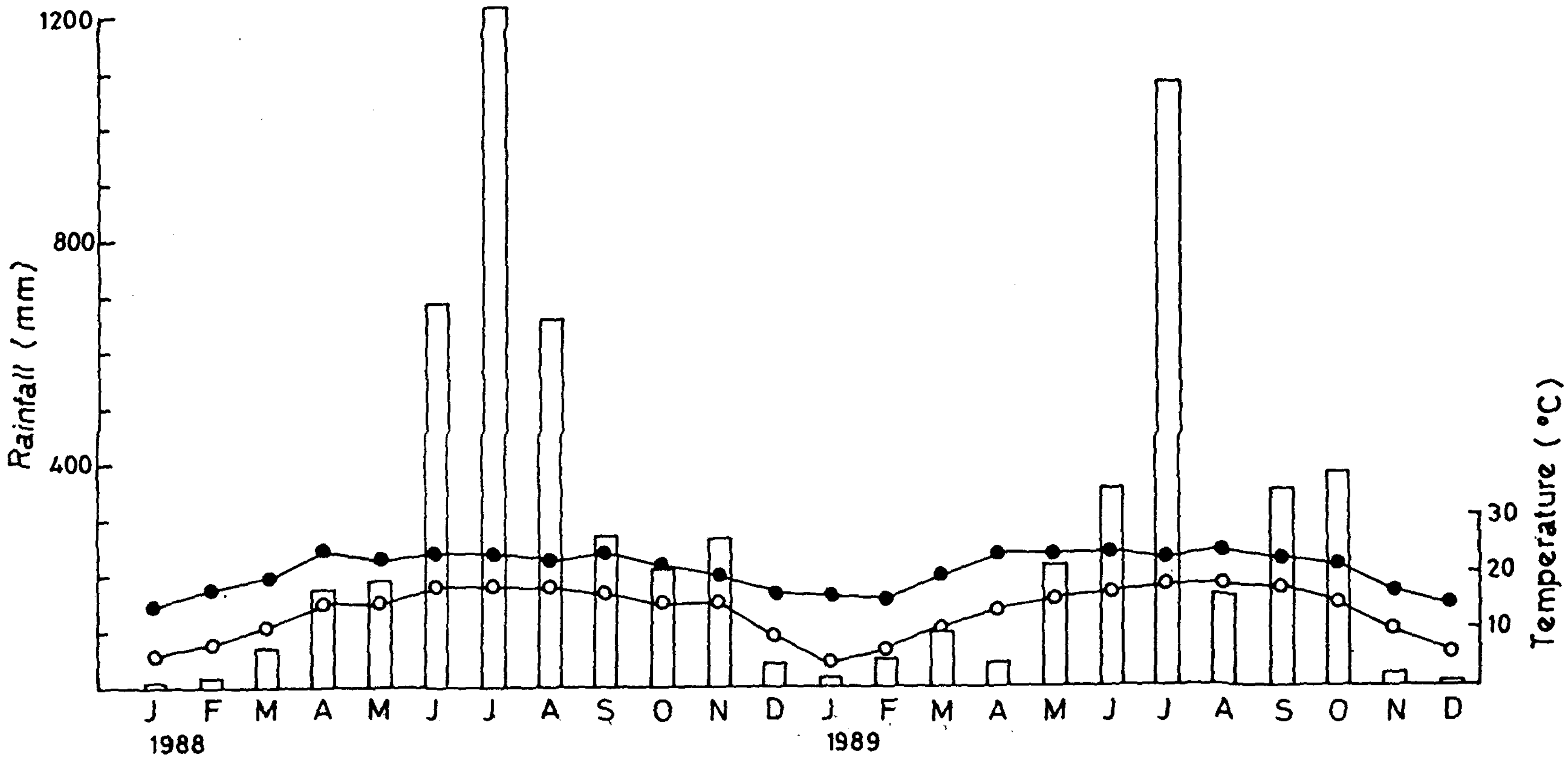

Fig. 2.1 Ombrothermic diagram for the study area. Mean monthly maximum (o--o) and minimum (o--o) temperature; monthly rainfall (bar).

(a) Winter (December to February)

(b) Spring (March to early May)

(c) Wet summer or rainy season (late May to September)

(d) Autumn (October and November)

The area through which the streams flow is called the Shillong plateau which is a horst block-uplifted to its present height of 610 to 1544 m above the mean sea level. Physiographically, the area represents a remnant of an ancient plateau of Pro-Cambrian Indian Peninsular shield block uplifted to its present height. The Kernel of the plateau is the exposed Archaen gneisses and schists covered in this area by Pre-Cambrian quartzites and Phyllites.

In stream bed the size of the rock fragments range from clay to boulders of diameter more than a metre. The rocks found in the stream bed mostly consist of granites, quartzite, coarser to medium grained sand stone, pebbles often associated with quartz veins. Most of the pebbles and boulders are subrounded to rounded in nature indicating their transport from a distance provenance. The big boulders are usually subangular to angular which suggest that these are separated from the main rock body from nearby source.

The soils of drainage areas are acidic (pH 4.6-5.0). The soil is laterite and loamy silt. The organic carbon and nitrogen contents vary between 1.4 to 3.2 and 0.17 to 0.28%, respectively (Rao et al. 1990).

The streams traverse through forest which is of subtropical type. The catchments exhibits 3 types of vegetational covers: (a) pure pine, (b) broad leaved, and (c) mixed (see Figs. 2.2 and 2.3).

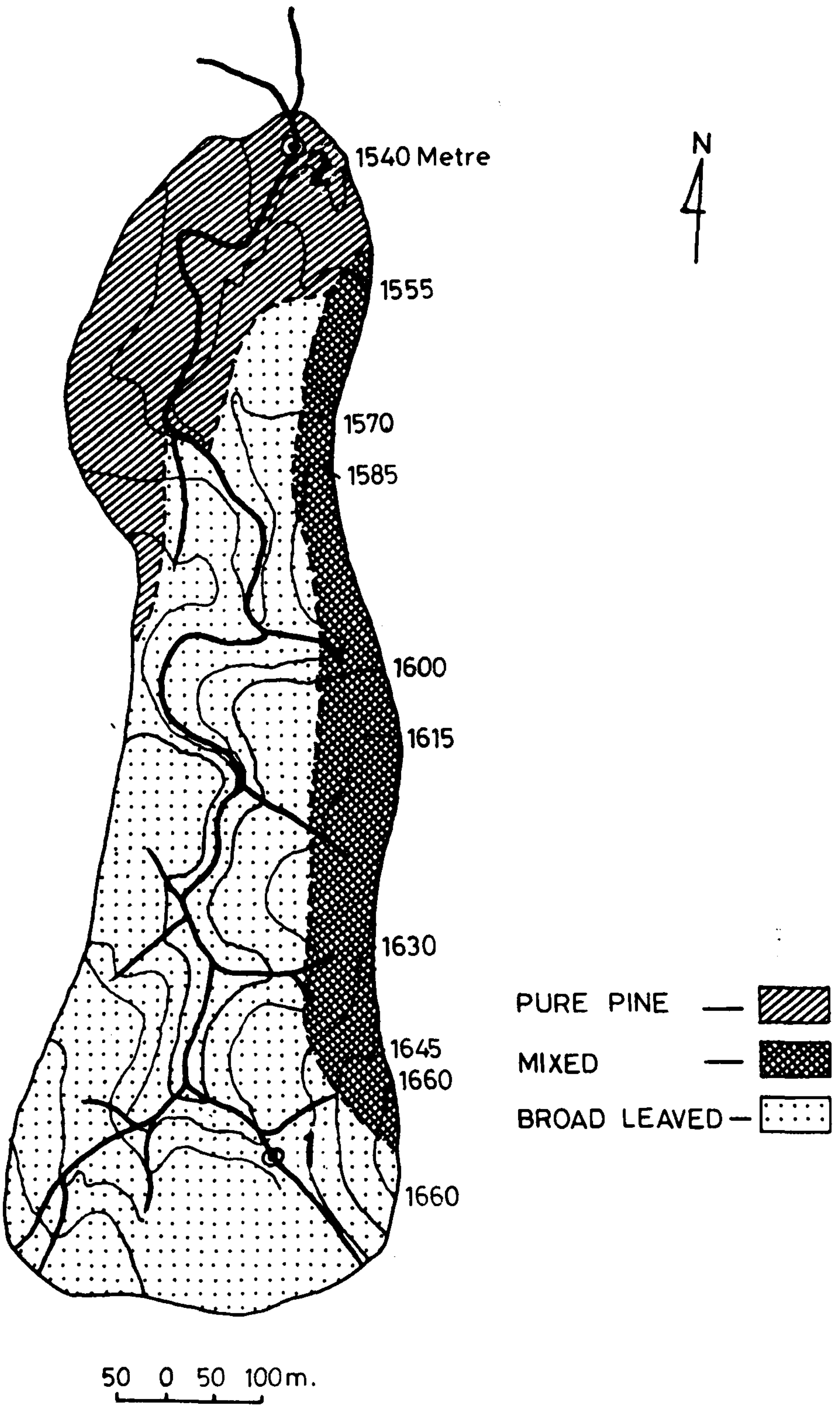

Fig. 2.2 Location of St. 1 and 2 on Wah Dienglieng stream showing the drainage area, contours and the type of vegetational cover. The stream flows to the north.

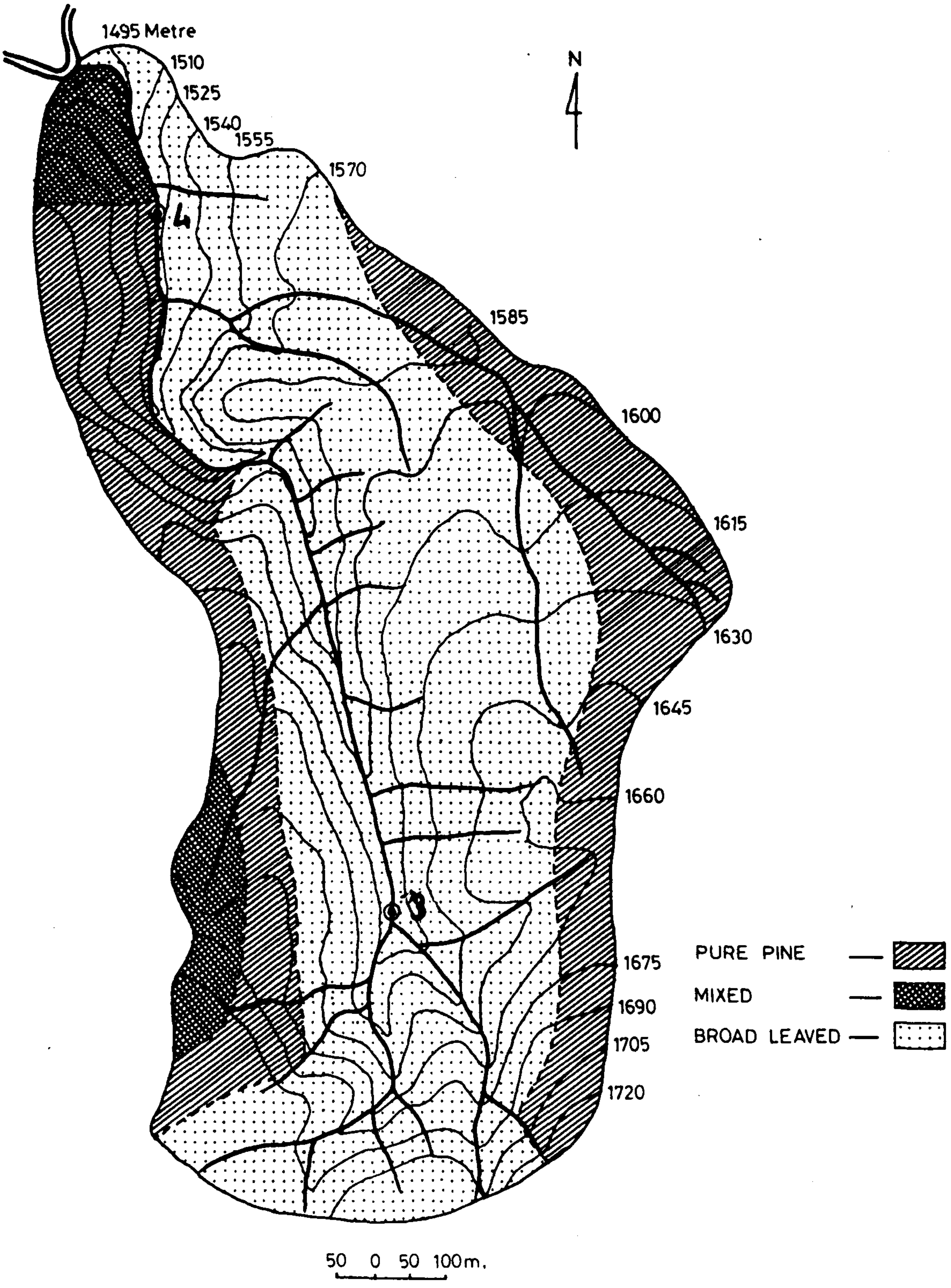

Fig. 2.3 Location of St. 3 and 4 on Wah Risa stream showing the drainage area, contours and the type of vegetational cover. The stream flows towards the north.

Along the upper reaches, i.e. at St. 1 and 3, the drainage areas are dominated by broad-leaved trees alone or together with the pine. Whereas St. 2 and 4 respectively show pure pine and all kinds of covers. The overstory is dominated by trees like Quercus dealbata, Daphneplum himalayana, Machlus kinnghaii, Schima khasiana, Schima wallichi, Myrica spp., Rhododendron arboracum and Pinus kesiya. Below the canopy formed by trees lies the shrub layer with species such as Daphne shillong Symplocus chenesis, Lantana camara, the species of Eupatorium, Sylex, Polygonum, Osbekia, Camellia, Callicarpa and Brymia. Some grasses and herbs constitute the lower most story. Pinus kesiya dominates at St. 2 and 4 and is regarded as a secondary successional species in the forest.

Sampling stations were selected in such a way so as to represent all the habitat types and obvious sections of the systems. Streams flow through two hillocks on either sides and contain swamplands on either banks formed by the seepage of water upwelling from ground water sources. The total drainage area between up- and downstream stations is ca. 7 km^2 in case of Wah Dienglieng, and 18 km^2 for Wah Risa. On a normal sunny day streams receive sunlight for approximately 5 to 6 h at St. 1, 8-9 h at St. 2, 6-7 h at St. 3 and 9-10 h at St. 4.

Current velocity is considerably less along the banks, and almost negligible in pools. All the stations experience uniform flow excepting rainy season when fast flooding takes place. Discharge rate varied from 0.1 to 1.0 m^3 s^{-1} at the selected sites. The mean width and depth have been shown in Table 2.1. In spite of a well developed riparian vegetation, nearly 30 to 40% and 75 to 80% area of the stream bed is exposed at St. 1 and St. 2, respectively. Similarly, St. 3 is 40-45% exposed, whereas nearly 80-90% of the streambed is exposed at St. 4.

Chapter 3

PHYSICO-CHEMICAL CHARACTERISTICS OF WATER AND EPILITHIC ALGAL ASSEMBLAGES IN SELECTED STREAMS

3.1 Introduction

Of the various kinds of periphytic algal assemblages, the epilithon are the most important primary producers in stream ecosystems. This is due mainly to the greater apportionment of epilithic algae to total algal biomass in the stream bottom. Autochthonous organic matter produced by epilithic algae is subsequently utilised as food by the herbivores (Lamberti & Resh 1983).

Epilithic algae are influenced by an array of environmental factors. Physical factors considered to be important for algal epilithon include water current, temperature and light (Moore 1977a, Gregory 1980, Stevenson 1983, 1984b, Keithan & Lowe 1985, Steinman & McIntire 1986). Water current of streams exhibit tremendous variability over both space and time. Although some algae, particularly freshwater rhodophytes, are restricted to flowing waters, high flow rates hamper the growth of epilithic algae (McIntire 1966, Stevenson 1983). Frequent incidence of floods can truncate algal succession in streams and favour those forms which can accumulate significant biomass between floods. In headwater streams with thick riparian vegetation, low availability of light due to canopy shading often limits the growth of epilithic algae (Fisher & Likens 1973, Vannote et al. 1980, Sheath & Burkholder 1985, Sheath et al. 1986, Hill & Knight 1988, Duncan & Blinn 1989, Stevenson et al. 1991). The removal or thinning of riparian vegetation has been found to enhance algal biomass as well as productivity (Lyford & Gregory 1975, Rounick & Gregory 1981, Lowe et al. 1986). Temperature is extremely important to epilithic algae, and is instrumental in determining the seasonal succession of this community (Hynes 1970, Moore 1977a).

Notwithstanding the continuous flow of water ensuring regular supply of nutrients to epilithic algae, definitive reports are available showing nutrient limitation of algal growth (Sommerfeld et al. 1974, Elwood et al. 1981, Grimm et al. 1981, Triska et al. 1983, Peterson et al. 1983). Increased input of nutrients into streams leads to excessive growth of epilithic algae. Welch et al. (1980) suggested that nuisance biomass of filamentous algae may be represented by a level greater than 100-150 mg chlorophyll a m^{-2}. Such high levels may be aesthetically displeasing and interfere with foot travel by fishermen. Horner & Welch (1981) studied the combined effect of flow rate and phosphorus concentration on epilithic algae of six western Washington streams. They found a strong relationship between current velocity and soluble-reactive phosphorus with more biomass occurring, as velocity increased to 50 cm sec^{-1}, at high (35 μg l^{-1}) compared to low (8 μg l^{-1}) phosphorus. Hence the influence of nutrient supply on epilithic algae cannot be described in isolation, flow conditions must be defined for meaningful interpretations.

Seasonal variations in epilithic assemblages have been observed by some workers who have related these changes to variations in light and temperature (Hynes 1970). Seasonal changes in algae of temperate streams can be summarised as maximum development during warm months, followed by minimum development in cold months (Whitton 1975). Diatoms generally dominate stream epilithon during the winter when water temperature is low. In early spring, diatoms are joined by genera like Hydrurus and Ulothrix and these cold water genera exist for longer or shorter periods depending on temperature regime and shade (Holmes & Whitton 1981). During the spring the winter diatoms decline and are joined by other diatoms and the number of green and blue-green algae increase. Rhodophytes and crustose green algae become more conspicuous. As the streams become shaded by leaves, the flora declines; however, even in streams open to the sky, green algae often decrease (Hynes 1970).

Studies on epilithic algae of streams have been carried out mainly in the temperate region: Canada (Stockner & Shortreed 1978, Ennis & Albright 1982), USA (Hansman & Phinney 1973, Gregory 1980, Grimm et al. 1981, Evenson et al. 1981, Wehr 1981, O'Quinn & Sullivan 1983, Chessman 1986, Rushforth et al. 1986, Miller et al. 1987, Robinson & Rushforth 1987, Duncan & Blinn 1989), England

(Douglas 1958, Hynes 1970, Whitton 1975, Marker 1976a, b, Saunders & Eaton 1976, Moore 1977a, b, c, Whitton 1977, Casey 1981, Holmes & Whitton 1981), Belgium (Descy 1973), Spain (Aboal 1987, 1989, Sabater 1987, 1990), Japan (Kobayasi 1961a, b, 1972, Tominaga & Ichimura 1966), New Zealand (Biggs & Close 1989). Similar efforts have been made in Antarctica (Broady 1982, Vincent & Howard-Williams 1984, Hawes 1989, Howard-Williams & Vincent 1989) and subarctic regions (Moore 1976, 1977b, 1978, Johansson 1980). It is particularly relevant to note that very few of the earlier studies have quantitatively examined both physical and chemical parameters concurrently to determine the importance of each variable for stream algal communities (Duncan & Blinn 1989). Moreover, no important contribution seems to have been made on the epilithic algae of the tropical and subtropical streams.

This chapter describes the structure of epilithic algal assemblages of the selected streams and their relation with physico-chemical characteristics of the environment.

3.2 Materials and Methods

Detailed field studies were carried out in the selected streams at four sampling stations (see Chapter 2 for the details of various sampling stations). Monthly samplings of stream water as well as the inhabiting epilithic assemblages were carried out for a period of two years (Jan '88 to Dec '89). Each sampling was conducted in the last week of the month. Specific details pertaining to the collection and analysis of algal and water samples and statistical methods employed for the processing of data are described under separate heads.

3.2.1 Collection and Analyses of Water Samples

Every month water samples were collected in triplicate in polyethylene bottles of 500 ml capacity. Before collection, the sample bottles were thoroughly washed successively with detergent, tapwater, 50% hydrochloric acid, tap water and finally rinsed with distilled water. Each bottle was rinsed twice with stream water from the collection sites before a sample was collected. Water samples for pH, dissolved oxygen and conductivity were rushed to the laboratory for immediate analysis. Measurements of current velocity and water temperature were made in the field itself. Water samples were filtered through a Whatman No. 42 filter paper before performing chemical analyses. All efforts were made to analyse the samples immediately after collection; however, storage became necessary some times for which standard protocols as given in APHA (1985) were followed. Ammonia-nitrogen was estimated within a few hours after collection. The water samples for nitrate-nitrogen and phosphorus were stored in a freezer for a period not exceeding 24 hours. The samples for silica and trace elements were also stored in a refrigerator before analysis took place. Standard methods were followed for chemical analyses (Wetzel & Likens 1979, Suess 1982, APHA 1985). A summary of various methods is given below.

Temperature: Water temperature was recorded with a mercury bulb thermometer at each station in the field itself.

Flow Rate: Current velocity measurements were carried out with a float and a stopwatch.

pH: It was measured with a combination pH electrode and a digital pH meter (Control Dynamics, model APX 175).

Conductivity: Conductivity was measured by a conductivity meter (Systronics, model 304). Before measurement, the instrument was calibrated with 0.1 N KCl.

Dissolved Oxygen: Winkler's method was followed for analysis. Water samples were collected in BOD bottles and treated with manganous sulphate, potassium hydroxide and potassium iodide (the last two reagents combined in one solution), and concentrated sulphuric acid. The precipitate of manganous hydroxide thus formed reacted with dissolved oxygen to form a brown precipitate of manganic hydroxide. Upon acidification, the manganic hydroxide formed manganic sulphate which acted as an oxidising agent to release the free iodine from potassium iodide. The iodine thus liberated, which is stoichiometrically equivalent to the amount of dissolved oxygen in the sample, was then titrated with sodium thiosulphate.

Soluble-Reactive Phosphorus (SRP): The ascorbic acid method was followed for estimation using filtered water samples. The principle of this method is that ammonium molybdate and potassium antimonyl tartarate react in acidic medium with SRP to form a heteropoly acid (phosphomolybdic acid) that is reduced to an intensely coloured molybdenum blue by ascorbic acid. Due to extremely low concentration of SRP in samples, the blue coloured complex was extracted in butyl acetate to increase the sensitivity of the method. The intensity of blue colour was measured at 885 nm. A standard curve was also prepared with known concentrations of SRP.

Total Phosphorus (TP): Unfiltered water samples were digested with potassium persulphate in an autoclave at 15 psi at 121°C for 30 min. This facilitated conversion of all forms of phosphorus into SRP which was estimated as described above.

Ammonia-Nitrogen (NH_4-N): An improved phenol-hypochlorite method was used for the measurement of ammonia-nitrogen in water samples. In this method, ammonia reacts with phenol and hypochlorite under alkaline conditions to form indophenol blue. The intensity of blue colour is proportional to the concentration of ammonia in samples. A standard curve was prepared following the above procedure with known concentrations of ammonia-nitrogen.

Nitrate-Nitrogen (NO_3-N): Nitrate was determined by the brucine method. This is based on the reaction between nitrate and brucine producing a yellow colour, the intensity of which depends on the amount of nitrate-nitrogen in the sample. The intensity of yellow colour was measured in a spectrocolorimeter at 410 nm. Due care was taken to avoid change in temperature during estimation as the brucine method is very much dependent on temperature.

Dissolved Silica (Si): It was estimated by the molybdosilicate method. In this method silicon in solution as silicic acid or silicate reacts with acidic ammonium molybdate to form a yellow silicomolybdate complex which is then reduced by sodium sulphite to form a blue colour. The intensity of blue colour was measured at

710 nm against a reagent blank. A standard curve was also prepared.

Cations and Trace Elements: After collection, the sample was filtered as soon as possible and the filtrate was immediately acidified to pH 2 with 1:1 redistilled nitric acid. As the samples contained extremely low levels of elements they were concentrated almost 5-times in a hot air oven at a temperature <60°C for slow evaporation of water. The concentrated water samples were aspirated into an atomic absorption spectrophotometer (Perkin Elmer, model 2380), and the concentrations of calcium, magnesium, potassium and trace elements (iron, copper, cobalt, zinc, lead, molybdenum and manganese) were measured.

3.2.2 Collection and Study of Epilithic Algal Assemblages:

The distribution of algal epilithon is extremely patchy due to the great degree of variability in the habitat. This has presented formidable difficulties to researchers in obtaining an actual representative sample of this assemblage. In accordance with the suggestions of Holmes & Whitton (1981) the line transect method was tried, however it was found to be cumbersome and hence the point intercept method was employed as it yielded results comparable to those obtained from the line transect method (Rout & Gaur 1990).

At each station, two reaches, each 10 m long, were identified for monthly sampling. During sampling, a 10 m long rope was laid at each of the reach. The presence or absence of perceptible algal growths was recorded on 200 points at 5 cm interval along the rope. Algal growths were classified into different physiognomic forms

(Holmes & Whitton 1981). Only three physiognomic forms were encountered: (i) encrusting, (ii) filaments, and (iii) filamentous flocs. The data thus obtained were used to calculate per cent cover of different physiognomic forms of algal epilithon. The samples of different physiognomic forms were collected from rocks in the vicinity of the reach. At least three samples of each physiognomic form were scrubbed from 4.5 cm^2 area of rock surface. This was done after removing from the stream bottom the rocks containing algal growths. The scrubbing of algae was done with a scalpel, and the detached algae were transferred to a screw cap tube along with some distilled water. The samples were immediately brought to the laboratory and one-half of each was used for chlorophyll a estimation. Chlorophyll extraction was carried out with 90% acetone. This involved the addition of 5 ml of 90% acetone to centrifuged algal samples, and repeated freezing and thawing till complete extraction of chlorophyll was achieved. The extracted samples were centrifuged once again and the supernatant was separated and its final volume adjusted to 5 ml with 90% acetone. The absorbance of supernatant was measured at different wavelengths using a Hitachi recording spectrophotometer (Model 220). The trichromatic equation given by Strickland & Parsons (1968) was used for calculating the amount of chlorophyll a in the epilithic samples.

$$\text{Chlorophyll } \underline{a} \text{ (mg } l^{-1}) = 11.6E_{665} - 1.3E_{645} - 0.14E_{630}$$

Where E_{665}, E_{645} and E_{630} are absorbance of extract at 665, 645 and 630nm, respectively, after turbidity correction at 750 nm. This equation gave chlorophyll a concentration in extract on a volume basis. Hence, the data were converted on an area basis.

The other half of the algal sample was utilised for identification and enumeration of algae. The volume of each sample was adjusted with distilled water and preservation was carried out with 5% buffered formalin solution (Wetzel & Likens 1979). All samples were thoroughly examined before adding the preservative, because many algal forms, particularly flagellates, are known to change their morphology after fixation. Algal identification was carried out with the help of keys given by several workers (Hustedt 1930, Smith 1950, Prescott 1951, Randhawa 1959, Desikachary 1959, Webber 1966, Patrick & Reimer 1975, Sheath & Hymes 1980, Sarode & Kamat 1984). The identification of diatoms was carried out after boiling the samples in acid solution which left behind silicified frustules. The samples were boiled in concentrated nitric acid solution containing a few crystals of potassium dichromate (Patrick 1959). The cleaned frustules were washed with distilled water, then taken on a slide and dried over a hot plate. Mounting was done using DPX mountant. The slides were examined at 1000X magnification with a Carl Zeiss Jena Microscope (model Laboval 4). Enumeration of algal species was carried out using a Spencer's brightline haemocytometer, or ütermohl chamber and inverted microscope (Will Wetzlar Ph). The cell volume of different species was determined by obtaining camera lucida drawings of about 20 specimens of each species and mean cell volumes calculated for each algal taxon on the basis of geometrical configuration (Clarke et al. 1987). Mean cell volumes were then multiplied by cell numbers to obtain biovolumes for each taxon. In the case of algae other than the diatoms, the average cell volume was estimated from direct measurements of length, breadth and depth(Moore 1977a). Average cell volume of each species was multiplied with their respective cell number to find out their total volume, a measure of biomass, for each sample. All data have been expressed on an area basis.

3.2.3 Statistical Analysis

The specific details relating to methods employed for data processing are given below:

Species Diversity (H'): The species diversity of epilithic assemblages was calculated using the expression of Shannon (1948)

$$H' = \sum_{i=1}^{k} Pi \ln Pi$$

where k is the number of categories and Pi is the proportion of the observations found in category i.

Species Evenness (J): The species evenness (Pielou 1966) was calculated by the following equation

$$J = \frac{H'}{\ln s}$$

where H' is the observed diversity and s is the total number of species.

Similarity and Cluster Analysis (SIMI): Cluster analysis based on similarity index (SIMI; Stander 1970) was performed to see similarities in algal communities occurring at different times at a particular site. SIMI was calculated by the following formula

$$\text{SIMI} = \frac{\sum_{i=1}^{s} Pij\ Pin}{\sqrt{\sum_{i=1}^{s} Pij^2}\ \sqrt{\sum_{i=1}^{s} Pin^2}}$$

where Pij and Pin are average relative abundance expressed as a proportion for the i-th species in j-th and n-th communities, respectively, and s is the number of species. SIMI values range from 0-1, and value 1 indicates identical communities. A computer program was developed for cluster analysis using SIMI data. A hierarchial distribution of algal species on seasonal basis was finally computed.

Canonical Correspondence Analysis (CCA): In order to understand species-environment relationships, monthly data of physico-chemical characteristics of water and biovolume of different algal species were analysed by CCA. Canonical correspondence analysis is the most recent method of multivariate analysis (ter Braak 1986). This analysis assumes a response model that is common to all species, and the existence of a single set of underlying gradients to which each of the species respond. CCA has the advantage over other techniques in that it focuses on the relationships between species and measured environmental variables, and hence facilitates an automated interpretation of the ordination axes. Canonical correspondence analysis of monthly data on algal biovolumes and physico-chemical characteristics of water was conducted at Computer Centre, North-Eastern Hill University.

3.3 Results

3.3.1 Physico-chemical Characteristics of Water

Figures 3.1 to 3.4 and Table 3.1 show physico-chemical characteristics of stream water at four sampling stations. The water temperature ranged from 10-20°C (Fig. 3.1). It was minimum during the winter. With the onset of the spring, water temperature increased reaching its maximum during the rainy season. Once again, declination occurred during the winter months. Water temperature was found to be the lowest during January at all sites. In general, temperature was always higher at St. 2 and 4 as compared to St. 1 and 3. Fig. 3.2 shows the data on flow rate of water at sampling stations. Distinct seasonality was evident: flow rate was minimum during Feb to Apr (late winter to spring), after which a dramatic increase occurred during the rainy season. Flow rate was maximum in Jul at all the stations. Subsequently, regular decrease in flow rate occurred till the spring of the next year. The water current was always higher at St. 2 and 4 than at St. 1 and 3. The stream water was found to be mildly acidic with pH ranging between 5.2 to 6.5 (Fig. 3.1). The variations in pH did not show any seasonal trend.

The conductivity of stream water collected from various stations varied from 120 to 480 $\mu S\ cm^{-1}$ (Fig. 3.1). Conductivity was always higher during the spring months (Apr to May) as compared to winter and rainy periods. St. 1 and St. 3 had relatively lower conductance than St. 2 and St. 4. Dissolved oxygen (Fig. 3.2) in water fluctuated from 6.4 to 9.8 mg l^{-1}, but for the extremely low values in Apr '88 (4.62 mg l^{-1}) and Apr '89 (5.67 mg l^{-1}). In general, dissolved oxygen concentration was relatively high during the winter. Dissolved silica was found within the concentration range 5.3 to 11.7 mg l^{-1} (Fig. 3.2). It was generally more during the periods of low discharge in comparison to the rainy season.

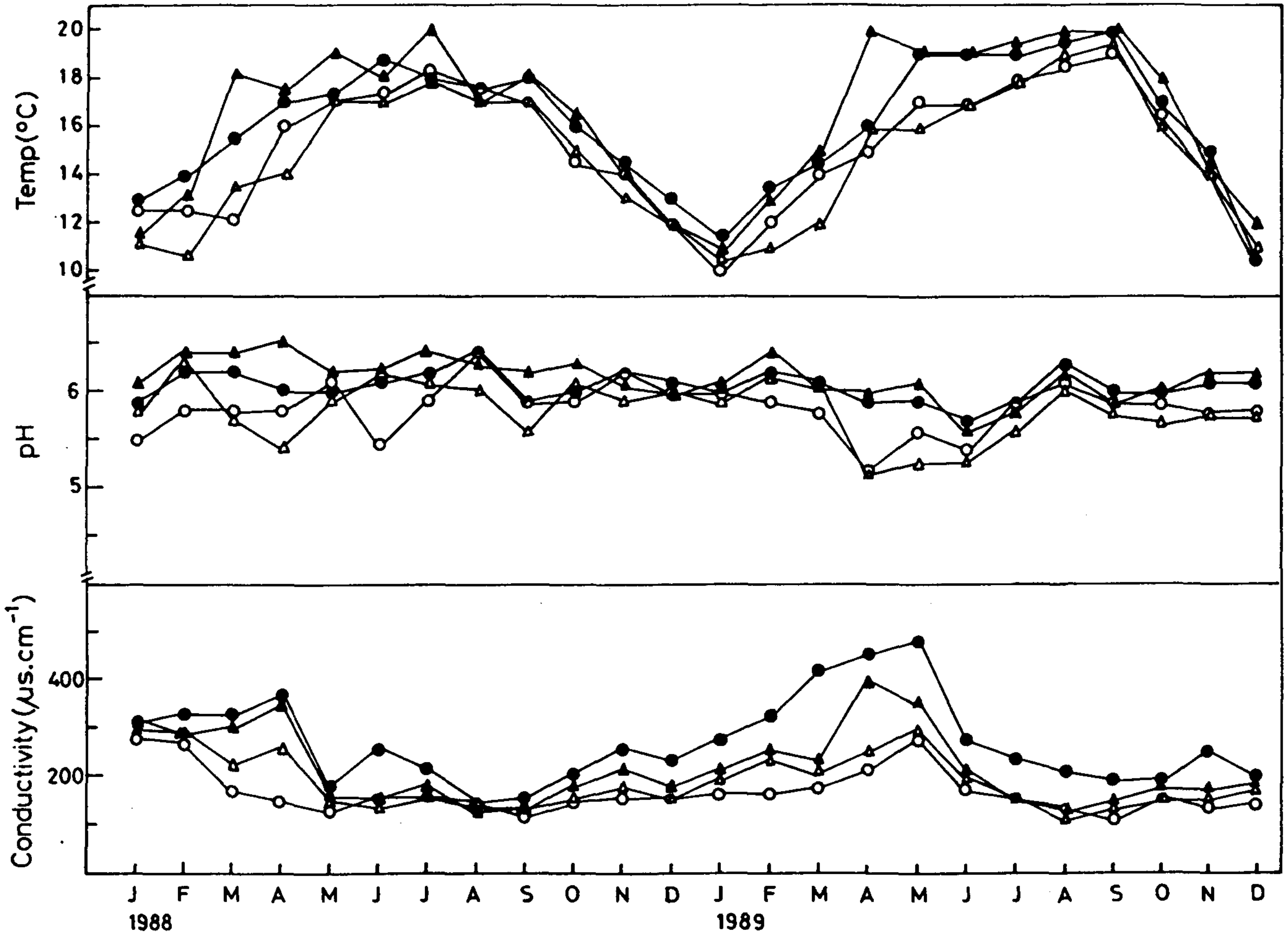

Fig. 3.1 Monthly variations in water temperature, *p*H and conductivity at four selected stations: 1 (△), 2 (▲), 3 (o) and 4 (●).

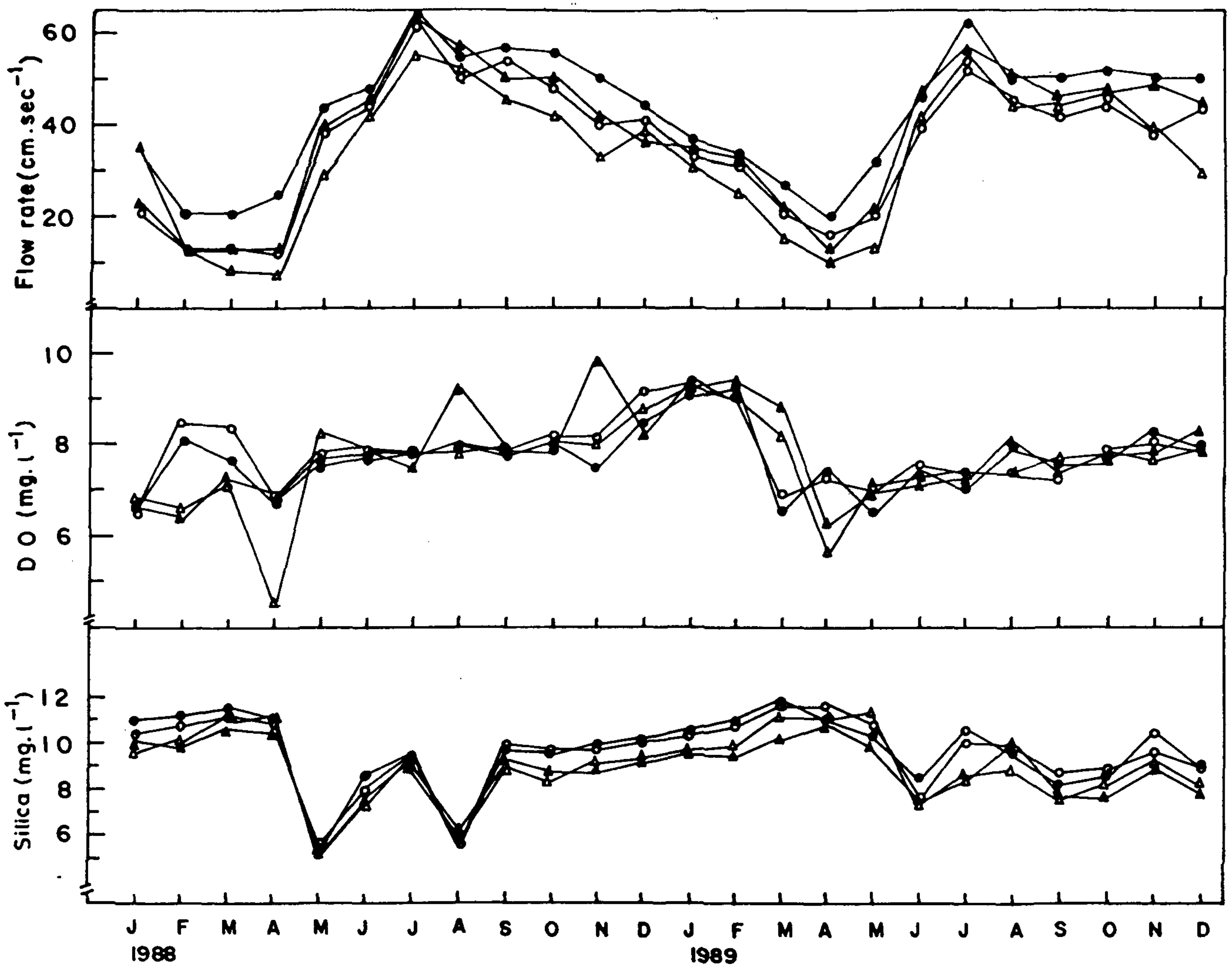

Fig. 3.2 Seasonal changes in flow rate, dissolved oxygen and silica at the sampling stations: 1 (△), 2 (▲), 3 (o) and 4 (●).

The soluble reactive phosphorus (SRP or PO_4-P) was found within 0.83 to 15.93 $\mu g\ l^{-1}$ (Fig. 3.3). The spring and autumn periods showed a relatively higher SRP concentration than rainy and winter seasons. Generally, St. 2 and St. 4 had more SRP than St. 1 and St. 3. Total phosphorus concentration (Fig. 3.3) ranged between 2.0 and 28.5 $\mu g\ l^{-1}$. The general trend for total phosphorus matched with that of SRP. The concentration of ammonia-nitrogen ranging between 2-92 $\mu g\ l^{-1}$ did not show distinct seasonality (Fig. 3.3). Although the temporal variations in NO_3-N did not follow a distinct seasonal variation, the concentrations were relatively higher during autumn and late winter. NO_3-N concentration was found between 0.07 and 4.33 mg l^{-1} (Fig. 3.4). The concentrations of calcium and magnesium respectively ranged from 0.13 to 1.92 mg l^{-1} and 0.04 to 0.33 mg l^{-1} (Fig. 3.4). The concentrations were markedly higher during the periods of low flow rate. Table 3.1 shows the levels of potassium and trace elements in stream water. Average potassium concentration in water samples of St. 1 and 2 was 0.95 mg l^{-1}, whereas St. 3 and St. 4 had 1.39 mg l^{-1}. Trace elements were found at low concentrations.

3.3.2 Characteristics of Epilithic Algal Assemblages

The data pertaining to per cent cover of different physiognomic forms have been shown in Fig. 3.5. The total per cent cover of algal epilithon ranged from 26.1 to 49.0. Late winter and early spring periods showed maximum per cent cover at all stations. The minimum was obtained during Jul in two consecutive years. The algal cover increased progressively towards the autumn which further increased in winter months during the study period.

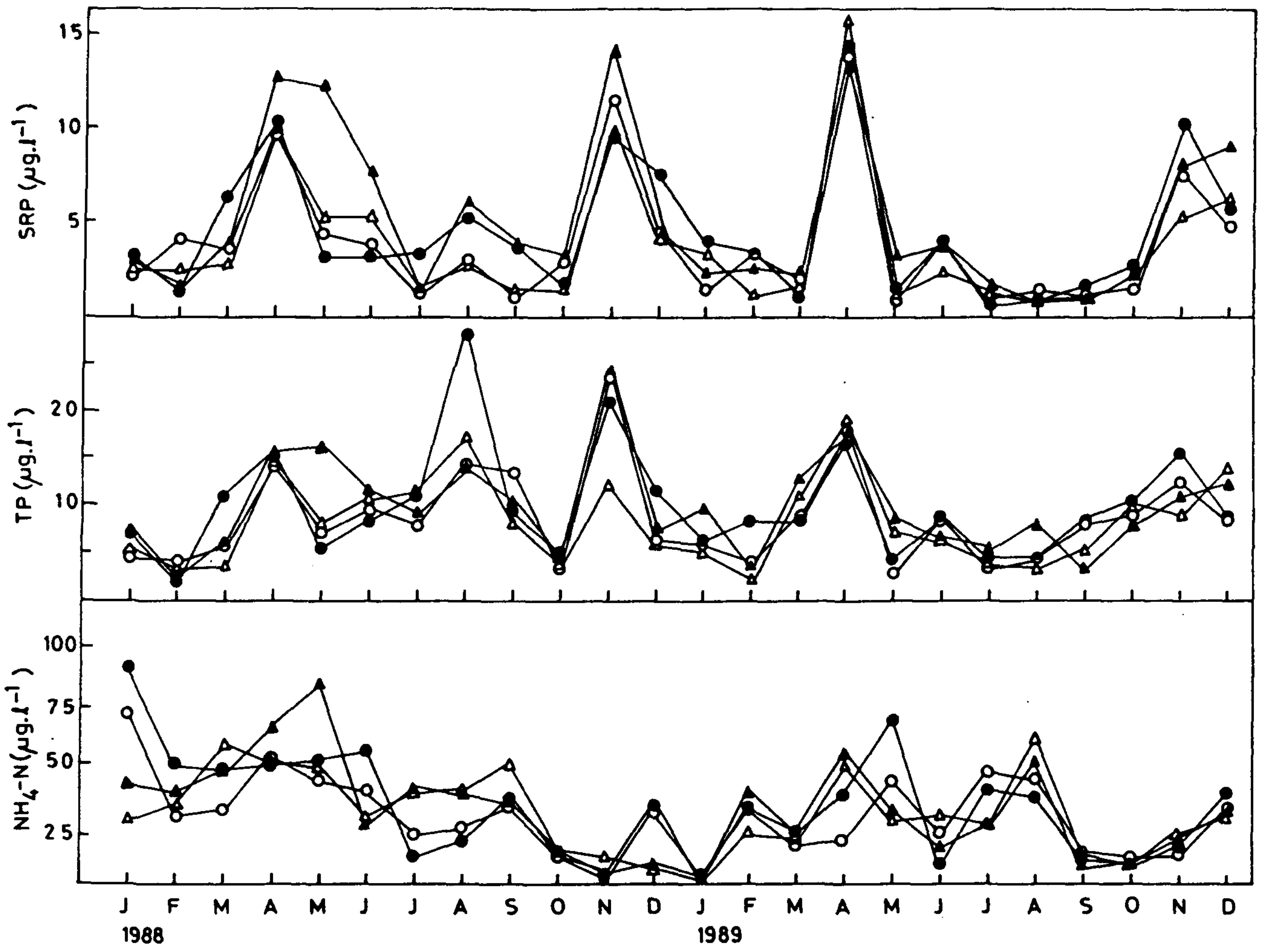

Fig. 3.3 Changes in concentrations of soluble-reactive phosphorus, total phosphorus and ammonia-nitrogen at the selected stations: 1 (△), 2 (▲), 3 (○), and 4 (●).

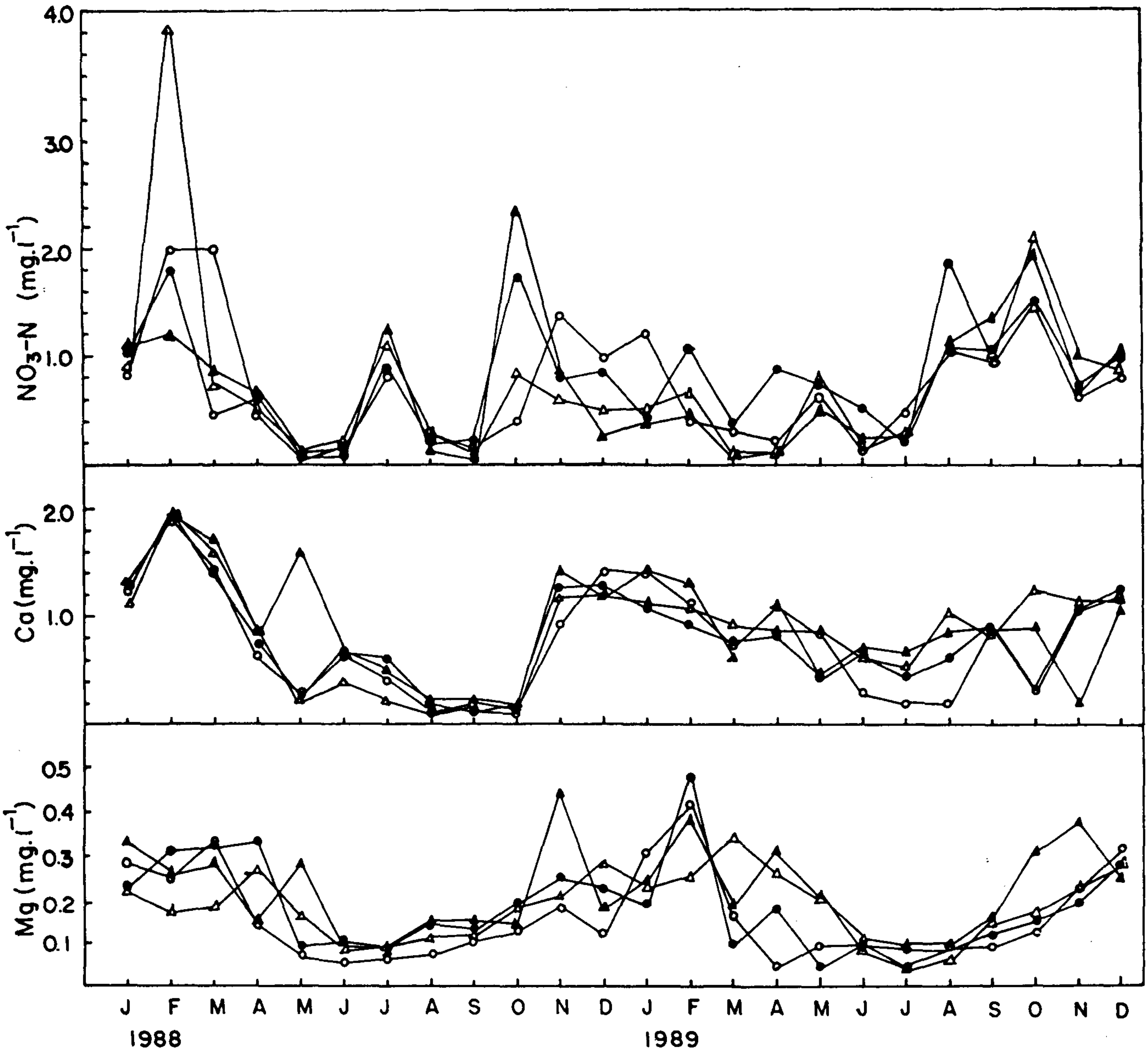

Fig. 3.4 Monthly fluctuations in nitrate-nitrogen, calcium and magnesium concentrations at St. 1 (Δ), St. 2 (▲), St. 3 (o) and St. 4 (●).

Table 3.1 Concentration of potassium and various trace elements ($mg\ l^{-1}$) in streams during the study period.

	Wah Dienglieng (St. 1 and 2)	Wah Risa (St. 3 and 4)
Potassium	0.95	1.39
Iron	0.28	0.08
Cobalt	0.07	0.03
Copper	0.01	0.03
Zinc	0.15	0.11
Lead	0.02	0.02
Molybdenum	0.03	0.02
Manganese	0.004	0.01

N.B. The data given are average values of 4-5 estimations carried out in different seasons.

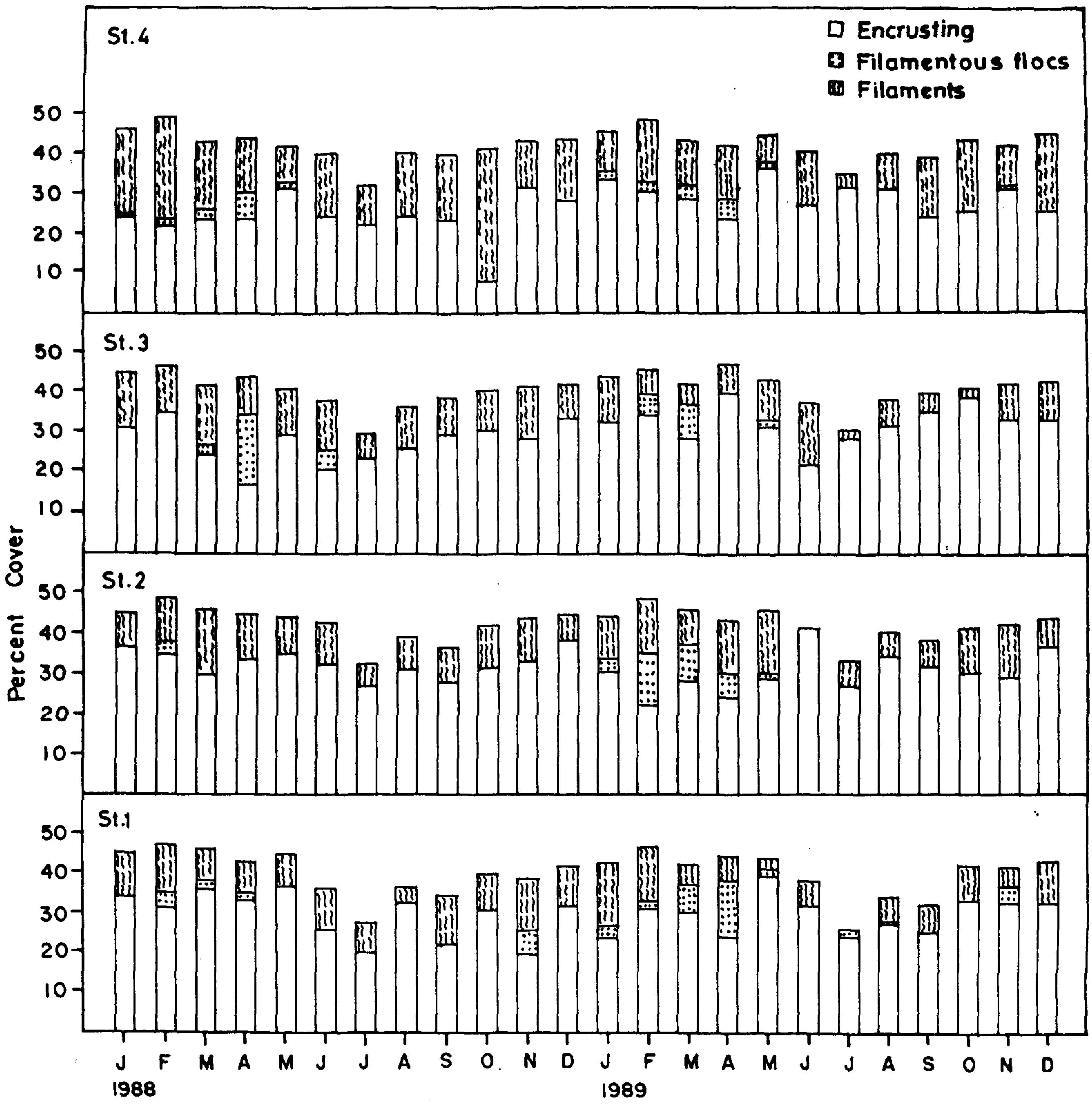

Fig. 3.5 Per cent cover of algal physiognomic forms (encrusting, filamentous flocs and filaments) in the epilithon at four stations.

Throughout algal cover was relatively higher at St. 2 than St. 1. Similarly St. 4 had greater algal cover in comparison to St. 2. The algal cover consisted mainly of three physiognomic forms (Plate III) namely, encrusting, filaments and filamentous flocs, of which encrusting forms were most well-represented followed by filaments whose cover ranged from 2 to 32.2%. The lower values were observed in the rainy season. The cover of filamentous flocs was much less than the filaments and encrusting algae. The filamentous flocs were encountered mainly in late winter/spring months at the selected stations.

The epilithic community was composed of 97-108 algal species at different stations. The members of Bacillariophyta showed maximum species richness (78-96 species) followed by Chlorophyta (9-13 species), Cyanophyta (6-10 species) and Rhodophyta (1-2 species) (Table 3.2). The total number of species recorded at four stations over a two year study period are shown in Fig. 3.6. The maximum number of taxa was recorded during Mar '88 and Feb '89, whereas the minimum number was found during the rainy months (Jul '88 and '89). After rainy season, the species number steadily increased at all sites reaching a maxima in late winter or spring. Subsequently, declination occurred with the onset of rainy season. In general, the species richness was always more at St. 2 and 4 in contrast to St. 1 and 3, respectively. The total number of individuals (see Fig. 3.6) was observed to be more in late winter and spring months (range 1,923 to 13,298 individuals cm^{-2}) than the rainy periods (range 1,600 to 5,938 individuals cm^{-2}) during the two years of study. Seasonal trend was found to be almost similar

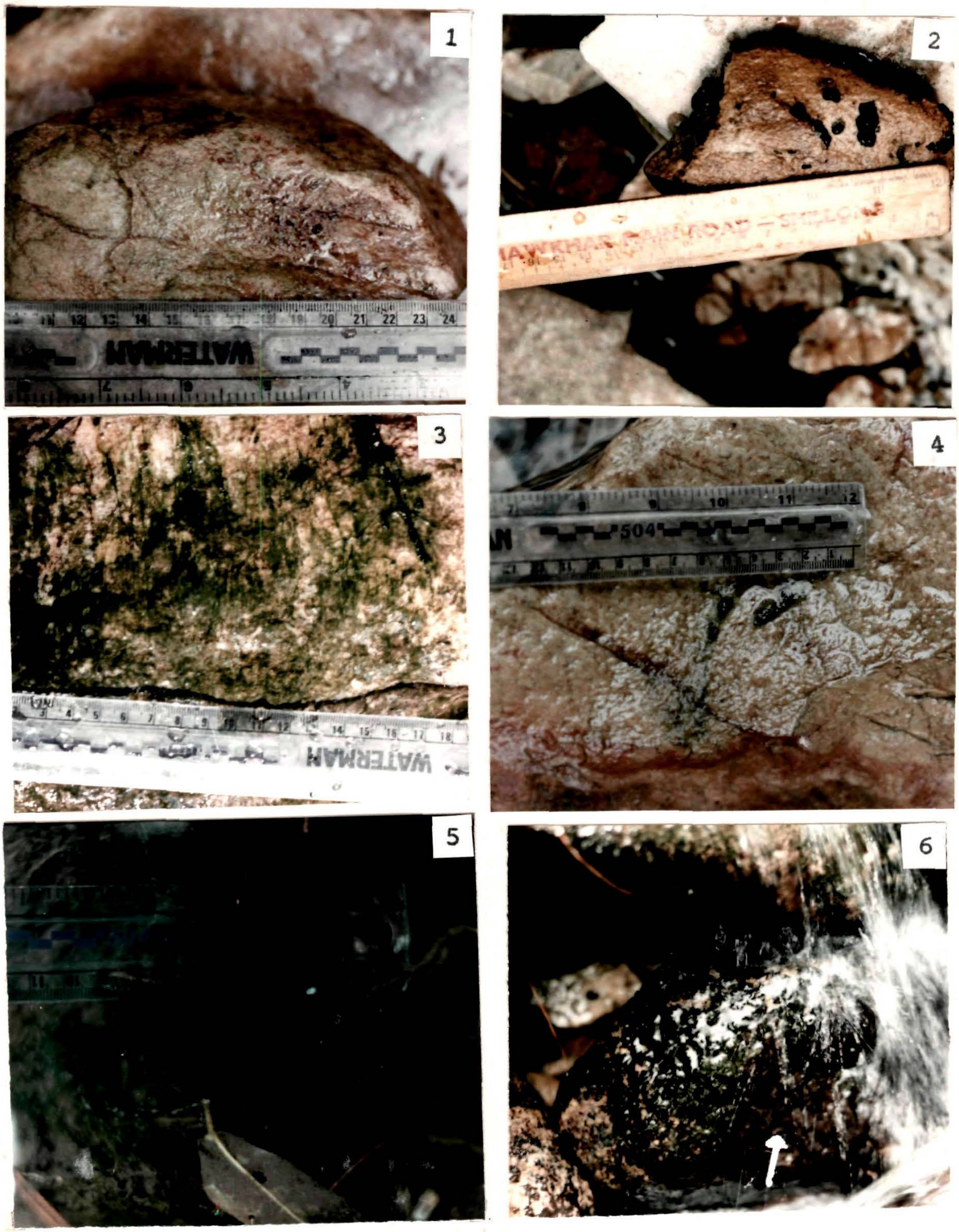

Plate III Photographs of epilithic physiognomic forms: 1-encrusting; 2 - filamentous flocs (<u>Tolypothrix distorta</u>); and 3 to 6 filaments (3 - <u>Cylindrocapsa conferta</u>; 4 - <u>Hormidium subtile</u>; 5 - <u>Spirogyra communis</u>; and 6 - <u>Audouinella violacea</u> shown by an arrow).

Table 3.2 Number of species of different algal groups observed in the epilithon during two-year study.

Algal group	St. 1	St. 2	St. 3	St. 4
Bacillariophyta	78	86	82	88
Chlorophyta	9	13	9	11
Cyanophyta	8	8	10	6
Rhodophyta	2	1	1	1
Total	97	108	102	106

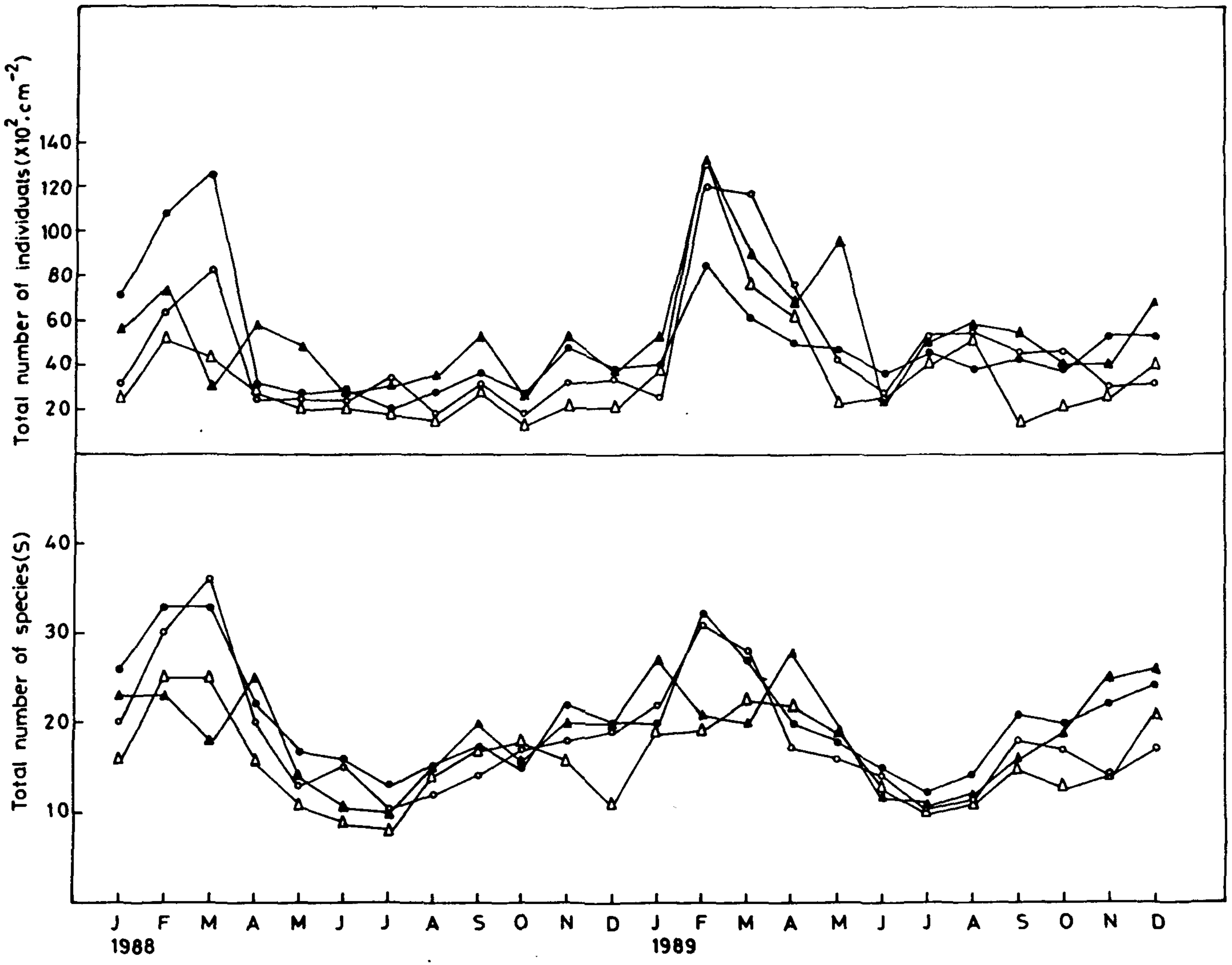

Fig. 3.6 Seasonal changes in total number of individuals and species number in the epilithon at the selected stations: 1 (Δ), 2 (▲), 3 (o) and 4 (●).

to the one obtained in the case of species richness. In most instances the total number of individuals was found to be more at St. 2 and 4 as compared to St. 1 and 3.

In total, 158 algal taxa were encountered in the epilithon during the study period (Table 3.3). This table shows the list of algal species and the numbers following the names of species denote their presence at St. 1, 2, 3 and 4. Species like *Achanathes microcephala*, *A. minutissima*, *Audouinella violacea*, *Caloneis silicula*, *C. ventricosa*, *Closterium acerosum*, *Cylindrocapsa conferta*, *Eunotia arcus*, *E. pectinalis*, six species of *Gomphonema*(*G. gracile*, *G. intricatum*, *G. lanceolatum*, *G. longiceps*, *G. olivaceum* and *G. parvulum*), *Hormidium subtile*, *Hyalotheca dissiliens*, *Mougeotia genuflexa*, nine species of *Navicula* (*N. avenacea*, *N. cincta*, *N. complanatula*, *N. cryptocephala*, *N. gracilis*, *N. lanceolata*, *N. protracta*, *N. radiosa* and *N. viridula*), *Neidium amphigomphous*, *N. iridis*, *Nitzschia amphibia*, *Nostoc communitum*, *Oscillatoria chlorina*, *O. willei*, *Pinnularia appendiculata*, *P. braunii*, *P. gibba* were commonly found in the epilithic assemblages at all the sampling sites. *Eunotia major*, *E. monodon*, *E. tschirchiana*, *Nitzschia vitrea*, *Phormidium retzii*, *Spirulina gigantea* were restricted to St. 1 and 3. The species confined to St. 2 and 4 are *Achnanthes biasolettiana*, *Caloneis formosa*, *Closterium moniliforme*, two species of *Cymbella* (*C. gracilis* and *C. hungarica*), *Eunotia gracilis*, *E. hebridica*, *Microspora stagnorum*, *Navicula reinhardtii* and *Synedra tabulata*. Algae like *Achnanthes affinis*, *A. coarctata*, *Chlorella vulgaris*, *Pinnularia panhalgarhensis*, *Synedra vaucheriae* were found only at St. 1 and 2, whereas *Cosmarium circulare*, *Fragilaria intermedia*, *Nitzschia palea* and

Table 3.3 List of algal species encountered in various life forms of the epilithon. The numbers following the names of species denote their presence at stations 1,2,3 and 4.

Algal species	Species code	Average biovolume of one individual (μm^3)	Life form		
			Encrusting	Filamentous flocs	Filaments
Bacillariophyta					
Achnanthes affinis Grun . (1,2)	ACH AFF	73	+	-	+
A. biasolettiana (Kütz.) Grun. (2,4)	ACH BIO	218	+	-	-
A. brevipes Ag. (2,3)	ACH BRE	5,014	-	+	-
A. coarctata Bréb. (1,2)	ACH COA	5,688	-	+	-
A. hungarica Grun. (2)	ACH HUN	1,799	+	-	+
A. lanceolata (Bréb.) Grun. (1,4)	ACH LAN	330	+	-	+
A. lapponica (Hust.) Hust. (2)	ACH LAP	396	+	-	+
A. microcephala (Kütz.) Grun. (1,2,3,4)	ACH MIC	352	+	+	+
A. minutissima (Kütz.) Grun. (1,2,3,4)	ACH MIN	437	+	-	-
Caloneis beccariana Grun. (1,4)	CAL BEC	4,315	+	+	+
C. formosa (Greg.) Cl. (2,4)	CAL FOR	9,735	+	-	+
C. silicula (Ehr.) Cl. (1,2,3,4)	CAL SIL	10,375	+	+	+
C. ventricosa (Ehr.) Meist (1,2,3,4)	CAL VEN	6,472	+	+	+
Cocconeis placentula Ehr. (1)	COC PLA	2,873	+	-	-
Cymbella cuspidata Gandhi (2)	CYM CUS	1,468	+	-	-
C. cymbiliformis (Ag.) Kütz. (2)	CYM CYM	6,835	+	-	+
C. gracilis (Rabh.) Cl. (2,4)	CYM GRA	797	+	+	-

C. hungarica (Grun.) Pant (2,4)	CYM HUN	4,315	+	-	+
C. nagpurensis Sarod & Kamat (4)	CYM NAG	1,202	+	-	-
Eunotia arcus Ehr. (1,2,3,4)	EUN ARC	2,878	+	+	+
E. camelus (Ehr.) A°. Berg (4)	EUN CAM	1,063	+	-	-
E. exigua (De Bréb.) Rabh. (1,4)	EUN EXI	84	+	-	+
E. fallax A. Cl. (1,3,4)	EUN FAL	173	+	+	-
E. gracilis (Ehr.) Rabh. (2,4)	EUN GRA	3,050	+	-	+
E. grunowi A°. Berg. (4)	EUN GRU	5,150	-	-	+
E. hebridica A° Berg. (2,4)	EUN HEB	1,590	+	+	+
E. lunaris (Ehr.) Grun. (2,3)	EUN LUN	1,255	+	-	+
E. major (W. Sm.) Rabh. (1,3)	EUN MAJ	2,339	+	+	-
E. monodon Ehr. (1,3)	EUN MON	4,611	+	-	+
E. parallela Ehr. (2,3)	EUN PAR	6,776	+	-	-
E. pectinalis (Kütz.) Rabh. (1,2,3,4)	EUN PEC	437	+	+	+
E. praerupta Ehr. (1,3,4)	EUN PRA	5,150	+	-	+
E. pseudoparallela A° Berg. (2,3,4)	EUN PSE	305	-	-	+
E. rostellata Hust. (2,3,4)	EUN ROS	531	+	-	+
E. tenella (Grun.) Hust. (2,3,4)	EUN TEN	157	+	+	+
E. tschirchiana O. Müll. (1,3)	EUN TSC	1,240	-	+	+
E. tumida Gandhi (1)	EUN TUM	157	+	-	+
Fragilaria intermedia Grun. (3,4)	FRA INT	5,690	-	-	+
Frustulia jogensis Gandhi (1,2,3)	FRU JOG	9,465	+	+	+
F. rhomboides (Ehr.) De Toni (1,3,4)	FRU RHO	9,920	+	+	+
F. vulgaris Thwaites (1,3,4)	FRU VUL	9,023	+	+	+
Gomphonema angustatum (Kütz.) Rabh. (1,4)	GOM ANG	4,284	+	-	-
G. bohemicum Reich. & Frick. (1)	GOM BOH	2,339	-	+	-
G. constrictum Ehr. (2)	GOM CON	7,581	+	-	-

G. gracile Ehr. (1,2,3,4)	GOM GRA	2,339	+	-	+
G. hebridense (Greg.) Her (1,2,3,4)	GOM HEB	1,976	+	+	+
G. intricatum Kütz. (1,2,3,5)	GOM INT	2,157	+		+
G. lanceolatum Ehr. (1,2,3,4)	GOM LAN	2,978	+	+	-
G. longiceps Ehr. (1,2,3,4)	GOM LON	5,251	-	-	+
G. montanum Schum. (1)	GOM MON	3,790	+	-	-
G. olivaceoides Hust. (1)	GOM OLI	1,078	+	-	-
G. olivaceum (Lyng.) Kütz. (1,2,3,4)	GOM OLV	2,477	+	+	-
G. parvulum (Kütz.) Grun. (1,2,3,4)	GOM PAR	1,618	+	+	+
G. subtile Ehr. (1,4)	GOM SUB	1,976	-	+	-
Gyrosigma scalproides (Rabh.) Cl. (2)	GYR SCA	4,337	+	-	-
Mastogloia recta Hust. (3)	MAS REC	618	+	-	-
Meridion circulare (Grev.) Ag. (3)	MER CIR	2,165	+	-	-
Navicula arenaria Donk. (1,2,3)	NAV ARE	5,393	-	-	+
N. avenacea Bréb. (1,2,3,4)	NAV AVE	4,064	+	+	+
N. cari Ehr. (1,3,4)	NAV CAR	1,063	+	+	+
N. cincta (Ehr.) Kütz. (1,2,3,4)	NAV CIN	887	+	+	+
N. complanatula Hust. (1,2,3,4)	NAV COM	2,339	+	+	+
N. conferracea Kütz. (3)	NAV CON	897	+	-	-
N. cryptocephala Kütz. (1,2,3,4)	NAV CRY	974	+	+	+
N. disjuncta Hust. (1)	NAV DIS	797	+	-	-
N. exigua (Greg.) O'Müll. (1,2,4)	NAV EXI	1,202	+	+	+
N. flanatica Grun. (2)	NAV FLA	1,418	+	-	-
N. gracilis Ehr. (1,2,3,4)	NAV GRA	4,064	+	+	+
N. graciloides A. Meyer (2)	NAV GRC	1,602	-	+	-
N. gregarica Donk. (1)	NAV GRE	442	-	-	+
N. grevillei Ag. (1,2,3)	NAV GRA	6,472	-	+	-

N. halophila (Grun.) (1,2,4)	NAV HAL	1,602	-	-	+
N. laterostrata Hust. (1,2,4)	NAV LAT	1,607	+	-	-
N. microcephala Grun. (2,3,4)	NAV MIC	218	+	-	+
N. minima Grun. (2,3,4)	NAV MIN	173	+	+	-
N. mutica Kütz. (2,3,4)	NAV MUT	8,993	+	-	+
N. protracta Grun. (1,2,3,4)	NAV PRO	1,737	+	+	+
N. pupula Kütz. (1,2,3)	NAV PUP	8,568	+	+	+
N. radiosa Kütz. (1,2,3,4)	NAV RAD	1,799	+	+	+
N. reinhardtii Grun. (2,4)	NAV REI	6,472	+	+	+
N. rhynchocephala Kütz. (2,3,4)	NAV RHY	3,525	+	+	+
N. similis Krauske (2,3)	NAV SIM	214	-	+	-
N. subdapaliformis Gandhi (3)	NAV SUB	4,064	+	-	+
N. subrhynchocephala Hust. (1,2,3)	NAV SUR	666	+	-	+
N. vanhoeffieniformis Gandhi (2)	NAV VAN	1,799	+	-	-
N. viridula Kütz. (1,2,3,4)	NAV VIR	3,790	+	+	+
Neidium amphigomphous (Ehr.) Cl. (1,2,3,4)	NEI AMP	3,325	+	-	+
N. iridis (Ehr.) Cl. (1,2,3,4)	NEI IRI	6,119	+	-	+
N. panhalgarhensis Gandhi (4)	NEI PAN	3,790	-	-	+
Nitzschia amphibia Grun. (1,2,3,4)	NIT AMP	2,515	+	-	+
N. angustata (W. Sm.) Grun. (1,3,4)	NIT ANG	2,003	+	+	+
N. filiformis (W. Sm.) Hust. (3)	NIT FIL	7,293	+	-	-
N. hantzschiana Rabh. (1,4)	NIT HAN	5,393	-	-	+
N. hungarica Grun. (1)	NIT HUN	5,393	+	-	+
N. nagpurensis Sarod & Kamat (3)	NIT NAG	1,063			
N. palea (Kütz.) W. Sm. (3,4)	NIT PAL	4,611	+	-	+

N. parvula Lewis (2,3)	NIT PAR	4,678	+	-	+
N. pseudofonticola Hust. (1,2,4)	NIT PSE	4,954	-	-	+
N. vitrea Norman (1,3)	NIT VIT	3,682	-	-	+
Pinnularia appendiculata (Ag.) Cl. (1,2,3,4)	PIN APP	524	+	+	+
P. braunii (Grun.) Cl. (1,2,3,4)	PIN BRA	4,337	+	-	+
P. brebissoni (Kütz.) (4)	PIN BRE	887	-	+	-
P. divergens W. Sm. (1,2,4)	PIN DIV	5,963	+	-	+
P. divergentissima (Grun.) Cl. (3,4)	PIN DIE	3,236	+	-	+
P. eburnea (Carlson) Zanon (3,4)	PIN EBU	6,119	-	-	+
P. gibba Ehr. (1,2,3,4)	PIN GIB	5,690	+	+	+
P. interrupta W. Sm. (1,2,3)	PIN INT	4,877	+	+	+
P. marathwadensis Sarod & Kamat (1)	PIN MAR	12,625	+	-	-
P. neglecta (Meyer) A°. Berg (3)	PIN NEG	67,457	+	-	-
P. panhalgarhensis Gandhi (1,2)	PIN PAN	8,993	+	-	+
P. sagittala Gandhi (3,4)	PIN SAG	7,589	+	-	+
P. stauroptera (Rabh.) Cl. (1,3,4)	PIN STA	6,237	+	-	+
P. viridis (Nitz.) Ehr. (1,2,4)	PIN VIR	19,712	-	-	+
Stauroneis phoenicenteron Ehr. (3)	STA PHO	35,114	+	-	-
Surirella smithii Ralfs. (2)	SUR SMI	156,367	+	-	+
S. elegans Ehr. (2)	SUR ELE	245,003	+	-	-
Synedra acus Kütz. (1,2,3,4)	SYN ACU	3,336	+	+	+
S. pulchella (Ralfs.) Kütz. (1,2,3,4)	SYN PUL	3,417	+	+	+
S. tabulata (Ag.) Kütz. (2,4)	SYN TAB	3,871	+	-	+
S. ulna (Nitz.) Ehr. (1,2,3,4)	SYN ULN	8,949	+	+	+
S. vaucheriae Kütz. (1,2)	SYN VAU	1,153	+	+	+

Chlorophyta

Ankistrodesmus falcatus (Corda) Ralfs. (2)	ANK FAL	3,814	-	-	+
Chlorella vulgaris Beiy (1,2)	CHL VUL	1,626	-	+	-
Closterium acerosum (Schrank) Ehr. (1,2,3,4)	CLO ACE	4,276	+	+	+
C. moniliforme (Borg) Ehr. (2,4)	CLO MON	4,947	-	-	+
C. parvulum Näg. (2)	CLO PAR	4,433	-	-	+
C. subtrunctatum W. and G.S. West (2)	CLO SUB	7,981	-	-	+
Cosmarium bioculatum Bréb. (1,2,3)	COS BIO	8,174	+	+	+
C. circulare Reinsch. (3,4)	COS CIR	18,538	-	-	+
C. contractum W. and G.W. West (4)	COS CON	3,251	-	-	+
C. punctulatum (Nordst.) Borg. (1)	COS PUN	3,783	-	-	+
Cylindrocapsa conferta W. West (1,2,3,4)	CYL CON	4,461	-	-	+
Hormidium subtile (Kulebsii) G.M. Sm (1,2,3,4)	HOR SUB	48,772	-	-	+
Hyalotheca dissiliens (J.E. Sm.) (1,2,3,4)	HYA DIS	203,411	+	-	+
Microspora stagnorum (Kütz.) Thur. (2,4)	MIC STA	57,016	-	-	+
Mougeotia genuflexa (Dillw.) Ag. (1,2,3,4)	MOU GEN	17,945	-	-	+
Mougeoptis calospora Palla (3)	MOU CAL	101,705	-	-	+
Oedogonium curtum Wittrock (4)	OED CUR	6,276	-	-	+
Selenastrum gracile Reinsch. (2)	SEL GRA	7,276	+	-	-
Spirogyra communis (Hassal) Kütz. (1,2,3,4)	SPI COM	2910,935	+	+	+
Synechococcus aeruginosum Näg (1)	SYN AER	1,078	-	+	-

Cyanophyta					
Lyngbya gracilis (Menegh.) Rabh. (2,3)	LYN GRA	3,569	+	+	-
Nostoc comminutum Kütz. (1,2,3,4)	NOS COM	539	-	-	+
Oscillatoria chlorina Kütz. (1,2,3,4)	OSC CHL	3,528	+	+	+
O. subuliformis Kütz. (1,2,3,4)	OSC SUB	1,078	+	-	+
O. willei Gardn. (1,2,3,4)	OSC WIL	10,787	+	+	+
Phormidium retzii (Ag.) Gom. (1,3)	PHO RET	21,575	-	+	-
Plectonema notatum Schmidle (4)	PLE NOT	10,283	-	-	+
Scytonema coactile Mont. (1,4)	SCY COA	5,403	+	+	+
Sphaeroplea annulina (Roth) C.A. Ag. (3)	SPA ANN	2,570	+	-	-
Spirulina gigentea Schmidle (1,3)	SPI GIG	2,359	-	+	+
Spirulina menighiniana Zanard (3)	SPI MEN	980	-	+	-
Stigonema minutum (Ag.) Hoss. (1,2,3)	STI MIN	2,289	+	-	+
Tolyphothrix distorta Kutz. ex. Born. et Flah. (1,2,4)	TOL DIS	56,397	-	+	-
Rhodophyta					
Audouinella violacea (Kütz.) Hamel (1,2,3,4)	AUD VIO	24,500	-	+	-
Batrachospermum moniliforme Roth	BAT MON	1,445	-	-	+

three species of *Pinnularia* (*P. divergentissima*, *P. eburnea*, *P. sagittata*) occurred at St. 3 and 4 only.

Among the three physiognomic forms observed in the present study, most of the algae were found in encrusting and filaments physiognomic forms. Algal taxa occurring in all the physiognomic forms are *Achnanthes microcephala*, *Caloneis beccariana*, *C. silicula*, *C. ventricosa*, *Closterium acerosum*, *C. bioculatum*, *Eunotia arcus*, *E. hebridica*, *E. pectinalis*, *E. tenella*, *Frustulia jogensis*, *F. rhomboides*, *F. vulgaris*, *Gomphonema hebridense*, *G. parvulum*, fourteen species of *Navicula* (*N. avenacea*, *N. cari*, *N. cincta*, *N. complanatula*, *N. cryptocephala*, *N. exigua*, *N. gracilis*, *N. lanceolata*, *N. protracta*, *N. pupula*, *N. radiosa*, *N. reinhardtii*, *N. rhynchocephala*, *N. viridula*), *Nitzschia angustata*, two species of *Oscillatoria* (*O. chlorina* and *O. willei*), four species of *Pinnularia* (*P. appendiculata*, *P. gibba*, *P. interrupta* and *P. subcapitata*), *Scytonema coactile*, *Spirogyra communis*, four species of *Synedra* (*S. acus*, *S. pulchella*, *S. ulna* and *S. vaucheriae*). Some particular algae like *Achnanthes brevipes*, *A. coarctata*, *Audouinella violacea*, *Gomphonema bohemicum*, *G. subtile*, *Navicula grevillei*, *Phormidium retzii*, *Pinnularia brebissoni*, *Spirulina menighiniana*, *Synechococcus aeruginosum* and *Tolypothrix distorta* were available only in filamentous flocs. Rest of the algal taxa fluorished either in encrusting or in filaments physiognomic form, or in both. The filaments life form was mainly dominated by *Spirogyra communis* and *Oscillatoria willei*, whereas diatoms dominated the encrusting life form.

The ranges of species diversity (H') and evenness (J) were respectively 1.09-4.17 and 0.68-0.91 at the selected stations (Fig.

3.7). The lower species diversity and evenness values were often associated with the rainy season. In some cases (Feb. '89 at St. 1, Feb '89 and Mar '89 at St. 2, and Mar '88 and May '88 at St. 3) the diversity and evenness values declined to a great extent due mainly to the predominance of certain filamentous algal species in the epilithic assemblages. This phenomenon was found to be associated with Oscillatoria willei, Audouinella violacea, Hormidium subtile, Spirogyra communis and Cylindrocapsa conferta.

Fig. 3.8 shows the graphic representation of biovolume contributed by four algal groups towards the total biovolume of algal epilithon at St. 1 over a period of two years. A consistent seasonal pattern was observed in both the years. It was found that the total biovolume was always more in spring months than other periods. The lowest value was observed during rainy and autumn months. Among the four groups of algae encountered, Cyanophyta and Bacillariophyta contributed maximally towards total biovolume followed by Rhodophyta. Chlorophyta members occurring sporadically did not contribute substantially to total epilithic biovolume. Fig. 3.9 shows similar data for St. 2. The total biovolume reached its maxima in May '88 and '89 followed by substantial declination in June and July. After rainy period, total biovolume rose once again. At this station Chlorophyta contributed maximally towards the total biovolume of epilithic assemblage. Bacillariophyta members were consistently present in the assemblage throughout the study period. Cyanophyta was equally important to the epilithic assemblages. Rhodophyta contributed least towards the total epilithic biovolume. The biovolume data for St. 3 (Fig. 3.10)

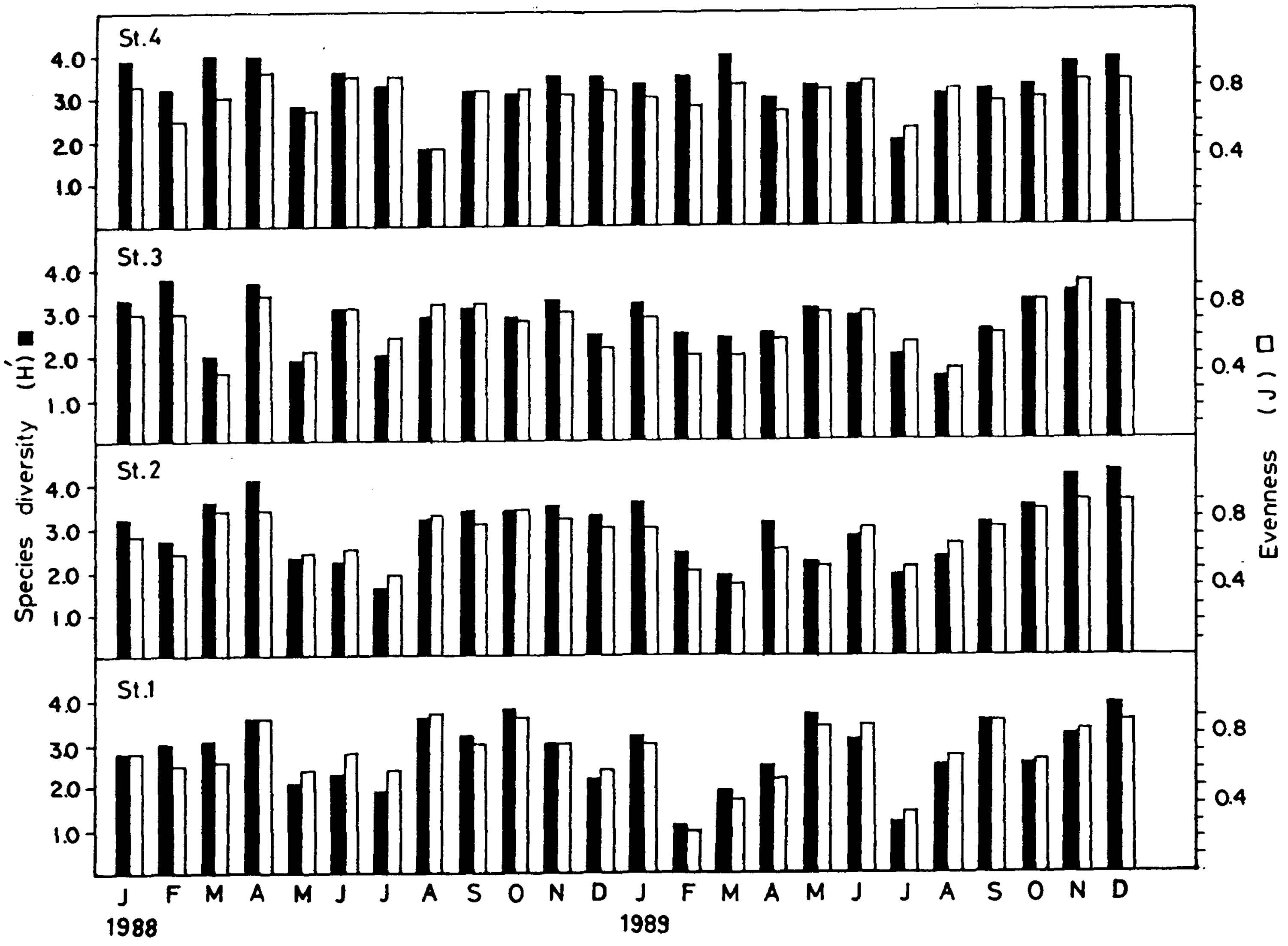

Fig. 3.7 Monthly variations in species diversity (H') and evenness (J) of epilithic algal assemblages of four stations.

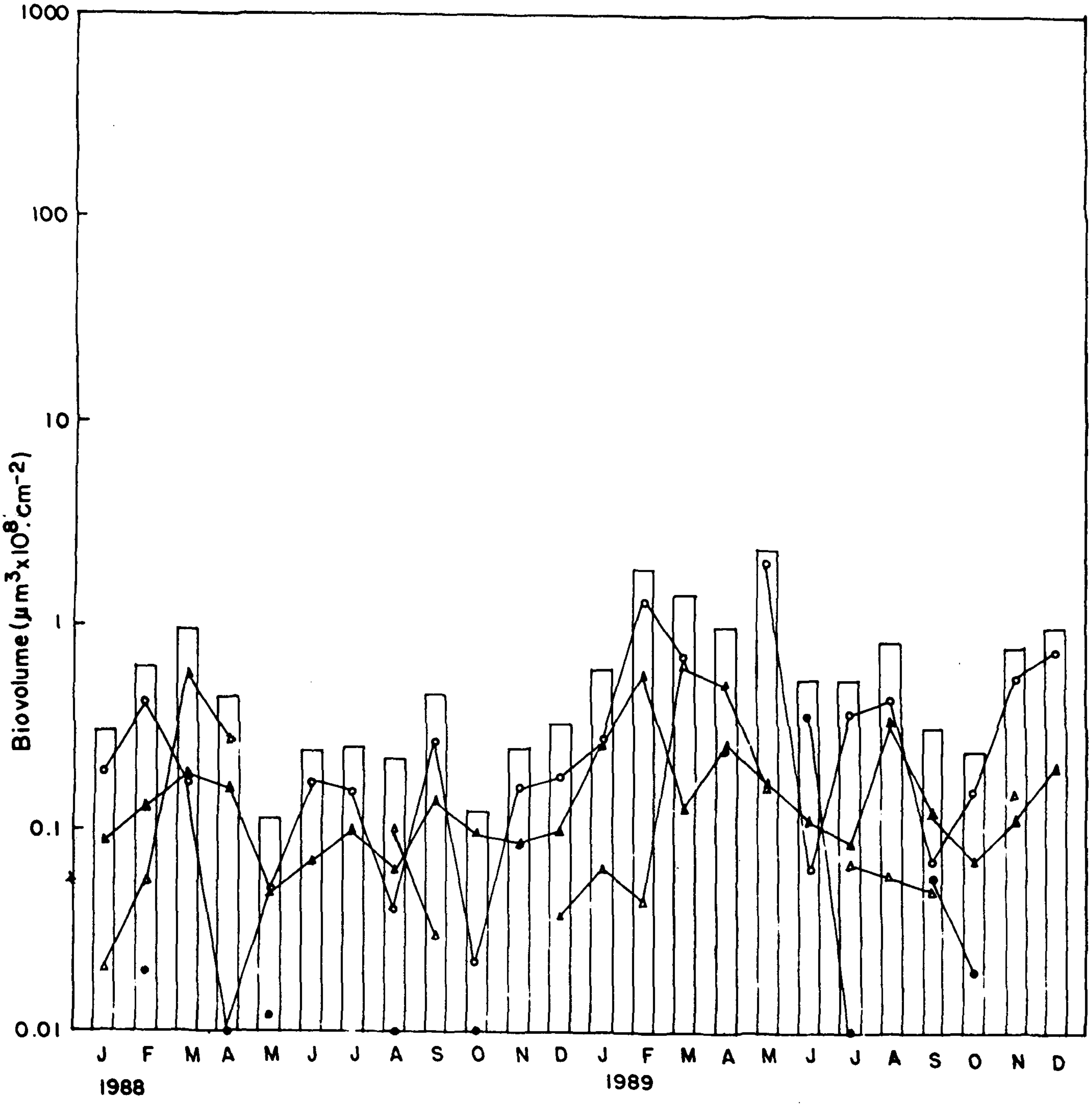

Fig. 3.8 Seasonal variations in total algal biovolume (bar), and biovolumes of different algal groups (△—△ Rhodophyta, ▲—▲ Bacillariophyta, ○—○ Cyanophyta, ●—● Chlorophyta) constituting the epilithic algal assemblage at St. 1.

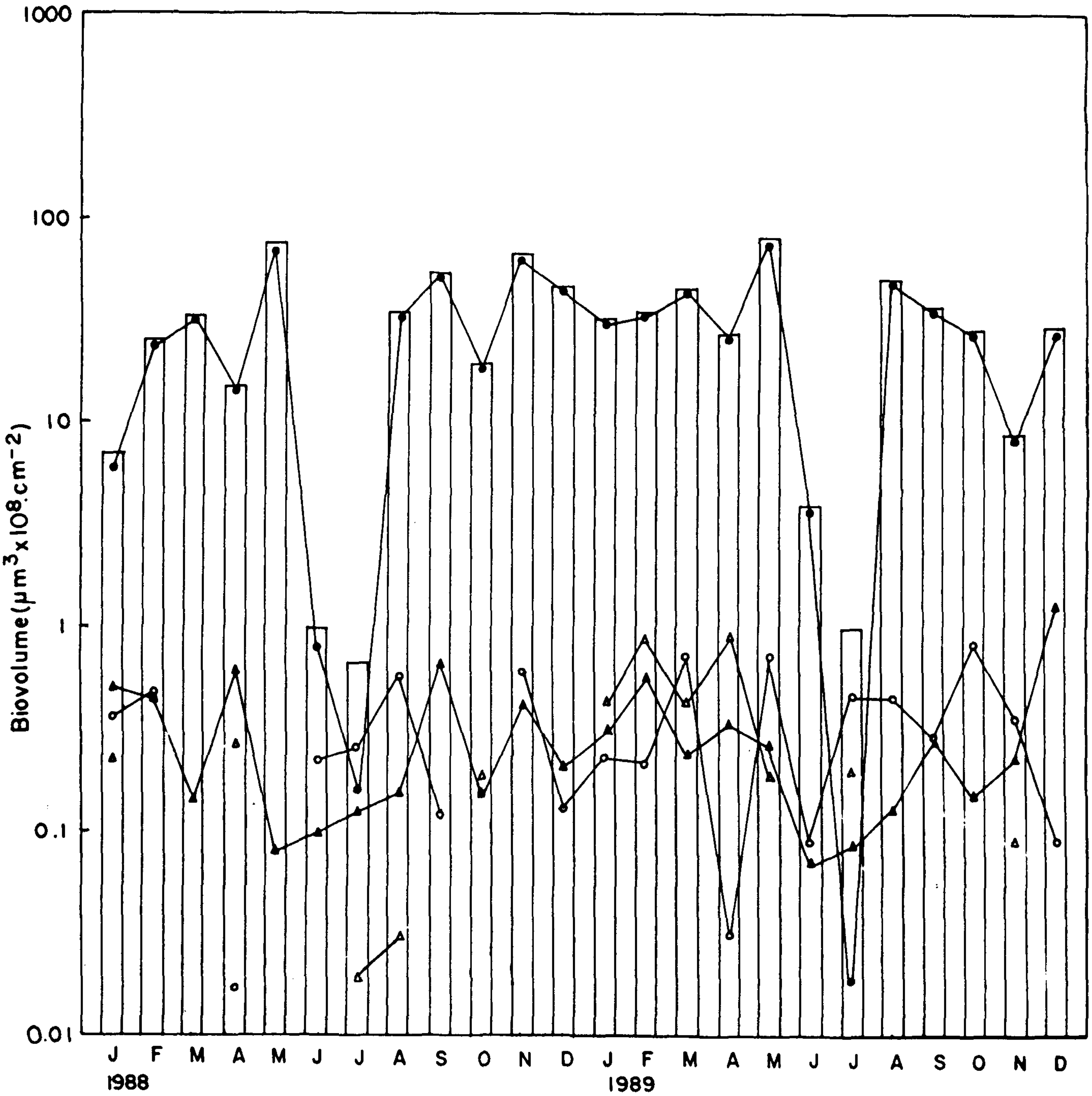

Fig. 3.9 Monthly fluctuations in total epilithic algal biovolume (bar) and biovolumes of various algal groups (△—△ Rhodophyta, ▲—▲ Bacillariophyta, ○—○ Cyanophyta, ●—● Chlorophyta) at St. 2.

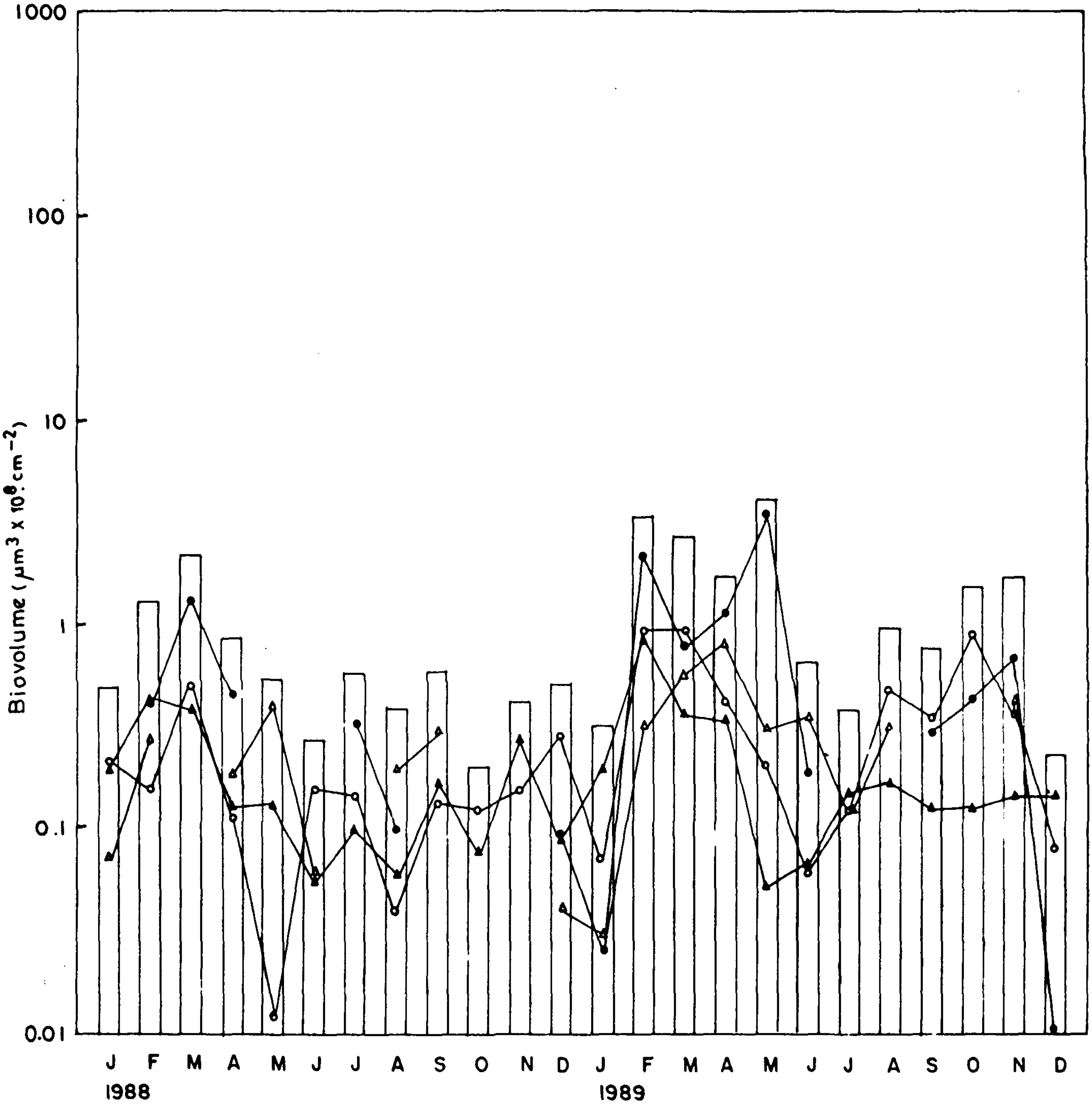

Fig. 3.10 Total algal biovolume (bar), and biovolumes of different algal groups (△—△ Rhodophyta, ▲—▲ Bacillariophyta, ○—○ Cyanophyta, ●—● Chlorophyta) in the epilithon at St. 3.

shows a clearcut seasonal trend matching with those obtained for the stations already described. Cyanophyta and Bacillariophyta contributed remarkably towards the total biovolume as their representatives were consistently present. Despite sporadic presence, the member of Chlorophyta, whenever occurring, had caused a substantial rise in total biovolume. The sole representative of Rhodophyta, Audouinella violacea, was not consistently present at St. 3. Chlorophyta and Rhodophyta members showed improved growth mainly in the spring months. Fig. 3.11 shows the pattern of epilithic biovolume for St. 4. The biovolume was notably decreased in the month of Jul '88 and '89. Feb '88 and '89 showed the highest values. Chlorophyta was the dominant group contributing maximally to the total biovolume. Cyanophyta and Bacillariophyta also contributed significantly to total biovolume. The sole member of Rhodophyta (Audouinella violacea) occurred only on three occasions out of 24 collections showing its least contribution towards the assemblage. St. 4 always showed more total biovolume in comparison to St. 3.

Fig. 3.12 shows algal biomass measured in terms of chlorophyll a concentration on a unit area basis. Evidently, the biomass levels at St. 1 and 3 are considerably lower than the values obtained for St. 2 and 4,respectively. At St. 1 chlorophyll a ranged from 5.28 to 20 mg m^{-2}. Rainy months generally showed the minimum values. The lowest biomass was recorded in Jul '88 (5.28 mg m^{-2}) and Jul '89 (7.99 mg m^{-2}). The biomass peaks were attained in Apr '88 and Feb '89. St. 2 showed almost a similar pattern with greater biomass accumulation during late winter and spring. In

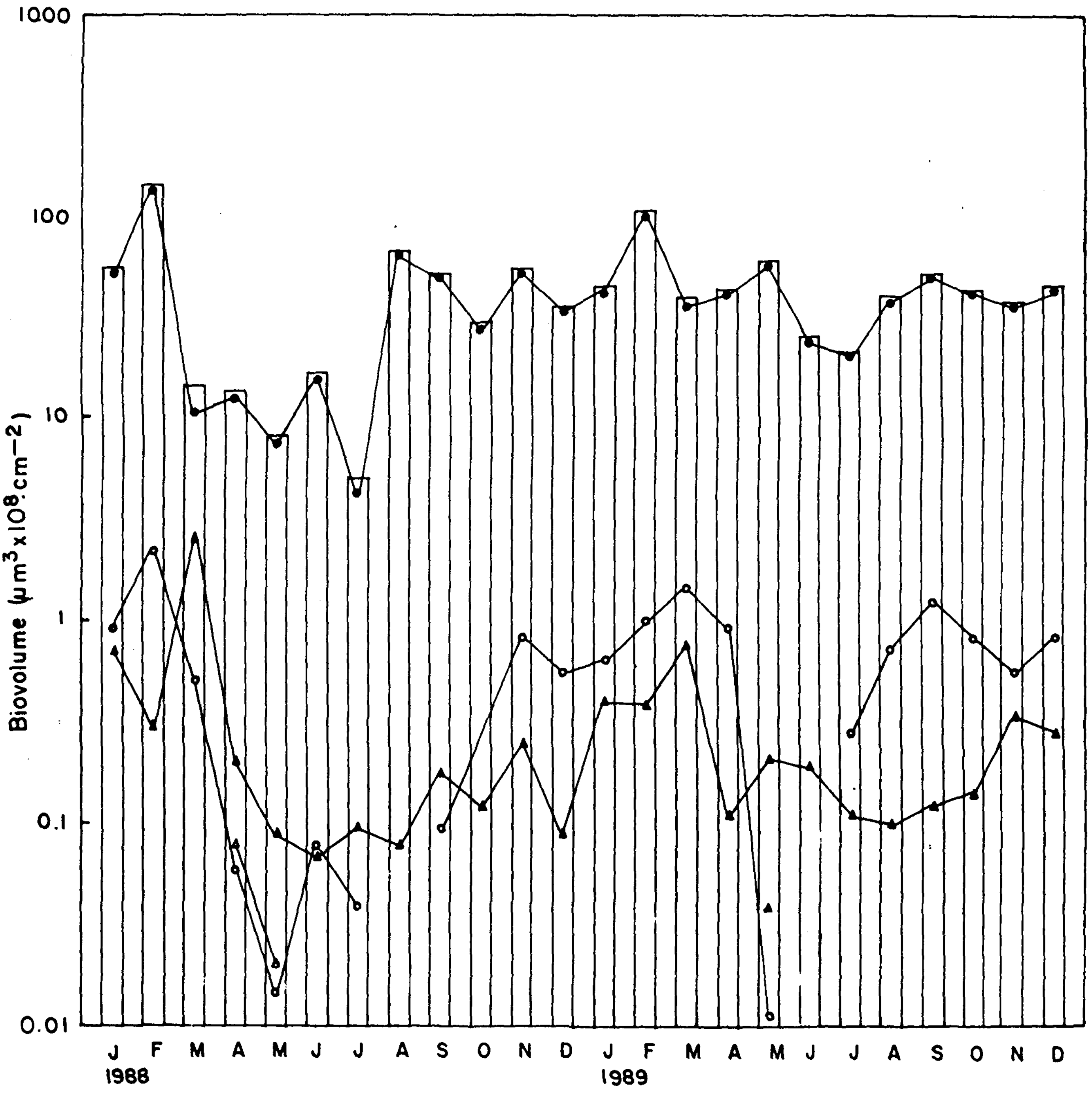

Fig. 3.11 Monthly changes in total epilithic algal biovolume (bar), and biovolumes of different groups (△—△ Rhodophyta, ▲—▲ Bacillariophyta, ○—○ Cyanophyta, ●—● Chlorophyta) at St. 4.

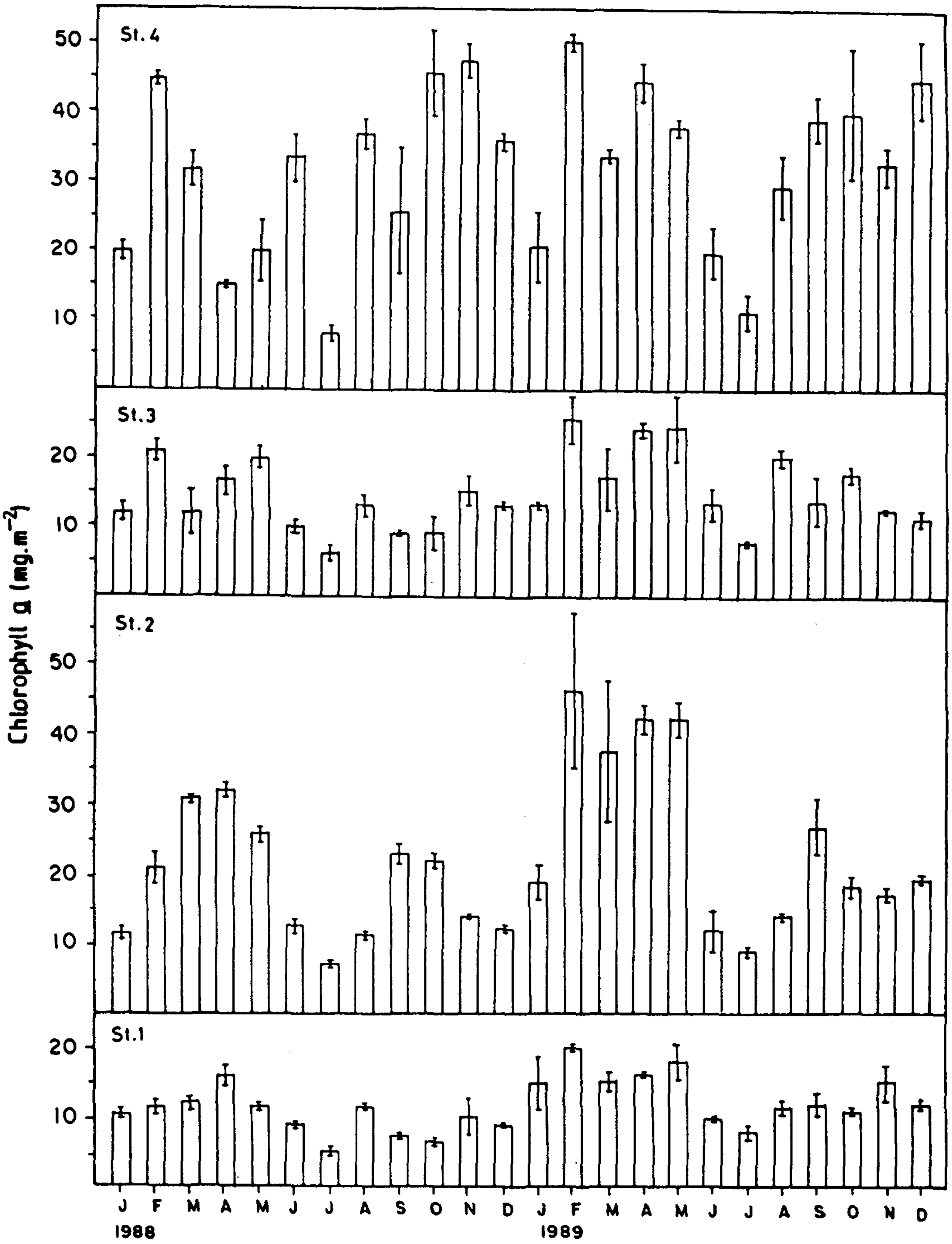

Fig. 3.12 Chlorophyll a (mg. m^{-2}) of algal epilithon at four sampling stations. Vertical bars denote ± SD of the mean.

1988, March and April months together showed the highest value, whereas in 1989 the biomass maxima extended from February to March. The general trend obtained for St. 3 was identical to those obtained for St. 1 and 2 with minimum value during the rainy season and the maximum values during late winter and the spring. St. 4 also exhibited a trend similar to other stations.

The per cent biovolume of dominant algal taxa have been shown in Fig. 3.13 to 3.16 for the four sampling stations. At St. 1 (Fig. 3.13) Oscillatoria willei and Audouinella violacea contributed maximally to total biovolume. These species persisted almost throughout the year but attained maxima at different periods. Audouinella violacea was found to have the maximum share of biovolume during Mar and Apr '88 and Apr'89. Oscillatoria chlorina made appearance on certain occasions. It contributed significantly in May '88 and Feb '89. Cylindrocapsa conferta appeared mainly during the rainy season. Despite the occurrence of many diatom species, their contribution to epilithic biovolume remained extremely small. Among the diatoms, Synedra ulna was present throughout '89, but showed occasional presence in the preceding year. This diatom could grow well even during the periods of high flow rate. Other diatom species were present in the epilithic assemblages almost throughout the year. At St.2(Fig.3.14)the pattern of dominance shifted in favour of two green algae, namely, Spirogyra communis and Hyalotheca dissiliens. S. communis contributed more than 70% to total epilithic biovolume throughout the year, although it disappeared in Jun, Jul '88, and Jul '89. Hyalotheca dissiliens was encountered on seven occasions. During Jun '88 this desmid

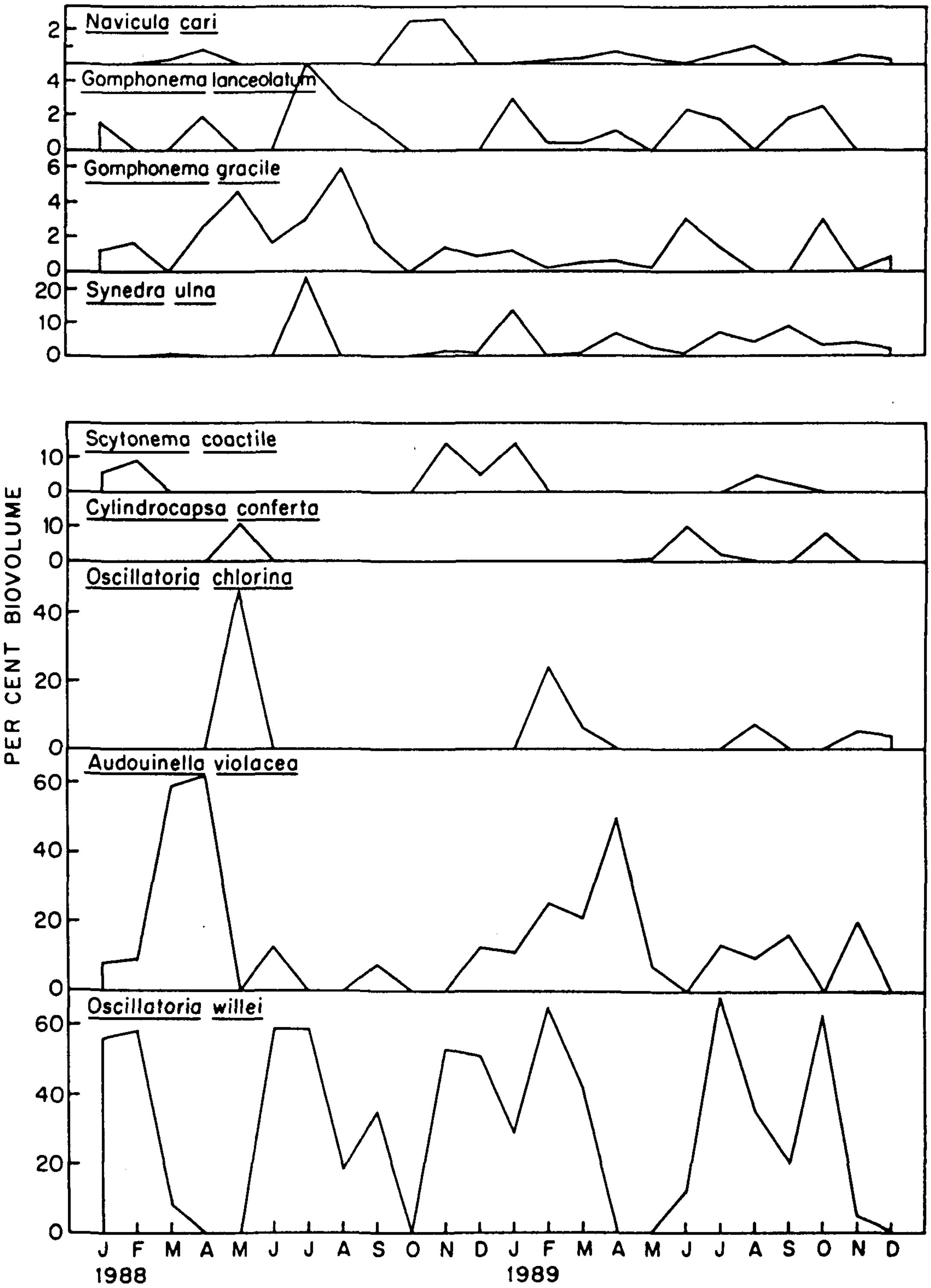

Fig. 3.13 Seasonal changes in the biovolume of dominant algal species at St. 1.

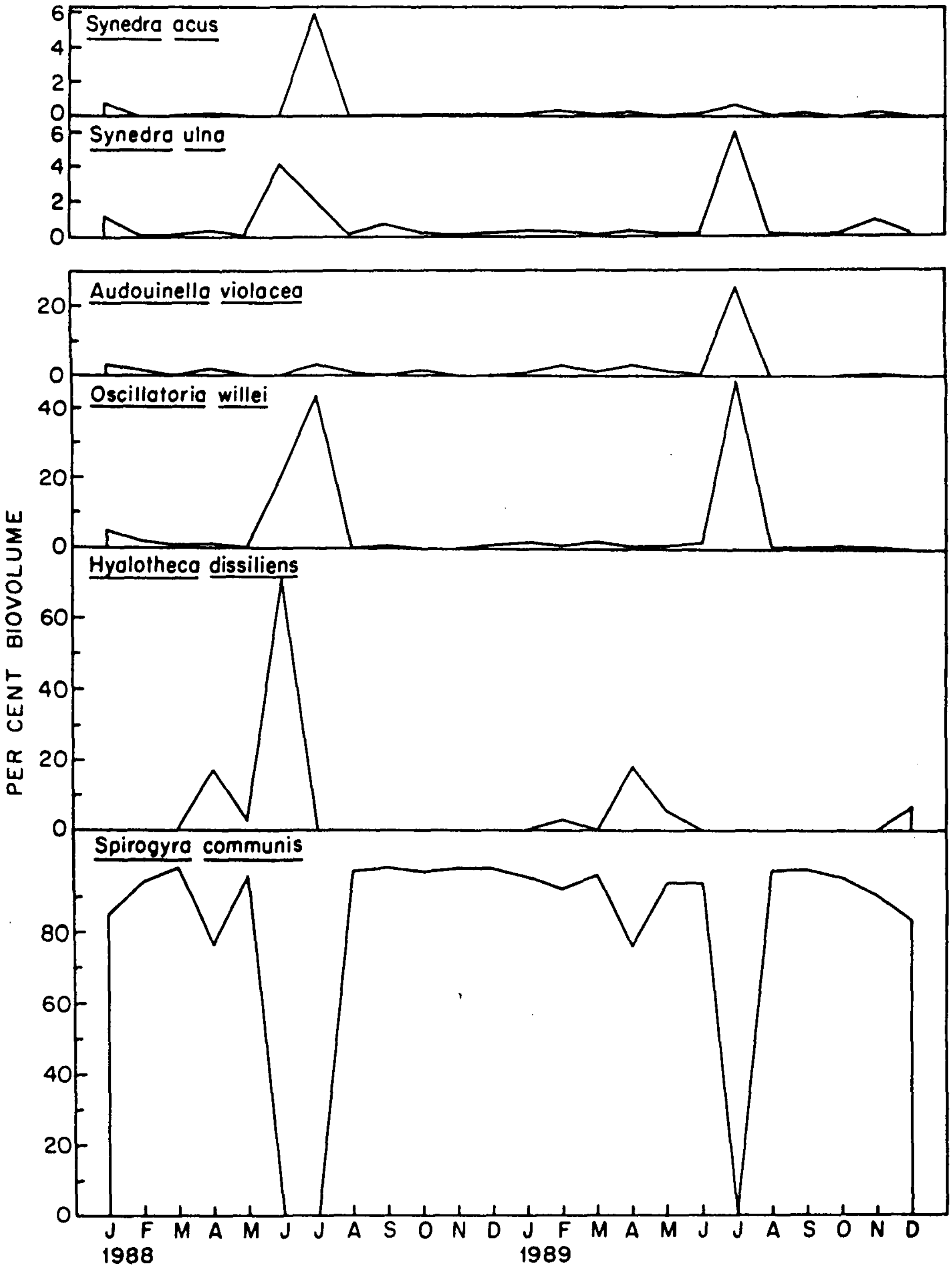

Fig. 3.14 Monthly variations in biovolume of dominant epilithic algal taxa at St. 2.

contributed >70% to total algal biovolume. *Oscillatoria willei* was the dominant blue-green alga at this station. This alga persisted throughout the year, however, its apportionment to total biovolume was marked on two occasions (Jul '88, '89). *Audouinella violacea* did not contribute substantially to the epilithic assemblage. In spite of year-round presence, the diatoms contributed very little to total algal biovolume. *Synedra ulna* and *S. acus* ranked among them.

Fig. 3.15 shows temporal changes in relative proportion of different algal species at St. 3. The relative proportion of *Oscillatoria willei* and *Audouinella violacea* to total biovolume was pronounced. *O. willei* was present throughout the year. Concomitantly, *A. violacea* showed biovolume peak in May '88. The value was, however, lower in Jun and Jul as compared to other times. *Oscillatoria chlorina* made little contribution towards total biovolume. *Cylindrocapsa conferta* could be seen only on five occasions. Among the diatoms, *Synedra ulna* persisted throughout the year. Even though *Gomphonema lanceolatum* and *G. gracile* could be seen frequently, their contribution was relatively small. Other diatoms did not contribute much towards the biovolume. At St. 4 (Fig. 3.16). *Spirogyra communis* dominated the epilithic algal assemblage. Most of the total biovolume was shared by this alga. Its dominance had lessened the importance of other algae at this station. The lowering of biovolume of this species in May '88 and Apr '89 led to increased importance of *Hyalotheca dissiliens* in the assemblage. *Synedra ulna* was present throughout the year and was the most abundant diatom. The presence of other diatoms did not contribute significantly towards the total biovolume.

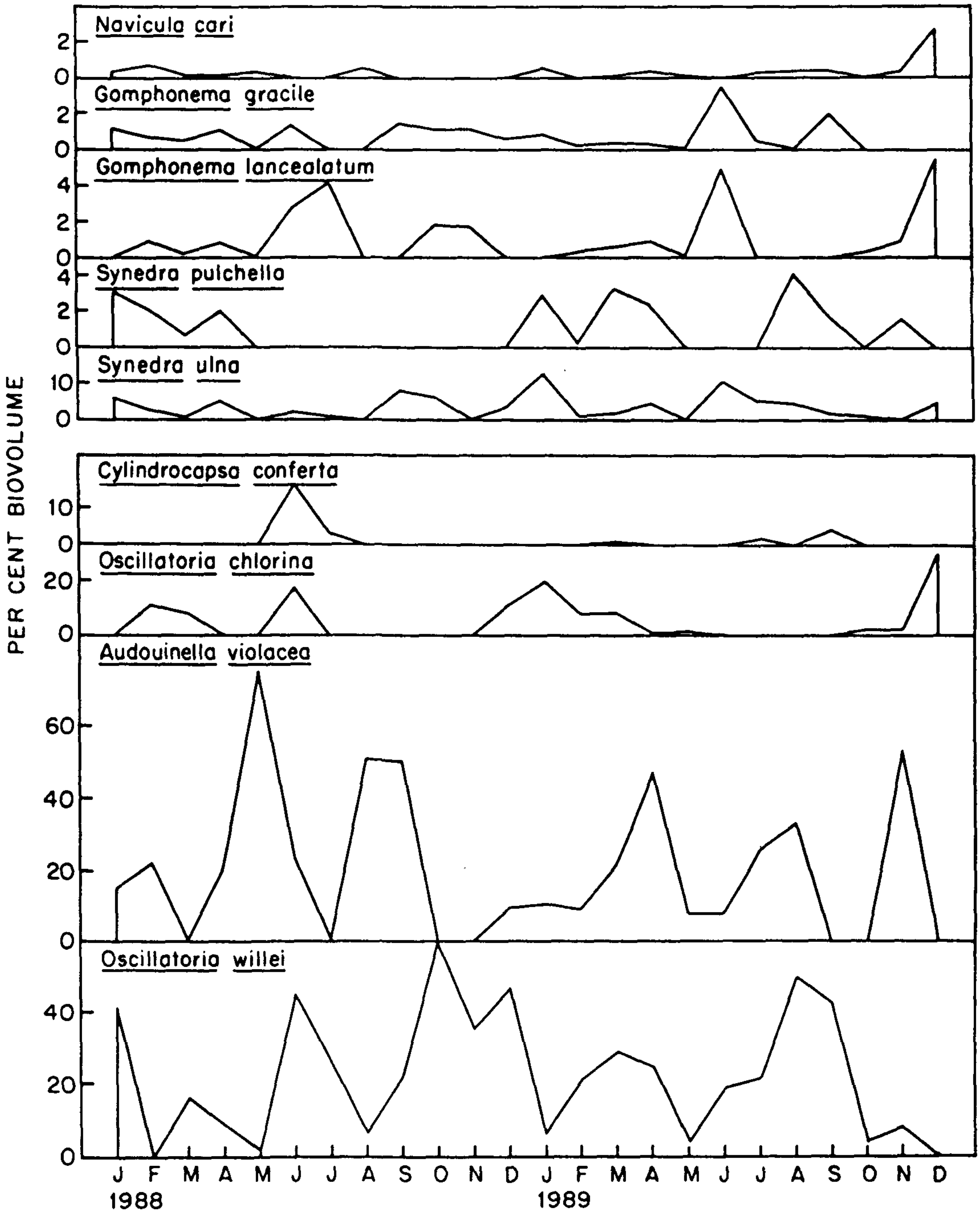

Fig. 3.15 Temporal changes in the biovolume of dominant algal species in epilithic assemblage of St. 3.

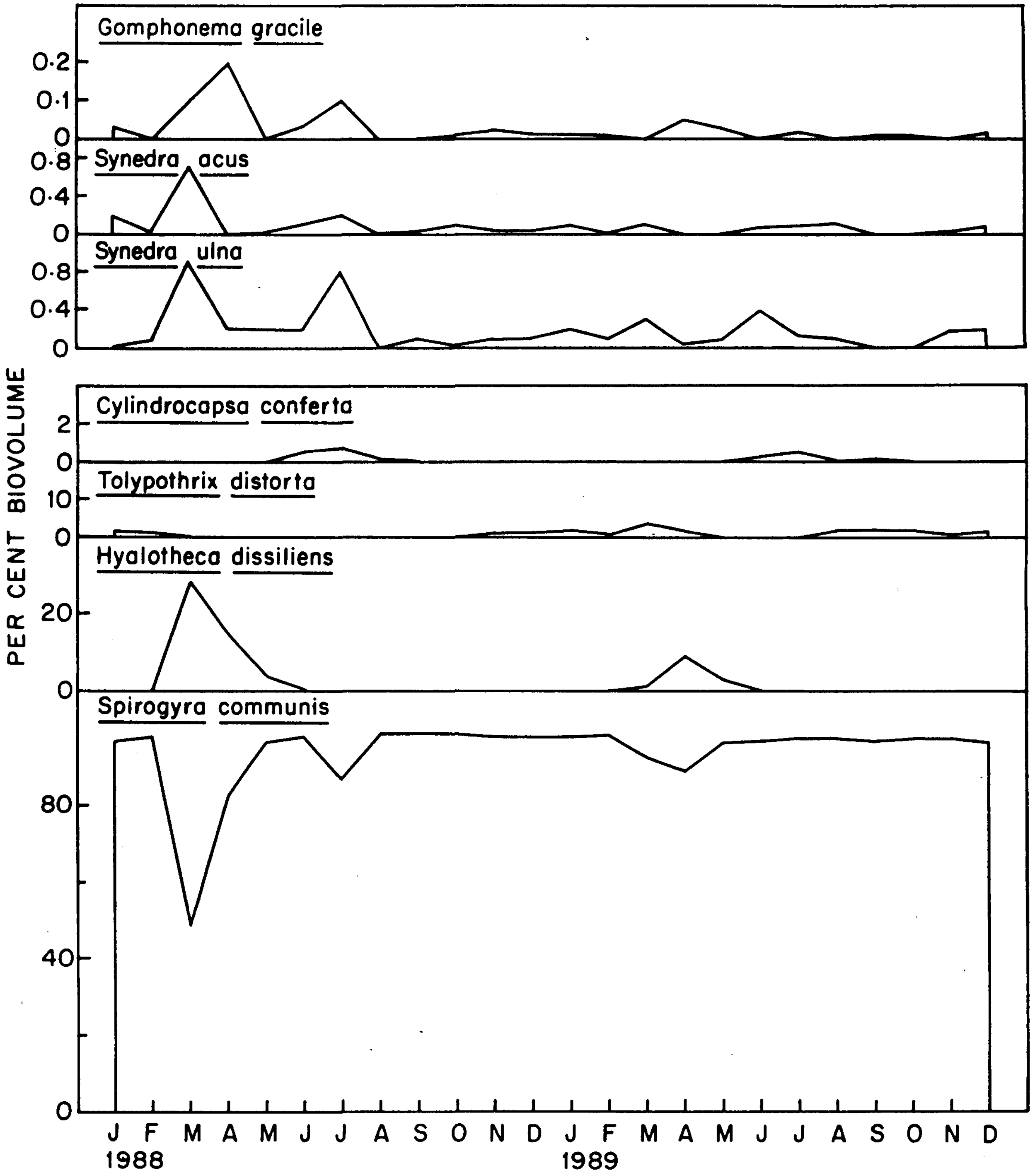

Fig. 3.16 Monthly fluctuations in biovolume data of dominant algal species at St. 4.

Cluster analysis of epilithic assemblages encountered on different dates was also done separately for each station. For this purpose a matrix of similarity amongst samples collected on 24 occasions was computed and cluster dendrograms were prepared for each station. Fig. 3.17 shows one such diagram prepared for St. 1. In this case three sampling times (Mar, Jul, Aug '89) had nearly idential communities at 0.99 SIMI. At 0.98 SIMI the communities of Feb '88, Dec '88, Feb '89 and Nov '89 united. The samples of autumn, winter and rainy months (Jul '88 and '89, Nov '88 , Jan '88 and '89 and Jun '88) intermingled at 0.85 level of similarity. The rest of the samples mostly of spring (5), autumn (3) and rainy (2) seasons did not show much similarity with each other. Cluster dendrogram for St. 2 is shown in Fig. 3.18. A cluster was formed of spring, early rainy and autumn periods at 0.95 SIMI. Six samples mainly of winter, autumn and spring aggregated at 0.85 SIMI. The remaining samples mainly of winter and rainy months did not display high similarity. At St. 3, algal assemblages, encountered during May, Aug, Sep and Oct '89 mainly of rainy seasons, showed the highest SIMI (Fig. 3.19). Six samples (Feb '88, Jan '89, Mar '89, Apr'89 Nov '88 and Dec '88) representing winter and spring communities clustered at 0.88 level, whereas 4 samples of rainy months (Aug '88, May '88, Jun '89 and Jul '89) and an autumn (Oct '88) sample showed similarity with each other at 0.78 level. Some samples of early winter, spring and rainy months clustered together at 0.55 SIMI. The remaining two samples (Jan and Jun '88) showed least similarity with other samples. At St. 4, four samples of winter (Dec '88, '89, Nov '89 and Jan '89) and two of rainy period (Aug '88 and '89) aggregated at 0.88 level (Fig. 3.20). Eight samples

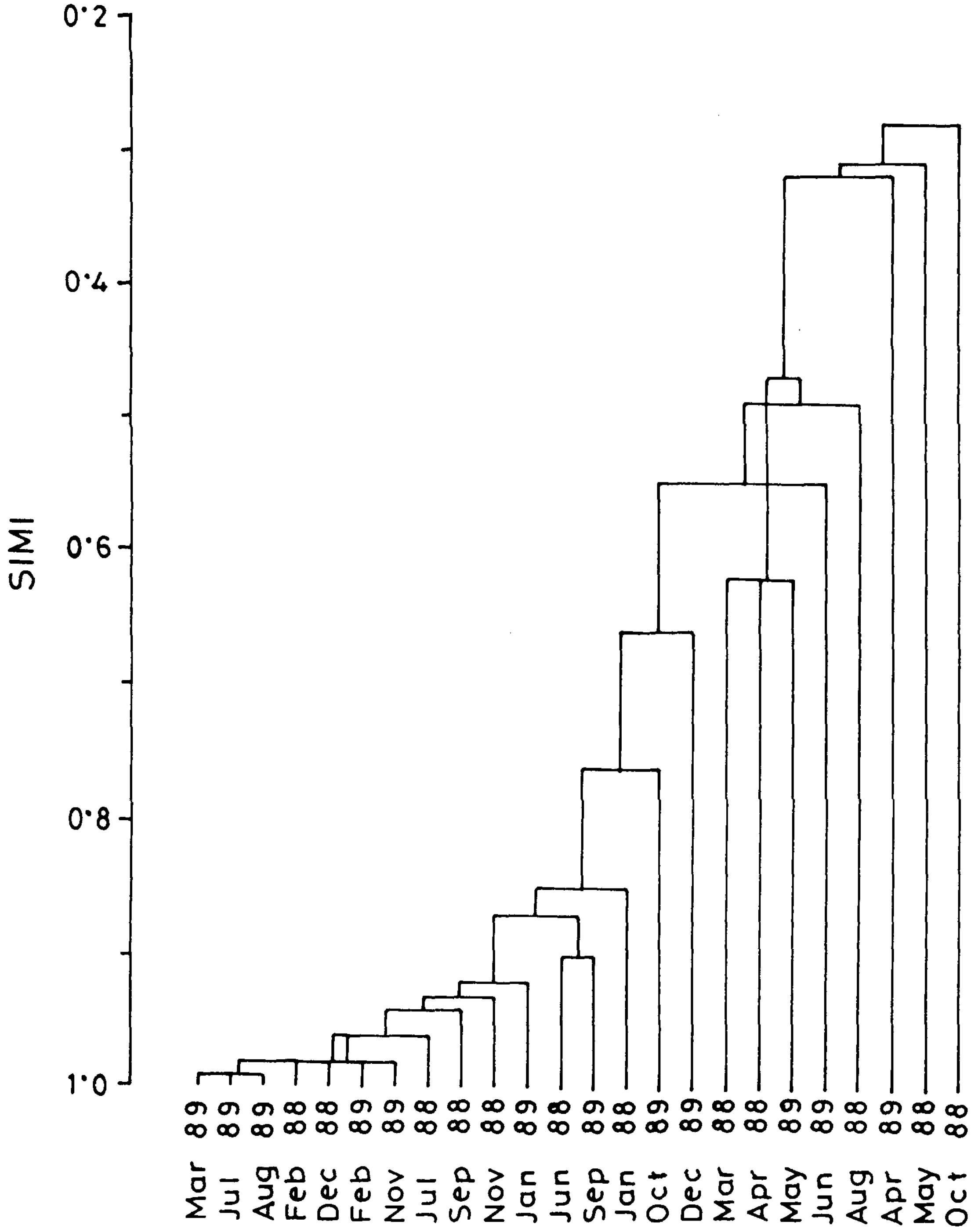

Fig. 3.17 Cluster dendrogram showing similarities of epilithic algal assemblages at St. 1 for different time periods. Similarity (SIMI) was calculated as suggested by Stander (1970).

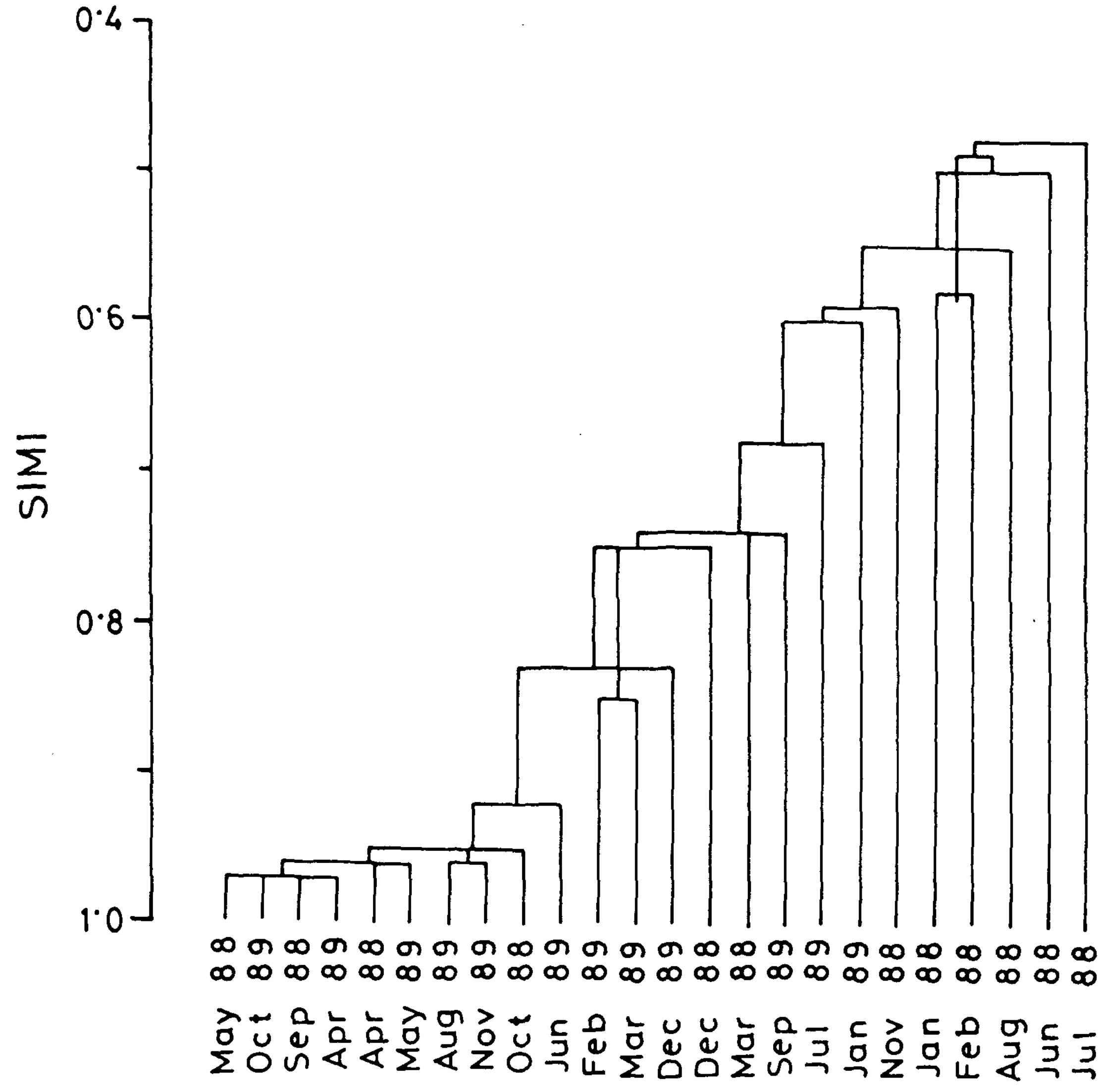

Fig. 3.18 Cluster dendrogram for St. 2 illustrating similarities among epilithic assemblages at various time periods.

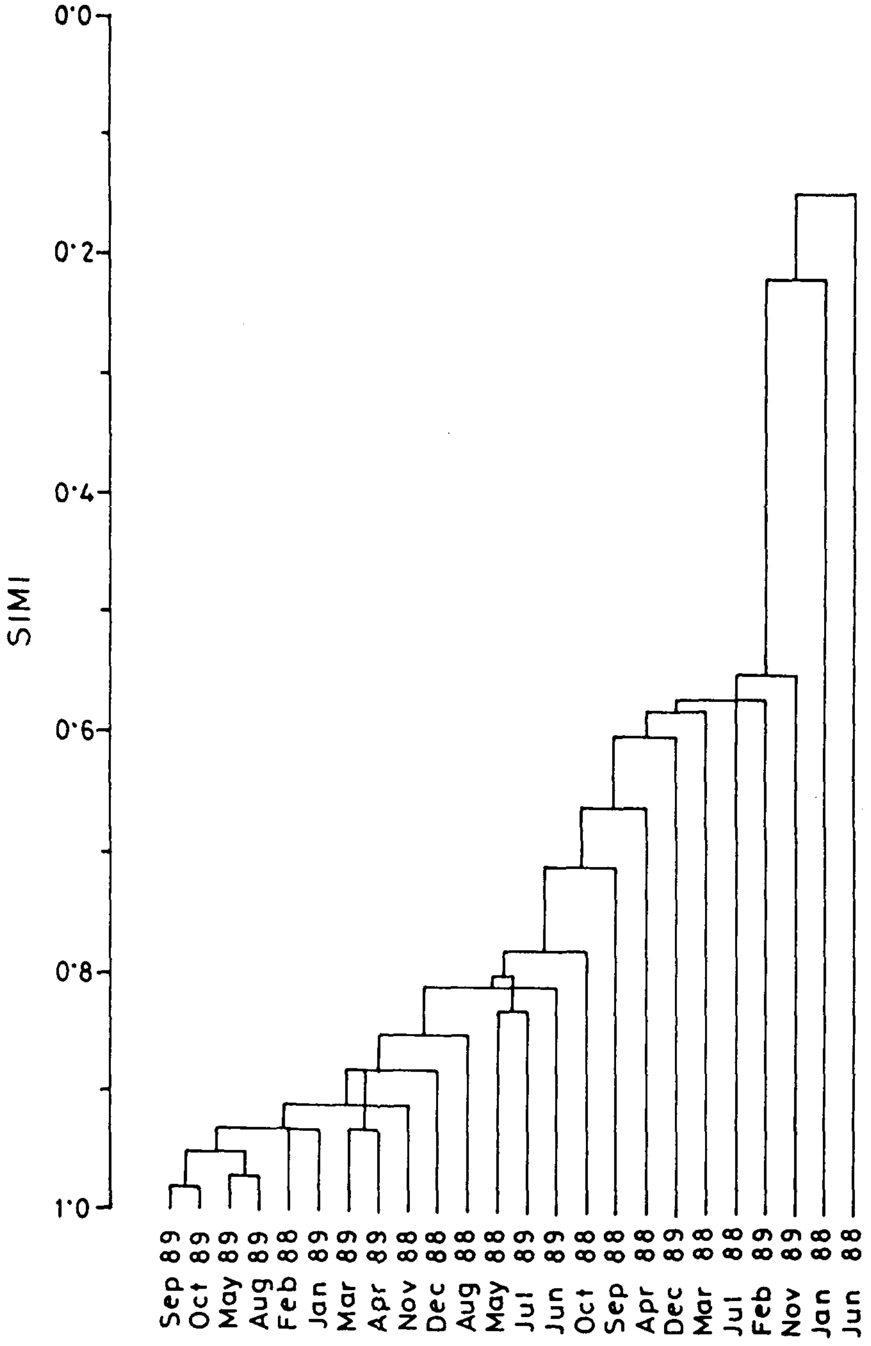

Fig. 3.19 Cluster dendrogram depicting similarities among epilithic algal assemblages observed at various times at St. 3.

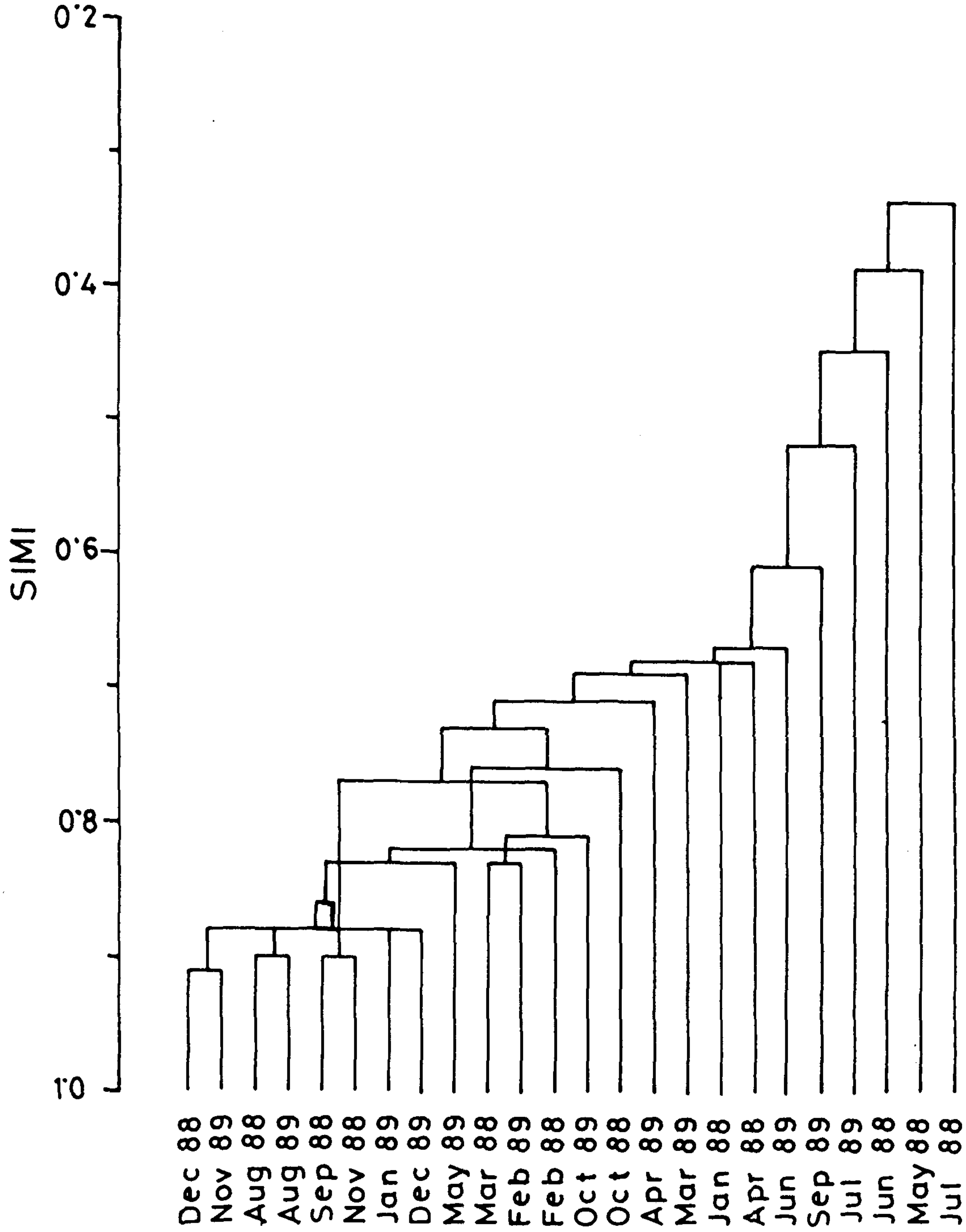

Fig. 3.20 Cluster dendrogram showing similarities among epilithic assemblages at various times at St. 4.

of Sep '88, Nov '88, May '89, Mar '88, Feb '88 and '89, Oct '88 and '89, mainly of autumn and spring, resembled each other at 0.76 SIMI, whereas four samples of spring clustered at 0.68 level. The rest of the samples, mainly of rainy period, clustered at less than 0.50 SIMI.

Canonical correspondence analysis (CCA) of data relating to physico-chemical characteristics of water and biovolume of different species was done separately for each station, and the ordination diagrams are presented in Figs. 3.21 to 3.24. In CCA, since species are assumed to have unimodal response surfaces with respect to linear combinations of the environmental variables, the species are logically represented by points corresponding to their approximate optima in the two-dimensional environmental subspace, and the environmental variables by arrows indicating their direction and rate of change through the subspace. The species points jointly reflected the species distributions along each of the environmental variables. The various environmental factors were found to be significantly related with the species composition over different time periods. Flow, phosphorus and NO_3-N, were found to be the most important factors at all the sampling stations. At St. 1, environmental variables like NO_3-N, flow and Si with longer arrows were strongly correlated with the ordination axes, and so more closely related to the pattern of community variations shown in the ordination diagram (Fig. 3.21). TP, temperature, NH_4-N, Ca and conductivity also had significance towards the community composition. Temperature, flow, TP, DO and pH were found to be the most important environmental factors controlling species

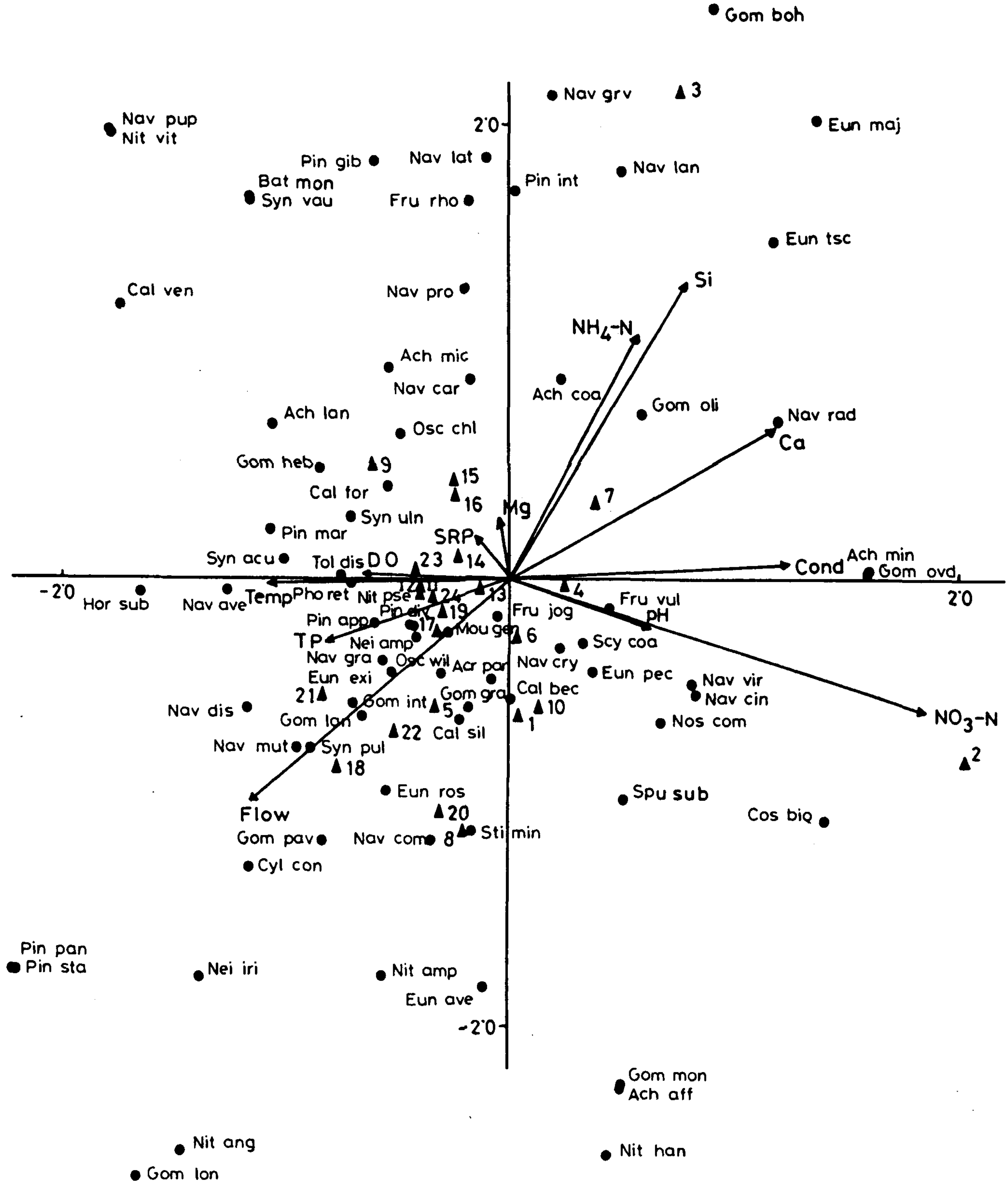

Fig. 3.21 Canonical correspondence analysis (CCA) ordination diagram showing monthly distribution of algal species (●) in relation to environmental variables (arrows) in the epilithon at St. 1. First axis is horizontal, second axis vertical. See Table 3.2 for species codes. Numbers (▲) representing the sampling months are: 1- Jan '88, 2 - Feb '88, 3 - Mar '88, 4 - Apr '88, 5 - May '88, 6 - Jun '88, 7 - Jul '88, 8 - Aug '88, 9 - Sep '88, 10 - Oct '88, 11 - Nov '88, 12 - Dec '88, 13 - Jan '89, 14 - Feb '89, 15 - Mar '89, 16 - Apr '89, 17 - May '89, 18 - Jun '89, 19 - Jul '89, 20 - Aug '89, 21 - Sep '89, 22 - Oct '89, 23 - Nov '89 and 24 - Dec '89.

composition at St. 2 (Fig. 3.22), whereas at St. 3 except SRP, pH, NH_4-N and DO with shorter arrows, all the factors were equally significant as depicted in Fig. 3.23. Flow, NO_3-N, conductivity, NH_4-N, SRP, Ca and Mg were the factors with greater weightage at St. 4 (Fig. 3.24).

Correlation coefficients or intraset coefficients of environmental factors with the first two axes of CCA are given in Table 3.4. The first axis at St. 1 is defined by high conductivity and NO_3-N, and the second axis by NH_4-N and silica. At St. 2 the areas with low flow on the first axis have high pH and total phosphorus, whereas the second axis shows nutrient deficient condition. The first axis at St. 3 shows that the areas with high flow have low silica, Ca, Mg and NO_3-N. At this station the second axis is defined by conductivity and total phosphorus. St. 4 shows greater significance of conductivity and NO_3-N in the first axis, whereas the second axis is defined by high flow.

The eigenvalue is a number between 0 and 1; the higher the value, the more important the ordination axis. In weighted averaging methods, the eigenvalue is a measure of separation of the species distributions along the ordination axis (Jongman et al. 1987). In Table 3.5, the eigenvalues show that the extracted gradients are quite short. The scores (optima) of most species therefore lie outside the centre region where the sites lie.

CCA ordination diagrams show that the samples of rainy season are highly influenced by flow. Temperature and TP were found to be important at this time also. Autumn months were found to be

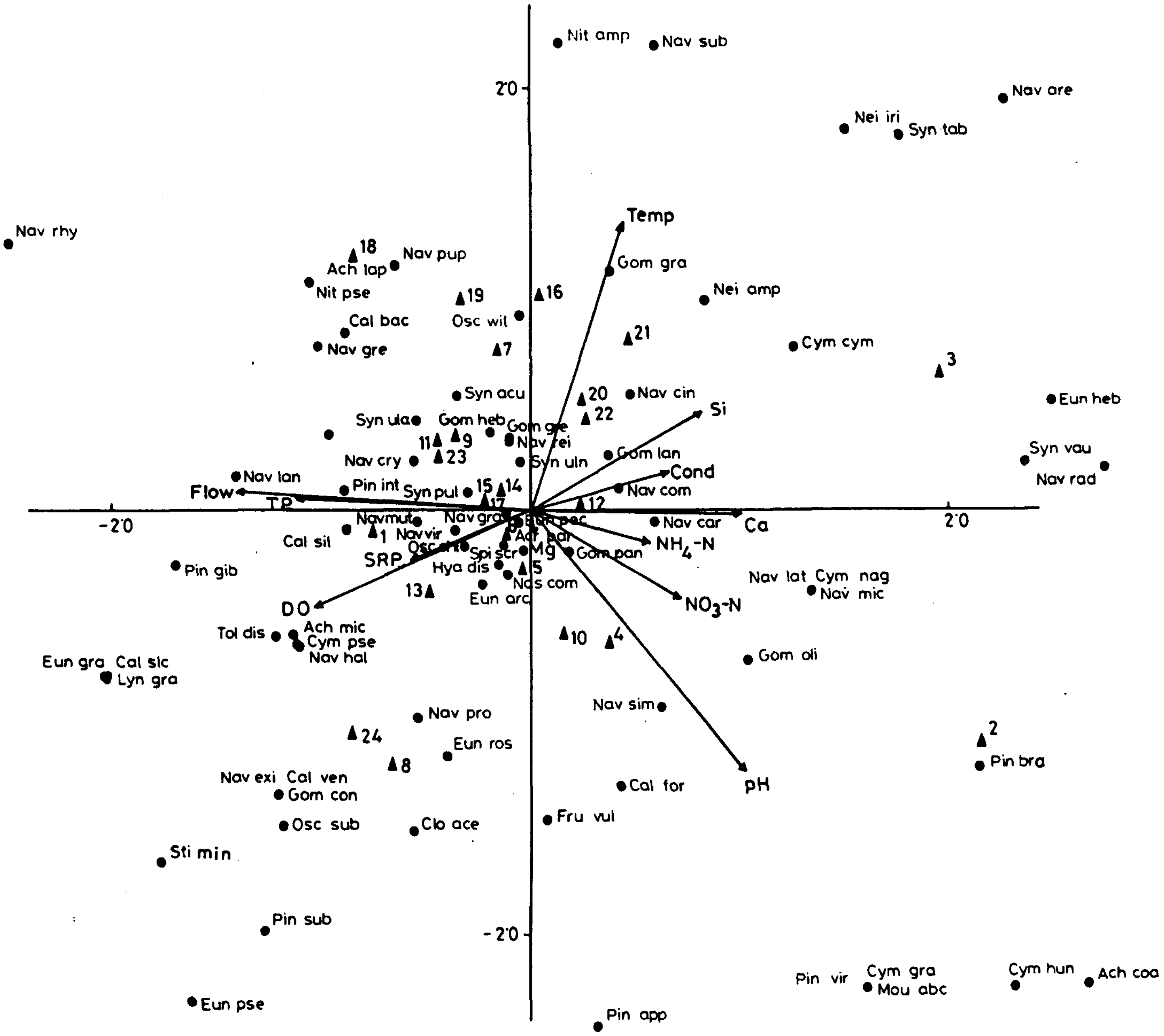

Fig. 3.22 CCA ordination diagram with epilithic algae (●), sampling period (▲) and environmental variables (arrows) at St. 2. Numbers representing the sampling months are as in Fig. 3.21. Table 3.2 contains codes for various species.

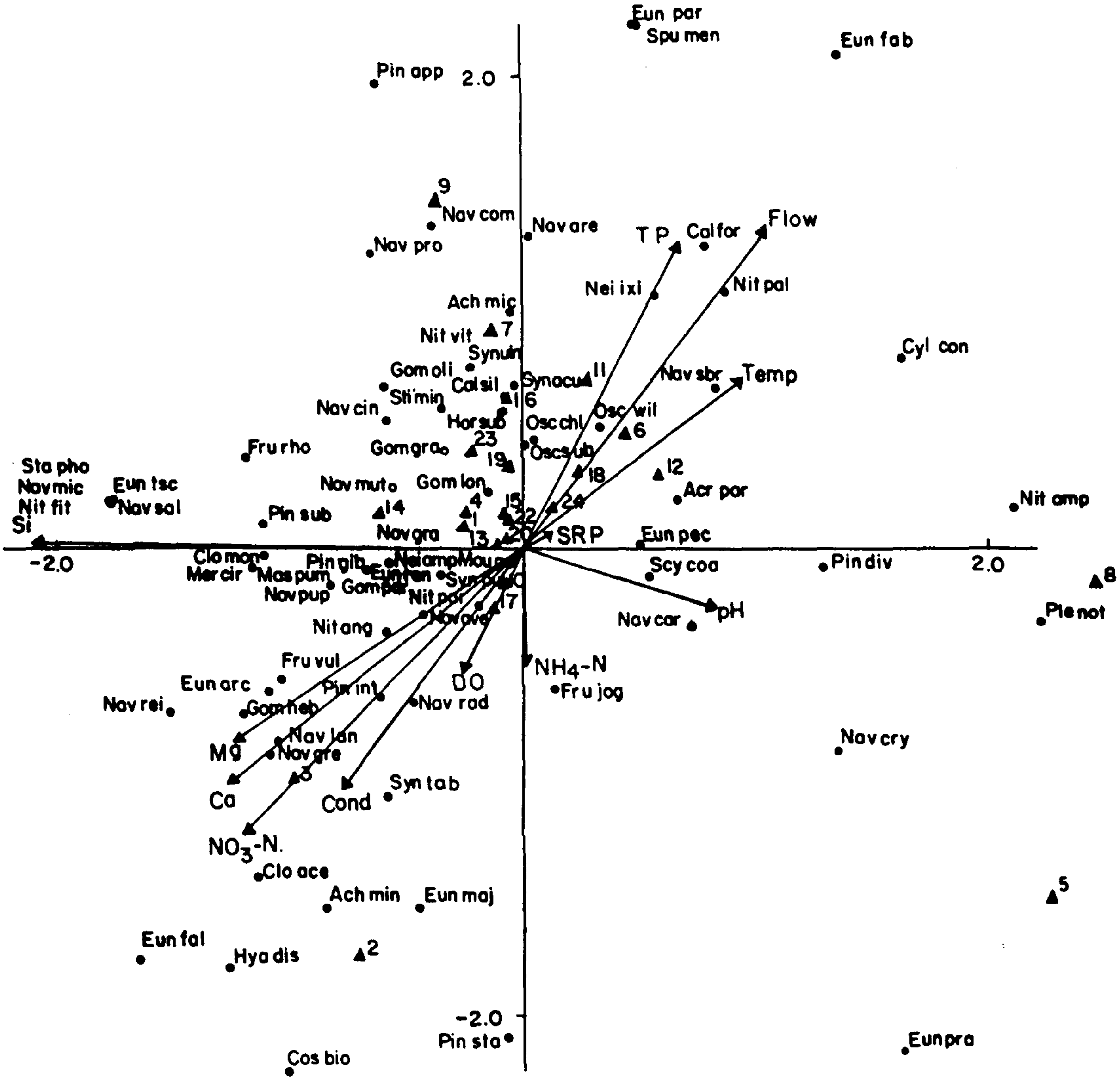

Fig. 3.23 CCA ordination diagram for St. 3 showing algal species (●), environmental variables (arrows) and sampling months (▲). Codes for various species are as in Table 3.2. Sampling months are as in Fig. 3.12.

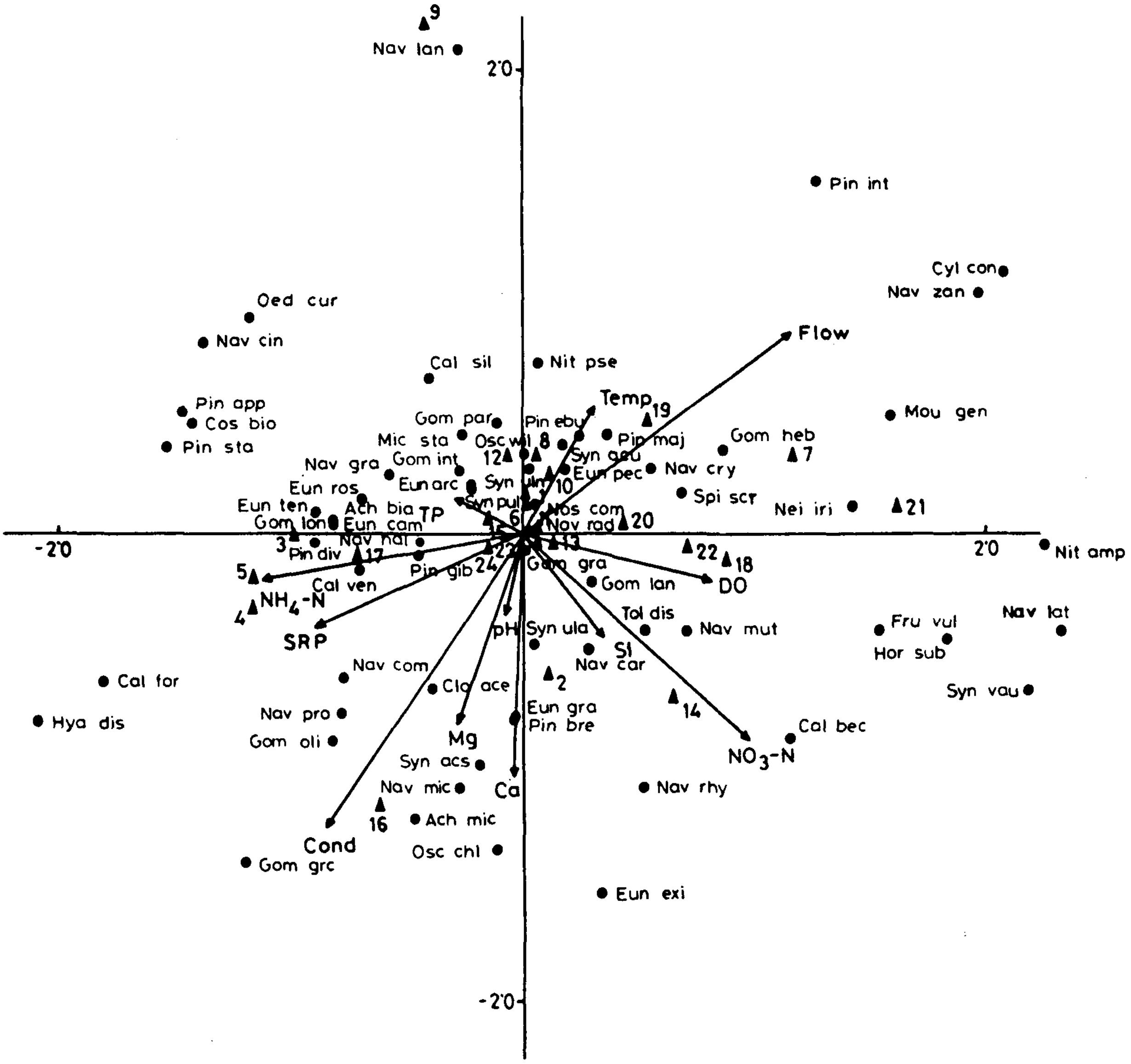

Fig. 3.24 Ordination diagram for St. 4 showing algal species (●), environmental variables (arrows), and sampling times (▲). Numbers representing the sampling months are as in Fig. 3.21. Table 3.2 contains codes for various species.

Table 3.4 Correlation coefficients or intraset coefficients of environmental variables with the first two axes of canonical correspondence analysis (CCA).

Axis variable	Intraset coefficients							
	St. 1		St. 2		St. 3		St. 4	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Temperature	-0.42	-0.01	0.18	0.57	0.38	0.30	0.13	0.22
pH	0.24	-0.09	0.41	-0.52	0.32	-0.10	-0.04	-0.14
Conductivity	0.48	0.02	0.27	0.08	-0.31	-0.42	-0.36	-0.53
Flow	-0.46	-0.41	-0.57	0.04	0.42	0.56	0.49	0.37
DO	-0.25	0.01	-0.41	-0.19	-0.10	-0.21	0.34	-0.08
SRP	-0.06	-0.08	-0.22	-0.10	0.05	0.02	-0.38	-0.16
TP	-0.32	-0.12	-0.46	0.03	0.27	0.53	-0.12	0.06
NH_4-N	0.22	0.43	0.23	-0.06	0.003	-0.20	-0.48	-0.08
NO_3-N	0.72	-0.24	0.28	-0.18	-0.47	-0.50	0.41	-0.37
Si	0.31	0.52	0.33	0.19	-0.83	-0.01	-0.14	-0.19
Ca	0.46	0.26	0.41	-0.01	-0.46	-0.41	-0.01	-0.44
Mg	-0.01	0.11	0.01	-0.05	-0.49	-0.34	-0.12	-0.34

Table 3.5 Eigen values of the four axes as obtained from CCA.

	Axis			
	1	2	3	4
St. 1	0.41	0.33	0.31	0.27
St. 2	0.34	0.30	0.26	0.25
St. 3	0.39	0.32	0.29	0.24
St. 4	0.30	0.27	0.24	0.22

influenced by temperature, TP and flow. NO_3-N, NH_4-N and Si showed secondary importance at these periods. During winter both temperature and phosphorus were extremely important for algal assemblages; besides flow, TP also had some role. The spring samples were mainly influenced by nutrients at all the sampling stations.

The dominant species encountered at various stations (Figs. 3.13 to 3.16) are present near the centroid of the ordination diagrams which is suggestive of their importance in the species composition of the epilithon. *Oscillatoria chlorina* was found near SRP at all the stations thereby suggesting that this alga prefers high concentrations of phosphorus. *O. willei* was greatly influenced by temperature, flow, TP and SRP at all stations. *Audouinella violacea* was similarly influenced by flow, temperature and phosphorus. *O. subuliformis* was influenced by DO, SRP, TP and flow at St. 2, whereas at St. 3 the latter three factors along with temperature determined the abundance of this alga. Another blue-green alga, namely, *Tolypothrix distorta* was found to be favoured by high levels of TP, SRP, temperature and DO at St. 1 and 2, but at St. 4 this alga showed greater preference for high NO_3-N and DO. Among the green filamentous algae, *Spirogyra communis* contributed maximum towards total algal biovolume. This alga was found to be rare at St. 1 and 3; however, it preferred moderate flow as observed in the ordination diagrams for St. 2 and 4. Other environmental factors like SRP, Mg, DO and temperature were found to influence the abundance of this alga. *Cylindrocapsa conferta*, showing its presence near flow at St. 1, 3 and 4 undoubtedly preferred high flow. Temperature and TP were additionally important for this alga. *Mougeotia genuflexa* was found to be infuenced by flow, TP and temperature at St. 1, whereas SRP and NH_4-N influenced this alga at St. 3. At St. 4 this alga showed its higher inclination towards flow, temperature and DO. *Hyalotheca dissiliens*, a filamentous desmid was found to be rare at St. 1. At St. 2, SRP, TP and DO influenced this alga to a great extent. This alga preferred low flow areas. *Synedra ulna*, one of the important diatom species, was found to be highly resistant to flow at all the sampling stations. *Synedra pulchella*, *S. acus* and *Neidium iridis* also preferred high flows. *Eunotia pectinalis* preferred high levels of nutrients and was also found to be sensitive to high pH. The ordination diagrams suggest that *Gomphonema hebridense* prefers low pH. In contrast, specific liking for high pH was seen in two species of *Frustulia* (*F. vulgaris* and *F. jogensis*) and *Scytonema coactile*. From the ordination diagram it is clear that *Gomphonema olivaceum* prefers low flow at all the sampling sites. *G. gracile* preferring high temperature was abundant at all the sampling stations. *Navicula cari* preferring NH_4-N was well marked in the ordination diagrams for all the sampling stations. *Caloneis silicula* was highly influenced by TP, temperature and flow in all the cases. *Pinnularia gibba* and *P. interrupta* preferred high nutrient condition. *Navicula cryptocephala* and *N. mutica* were found to be influenced mainly by flow and TP. *Navicula gracilis*, showed preference for high phosphorus concentration. *Nitzschia pseudofonticola* was found to be influenced by flow, temperature and TP at St. 1, 2 and 4. The desmids, namely, *Closterium acerosum* and *Cosmarium bioculatum* preferred high nutrient condition.

3.4 Discussion

The streams selected for the present work were found to be softwater due to low levels of calcium and magnesium, and are slightly acidic as pH always remained <7. Although the levels of calcium and magnesium are considerably lower as compared to some reports (Moore 1977a, Holmes & Whitton 1981), the general trend matches with softwater streams of North America and Europe (Miller 1961, Marker 1976). Sutcliffe & Carrick (1973) believe that most of the mountain streams are mildly acidic, and their contention, seems to be applicable in the present work. Water current of selected streams varied depending on the pattern and quantum of rainfall. Minimum flow rates during the winter and spring are due to the fact that no rainfall occurred during these times. With increase in rainfall during rainy season, the flow rate showed a proportionate increase reaching the maxima in July. The temperature of stream water showed increase with rise in atmospheric temperature during the spring and rainy seasons. Our results reveal that the temperature of stream water at St. 2 was always slightly higher than at St. 1. Likewise, stream water at St. 4 was relatively warmer than at St. 3. This variability could be explained in terms of differences in the amount of insolation received at these stations. St. 2 and 4 are relatively more exposed with thinner riparian vegetation than St. 1 and 3, respectively.

The level of silica always remained markedly high (5.3-11.4 mg l^{-1}), and the values obtained are higher in comparison to streams at other places (Moore 1977a, Holmes & Whitton 1981, Casey et al.

1981, Lay & Ward 1987). The high concentration of silica in stream water is on account of predominance of silica-rich rocks in the stream bottom (see Chapter 2). Excepting silica, all other nutrients occurred at low concentrations in stream waters. This could inter alia be ascribed to the presence of nutrient impoverished soil in the drainage area (Singh 1990), and the absence of eutrophication triggering activities, such as, the disposal of sewage and other kinds of waste materials, deforestation, agriculture, etc. The present observations thus agree with previous reports showing low levels of nutrients in pristine streams which however increase following deforestation or degradation of the drainage area (Graynoth 1979, Webster & Waide 1982, Shortreed & Stockner 1983, Campbell & Doeg 1989). In general, the levels of nutrients in selected streams are well within the limits reported for soft-water streams at other places (Stockner & Shortreed 1976, Marker 1976, Martin 1979, Peterson et al. 1983, Perrin et al. 1987). Ammonia-nitrogen occurred at low concentrations since the streams are well aerated systems without excessive organic loading (Welch et al. 1988). The atomic ratio of nitrogen (excluding organic fraction) to phosphorus, or the Redfield ratio was always >16 thereby suggesting algal growth limitation due to low phosphorus supply (Redfield et al. 1963). The concentrations of various trace elements were as expected low but not limiting, and were much below the levels considered to be toxic to algae (see Rai et al. 1981).

Conductivity was found to be inversely related with flow as highest concentrations of major ions occurred during the periods of low flow. Similar observations have been made by other workers

(Mosley & Rowe 1981, Biggs & Close 1989). Hem (1985) states that this pattern occurs in streams which have more complicated runoff patterns and solute load sources. This is probably the case in the present study. Conductance values decreased to a greater extent during high rainfall and rapid runoff, an indication that the system was being flushed out (cf. Deniseger et al. 1986). Ionic loadings were found to be inversely related with flow rate. This observation is in agreement with Howard-Williams et al. (1986) and Biggs & Close (1989). In temperate streams, Taylor & Kunishi (1971), Hobbie & Likens (1973), McColl et al. (1975) and Meyer & Likens (1979) found no significant relationship between soluble phosphorus and discharge rate. Whereas, Smith (1976), McColl et al. (1977) and Munn & Prepas (1986) found a positive relation between the two variables. A strong positive correlation between flow and TP and TKN was reported by Biggs & Close (1989). Our results show lowering of phosphorus concentration with increasing discharge, a trend similar to Taylor & Kunishi (1971). Streams are extremely complex systems, and the relationships between flow and physico-chemical parameters are far from being clear. Variations may occur from place to place even along the adjacent points in the same stream. Both inverse and positive relation between flow and some physico-chemical variables have been observed by Casey & Newton (1972, 1973) in chalk streams of the same district in southern England.

The epilithic algal assemblages of studied streams show broad compositional similarity with streams of North America and Europe (Marker 1976, Moore 1977a, Ennis & Albright 1982, Whitton et al. 1986, Rushforth et al. 1986, Hamilton & Duthie 1987, Robinson &

Rushforth 1987, Steinman & Lamberti 1988). Even the total number of algal species observed during the present study is similar to streams at other places; 147 (English streams; Moore 1977a); 182 (Fleming Creek, Michigan; Stevenson 1981); 125 (Spanish Gurri stream; Sabater 1990); 111 (Oak Creek, Arizona; Duncan & Blinn 1989); 203 (mountain stream, British Columbia; Wehr 1981). The occurrence of greater number of diatom species is similar to temperate streams (Marker 1976, Peterson et al. 1983, Hamilton & Duthie 1987, Keithan et al. 1988, Duncan & Blinn 1989). Nevertheless, the contribution of diatoms to total biovolume is relatively small. The greater species richness at St. 2 and 4 in comparison to St. 1 and 3 was particularly evident. This could be due to the reason that St. 2 and 4 are relatively less shaded with better light conditions.

Like cold water streams at other places, the studied streams showed the presence of two Rhodophyta members, namely, _Batrachospermum moniliforme_ and _Audouinella violacea_. Of which, the first was encountered only on one occasion. The red algae were always found in unexposed areas, and this agrees with Dillard (1966), Rider & Wagner (1972) and Parker et al. (1973), who have suggested their preference for low light conditions. _Audouinella violacea_ occurred at St. 1 and St. 3 abundantly in unexposed microhabitats, although _Batrachospermum moniliforme_ could be seen only on a single instance at St. 1. The red algae observed in the present study are indifferent to pH as they exhibit a wide tolerance to pH, ranging from 3.8 to 8.2 (Sheath & Hymes 1980, Sheath & Burkholder 1980). Israelson (1942) and Whitton (1975) found that freshwater Rhodophytes are localized in running waters in flows exceeding 5 m s^{-1}, whereas the Ontario red algae (Sheath & Hymes 1980) are restricted to streams or rivers with a minimum average flow rate of 15 cm s^{-1}. In the present study spring period showed highest abundance when the flow was at its minimum. This study coincides with observations of other workers (Sheath & Hymes 1980, Sheath & Burkholder 1985, Sheath et al. 1986a). The absence of Cladophora and Stigeoclonium spp. is particularly intriguing as they have rarely been found missing by stream algologists elsewhere (Whitton 1970, Harding & Whitton 1976, Holmes & Whitton 1981, Sheath et al. 1989). The absence of Xanthophyta members in selected streams cannot be explained, although they are commonly found in streams of North America and Europe (Sheath & Burkholder 1985, Sheath et al. 1986b). The contribution of blue-green algae to algal epilithon, in terms of species number or biovolume, was relatively small. This could be attributed to low pH of stream water (see Maurice et al. 1987).

Although low pH has been implicated for diminutive flora in some streams (Descy 1979, Van Dam et al. 1981, Maurice et al. 1987), the range of pH, and the presence of highly diverse algal assemblage in selected streams does not reflect the acidic nature of the habitat. In fact, many diatoms encountered in the present work have been listed as either indifferent to pH or alkaliphilous in the compilation made by Lowe (1974). Canonical correspondence analysis showed preferences of some species to low pH (Hyalotheca dissiliens, Gomphonema olivaceum, G. hebridense) and high pH (Scytonema coactile, Frustulia vulgaris, F. jogensis). However, the majority of species did not show any reaction to variations in pH of stream water.

Among various physical factors, light, temperature and flow rate elicited pronounced influence on stream epilithon. Nothwithstanding, it does not seem possible to precisely ascertain the impact of these factors in isolation. For example, high light conditions during the spring were accompanied by elevated water temperature, and the rainy season had both high temperature as well as water current. Despite the fact that the measurements of PAR were not carried out on a regular basis, light has definitely influenced the epilithic algal assemblages of selected streams. This contention gets support from the observation that epilithic biomass and species richness were always higher at St. 2 and 4 in contrast to St. 1 and 3, respectively, due mainly to greater light availability at former two stations. Moreover, late winter and spring periods favoured most the growth of the epilithic algae due inter alia to extended photoperiod and increased light intensity. Gregory (1980) has reasoned that light is the most crucial factor for primary production in forested streams. Increased light availability following clearcutting of forests has been cited as the reason for increased algal biomass and productivity (Hansman & Phinney 1973, Lyford & Gregory 1975, Murphy & Hall 1981, Webster et al. 1983). Similar effects have been observed in laboratory channels after augmentation of light availability (Bothwell 1983). It has been shown that light saturation of epilithic photosynthesis may occur at light intensity of 200 μE m^{-2} s^{-1} (Turner et al. 1983). In the present work PAR at water surface ranged from 300-1800 μE m^{-2} s^{-1} and was perhaps never limiting to the growth of algal epilithon.

Some algal species, notably, the filamentous chlorophytes, increased in abundance at St. 2 and 4 due mainly to greater intensity of light. Similar observations have been made by Sabater (1990) in a Spanish stream, and by others after canopy removal in North American streams (Hansman & Phinney 1973, Lyford & Gregory 1975, Shortreed & Stockner 1983, Lowe et al. 1986). The requirement of high intensity by green algae may inter alia be due to their lack of pigment diversity (Round 1965). Blue-green algae were more abundant at St. 1 and 3, in comparison to St. 2 and 4. This agrees with Regan (1988) who suggested favourable effect of low light intensity on blue-green algae due to their low light intensity compensation point. Light was never found inhibitory to epilithic algae, although Duncan and Blinn (1989) ascribed reduced periphytic biomass in a canyon stream to photoinhibitory effect of high light intensities. Water temperature was also found to influence many epilithic algae (Figs. 3.21 to 3.24). Cyanophytes, chlorophytes and rhodophytes generally showed their liking for high temperatures. This observation is in agreement with reports on temperate streams (Hynes 1970, Kilkus et al. 1975, Sheath & Burkholder 1985, Duncan & Blinn 1989). However, the periods of high temperature had high insolation as well thereby making it difficult to distinguish the effect of temperature from the effect of illumination. The range of temperature observed is well within the range which diatoms are known to tolerate (Patrick 1977).

Water current has been regarded as the most important variable which Douglas (1958) believes regulated periodicity of diatoms in a stony stream studied by her. Several epilithic algae reacted markedly to variations in flow conditions in the selected streams. The total epilithic biomass, species richness and diversity showed their minima in Jul '88 and '89 due mainly to extremely high flow rates (52 to 64 cm s^{-1}). Although many epilithic algae do require a continuous flow of water to facilitate their immigration, growth and metabolism (Whitford 1960, Whitford & Schumacher 1961, Lock & John 1979, Stevenson 1983, Stevenson & Peterson 1989), extremely high flow rate exerts mechanical stress and causes abrasion of algae from the rock surfaces (Moore 1977a, Rounick & Gregory 1981, Horner & Welch 1981). It has been envisaged that the relationship between water current and algal accrual on rocks is dual (McIntire 1966, Reisen & Spencer 1970): relationship is positive at low current velocities but becomes negative with increase in current velocities. Variations in stream flow are not only temporal but spatial as well. It has been found that the pattern and intensity of water current varies tremendously on different sides and surfaces of a substratum lying in the stream bottom (Round 1981). The riffle zones of streams are colonised by algae attached firmly to rock surfaces, whereas the areas with low flow and the pool contain loosely attached forms and planktonic elements (Tett et al. 1978, Fisher & Grimm 1988, Biggs & Close 1989). The present work shows specific flow requirements of some species: high to moderate flow (Audouinella violacea, Cylindrocapsa conferta, Synedra spp.), low flow (Hyalotheca dissiliens, Gomphonema olivaceum). The persistence of Spirogyra communis at some stations even during periods of high discharge is due to the fact that this alga colonises sheltered microhabitats.

In streams, continuous flow of water causes nutrient replenishment around the epilithic growths, however, reports are available suggesting nitrogen and phosphorus limitation of algal growth (Sommerfeld et al. 1974, Grimm et al. 1981, Gregory 1980, Triska et al. 1983, Elwood et al. 1981, Peterson et al. 1983). Low concentration of silica may also limit the growth of diatoms, however, its high concentration in the selected streams throughout remained above the saturating level (Kilham 1975). The presence of high N:P atomic ratio is suggestive of phosphorus limitation. Canonical correspondence analysis showed that a majority of green algae were stimulated by increased level of phosphorus in stream waters. In this context it is pertinent to note that the filamentous algae have a relatively higher phosphorus requirement as compared to diatoms (Bostwell 1985, Seeley 1986). Low phosphorus concentration seems to be responsible for low epilithic biomass (5.3-51.3 mg m^{-2}) in the present study.

Table 3.6 compares epilithic algal biomass in stream bottom as obtained by others and in the present study. The values obtained for four stations are within the range obtained by most of the earlier workers. Horner et al. (1983) found SRP levels of 15-25 µg P l^{-1} producing nuisance biomass of 100-150 mg chlorophyll *a* m^{-2}. Low levels of chlorophyll *a* as well as SRP in the studied streams suggests that the epilithic biomass has not yet reached the nuisance level. Herbivory by aquatic invertebrates or grazers can reduce algal biomass (Sumner & McIntire 1982, Lamberti & Resh 1983, McAuliffe 1984, Jacoby 1985, Steinman et al. 1987, Hill & Knight 1987, 1988), however, no grazers were found associated with epilithic assemblages.

Table 3.6 A summary of data on epilithic algal biomass (chlorophyll *a*, mg m^{-2}) in streams reported by others and in the present study.

Chlorophyll (mg m^{-2})	Location/Characteristics of stream	Reference
300-600	Mountain streams (Japan)	Tominaga & Ichimura (1966)
20-300	Hardwater streams (England)	Marker (1976)
10-50	Softwater streams (England)	Marker (1976)
2.1-39.9	A coastal rainforest stream (Vancouver Island, British Columbia, Canada)	Stockner & Shortreed (1976)
15-70	A softwater stream (British lake district, England)	Jones (1978)
6.5-138	A lowland stream (Massachusetts, USA)	Sumner & Fisher (1979)
0-90	Six streams (Seattle, Washington, USA)	Horner & Welch (1981)
<80	A desert stream following flash flooding (Phoenix, Arizona, USA)	Fisher et al. (1982)
0.63-136.2	Four temperate streams (Michigan, Pennsylvania, Idaho and Oregon, USA)	Bott et al. (1985)
92	Streams with algal grazers	Jacoby (1985)
33	Streams without algal grazers (Cascade mountains of western Washington, USA)	Jacoby (1985)
>150	Antarctic streams (Victoria land, in the Miers and Fryxell Valley)	Howard-Williams & Vincent (1986)

23-166	Six western Washington streams with different levels of phosphorus	Welch et al. (1988)
3-312	Six Swedish streams	Welch et al. (1988)
60	Deforested streams (Hong Kong)	Dudgeon (1989)
20-400	A freshwater stream (Signy island, Antarctica)	Hawes (1989)
2.87-9.49	Subarctic streams (Alaska, USA)	LePerriere et al. (1989)
50-180	Limestone stream (Catalonica, Spain)	Sabater (1990)
5-54	Two forested streams (Shillong)	Present study

Seasonal changes in the epilithic assemblage of the streams sampled seem to have been caused mainly by the variation in flow rate and changes in other factors had exerted minor influence. Epilithic biomass and species diversity were lowest during rainy season due mainly to exceptionally high flow rates which caused scouring of loosely attached forms. With the onset of autumn water current declined and recrudescene of epilithic growth occurred. During winter also flow conditions remained optimum, and despite low availability of light and reduced photoperiod epilithic biomass and species richness remained high in contrast to rainy season. Late winter/spring was the most favourable period for epilithic algae due mainly to low flow and enhanced illumination. Rise in concentration of nutrients could also be responsible for the best growth of algal epilithon during the spring. This pattern of epilithic seasonality broadly resembles the pattern obtained for the temperate streams (Westlake et al. 1972, Marker 1976, Moore 1977a, Holmes & Whitton 1981, Duncan & Blinn 1989, Sabater 1990). However, there are some differences as well. For example, the standing crop of epilithic algae in temperte streams is minimum during the winter season on account of extremely low temperature (Flemer 1970, Whitton 1975, Lyford & Gregory 1975, Stockner & Shortreed 1976, Rounick & Gregory 1981). The present data show that epilithic algae could grow well during the winter due obviously to the reason that winter temperature in these streams is far higher than the temperate streams. In temperate streams the peak of algal standing crop has been observed in the summer also (Butcher et al. 1937, Squires et al. 1973), nevertheless, the present findings do not agree with this as the study area is characterised by summer with heavy rainfall and high flow rate.

Chapter 4 SEASONAL VARIATIONS IN EPIPELIC ALGAL ASSEMBLAGES OF SELECTED STREAMS

4.1 Introduction

The epipelon is another important algal assemblage occurring in the surface layers of submerged sediment (Round 1961). The epipelic assemblages are dominated by pennate diatoms, coccalean green and blue-green algae, although euglenoids and motile species of other groups are also present (Round 1981). Despite being not a component of epipelic flora, a transitory assemblage of desmids, Spirogyra and other members of Zygnematales may often colonise the sediment surfaces in areas protected from swift currents (Darley 1982). It should be kept in view that the contribution of algal epipelon to primary production is significant, albeit relatively smaller as compared to the epilithon. The epipelic habitat is rather unique due to the following features (Moss 1977): (i) it is illuminated only in the surface layers, (ii) it is susceptible to disturbances due to high water current, and the activities of burrowing animals, and (iii) it is anaerobic excepting the surface layers. The epipelic algae are threatened of burrial due to continuous deposition of sediment. As a result, a majority of epipelic algae are capable of movement which enables them to come to the surface for utilising solar radiation (Harper 1969). The circadian rhythm of movement besides ensuring exposure to light during the day also causes migration or sinking of cells during darkness or low availability of light (Round & Eaton 1966, Round & Happey 1965, Round & Palmer 1966). The ecological significance of downward migration of epipelic algae during dark is not clearly understood, but could be related to predator avoidance or nutrient utilisation from the sediment. Frequent light limiting conditions in the epipelon is suggestive of facultative heterotrophy in algae of this particular habitat. Indeed, many epipelic diatoms have been found endowed with this ability. Nevertheless, the contribution of the facultative heterotrophy to the overall metabolism of the epipelon is far from being clear till date (Darley 1982). The epipelic algae differ widely from their counterparts in the epilithon with regard to their sources of nutrients, whereas the latter algae depend on nutrients dissolved in water, the former derive nutrients from water and to some extent from the sediment.

The studies on epipelic algae have been carried out mainly in standing waters, such as, ponds and lakes (examples, Round & Eaton 1966, Round & Palmer 1966, Moss 1969, 1977, Gruendling 1971, Moore 1980, Roberts & Boylen 1988, Carlton & Wetzel 1988), marshes (Sullivan & Moncreiff 1988), and swamps (Schoenberg & Oliver 1988). The response of epipelic diatoms of the lake Wabamum to thermal pollution was evaluated by Hickman (1974). The sedimentary diatoms of estuaries have also been studied (McIntire & Overton 1971, Amspoker & McIntire 1978). The general lack of information on lotic epipelic assemblages is not due to the scarcity of sediment in rivers and streams. In many cases workers have obviously sampled the epipelon only to pool the samples with epilithic, epipelic and epiphytic collections (Fee 1967, Neel 1968, Say & Whitton 1970, Kawecka et al. 1971, Edwards & Christensen 1973, Main 1977, Olive & Price 1978). In other studies, artificial substrata were used to sample the algal assemblages from streams with sandy sediment (Ball et al. 1969, Dillard 1969, 1971, Wilhm et al. 1978, Marcus 1980, Krejci & Lowe 1987, Stevenson & Hashmi 1989). It is impossible to determine from these studies which taxa belong to the epipelon. Notwithstanding, a few workers have categorically studied the epipelic assemblages of running waters. Algal epipelon of an eutrophic farmland stream were studied by Moore (1977 c), who concomitantly made a similar study in a subarctic stream (Moore 1977b). Czarnecki (1979) compared the epipelic and epilithic communities growing in the outlet of Montezuma Well, National monument (Arizona, USA) and found the two assemblages to be structurally similar. Roeder (1977) hypothesized the origin of the phytoplankton from the epipelon in a central Iowa stream. Stevenson (1984a) successfully used epipelic assemblages for water quality assessment.

Lack of adequate information on epipelic algae of streams was the main consideration for studying these assemblages as well in the present work. This chapter discusses the structure of epipelic algal communities in relation to physico-chemical characteristics of water. Also included is a brief account of interrelationship between the epipelic and epilithic assemblages.

4.2 Materials and Methods

Chapter 3 contains the details of sampling procedure and the methods employed for physico-chemical analyses of water.

Monthly collection of epipelic assemblages commenced in Nov '88 and continued till Oct '89 from four selected stations. Sampling of the epipelon was done by sucking up the sediment from the upper 3-5 mm layer of primarily silt-sized particles with a dropper from 4-5 random areas. The epipelon samples were diluted with 5 ml water, mixed thoroughly by shaking and preserved in 5% formalin solution for further analysis. For the identification of diatoms, a part of the aliquot was treated with concentrated nitric acid and potassium dichromate (Patrick 1959) to oxidize the organic material, leaving behind the siliceous diatom frustules (Hohn & Hellerman 1963). The silicified frustules were 3-4 times washed with distilled water to remove acid and dichromate and slides were prepared for identification. The identification and enumeration was done as described in Chapter 3. The population densities and algal biovolume were calculated on an area basis.

Statistical analyses were done as already described (see Chapter 3).

4.3 Results

The algal taxa encountered in the epipelic algal assemblages of four sampling stations are listed in Table 4.1. In total, 123 algal species were observed. The representation of different algal groups is as follows: Bacillariophyta, 102 spp.; Chlorophyta 14 spp.; Cyanophyta 6 spp.; and Rhodophyta 1 sp. The number of species belonging to four algal divisions are given separately for each station in Table 4.2. Diatoms were represented by several species in epipelic assemblages at various stations. The dominant genera were *Caloneis* (5 spp.), *Eunotia* (16 spp.), *Gomphonema* (13 spp.), *Navicula* (21 spp.), *Nitzschia* (9 spp.), *Pinnularia* (14 spp.) and *Synedra* (5 spp.). Other genera considered important for the epipelic assemblage include *Audouinella*, *Amphora*, *Ankistrodesmus*, *Closterium*, *Cylindrocapsa*, *Cymbella*, *Frustulia*, *Hormidium*, *Hyalotheca*, *Neidium*, *Nostoc*, *Oscillatoria*, *Netrium*, *Scytonema*, *Spirulina*, *Stauroneis* and *Surirella*. Table 4.1 contains biovolume of one individual of different species; these data were computed considering a single cell for unicellular algae or a single filament for filamentous algae. The species codes mentioned in this table have been used for CCA ordination diagrams.

Monthly variations in species number at four stations are shown in Fig. 4.1. The species richness was maximum in Feb (27 spp; St. 1), Mar '89 (25 spp; St. 2), Apr '89 (28 spp; St. 3) and May '89 (27 spp; St. 4). The minima were recorded during rainy season in Jul '89 at St.1,2 and 4, and in Jun '89 at St. 3. In general, the species richness was always more at St. 2 and 4 in contrast to St. 1 and 3, respectively. The total number of individuals followed the same trend showing peak during late winter and spring, and the lowest values during the rainy periods (Fig.

Table 4.1 Checklist of epipelic algal species, species codes and biovolumes. The numbers in parentheses following the names of species denote their presence at St. 1, 2, 3 and 4.

Algal species	Species code	Average biovolume of one individual (μm^3)
Bacillariophyta		
Amphora ovalis (Kütz.) (2)	AMP OVA	17,150
Caloneis beccariana Grun. (1,2,3,4)	CAL BEC	4,315
C. formosa (Greg.) Cl. (1,2,3)	CAL FOR	9,735
C. pulchra Messik (2)	CAL PUL	5,409
C. silicula (Ehr.) Cl. (1,2, 4)	CAL SIL	10,375
C. ventricosa (Ehr.) Meist (1,2,4)	CAL VEN	6,472
Cymbella cymbiliformis (Ag.) Kütz. (2,3)	CYM CYM	6,835
C. hungarica (Grun.) Pant (1,2,3)	CYM HUN	4,315
C. pseudocuspidata Gandhi (1,2,3,4)	CYM PSE	1,468
C. tumida (Bréb) V.H. (4)	CYM TUM	13,553
Eunotia arcus Ehr. (1,2,3,4)	EUN ARC	2,878
E. alpina (Näg) Hust. (1)	EUN ALP	1,049
E. exigua (DeBréb) Rabh. (2)	EUN EXI	84
E. gracilis (Ehr.) Rabh. (1)	EUN GRA	3,050
E. grunowi Å. Berg (3)	EUN GRU	5,150
E. hebridica Å. Berg (4)	EUN HEB	1,590
E. lunaris (Ehr.) Grun. (1)	EUN LUN	1,255
E. major (W. Sm.) Rabh. (3,4)	EUN MAJ	2,338
E. monodon Ehr. (1,3,4)	EUN MON	4,611
E. parallela Ehr. (3)	EUN PAR	6,776
E. pectinalis (Kutz) Rabh. (1,2,3,4)	EUN PEC	437
E. praerupta Ehr. (1,2,4)	EUN PRA	5,150
E. pseudoparallela Å. Berg (3)	EUN PSE	305
E. rostellata Hust. (1,3,4)	EUN ROS	531
E. tenella (Grun.) Hust. (2,3)	EUN TEN	157
E. tschirchiana O Müll (1,4)	EUN TSC	1,240
Frustulia jogensis Gandhi (1)	FRU JOG	9,465
F. rhombodies (Ehr.) De Toni (1,2,3,4)	FRU RHO	9,920
F. vulgaris Thwaites (1,2,3,4)	FRU VUL	9,023
Gomphonema aquatoriale Hust. (4)	GOM AQU	8,995
G. constrictum Ehr. (1,2)	GOM CON	7,581
G. gracile Ehr. (1,2,3,4)	GOM GRA	2,339
G. hebridense Greg. Her (2,4)	GOM HEB	1,976
G. intricatum Kütz (1,2,3,4)	GOM INT	1,517
G. lanceolatum Ehr. (1,2,3,4)	GOM LAN	2,978
G. longiceps Ehr. (4)	GOM LON	5,251
G. magnifica Gandhi (3)	GOM MAG	6,286
G. montanum Schum. (4)	GOM MON	3,790
G. olivaceoides Hust. (1)	GOM OLI	1,078
G. olivaceum (Lyng.) Kütz. (2,4)	GOM OLV	2,477

G. parvulum (Kütz) Grun. (1,3)	GOM PAR	1,618
G. subtile Ehr. (1,2)	GOM SUB	1,976
Navicula arenaria Donk. (1,4)	NAV ARE	5,393
N. avenacea Bréb. (1,2,4)	NAV AVE	4,064
N. cari Ehr. (1,2,3,4)	NAV CAR	1,063
N. cincta Ehr. Kütz. (1,2,3)	NAV CIN	887
N. complanatula Hust. (1,2,3,4)	NAV COM	2,39
N. cryptocephala Kütz. (1,2,3)	NAV CRY	974
N. cuspidata Kutz. (1,4)	NAV CUS	13,553
N. exigua (Greg.)O Müll. (2)	NAV EXI	1,202
N. gracilis Ehr. (1,2,3,4)	NAV GRA	4,064
N. grevillei Ag. (1,2,3,4)	NAV GRE	6,472
N. lanceolata (Ag.) Kütz (1,2)	NAV LAN	974
N. minuta (Cl.) A. Cl. (1,2,4)	NAV MIN	1,352
N. mutica Kütz. (1,2,3,4)	NAV MUT	8,993
N. protracta Grun. (1,2,3,4)	NAV PRO	1,737
N. pupula Kütz. (1,2)	NAV PUP	8,568
N. radiosa Kütz. (1,2,3,4)	NAV RAD	1,799
N. reinhardti Grun. (1,2,4)	NAV REI	6,472
N. rhynchocephala Kütz. (2,4)	NAV RHY	3,525
N. subdapaliformis Gandhi (4)	NAV SUB	4,064
N. subtenelloides Cholonky (2)	NAV SUT	305
N. viridula Kütz. (1,2,3,4)	NAV VIR	3,790
Neidium affine (Ahr.) Cl. (4)	NEI AFF	618
N. amphigomphous (Ehr.) Cl.	NEI AMP	3,525
N. hercynicum Mayer (4)	NEI HER	3,768
N. indicum Gonzalves et Gandhi (2)	NEI IND	6,835
N. iridis (Ehr.) Cl. (1,2,3,4)	NEI IRI	6,119
Nitzschia amphibia Grun. (1,2,3,4)	NIT AMP	2,515
N. angustata (W. Sm.) Grun. (1,2,3,4)	NIT ANG	2,003
N. apiculata (Greg.) Grun. (1,2,3,4)	NIT API	5,393
N. fruticosa Hust. (3)	NIT FRU	8,113
N. hantzschiana Rabh. (3)	NIT HAN	5,393
N. kuetzingiana Hilse (4)	NIT KUE	2,438
N. palea (Kutz.) W.Sm. (1,2,3,4)	NIT PAL	4,611
N. parvula Lewis (3,4)	NIT PAR	4,678
N. pseudofonticola Hust. (1,2)	NIT PSE	4,954
Pinnularia braunii (Grun.) (1,2)	PIN BRA	4,337
P. brebissoni (Kütz.) (4)	PIN BRE	887
P. divergens W.Sm. (1,2,3,4)	PIN DIV	5,963
P. esox (4) Ehr.	PIN ESO	14,647
P. gibba Ehr. (1,2,3,4)	PIN GIB	5,690
P. graciloides Hust. (4)	PIN GRA	8,640
P. interrupta W. Sm. (1,2,3,4)	PIN INT	4,877
P. major (Kütz.) (1,2,3,4)	PIN MAJ	15,784
P. marathwadensis Sarode & Kamat (1,2,4)	PIN MAR	12,625
P. panhalgarhensis Gandhi (1,2,3,4)	PIN PAN	8,993
P. sagittata Gandhi (1,2,4)	PIN SAG	7,589
P. stauroptera (Rabh.) (1,2,3,4)	PIN STA	6,237
P. subcapitata Greg. (3,4)	PIN SUB	2,515
P. viridis (Nitz.) Ehr. (2,4)	PIN VIR	19,712
Stauroneis phoenicenteron Ehr. (1,2,3,4)	STA PHO	35,114
Surirella capronioides Gandhi (3)	SUR CAP	81,593

S. elegans Ehr. (1,2)	SUR ELE	245,033
S. linearis W. Sm. (3)	SUR LIN	45,219
S. smithii Ralfs (1,2,3,4)	SUR SMI	156,367
S. tenera Greg. (1,2,3,4)	SUR TEN	48,869
Synedra acus (Kütz.) (1,2,3,4)	SYN ACU	3,336
S. pulchella (Ralfs) Kütz. (3,4)	SYN PUL	3,417
S. tabulata (Ag.) Kütz. (1,2,3,4)	SYN TAB	3,871
S. ulna (Nitz.) Ehr. (1,3,4)	SYN ULN	8,949
S. vaucheriae Kütz. (1)	SYN VAU	1,153

Chlorophyta

Ankistrodesmus falcatus (Corda) Ralfs. (2)	ANK FAL	3,814
Closterium acerosum (Schrank) Ehr. (1,2,3,4)	CLO ACE	4,276
C. moniliforme (Bory) Ehr.	CLO MON	4,947
C. parvulum Näg. (1,4)	CLO PAR	4,433
C. subtrunctatum W. & G.S. West (1)	CLO SUB	7,981
Cosmarium bioculatum Bréb. (1,2,3,4)	COS BIO	8,174
C. circulare Reinsch. (2,4)	C IR BIO	8,174
C. contractum W. & G.W. West (4)	COS CON	3,251
Cylindrocapsa conferta W.West (2,3)	CYL CON	4,461
Hormidium subtile (Klebse.)	HOR SUB	48,772
Hyalotheca dissiliens (J.E. Sm.) (2,3,4)	HYA DIS	203,411
Netrium digitus (Ehr.) Itz & Oth (3,4)	NET DIG	21,150
Spirogyra communis (Hassal) Kütz. (1,2,3,4)	SPI COM	2,910,935

Cyanophyta

Gleotrichia echinulata P. Richt. (1)	GLE ECH	203,982
Nostoc comminutum Kütz. (1,2,3)	NOS COM	539
Oscillatoria chlorina Kütz. (1,2,3)	OSC CHL	3,528
O. subuliformis Kütz. (2,3,4)	OSC SUB	1,078
O. willei Gardn. (1,2,3)	OSC WIL	10,787
Scytonema coactile Mont. (3)	SCY COA	5,403
Spirulina gigantea Schmidle (3,4)	SPI GIG	2,359

Rhodophyta

Audouinella violacea (Kütz.) Hamel (2,3,4)	AUD VIO	24,500

Table 4.2 Number of epipelic species belonging to four algal divisions encountered at the sampling stations during one year study.

	St. 1	St. 2	St. 3	St. 4
Bacillariophyta	66	67	61	67
Chlorophyta	6	7	7	10
Cyanophyta	4	4	6	2
Rhodophyta	-	1	1	1
Total	76	79	75	80

4.1). Temporal changes in total biovolume of the epipelic algal assemblages are given in Table 4.3. The value was observed to be extremely low in rainy months as compared to other times. The total biovolume showed a range 29.2 x 10^6 to 2254.6 x 10^6 μm^3 cm^{-2} at the selected sampling stations. The tremendous increase in total biovolume observed at times was due mainly to large populations of filamentous algae like *Spirogyra communis*, *Oscillatoria willei*, *Hyalotheca dissiliens*, and *Surirella* spp. in the assemblages. Generally, a high standing crop was maintained from Sep to Nov mostly in late rainy/autumn months. After this period decline occurred in biovolume which, however, started increasing again attaining another peak during the spring. The total biovolume declined during the rainy months. In many instances, St. 2 and 4 exhibited higher values as compared to St. 1 and 3, respectively. The species contributing maximum biovolume at the selected sampling stations are shown in Tables 4.4 to 4.7. Exceptionally high biovolume in many cases was due mainly to large populations of *Spirogyra communis*. The seasonality of this species is conspicuous as it showed preference for the autumn months followed by the spring. Like *Spirogyra communis*, rise in population size of other algae contributed to extremely high total biovolume. These species are *Hyalotheca dissiliens*, *Surirella elegans*, *Stauroneis phoenicenteron*, *Surirella tenera*, and *Gloeotrichia echinulata*. The latter species was found only at St. 1 mainly during the late spring period. *Hyalotheca dissiliens* appeared only during the spring. Periodic occurrence of *Frustulia vulgaris* was observed at St. 1 with maxima in the spring (Table 4.4). Similar patterns were observed for *Surirella tenera* and

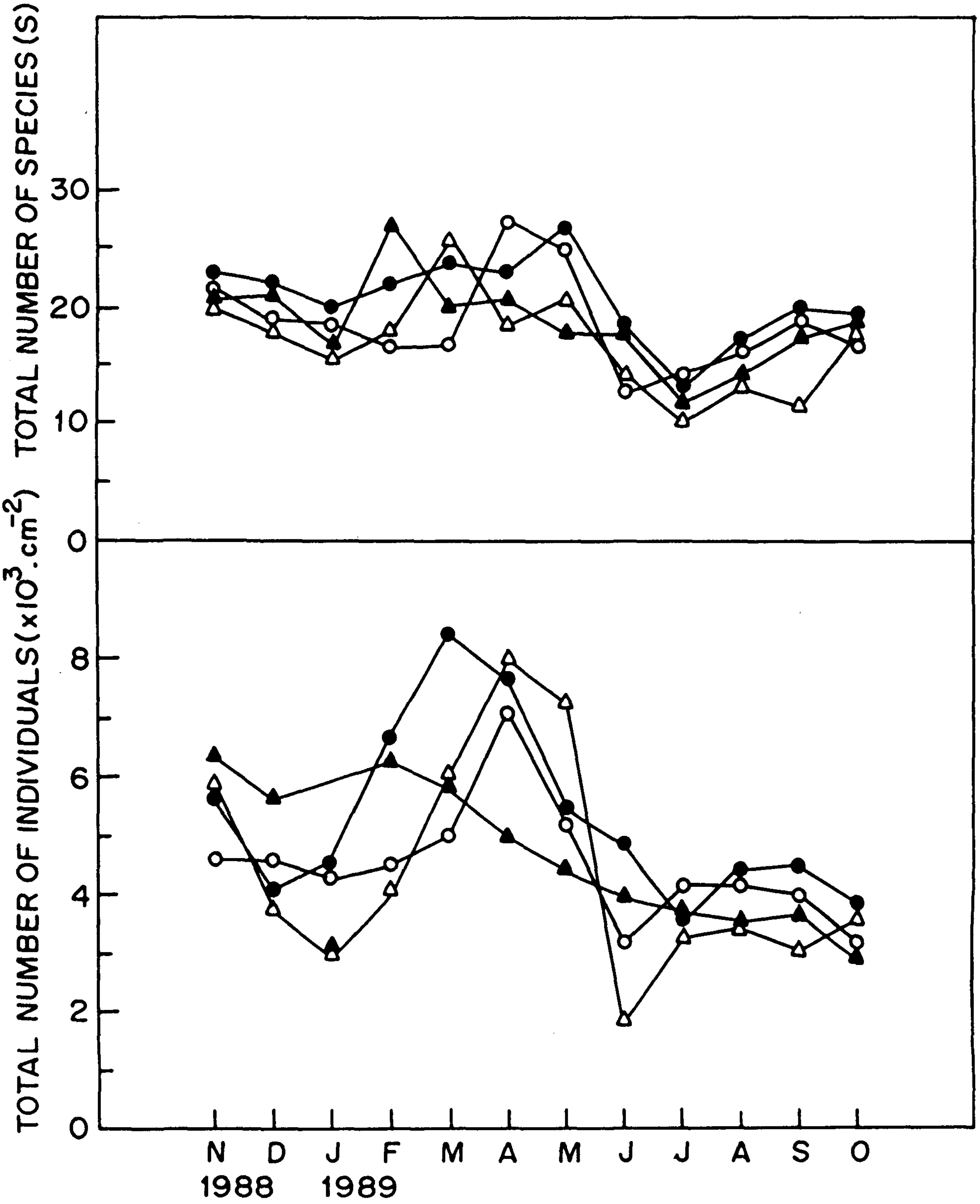

Fig. 4.1 Temporal variations in species richness (S) and population density of epipelic algal assemblages at four sampling sites: △ - St. 1, ▲ - St. 2, o - St. 3, and ● - St. 4.

Table 4.3 Total biovolume of algal epipelon at four stations.

Month	Biovolume ($\mu m^3 \times 10^6\ cm^{-2}$)			
	St. 1	St. 2	St. 3	St. 4
Nov '88	1451.6	1235.4	63.9	2254.6
Dec '88	46.2	171.1	51.8	925.5
Jan '89	40.9	29.2	131.3	67.4
Feb '89	76.0	197.4	72.1	1231.1
Mar '89	105.6	66.3	269.1	1924.6
Apr '89	139.5	199.1	223.4	475.8
May '89	180.1	129.9	256.4	208.9
Jun '89	23.4	51.6	35.9	52.2
Jul '89	157.6	70.7	43.7	42.2
Aug '89	66.3	153.4	47.7	63.5
Sep '89	151.4	1410.8	70.6	37.2
Oct '89	53.6	709.6	31.2	1380.0

Table 4.4 Biovolume ($\mu m^3 \times 10^6$ cm^{-2}) of dominant epipelic taxa (% biovolume in parentheses) at St. 1.

Name of species	1988		1989									
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Frustulia vulgaris	6.6 (0.5)	2.3 (4.9)	-	3.6 (4.8)	4.2 (3.9)	7.1 (5.0)	-	-	-	-	-	-
Gleotrichia echinulata	-	-	-	-	-	59.6 (42.8)	87.0 (48.3)	-	-	37.7 (56.7)	-	-
Gomphonema gracile	-	-	2.0 (4.9)	2.7 (3.5)	4.2 (3.9)	2.8 (2.8)	4.2 (2.3)	-	2.7 (1.8)	1.3 (1.9)	2.9 (1.9)	1.3 (2.4)
Navicula gracilis	-	1.1 (2.3)	-	0.9 (1.2)	7.4 (7.0)	5.8 (4.1)	5.1 (2.9)	-	-	1.1 (1.7)	-	-
Neidium iridis	6.1 (0.4)	-	1.9 (4.7)	1.7 (2.2)	3.0 (2.9)	3.6 (2.6)	2.5 (1.3)	1.0 (4.2)	1.8 (1.1)	1.3 (1.9)	-	-
Nitzschia amphibia	2.9 (0.2)	3.6 (7.8)	1.8 (4.4)	-	2.6 (2.4)	2.0 (1.4)	3.3 (1.9)	-	-	-	2.9 (1.9)	1.7 (3.2)
Pinnularia gibba	-	-	4.5 (11.0)	5.3 (6.9)	3.9 (3.7)	6.7 (4.6)	-	-	4.8 (3.0)	4.0 (6.0)	3.3 (2.2)	2.8 (5.2)
Spirogyra communis	1351.1 (93.1)	-	-	-	-	-	-	-	-	-	-	-
Surirella elegans	32.3 (2.2)	-	-	-	14.9 (14.1)	-	-	-	136.2 (86.4)	-	129.7 (85.7)	-
Synedra ulna	12.9 (0.9)	5.1 (11.0)	-	10.5 (13.9)	-	-	12.5 (6.9)	4.2 (17.9)	2.2 (1.3)	4.3 (6.4)	1.8 (1.2)	7.3 (13.7)

Table 4.5 Biovolume (μm^3 x 10^6 cm^{-2}) of some dominant epipelic algal taxa (% biovolume in parentheses) at St. 2.

Name of species	1988		1989									
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Caloneis silicula	2.3 (0.2)	1.9 (1.1)	2.3 (7.9)	2.7 (1.3)	6.9 (10.4)	2.5 (1.3)	2.8 (2.1)	-	-	-	2.3 (0.1)	-
Hyalotheca dissiliens	-	-	-	-	-	115.3 (57.9)	77.9 (60.0)	-	-	67.2 (43.8)	-	-
Navicula gracilis	3.1 (0.2)	1.5 (0.9)	-	2.9 (1.5)	2.6 (3.9)	1.0 (0.5)	1.3 (1.0)	1.3 (2.5)	-	0.6 (0.4)	1.5 (0.1)	1.3 (0.2)
Pinnularia gibba	-	4.6 (2.7)	2.1 (7.2)	33.0 (16.8)	5.2 (7.9)	-	4.9 (3.8)	4.5 (8.8)	4.4 (6.2)	-	3.8 (0.3)	2.4 (0.3)
Pinnularia interrupta	2.9 (0.2)	4.6 (2.7)	2.4 (8.2)	3.4 (1.8)	4.3 (6.4)	-	-	-	-	3.4 (2.2)	2.1 (0.1)	2.1 (0.3)
Spirogyra communis	1115.3 (90.3)	-	-	-	-	-	-	-	-	-	1135.1 (95.8)	605.5 (85.3)
Surirella elegans	-	-	-	65.3 (33.1)	-	-	-	-	-	-	-	-
Surirella tenera	26.6 (2.1)	90.9 (53.1)	-	-	-	-	-	-	32.4 (45.9)	-	33.8 (2.4)	12.6 (1.8)
Synedra acus	6.4 (0.5)	-	-	5.3 (2.7)	-	3.9 (2.0)	-	3.9 (7.5)	2.5 (3.5)	1.9 (1.2)	-	9.7 (1.9)
Synedra ulna	11.1 (0.9)	27.6 (16.1)	-	3.3 (7.7)	-	14.2 (7.1)	-	9.8 (19.0)	2.2 (3.1)	8.6 (5.6)	1.3 (0.1)	1.7 (0.2)

Table 4.6 Biovolume ($\mu m^3 \times 10^6$ cm^{-2}) of dominant epipelic species (% biovolume in parentheses) at St. 3.

Name of species	1988		1989									
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Gomphonema gracile	0.8 (1.2)	1.2 (2.3)	2.6 (1.9)	2.3 (3.2)	2.2 (0.9)	4.0 (1.8)	1.6 (0.6)	1.5 (4.1)	3.2 (7.3)	-	-	-
Hyalotheca dissiliens	-	-	-	-	-	94.4 (42.3)	109.6 (42.7)	-	-	-	-	-
Navicula gracilis	-	1.3 (2.5)	0.8 (0.6)	-	1.7 (0.7)	3.8 (1.7)	2.4 (0.9)	1.4 (3.9)	-	3.1 (6.5)	0.6 (0.8)	1.2 (3.8)
Neidium iridis	2.2 (3.4)	3.0 (5.8)	-	1.4 (1.9)	3.8 (1.4)	3.2 (1.4)	-	-	3.0 (6.9)	2.4 (5.0)	2.3 (3.2)	1.4 (4.4)
Nitzschia amphibia	5.2 (8.1)	4.3 (8.3)	-	-	-	3.7 (1.7)	-	-	6.6 (15.1)	1.5 (3.1)	8.0 (11.3)	2.0 (6.4)
Pinnularia gibba	-	-	5.3 (4.0)	5.7 (7.9)	5.0 (1.9)	6.3 (2.8)	7.4 (2.9)	-	4.8 (10.9)	3.7 (7.8)	2.4 (3.4)	4.0 (12.8)
Spirogyra communis	-	-	61.7 (47.0)	-	-	-	-	-	-	-	-	-
Stauroneis phoenicenteron	-	-	-	-	75.8 (28.2)	10.8 (4.8)	58.2 (22.7)	-	-	18.2 (38.2)	-	-
Surirella tenera	-	-	-	18.7 (25.9)	76.0 (28.2)	21.0 (9.4)	27.2 (10.6)	-	-	-	-	-

Table 4.7 Biovolume ($\mu m^3 \times 10^6 cm^{-2}$) of dominant epipelic algal species (% biovolume in parentheses) at St. 4.

Name of species	1988		1989									
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Gomphonema gracile	1.3 (0.1)	1.4 (0.1)	1.2 (1.8)	2.8 (0.2)	3.5 (0.2)	3.6 (0.8)	-	2.3 (4.4)	2.3 (5.4)	1.7 (2.7)	2.4 (6.4)	1.5 (0.1)
Gomphonema lanceolatum	2.4 (0.1)	1.3 (0.1)	-	3.1 (0.2)	3.0 (0.1)	7.5 (1.6)	2.2 (1.0)	3.5 (6.7)	-	-	1.3 (3.5)	2.9 (0.2)
Hyalotheca dissiliens	-	-	-	-	77.9 (4.1)	342.2 (71.9)	59.5 28.5)	-	-	-	-	-
Pinnularia interrupta	2.5 (0.1)	4.0 (0.4)	4.4 (6.5)	4.4 (0.3)	-	-	7.7 (3.7)	5.2 (9.9)	3.1 (7.3)	2.8 (4.4)	2.9 (7.8)	-
Nitzschia amphibia	3.3 (0.1)	1.7 (0.2)	3.3 (4.9)	-	-	-	-	-	-	2.3 (3.6)	-	-
Spirogyra communis	2144.8 (95.1)	851.2 (91.9)	-	1115.3 (90.6)	1770.5 (91.9)	-	-	-	-	-	-	1259.5 (91.2)
Surirella smithii	-	10.4 (1.1)	-	-	-	-	-	-	-	14.3 (22.5)	-	-
Synedra acus	2.7 (0.1)	5.3 (0.6)	7.4 (10.9)	7.4 (0.6)	7.4 (0.4)	4.0 (0.8)	6.5 (3.1)	5.3 (10.1)	-	3.9 (6.1)	2.5 (6.7)	4.5 (0.3)
Synedra ulna	19.8 (0.9)	17.0 (1.8)	8.1 (12.0)	31.7 (2.5)	35.5 (1.8)	31.8 (6.7)	9.4 (4.5)	9.7 (18.6)	1.9 (4.5)	17.2 (27.0)	1.9 (5.1)	7.0 (0.5)

Stauroneis phoenicenteron at St. 3 (Table 4.6). High biovolume was contributed by Synedra ulna even during the rainy season. Caloneis silicula became prominent during the winter and the spring (Table 4.5). On the other hand, Nitzschia amphibia preferred the autumn although it thrived well in winter also (Table 4.7). Navicula gracilis and Gomphonema lanceolatum exhibited high biovolume during the spring. Pinnularia spp. (P. gibba and P. interrupta) colonized well throughout the year exhibiting high biovolume even during the rainy period. Synedra acus did not show any definite seasonal trend though its per cent biovolume was maximum during Jan '89. Surirella elegans and S. smithii made very irregular appearances. Not much fluctuation was seen in the case of Neidium iridis, but a slight rise of its biovolume occurred in Jan '89 at St. 1 and Jul '89 at St. 3.

Fig. 4.2 shows species diversity and evenness at the sampling stations over a period of one year. The species diversity and evenness ranged from 2.95 to 4.29 and 0.73 to 0.95, respectively. Species diversity showed the minimum in the rainy season at all the stations, and the maxima were obtained during the late winter or the spring. Temporal changes in evenness did not follow any specific trend. Cluster analysis of epilithic assemblages collected on different dates was done for each of the four stations separately. The values of SIMI were computed for 12 collections taking all pair-wise combinations, and cluster dendrograms were constructed. Fig. 4.3 shows the cluster dendrogram for St. 1. In this case, three sampling times mainly of the spring months (Apr '89, May '89 and Mar '89) showed identical communities at 0.89 SIMI. At 0.60 SIMI one sample of the winter

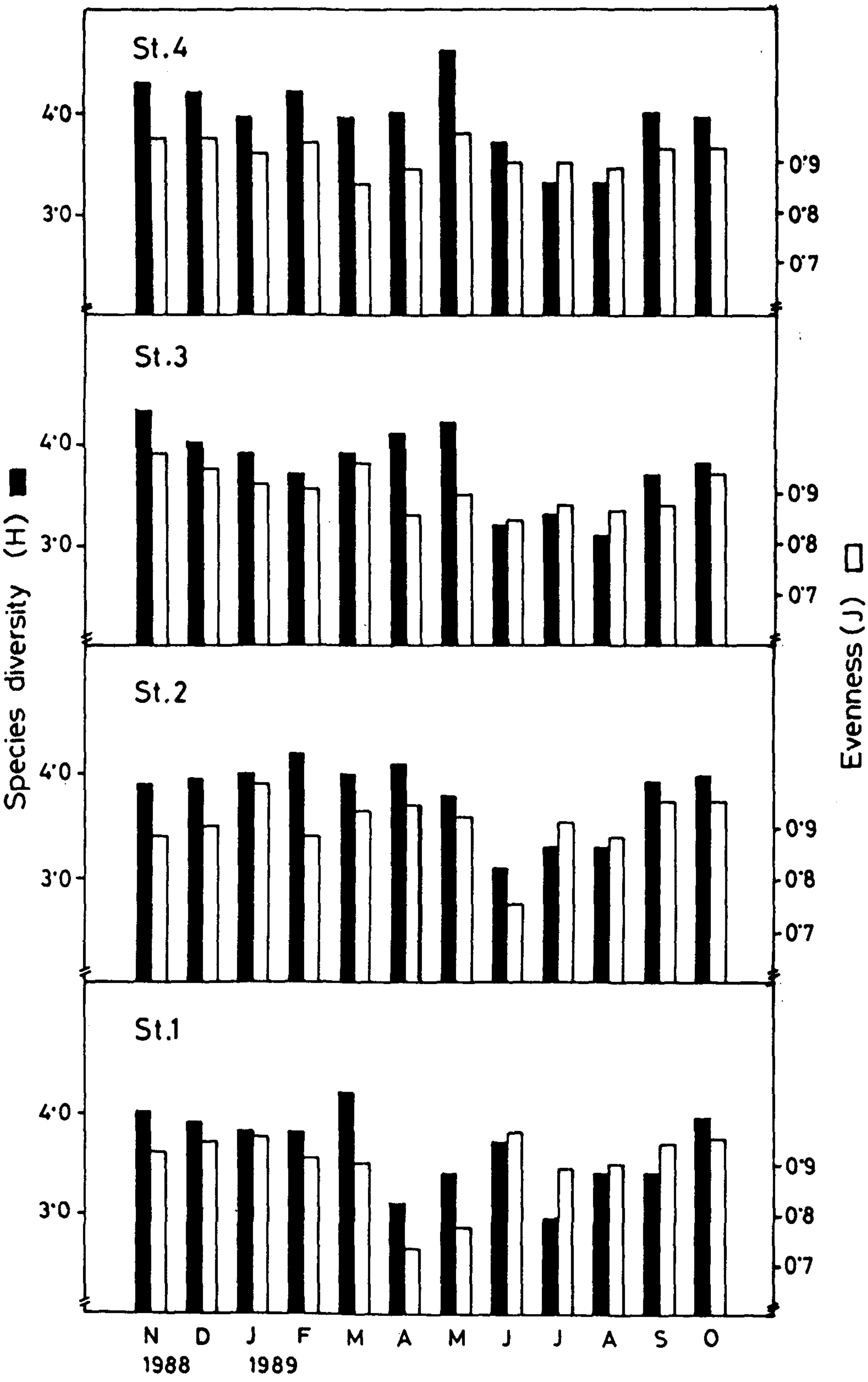

Fig. 4.2 Shannon diversity (H') and evenness (J) data for epipelic algal assemblages.

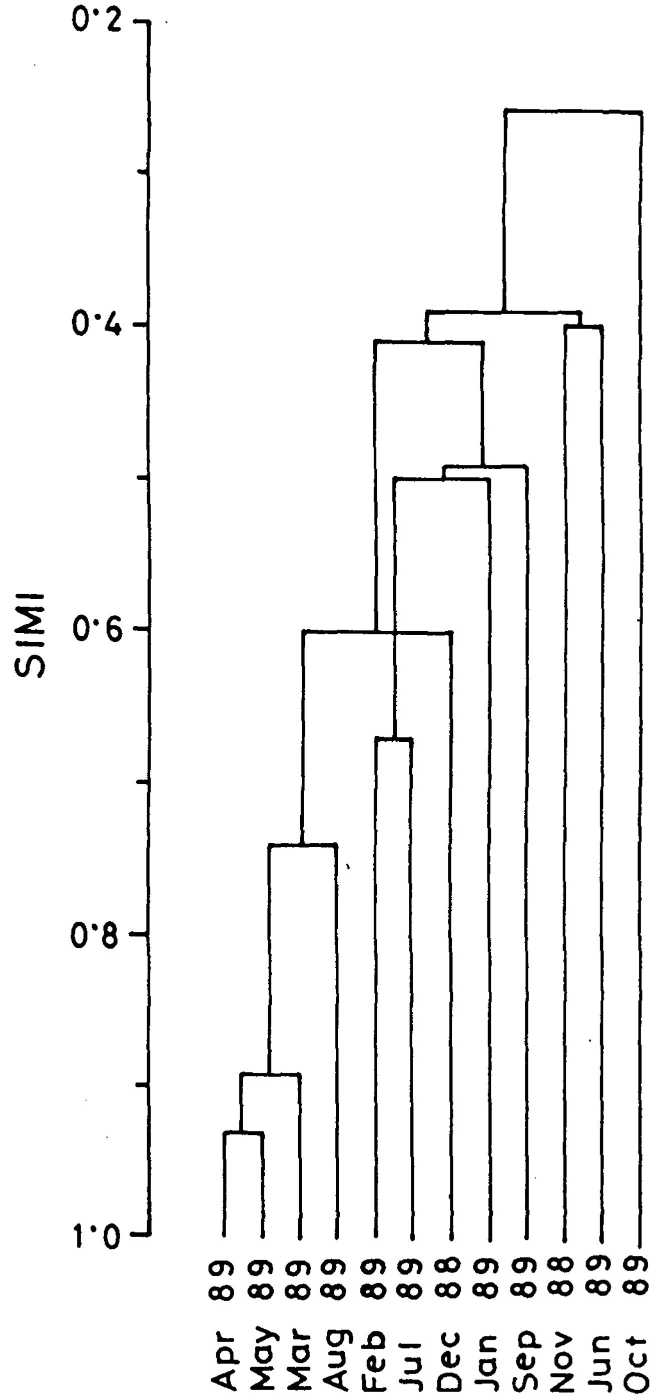

Fig. 4.3 Cluster dendrogram for St. 1 illustrating similarities of epipelic algal assemblages encountered on different dates.

(Dec '88) and another sample of the rainy period (Aug '89) merged together. The samples of winter/rainy months (Feb '89, Jul '89, Jan '89, Sep '89) clustered at 0.49 level of SIMI. The remaining samples of the autumn and rainy periods (Nov '88, Jun '89 and Oct '89) showed least SIMI. At St. 2 the epipelic algal assemblages encountered during winter/spring/autumn (Mar '89, Apr '89, Dec '88, Oct '89) showed the highest SIMI at 0.77 level (Fig. 4.4). Four samples of rainy period and one from winter (Jan '89) clustered together at 0.45 SIMI. The remainder 3 samples comprising autumn/winter periods did not show much similarity at this station. Cluster dendrogram for St. 3 shows a cluster of spring/rainy periods at 0.87 SIMI (Fig. 4.5). Six samples from all the seasons intermingled at 0.68 level of similarity. The rest of the three samples showing low similarity clustered at 0.44 level. At St. 4 (Fig. 4.6) two samples of rainy months (Jul '89 and Aug '89) showed highest similarity at 0.86 level with whom a sample of Jan '89 united at 0.84 level. On the other hand, 5 samples of autumn/ spring/rainy intermingled at 0.76 SIMI. The rest of four samples mainly of autumn/spring showing lower similarity values clustered at 0.49 level.

CCA showed flow and silica to be the most important factors at all the sampling stations. At St. 1 (Fig. 4.7) environmental variables like Si, flow and NH_4-N with longer arrows were strongly correlated with the ordination axes, relating more closely to the pattern of community variations as shown in this ordination diagram. Silica, flow and NO_3-N were the factors with greater weightage at St. 2 (Fig. 4.8). Ammonia-nitrogen, SRP, pH and conductivity also had significance towards the community

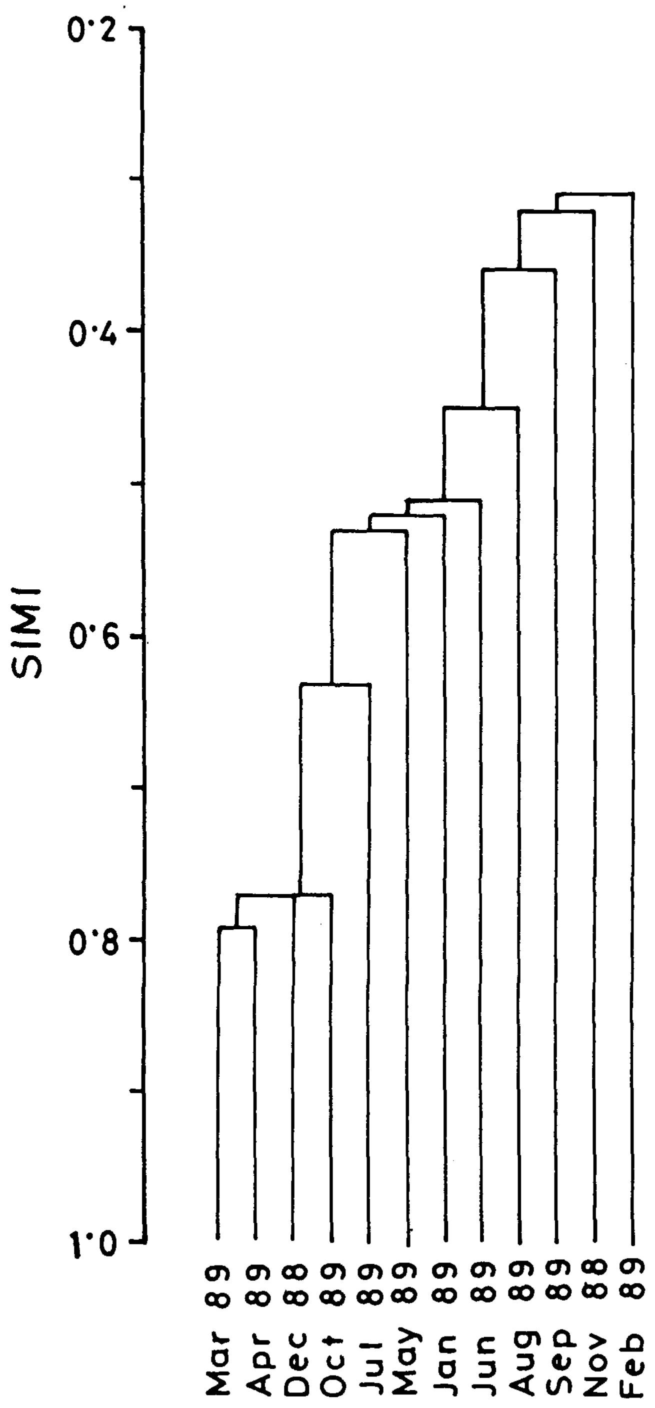

Fig. 4.4 Cluster dendrogram of various sampling months using SIMI of algal epipelon at St. 2.

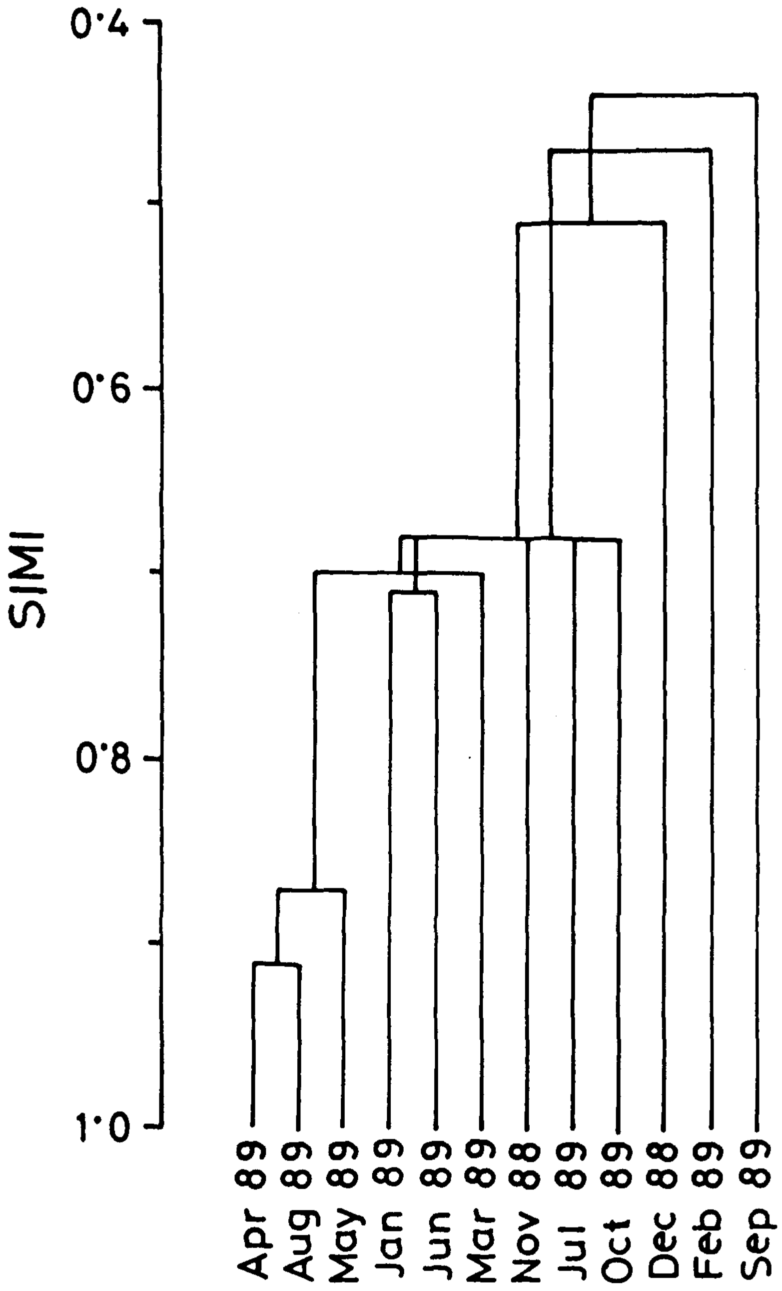

Fig. 4.5 Hierarchical distribution of sampling months depicting similarities of epipelic assemblages at St. 3.

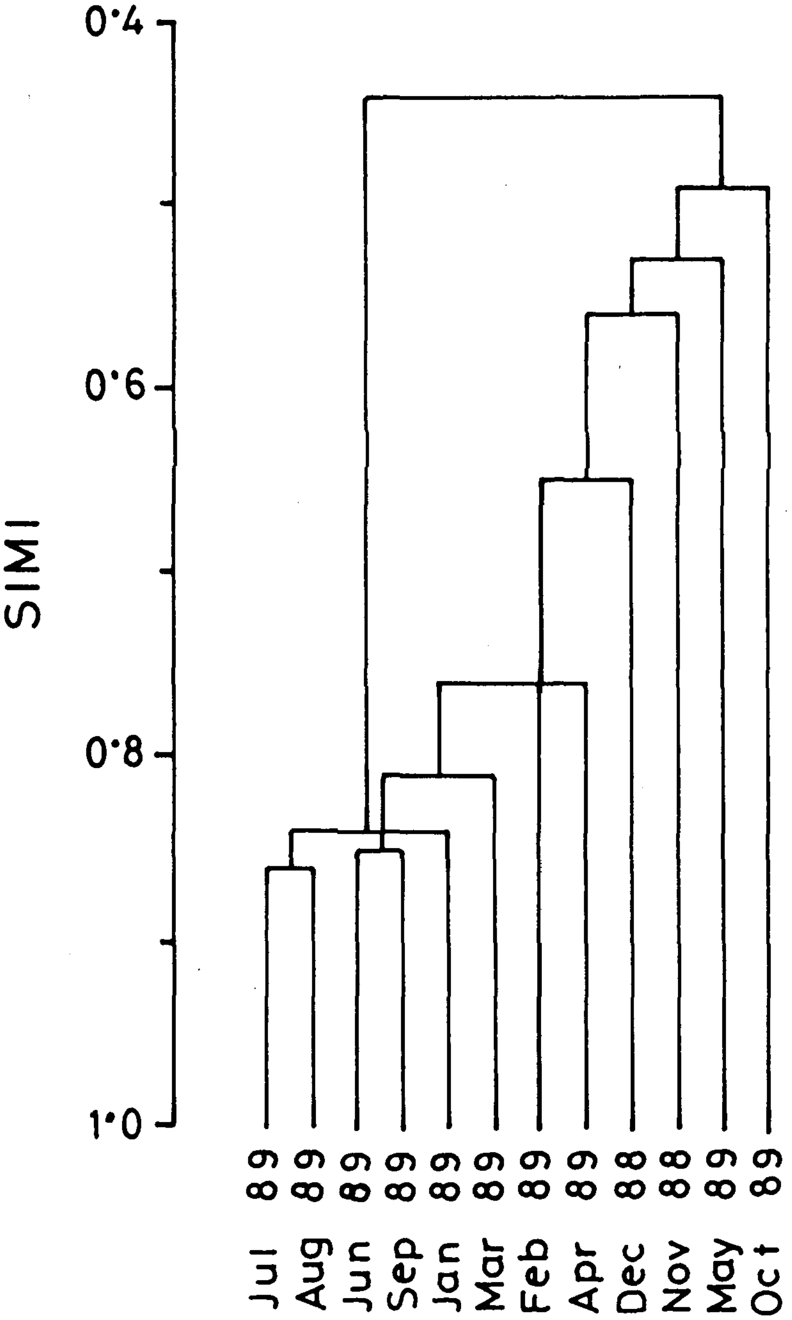

Fig. 4.6 Cluster dendrogram of sampling months based on similarity of epipelic assemblages at St. 4.

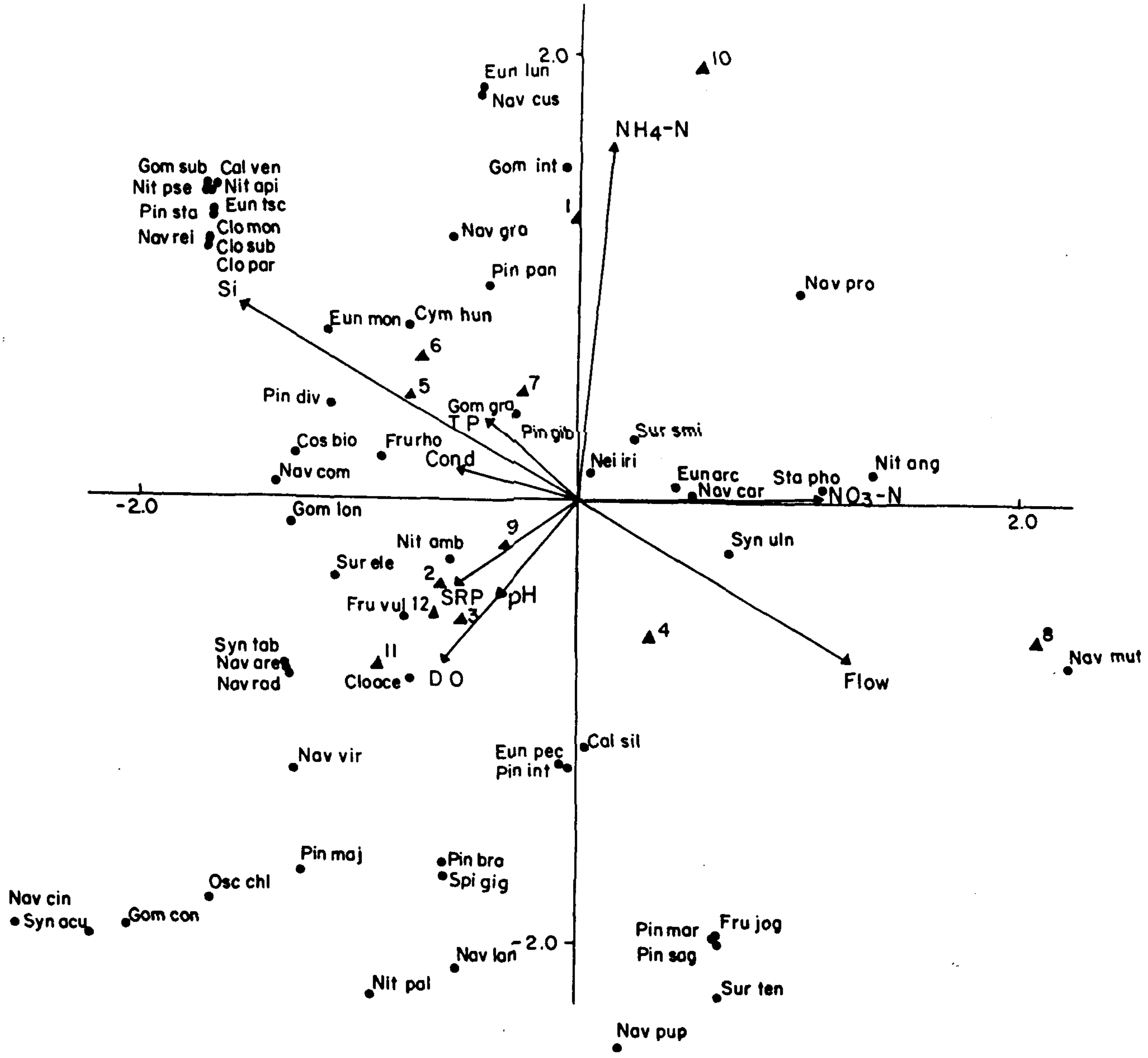

Fig. 4.7 CCA ordination diagram with algal species (●) in the epipelon, sampling periods (▲) and environmental variables (arrows) for St. 1. The first axis is horizontal, second axis vertical. Codes for different species are given in Table 4.1. Numbers denote sampling months: 1 - Nov '88, 2 - Dec '88, 3 - Jan '89, 4 - Feb '89, 5 - Mar '89, 6 - Apr '89, 7 - May '89, 8 - Jun '89, 9 - Jul '89, 10 - Aug '89, 11 - Sep '89 and 12 - Oct '89.

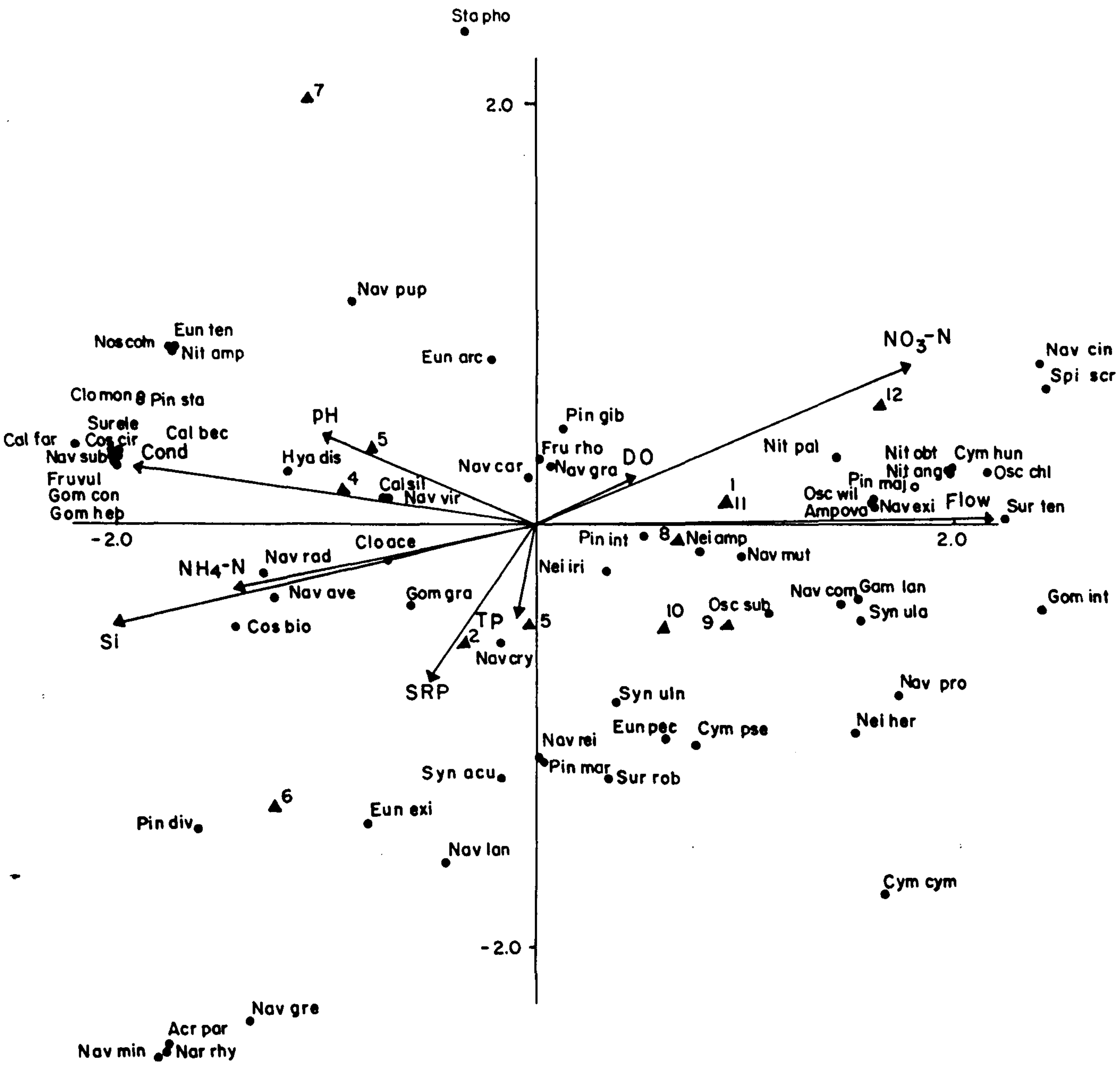

Fig. 4.8 CCA ordination diagram with epipelic algae (●), sampling months (▲) and environmental variables (arrows) for St. 2. The numbers represent sampling months similar to those in Fig. 4.7. Species codes are as in Table 4.1.

composition. At St. 3 except for DO, SRP and TP, all other factors were equally significant as observed from the ordination diagram (Fig. 4.9). Electrical conductivity alongwith flow, Si, pH and NH_4-N were found to be the most important environmental variables influencing the epipelic algal assemblage at St. 4 (Fig. 4.10).

Intraset coefficients of environmental factors with the first two axes of CCA are given in Table 4.8. The first axis at St. 1 is mainly defined by high flow and NO_3-N, whereas the second by NH_4-N and Si. The first axis at St. 2 shows that the areas with high flow have low silica and nutrient contents. At this station the second axis is again defined by phosphorus deficient conditions. At St. 3, the first axis has the areas of high flow with low silica and SRP, whilst flow and pH showed their significance at the second axis. The first axis is defined by high flow areas with low silica and nutrient poor conditions at St. 4. The second axis shows greater significance of Si and pH. In Table 4.9, the eigenvalues show that the extracted gradients are quite short. The scores of most species therefore lie outside the centroid.

CCA ordination diagrams show that the samples of rainy season are highly influenced by flow. Silica and phosphorus were extremely important for algal assemblages during the spring period. Ammonia-nitrogen was also found to play an important role during these periods. Nitrate-nitrogen and phosphorus influenced the epipelic algal community in the autumn and winter. Besides, flow and silica also had some role during these periods.

In CCA ordination diagram the species like Calonies silicula,

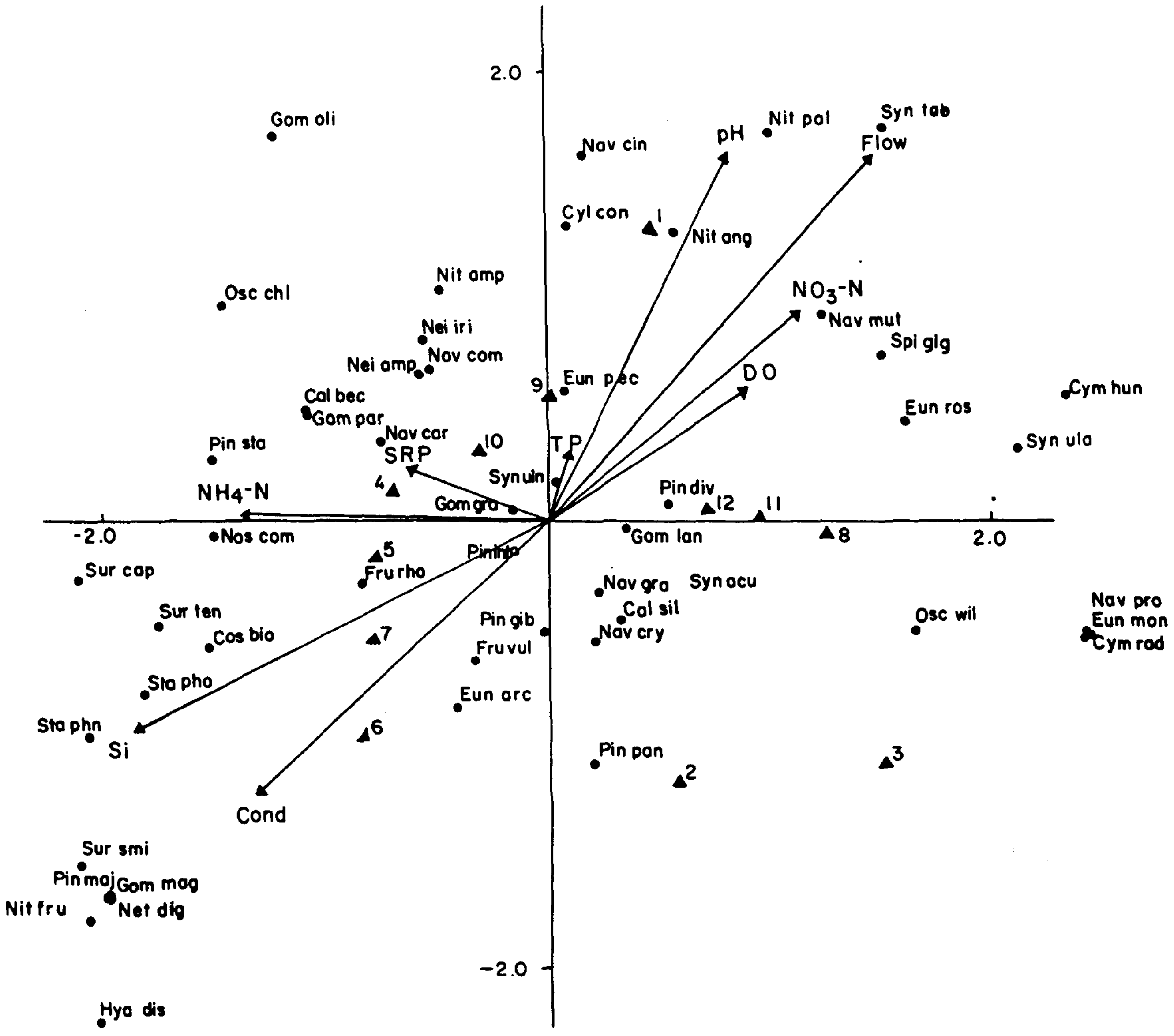

Fig. 4.9 Ordination diagram with epipelic algal species (●), environmental variables (arrows) and months (▲) for St. 3. Table 4.1 contains codes for various species. The sampling months are as in Fig. 4.7.

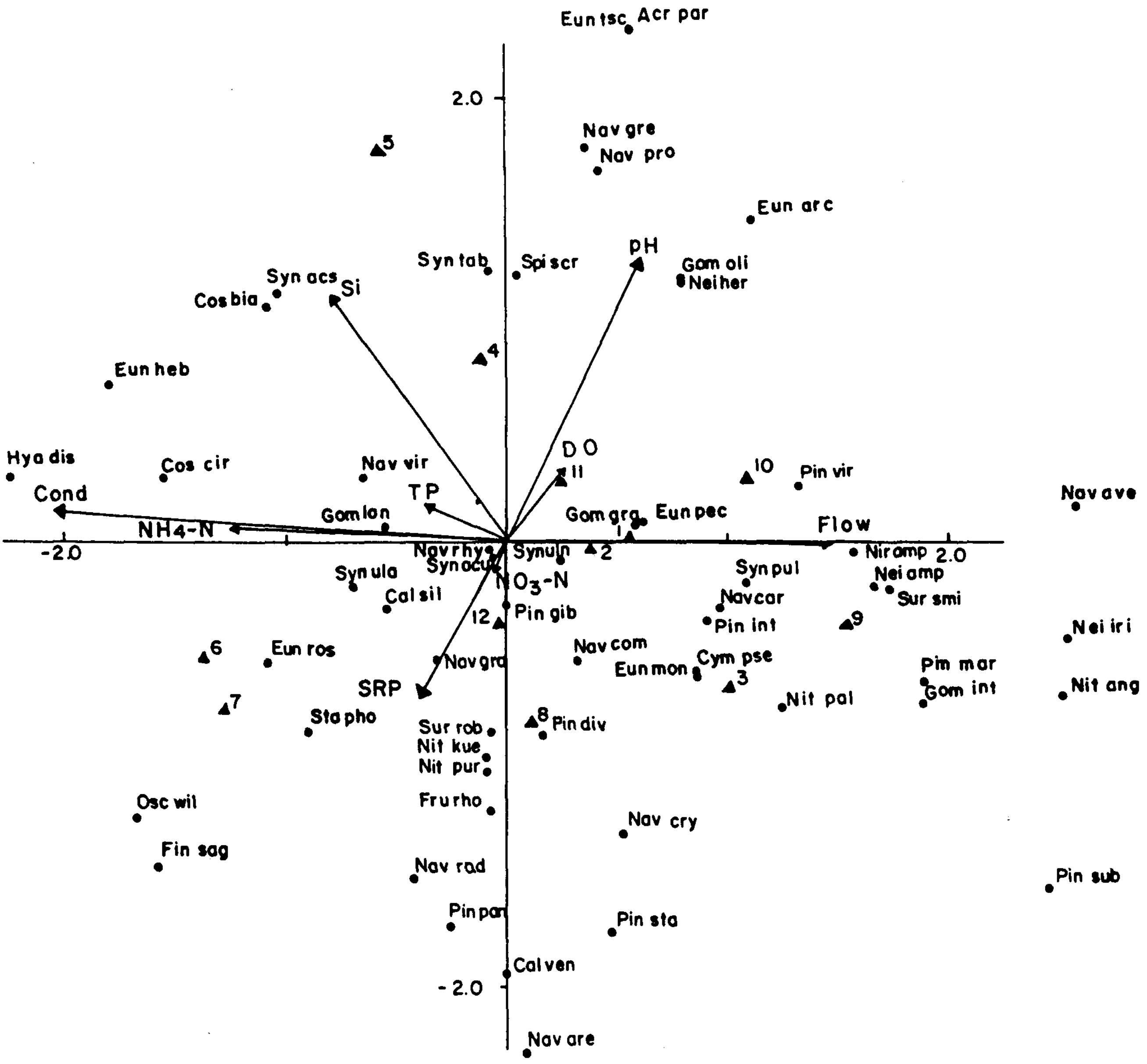

Fig. 4.10 Ordination diagram for St. 4 based on CCA analysis of epipelic algae (●) with respect to environmental variables (arrows) on different time periods (▲). The sampling months displayed by numbers are similar to Fig. 4.7. Codes for different algal species are as in Table 4.1.

Table 4.8 Intraset coefficients of environmental variables with the first two axes of CCA in the epipelon.

Variable	Intraset coefficients							
	St. 1		St. 2		St. 3		St. 4	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
pH	-0.16	-0.18	-0.44	0.17	0.33	0.67	0.24	0.52
Conductivity	-0.23	0.06	-0.76	0.11	-0.53	-0.50	-0.82	0.05
Flow	0.50	-0.29	0.87	0.01	0.59	0.67	0.60	-0.001
DO	-0.24	-0.29	0.11	0.08	0.36	0.24	0.11	0.14
SRP	-0.22	-0.15	-0.20	-0.31	-0.25	0.09	-0.16	-0.28
TP	-0.17	0.14	-0.03	-0.17	0.04	0.12	-0.15	0.06
NH_4-N	0.06	0.64	-0.57	-0.13	-0.56	0.003	-0.50	0.02
NO_3-N	0.44	0.01	0.71	0.30	0.46	0.38	-0.02	-0.06
Si	-0.62	0.35	-0.80	-0.20	-0.76	-0.39	-0.30	0.45

Table 4.9 Eigenvalues for the four axes derived from canonical correspondence analysis carried out separately for four stations.

	Axis			
	1	2	3	4
St. 1	0.45	0.39	0.38	0.35
St. 2	0.47	0.39	0.37	0.36
St. 3	0.40	0.35	0.35	0.31
St. 4	0.42	0.36	0.33	0.31

Eunotia arcus, *E. pectinalis*, *Frustulia rhomboides*, *Gomphonema gracile*, *G. lanceolatum*, *Navicula cari*, *N. complantula*, *N. gracilis*, *Neidium iridis*, *Pinnularia gibba* and *P. interrupta* encountered at various stations are mostly present near the centroid which is suggestive of their importance in the epipelic algal assemblage. Different species showed preferences for different environmental factors. Among the diatoms, species requiring different flow conditions were evident; high flow (*Synedra ulna*, *Navicula mutica*, *Frustulia jogensis*, *Surirella tenera*, *Cymbella hungarica*, *Nitzschia apiculata* *N. angustatum*, *Pinnularia major*, *Synedra tabulata*, *Gomphonema intricatum*, *Nitzschia palea*, *N. amphibia* and *Pinnularia marathwadensis*), moderate flow (*Navicula cari*, *Surirella smithii*, *Neidium iridis*, *N. amphigomphous*, *Pinnularia interrupta*, *P. gibba* and *Eunotia pectinalis*), and low flow (*Navicula gracilis*, *Frustulia rhomboides*, *Hyalotheca dissiliens*, *Eunotia arcus*, *Stauroneis phoenicenteron*, *Gomphonema gracile*, *Caloneis* spp., *Pinnularia stauroptera* and *Frustulia vulgaris*). Two species, *Oscillatoria chlorina* and *O. willei*, preferred high concentration of soluble-reactive phosphorus. Desmids (*Hyalotheca dissiliens*, *Cosmarium* spp. and *Closterium* spp.) preferred low flow and high phosphorus. The diatoms preferring high phosphorus include *Frustulia* spp., *Neidium* spp., *Gomphonema gracile*, *G. lanceolatum*, *G. parvulum*, *Navicula cari*, *N. cryptocephala* and *N. viridula*. Some algae showed liking for specific pHs: high pH (*Gomphonema olivaceum*, *Navicula cincta*, *N. gregarica*), moderate pH (*Eunotia pectinalis*, *Gomphonema gracile*, *Navicula viridula*), low pH (*Navicula protracta*). Changes in ammonia-nitrogen and nitrate-nitrogen affected some algae. Whereas the elevation of ammonia-nitrogen concentration favoured

Gomphonema intricatum, *Navicula avenacea*, *N. radiosa* and *Pinnularia stauroptera*, increase in nitrate-nitrogen was liked by *Nitzschia angustata*, *Navicula mutica*, *Pinnularia gibba* and *Stauroneis phoenicenteron*.

4.4 Discussion

The epipelic habitat is generally not considered as a favourable environment due to low availability of light and anoxic conditions in the deeper strata of the sediment. Due to this presumption the epipelic algal assemblages of streams have not been as extensively studied as the epilithon. The present work showed a highly diverse epipelic assemblage at all stations. The epipelic assemblages of the selected streams show broad compositional similarities with those at other places (Moore. 1974, Round & Happey 1965, Moore 1977a, Ampspoker & McIntire 1978, Stevenson & Hashim 1989). Excepting a few anomalies, majority of taxa encountered by us have been observed elsewhere in the epipelon of freshwaters (Blum 1954, Round 1957, 1959, Müller-Haeckel 1966, Moore 1977a, 1980). The greater number of diatom species (98) as compared to non-diatom species (22) is in agreement with previous reports. This seems to be related to high concentration of silica in stream water and low light requirement of diatoms (Eppley 1977). It is interesting to note the similarity of the epipelic flora of selected streams with the epipelic assemblages of ponds (Round & Eaton 1966, Moss 1977, 1969, Moore 1974) and lakes (Hickman 1974, Charles 1985). Some workers have reported Shannon diversity values for the lotic epipelon (Czarnecki 1979, Stevenson 1984a). The diversity values obtained in the present case are well within the range obtained by Stevenson (1984a);however, these are much higher than similar data reported by Czarnecki (1979). High species diversity may have resulted from reduced competition among organisms because an overstory cannot develop (Miller et al. 1987). Low species diversity has been related to nutrient limiting condition (Stevenson 1984a,Chessman 1986) and low light availability (Moore & McIntire 1977). Since epipelic algae derive their nutrients from water as well as from sediment, they rarely experience nutrient limitation (Darley 1982). Moreover, the selected streams were most of the time shallow and hence light was perhaps never limiting.

The epipelic assemblages were found to have a good representation of motile algae, namely, *Nitzschia*, *Navicula*, *Caloneis*, *Surirella*, *Stauroneis*, *Neidium* and *Oscillatoria* spp. Motility is advantageous to epipelic algae as it allows them to regain to the surface for utilizing solar radiation, and impedes their burial in sediment. Several non-motile algal species were abundantly found in the epipelon. Many of which (e.g., *Spirogyra communis*, *Hyalotheca dissiliens*) colonized the upper surface of the sediment during the periods of low discharge when streams were relatively shallower and light penetration was high. In addition, the possibility of elements from other assemblages entering into the epipelon also exists. In the present work, the method followed for the sampling of the epipelic algae perhaps also included epipsammic components particularly those found loosely attached to sand grains. Hence, the presence of some epipsammic components in the samples cannot be ruled out.

A comparison of epipelic and epilithic communities (see Table 4.10) suggests a lot of similarities between the two assemblages.

Table 4.10 A comparative account of algal flora in the epilithic and epipelic assemblages.

	Species list
Species common to epilithic and epipelic assemblages	Caloneis beccariana, C. formosa, C. silicula, C. ventricosa, Cymella cymbiliformis, C. hungarica, Eunotia arcus, E. exigua, E. gracilis, E. grunowii, E. hebridica, E. lunaris, E. major, E. monodon, E. parallela, E. pectinalis, E. praerupta, E. pseudoparallela, E. rostellata, E. tenella, E. tschirchiana, Frustulia jogensis, F. rhombodies, F. vulgaris, Gomphonema constrictum, G. gracile, G. herbridense, G. intricatum, G. lanceolatum, G. longiceps, G. montanum, G. olivaceoides, G. olivacum, G. parvulum, G. subtile, Navicula arenaria, N. cincta, N. complanatula, N. cryptocephala, N. exigua, N. gracilis, N. grevillei, N. mutica, N. protracta, N. pupula, N. radiosa, N. reinhardtii, N. rhynchocephala, N. subdapaliformis, N. viridula, Neidium amphigomphous, N. iridis, Nitzschia amphibia, N. angustata, N. hantzschiana, N. palea, N. parvula, N. pseudofonticola, Pinnularia braunii, P. brebissoni, P. divergens, P. gibba, P. interrupta, P. marathwadensis, P. panhalgarhensis, P. sagittata, P. stauroptera, Stauroneis phoenicenteron, Surirella smithii, S. elegans, Synedra acus, S. pulchella, S. tabulata, S. ulna, S. vaucheriae, Ankistrodesmus falcatus, Closterium acerosum, C. moniliforme, C. parvulum, C. subtrunctatum, Cosmarium bioculatum, C. circulare, C. contractum, Cylindrocpsa conferta, Hormidium subtile, Hyalotheca dissiliens, Spirogyra communis, Nostoc comminutum, Oscillatoria chlorina, O. subuliformis, O. willei, Scytonema coactile, Spirulina gigantea, Audouinella violacea, Navicula avenacea, N. cari.
Species restricted to epilithon	Achnanthes afinis, A. biasolettiana, A. brevipes, A. coarctata, A. hungarica, A. lanceolata, A. lapponica, A. microcephala, A. minutissima, Coconeis placentula,

	Cymbella cuspidata, *C. gracilis*, *C. nagpurensis*, *Eunotia camelus*, *E. fallax*, *E. tumida*, *Fragilaria intermedia*, *Gomphonema angustatum*, *G. bohemicum*, *Gyrosigma scalproides*, *Mastogloia recta*, *Meridion circulare*, *Navicula conferracea*, *N. disjuncta*, *N. flanatica*, *N. graciloides*, *N. gregarica*, *N. halophila*, *N. laterostrata*, *N. microcephala*, *N. minima*, *N. similis*, *N. subrhynchocephala*, *N. vanhoeffieniformis*, *Neidium panhalgarhensis*, *Nitzschia filiformis*, *N. hungarica*, *N. nagpurensis*, *N. vitrea*, *Pinnularia appendiculata*, *P. divergentissima*, *P. eburnea*, *P. neglecta*, *P. viridis*, *Chlorella vulgaris*, *Cosmarium punctulatum*, *Microspora stagnorum*, *Mougeotia genuflexa*, *Mougeopsis calospora*, *Oedogonium curtum*, *Selenastrum gracile*, *Synechococcus aeruginosum*, *Lyngbya gracilis*, *Phormidium notatum*, *Sphaeroplea annulina*, *Stigonema minuta*, *Tolypothrix distorta*, *Batrachospermum moniliforme*.
Species restricted to epipelon	*Amphora ovalis*, *Caloneis pulchra*, *Cymbella Pseudocuspidata*, *C. tumida*, *Eunotia alpina*, *Gomphonema aquatoriale*, *G. magnifica*, *Navicula cuspidata*, *N. lanceolata*, *N. minuta*, *N. subtenelloides*, *Neidium affine*, *N. hyrcynicum*, *N. indicum*, *Nitzschia apiculata*, *N. fruticosa*, *N. kutzingiana*, *Pinnularia esox*, *P. graciloides*, *P. subcapitata*, *P. major*, *Surirella capronoides*, *S. linearis*, *S. tenera*, *Gleotrichia eichinulata*, *Netrium digitus*.

Of 123 epipelic taxa, 97 were common to the epilithon, and a mere 26 species were restricted to the epipelon. Fifty-eight taxa were confined to the epilithon. The sharing of an extremely large number of algal taxa by the epilithon and the epipelon suggests that such taxa have wide ecological amplitudes and can thrive well in either of the microhabitat. The confinement of certain taxa to the epipelon, or to the epilithon, reflects the specific preferences of the species. Of particular interest is the presence of 5 species of *Surirella* exclusively in the epipelon. Round (1964) has listed this genus as one of the commonest diatom taxon in the freshwater epipelon.

In the epipelon, Round (1972) has envisaged a seasonal sequence of species comparable to that of phytoplankton where no taxon extends over the whole year. This is definitely not the case in the present work as most of the species were persistent throughout the year although they waxed and waned with time. This is a reflection of the stability of the system. A perusal of the data obtained suggests that the rainy season was most unfavourable for the growth of epipelic algae. This was due mainly to extremely high flow rate which is well known to (i) disturb the sediment accumulated in stream bottom, and (ii) dislodge loosely attached forms and transports them, together with the motile elements, downstream. Very few species could survive abrasive effects of high water current during rainy season. As expected, filamentous forms were most vulnerable to high flow conditions. The studied streams showed distinct seasonality in biomass accumulation. The autumn and spring were found to be the most favourable periods for the growth of the epipelon. The autumn peak was much higher than the spring peak due obviously to greater proportion of *Spirogyra* communis. This species has very large individuals, and hence its biovolume is several-folds higher in comparison to any other species (Table 4.1). The spring peak was due to the better growth of several species of diatoms together with a filamentous desmid (Hyalotheca dissiliens). Very few reports are available on epipelon seasonality, and this has made extremely difficult our efforts to explain seasonality as observed in this study. Round (1964) found maximum growth of epipelic algae in lakes during the spring with a small peak during the autumn, but ponds showed peak only during the mid-summer. According to him streams show early spring and late spring epipelic blooms with little growth during mid-summer or autumn periods. Moore (1977a) similarly observed spring as the most favourable period for the growth followed by the autumn. It is pertinent to mention here that all previous works on epipelon seasonality have been carried out by considering the number of individuals, and not biovolume as done in the present case. If the number of individuals is taken into consideration, instead of the biovolume, the trend for epipelic seasonality obtained in the present study closely matches the earlier reports. The spring maxima of the epipelon can be related to increased photoperiod and hence greater light availability (Round 1960, 1961 Moss & Round 1967, Moore 1977a). The autumn peak can be explained in terms of large population of Spirogyra communis, although this phenomenon is difficult to explain as this alga was most favoured by the spring in case of epilithic community.

Chapter 5

LABORATORY BIOASSAY OF STREAM WATER FOR ASSESSING NUTRIENT AVAILABILITY TO ALGAE

5.1 Introduction

In addition to carbon, hydrogen, and oxygen, algae require some 13-15 additional elements to grow and reproduce (Miller et al. 1978). Algal growth in seawaters is often limited due to low nitrogen supply, whilst freshwater habitats, particularly lakes, often display phosphorus or silica limiting condition (Round 1982). In the streams of North America and Europe, limitation of algal growth has been demonstrated due to the reduced supply of nitrogen (Sommerfeld et al. 1974, Triska et al. 1983) and phosphorus (Elwood et al. 1981, Peterson et al. 1983). Nevertheless, similar information is scarcely available for the tropical streams. This ignorance is causing concern in view of the ongoing rapid degradation of tropical watersheds, and the probability of nutrient export to streams in the event of heavy rains (Bormann & Likens 1977).

Nutrient limitation of algal growth in natural waters can be identified by performing chemical analysis of test waters for various nutrients. But chemical analysis may not necessarily reflect the availability of a particular nutrient for algal growth. Fairly reliable information concerning the growth limiting nutrients can, however, be obtained by performing algal assay of test waters under controlled laboratory conditions (Middlebrooks et al. 1971, Miller et al. 1978). These tests are based on assessing the biomass yield attained by a test alga in sterilized natural water enriched with nutrients. Increase in biomass yield following the enrichment with a particular nutrient suggests its limitation in a water sample. Selenastrum capricornutum Printz has been extensively used for such bioassays due to (i) ease in culture, maintenance and enumeration, and (ii) sensitive reaction to nutrients and toxicants (Anonymous 1971, Miller et al. 1978).

Algal bioassays of stream water, collected from four sampling stations, were conducted in batch culture using Selenastrum capricornutum as the test organism. This chapter describes and discusses the results of bioassay tests carried out on three different occasions.

5.2 Materials and Methods

Samplings were carried out during the last week of Nov '88, Mar '89 and Aug '89. Sampling and methodological details have already been included in Chapter 3. Water samples collected from various stations were analysed as described before, and algal assays were performed.

Algal assay procedure employed for the study has been described in detail elsewhere (US EPA 1971). The culture of test alga S. capricornutum Printz was kindly supplied by Dr. Olav M. Skulberg, Norwegian Institute of Water Research, Oslo. The synthetic algal nutrient medium (US EPA 1971) was used for the maintenance of stock cultures. The algal nutrient medium contained the following salts (mg l^{-1}): sodium nitrate 25.5, dipotassium hydrogen phosphate 1.0, magnesium chloride 5.7, magnesium sulphate 14.7, calcium chloride 4.4, sodium bicarbonate 15.0. Other salts added to the nutrient medium are (μg l^{-1}): boric acid 185.5, manganese chloride 264.2, zinc chloride 32.7, cobalt chloride 0.7, copper chloride 0.009, sodium molybdate 7.2, ferric chloride 96.0, disodium EDTA 300.0. The stock cultures were maintained in Erlenmeyer flasks of 250 ml capacity. Autoclaved glasswares were used to maintain the stock as well as to perform the experiments. Log-phase algal cultures were aseptically transferred to centrifuge tubes, and centrifuged for 5-10 min in order to harvest the algal cells. Subsequently, the algal cells were thoroughly washed twice with autoclaved nutrient medium. The algal inocula were aspetically introduced into the autoclaved nutrient medium, and kept in the BOD incubator at 24±1°C in a 14 h light (PAR 70 $\mu E\ m^{-2}\ s^{-1}$) and 10 h dark cycle. The cultures were hand-shaken minimum 2 to 3 times daily to resuspend the algal cells. The bioassay experiment was designed in a manner so as to define algal growth limitation in stream water due to low supply of nitrogen, phosphorus or trace elements. The test waters were autoclaved and aseptically spiked with various concentrations of nitrogen (NO_3-N), phosphorus (PO_4-P) and trace elements singly and in different combinations. The concentration of nutrients taken are: low N (0.05 mg l^{-1}), high N (1.0 mg l^{-1}), low P (0.025 mg l^{-1}), high P (0.05 mg l^{-1}), and trace elements at concentrations used in synthetic nutrient medium (US EPA 1971).

The bioassays were carried out in culture tubes (38 x 150 mm) containing 10 ml of test waters and the initial cell density was 10^3 cells ml^{-1} in all the cases. The temperature and light conditions were similar to those used for maintaining the stock cultures. The maximum standing crop of test alga was measured on the 14th day by counting the number of cells in the culture suspension with a haemocytometer (Miller et al. 1978).

The data obtained from bioassay experiments were subjected to ANOVA and least significant difference ($P<0.05$) was calculated to compare the algal biomass obtained after different treatments (Snedecor & Cochran 1967).

5.3 Results

The important physico-chemical characteristics of stream water collected from various sampling stations are depicted in Figs. 3.1 to 3.4. Even though the physico-chemical properties of stream water have earlier been discussed in Chapter 3, a brief description for Nov '88, Mar '89 and Aug '89 months, during which bioassay experiments were carried out, is given hereafter. Streams were found to be acidic (pH <7) (see Fig. 3.1). Marked variations in current velocity could be observed with lowest in Mar '89 than the other two sampling periods (Fig. 3.2). Conductivity exhibited an inverse relationship with flow (Fig. 3.1 and Fig. 3.2). The level of ammonia-nitrogen was higher in Aug (50-95 $\mu g\ l^{-1}$) than Nov (20-25 $\mu g\ l^{-1}$) and Mar (4-10 $\mu g\ l^{-1}$). Soluble-reactive phosphorus varied tremendously during the three samplings (Fig. 3.3). However, nitrate-nitrogen did not vary much in streams throughout the study (Fig. 3.4). Changes of dissolved silica (see Fig. 3.2) were not pronounced. Concentrations of calcium and magnesium fluctuated showing greater value in Nov than Mar and Aug (Fig. 3.4).

Laboratory bioassays showed that phosphorus enrichment to stream water increased the ultimate biomass of S. capricornutum much more effectively than did nitrogen and trace elements (Figs. 5.1 to 5.4). The increase of standing crops were more pronounced by nutrient addition in combination rather than in single treatments. The standing crop did not increase significantly by nitrogen enrichment at two concentrations in the stream water collected from St. 1 (Fig. 5.1). But phosphorus supplementation enhanced the growth in a concentration-dependent fashion. A 0.05 $\mu g\ l^{-1}$ phosphorus was found to be more stimulatory as compared to 0.025 $\mu g\ l^{-1}$. Moreover, a sharp increase in standing crop was observed with combined enrichment of nitrogen and phosphorus reaching almost the level attained by the test alga in the full strength basal medium. Trace element addition did not improve the

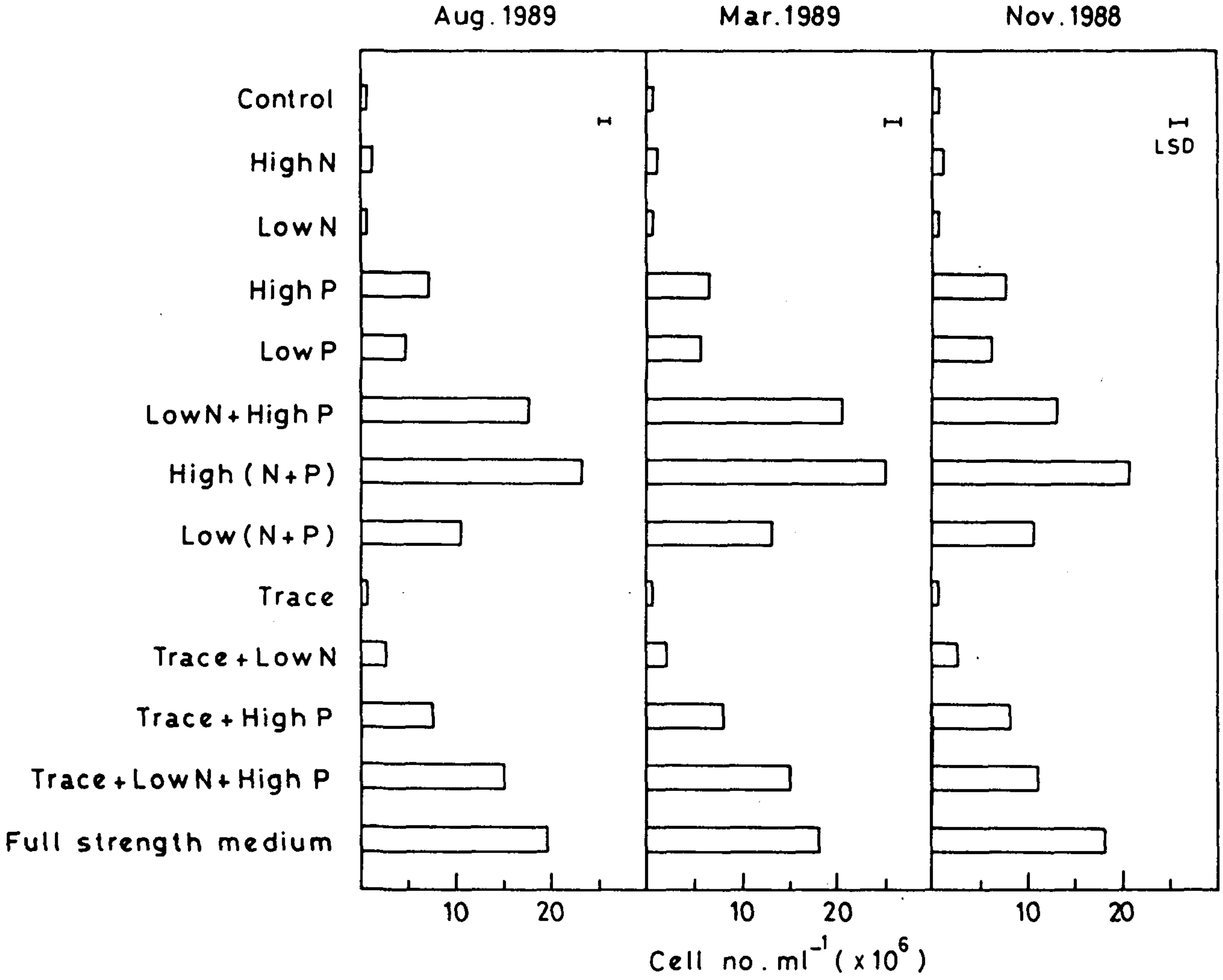

Fig. 5.1 Final standing crop (cell number on the 14th day) of *S. capricornutum* attained in stream water collected from St. 1 and supplemented with different levels of nitrogen, phosphorus and trace elements, singly and in various combinations. See section 5.2 for detailed design of nutrient supplementation. Bar at the upper right of each histogram represents the least significant difference ($P < 0.05$).

growth of the test organism. The growth of S. capricornutum was maximized at 0.05 $\mu g\ l^{-1}$ of phosphorus.

The results of algal bioassay performed with water samples from other stations (see Figs. 5.2, 5.3 and 5.4) exhibited trend matching with that for St. 1. In all the cases phosphorus enrichment to stream water effectively increased the final standing crop of S. capricornutum. Trace element addition did not increase the growth of test organism. At St. 4 nitrogen supplementation increased the final biomass of test organism. However, the limitation of phosphorus was more acute than that of nitrogen.

5.4 Discussion

At all sites, stream water had low levels of nutrients thereby reflecting its oligotrophic nature. In addition, they can be regarded as softwater streams due to extremely low concentrations of calcium and magnesium. The epilithic algal biomass in terms of chlorophyll a generally remained low, but was within the limit (10-50 mg m^{-2}) obtained by Marker (1986) for softwater streams of southern England. He found 200-300 mg chlorophyll a m^{-2} in hardwater streams, and cites a few reports of even much higher levels (300-600 mg m^{-2}) in natural and laboratory streams.

The atomic ratio of nitrogen and phosphorus or Redfield ratio is a powerful criterion for identifying nutrient limitation (Redfield et al. 1963). If the ratio is >16 the water in question is phosphorus limited; conversely, nitrogen limiting conditions occur when the ratio is <16. In the present case, the ratio always remained more than 16 thereby indicating the persistence of

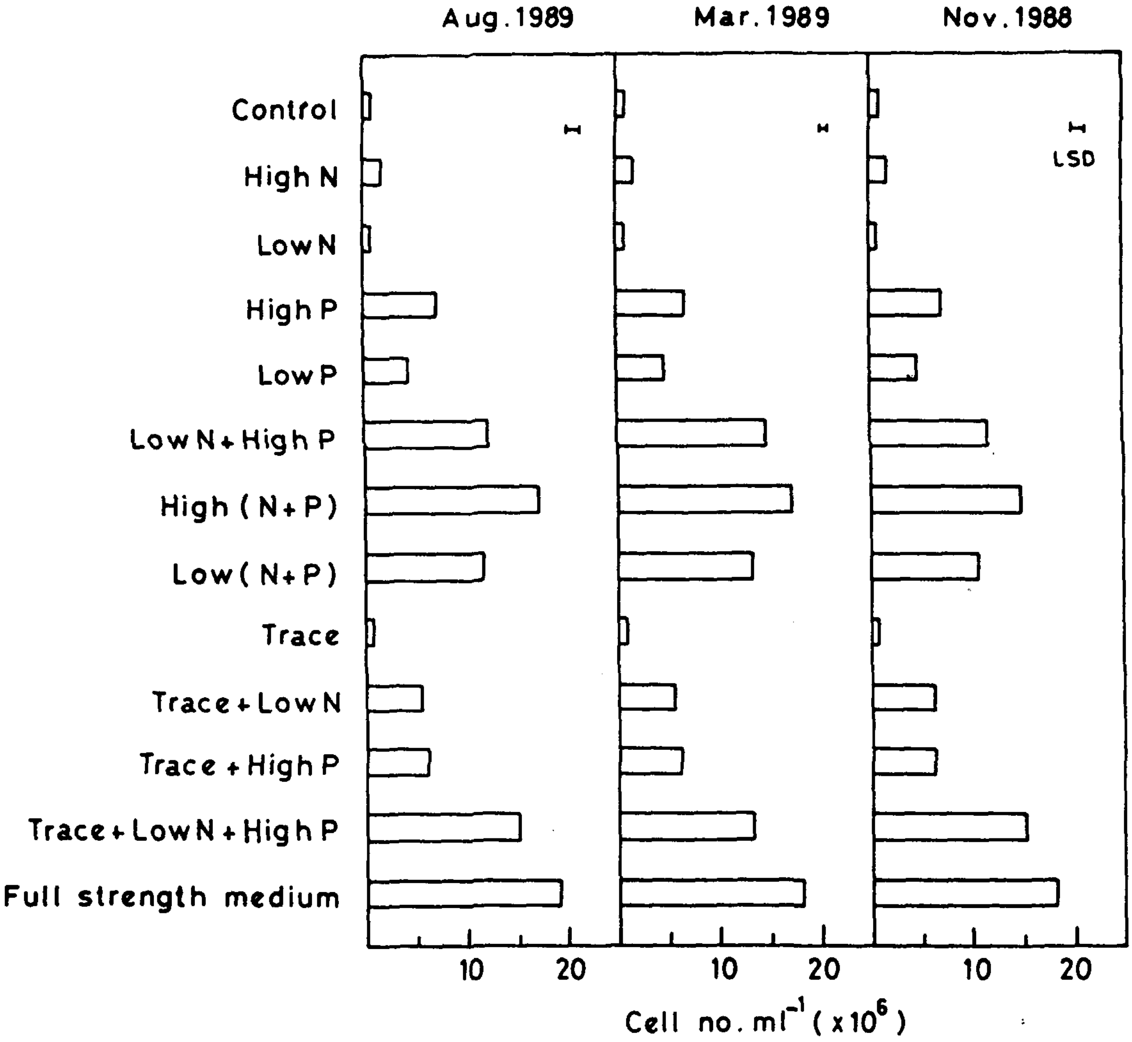

Fig. 5.2 Standing crop of the test alga on the 14th day in stream water from St. 2 after various treatments. The values of least significant difference ($P < 0.05$) have been shown.

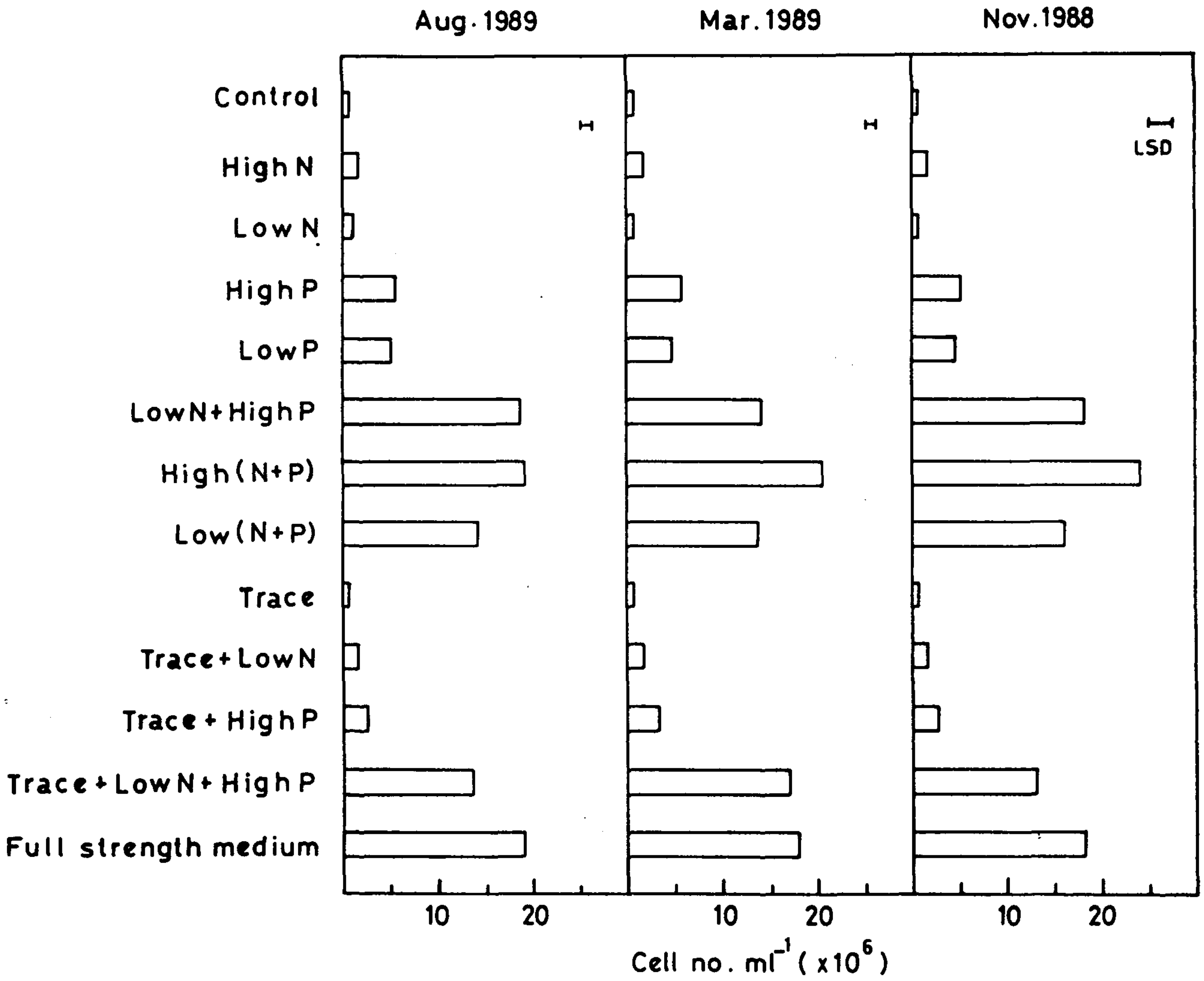

Fig. 5.3 Algal biomass in terms of cell number on the 14th day in water from St. 3 supplemented with different nutrients. Least significant difference ($P < 0.05$) has been shown for each sampling interval.

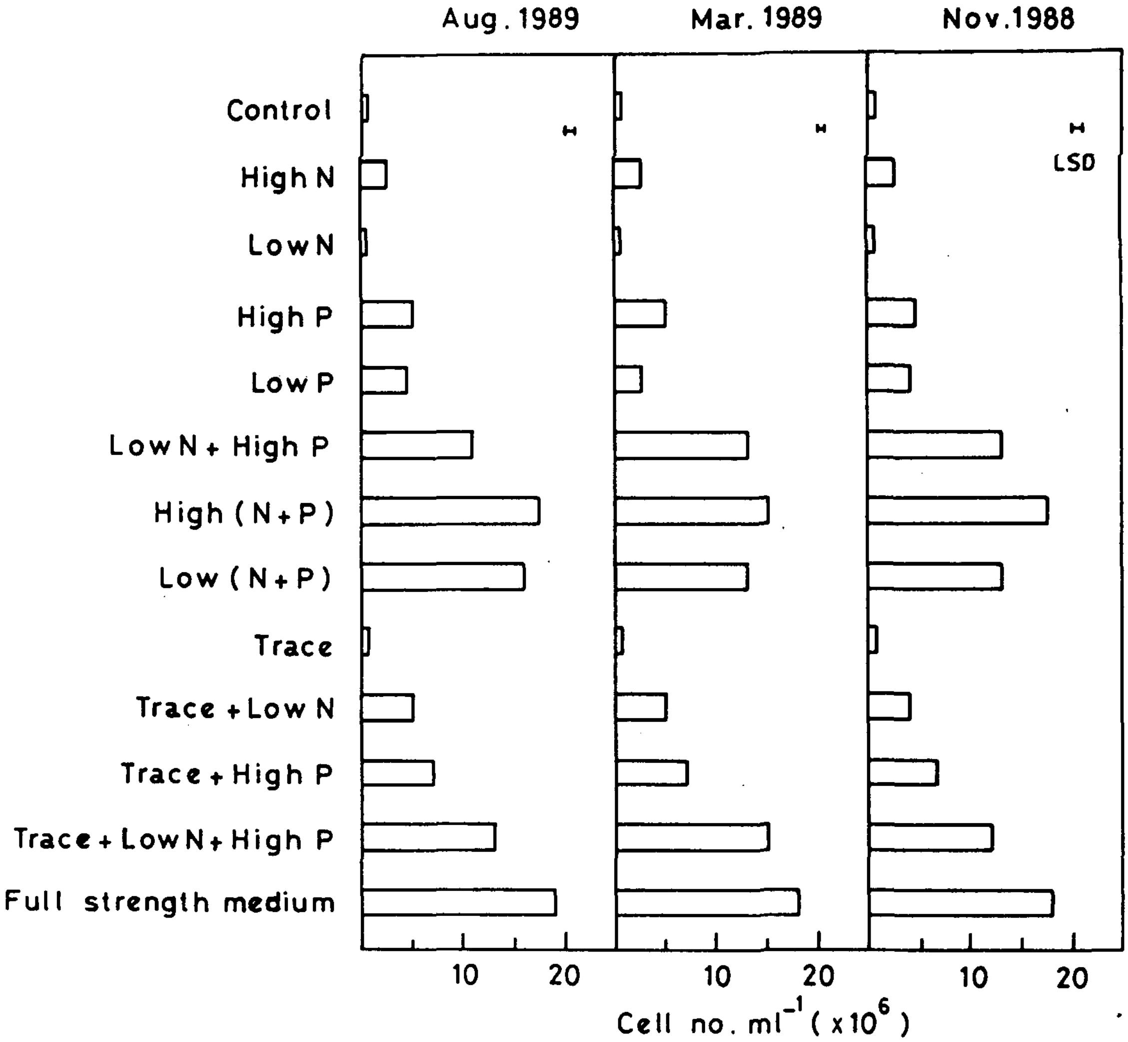

Fig. 5.4 Cell yield of test alga on the 14th day in stream water from St. 4 after various treatments. Least significant difference ($P < 0.05$) has been depicted for each histogram.

phosphorus limiting condition. Algal assay of stream water with _S. capricornutum_ as the test organism reinforces our contention of phosphorus limited algal growth. This situation was encountered at all sites regardless of the sampling interval. Phosphorus limitation has been reported by Stockner & Shortreed (1978), Elwood et al. (1981) and Pringle & Bowers (1984) for the temperate streams of North America. Nitrogen limitation was not very conspicuous except at St. 4. At other sites also, nitrogen supplementation did not stimulate algal growth, if done singly, but, in combination with phosphorus seemed to increase the standing crop of test alga. Algal growth limitation due to nitrogen in some of these cases appears to be secondary in nature. The stream waters possibly have adequate concentrations of trace elements, because their enrichment with trace elements did not enhance the growth of test alga. But, micronutrients have been found to limit algal growth in streams at other places (Wuhrmann & Eichenberger 1975, Pringle et al. 1986).

Welch et al. (1988) suggested that a nuisance biomass of stream algae may be represented by a level greater than 100 to 150 mg chlorophyll _a_ m^{-2}. In selected streams, however, the biomass remained much below the limit proposed by them. One of the reasons for this could be low concentration of soluble reactive phosphorus, which generally remained below the level (7 $\mu g\ l^{-1}$) considered to be saturating for algal growth (Seeley 1986). The present status of nutrients indicates acceptable level of algal biomass in selected streams. However, the streams may face the problems of nutrient enrichment and excessive algal growth if any of the following practices are encouraged: (i) logging in the catchment, (ii) fertilizer application for silvicultural purposes, and (iii) nutrient enrichment of streams for pisciculture. We feel that _S. capricornutum_ can be employed on a regular basis for the biomonitoring of nutrient level in streams.

Chapter 6

INFLUENCE OF LIGHT ON ALGAL COLONIZATION OF ARTIFICIAL SUBSTRATA

6.1 Introduction

Light, in terms of photoperiod and quality (wavelength) as well as intensity, is of paramount importance to algae. In addition to its obvious significance as an energy source for photosynthesis, the fact that light fluctuates tremendously in both space (depth and latitude) and time (daily and seasonally) suggests that light will often be limiting for algal growth. In low order streams of forested watersheds most of the energy that enters the system is allochthonous, derived from surrounding terrestrial vegetation (Vannote et al. 1980). The productivity appears to be light limited in such systems (Whitton 1975, Sumner & Fisher 1979, Gregory 1980, Keithan & Lowe 1985) due mainly to stream side vegetation preventing primary production to exceed community respiration (Fisher & Likens 1973, Vannote et al. 1980). However, under unshaded conditions, low ambient nutrient levels can assume limiting roles for algal growth (Stockner & Shortreed 1978, Hill & Knight 1988).

Compared to lentic systems, researches on the effect of light variations on primary production have been limited in streams. Only a few experiments have directly examined the effect of varied light levels on stream algal assemblages. In a shaded Oregon stream, Gregory (1980) found stimulation of primary production after augmentation of light levels, and Triska et al. (1983) have reported decreased periphytic biomass in experimentally shaded channels of northern Californian stream. Other studies have reported light-induced increase in algal biomass and changes in community structure, often after clear-cutting (Hansmann & Phinney 1973, Murphy & Hall 1981, Webster et al. 1983, Shortreed & Stockner 1983, Lowe et al. 1986). Differences in light energy at the stream bed can generate a spatial distribution of periphyton that is heterogeneous in biomass, taxonomic composition, and productivity (Yount 1956, Parker et al. 1973, Lyford & Gregory 1975, Murphy & Hall 1981, Rounick & Gregory 1981). DeNicola & McIntire (1990) have suggested that in natural streams, periphyton patches are produced by large differences in irradiance which ultimately have a greater effect on periphyton heterogeneity than substratum-induced patches. Moreover, the heterogeneity of algal patches produced by hydrologic differences over a substratum is constrained by irradiance level.

Most of the studies on effect of light have been performed in laboratory streams. Moreover, workers have studied the effect of light in combination with environmental factors like pH (Phinney & McIntire 1965, Keithan & Lowe 1985), temperature (Whitford & Schumacher 1963, Steinman & McIntire 1986), nutrients (Hill & Knight 1988, Stevenson et al. 1991), and current speed (Steinman & McIntire 1986). All the aforementioned works have been carried out in temperate region. Excepting Bothwell et al. (1989) nobody has made an effort to study the effect of light alone on lotic algae. Nevertheless, Bothwell et al. have carried out their study in laboratory streams.

The work presented in this chapter was prompted by the consideration that individual effect of light on algae of natural streams has not been studied so far. This chapter discusses the data obtained from short-term experiments aimed at studying the response of periphytic algae to variations in light conditions. In these experiments, all other conditions were similar for various light treatments.

6.2 Materials and Methods

The study was carried out at St. 4 using glass slides, routinely used in microscopic studies, as the substrata for periphytic colonization and growth under various light regimes. The use of artificial substrata was necessary in order to overcome differences in algal accrual due to tremendous variabilities in surface characteristics of naturally occurring substrata.

Canopy development at this station is comparatively less than other stations. As a consequence, occasional patches of shade over the stream were observed which best suited to the objectives of the experiment. The description of the study site is given in Chapter 2. The study was carried out in the month of Mar '90 during which rain did not occur and the stream maintained a low and constant flow rate. The four light conditions selected for the present work are detailed in Table 6.1. The open area in the streambed where full sunlight impinges was considered as exposed, the microhabitats having the same flow rate but showing different degrees of shading were also selected. The habitats experiencing different light conditions were adjacently located, and all variables, except for light, remained constant at these places.

Measurements of light intensities (in terms of photosynthetically available radiation) were conducted at all the selected habitats. The water samples were collected and various physicochemical characteristics measured following the methodologies described in Chapter 3. The glass-slide substrata were used for the colonization of periphytic algae. Glass microscope slides in triplicate were glued on a glass plate and five sets of such fixed slides were kept in the stream bed horizontally under each of the four light conditions. The substrata were sampled at weekly interval for a period of five weeks, and while transporting these were wrapped carefully with an aluminium foil and rushed immediately to the laboratory. The periphytic algae were scrapped from an area of 4.5 cm^2 with a minimum of three replicates for each estimation. The algal identification, enumeration and chlorophyll estimations were performed according to the methods already described in Chapter 3. The biovolume and amount of chlorophyll a have been expressed on an area basis.

Scanning Electron Microscopy (SEM) was employed to observe the pattern of algal colonization on glass slide substrata placed in exposed and shaded conditions only. The substrata from exposed and shade conditions containing periphytic assemblages were prepared for SEM by cutting each glass slide into several pieces (each 5 mm^2 in surface area). Due care was taken to avoid drying of periphytic algae during cutting. Each piece was immediately fixed in phosphate buffered 2.5% glutaraldehyde solution (pH 7.2). After 2 h they were then transferred to phosphate buffer solution, kept overnight in a refrigerator, and were successively dehydrated in graded acetone series (30, 70, 80, 90, 95 and 99 per cent) for 30 min in each case. Finally, the samples were kept in dehydrated acetone. Then, the samples were subjected to critical point drying and were mounted with adhesive on SEM stubs. These were coated with thermally evaporated gold using a vacuum evaporator and examined with a Jeol 35-CF scanning electron microscope operated at 20 KV. One glass piece from each sample was scanned and appropriate areas of periphytic assemblages were photographed.

6.3 Results

Table 6.1 shows the range of PAR value under four degrees of exposure. The highest value was observed in exposed condition

Table 6.1 Range of photosynthetically active radiation (PAR) under four light conditions.

Condition	PAR (μE m^{-2} s^{-1})
Exposed	320-1930
Partially-shaded	144-860
Partially-exposed	29-170
Shaded	0-10

N.B. PAR was measured at water surface.

with a range of 320-1930 µE m^{-2} s^{-1}; in contrast, the PAR was almost negligible in shaded places. The maximum value in the range was observed at noon hour, whereas the minimum occurred early in the morning or late during the evening. The data for physico-chemical properties of water are given in Table 6.2. The mean water temperature was 14.5°C. The stream water was acidic in nature (pH approx. 7). Water current was moderate and did not allow sediment deposition on the surfaces of substrata. The water contained a high level of silica. The concentration of phosphorus was found to be much lower as compared to nitrogen. The low concentrations of calcium and magnesium were found in the stream water. A total of 35 algal species was encountered in periphytic assemblages on artificial substrata representing 3 groups: Chlorophyta (6 spp.), Cyanophyta (1 sp.) and Bacillariophyta (28 spp.) (Table 6.3). The algal assemblages were dominated mainly by diatoms followed by green filamentous algae. Among diatoms the predominance of <u>Eunotia</u> (9 spp.), <u>Gomphonema</u> (5 spp.) and <u>Navicula</u> (5 spp.) was quite evident. The number of algal taxa was found to be significantly different among various treatments (Fig. 6.1). Twenty-six species occurred on exposed, 20 on partially shaded, 17 on partially exposed, and 11 on shaded substrata during the tenure of the experiment. A progressive increase in species richness occurred with increase in time. After 3 weeks the number of algal species did not show much fluctuations. The periphytic biomass (chlorophyll <u>a</u>) was substantially greater in the exposed condition than others (Fig. 6.2). The maximum value (7.26 mg m^{-2}) was observed on exposed

Table 6.2 Physico-chemical characteristics of water at St. 4 during the course of experiment.

Parameter	Mean ± SD
Temperature (°C)	14.5 ± 0.0
pH	6.06 ± 0.01
Conductivity	413.3 ± 11.5
Flow rate (cm sec^{-1})	32.0 ± 1.7
DO	6.60 ± 0.10
SRP (ug l^{-1})	2.97 ± 0.15
TP	8.43 ± 0.57
NO_3-N (mg l^{-1})	0.73 ± 0.02
NH_4-N (ug l^{-1})	45.0 ± 0.3
Si (mg l^{-1})	11.53 ± 0.31
Ca (mg l^{-1})	0.74 ± 0.07
Mg (mg l^{-1})	0.30 ± 0.02

Table 6.3 List of algal species encountered on artificial substrata.

Chlorophyta

Closterium acerosum (Schrank) Ehr.
Cosmarium bioculatum Bréb.
Hyalotheca dissiliens (J.E. Sm.)
Mougeotia genuflexa (Dillw.) Ag.
Spirogyra communis (Hassal) Kütz.
Zygnema gingeticum Rao

Cyanophyta

Tolypothrix distorta Kütz. ex Born. et Flah.

Bacillariophyta

Achnanthes microcephala (Kütz.) Grun.
Caloneis silicula (Ehr.) Cl.
Eunotia arcus Ehr.
E. exigua (De Bréb.) Rabh.
E. formica (Greg.) Cl.
E. hebridica A°. Berg
E. monodon Ehr.
E. pectinalis (Kütz.) Rabh.
E. praerupta Ehr.
E. rostellata Hust.
E. tenella (Grun.) Hust.
Frustulia vulgaris
Gomphonema gracile Ehr.
G. intricatum Kütz.
G. lanceolatum Ehr.
G. longiceps Ehr.
G. parvulum (Kütz.) Grun.
Navicula cari Ehr.
N. complanatula Hust.
N. cryptocephala Kütz.
N. gracilis Ehr.
N. lanceolata (Ag.) Kütz.
Pinnularia gibba Ehr.
P. interrupta W. Sm.
P. viridis (Nitz.) Ehr.
Synedra acus Kütz.
S. tabulata (Ag.) Kütz.
S. ulna (Nitz.) Ehr.

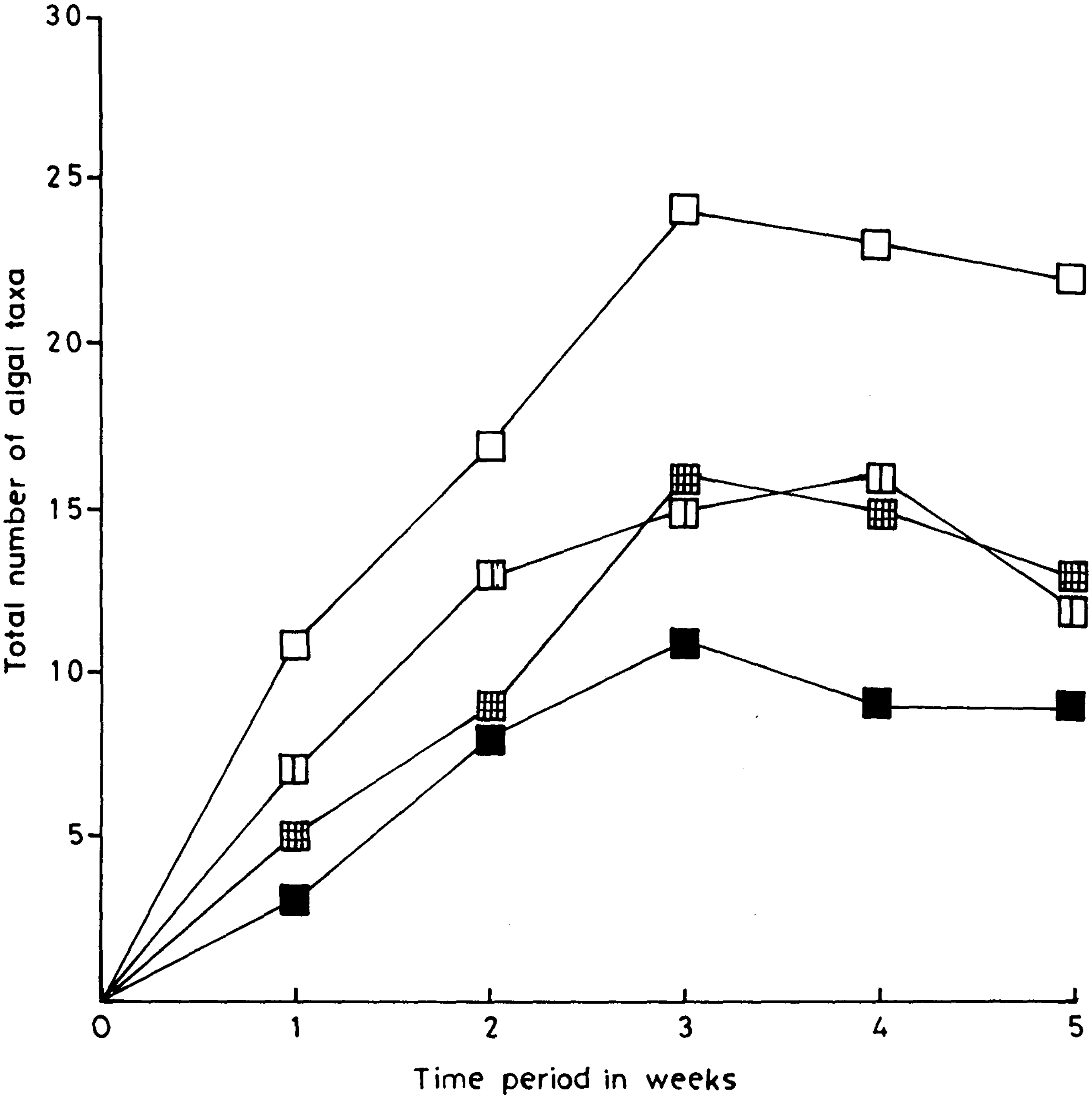

Fig. 6.1 Total number of algal taxa in the periphytic assemblages developing under different light conditions: □ Exposed; ◫ Partially-shaded; ▦ Partially-exposed; and ■ Shaded.

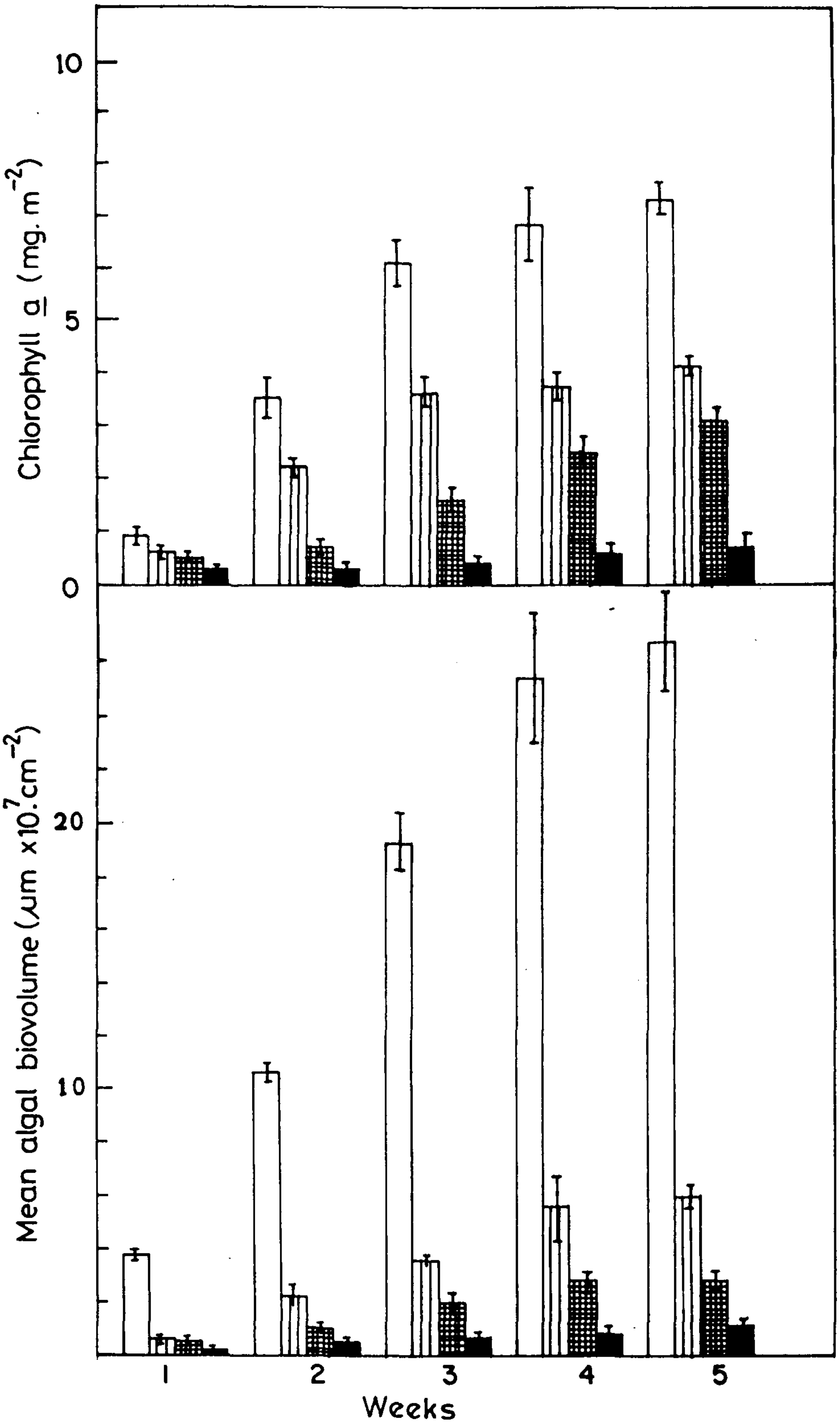

Fig. 6.2 Weekly variations in chlorophyll a concentration (mg m^{-2}) and mean algal biovolume ($\mu m^3 \times 10^7$ cm^{-2}) under four light conditions; ☐ Exposed; ◫ Partially - shaded; ▦ Partially-exposed; and ■ shaded.

substrata in the 5th week, as compared to shaded one, where the value was concomitantly found to be the lowest (0.67 mg m^{-2}). Although periphytic biomass under partially-shaded and partially-exposed conditions were more than under shaded condition, these were considerably lower than the biomass attained under exposed condition. The temporal pattern of increase in biomass was marked in all the light conditions. At the end of the experiment it was found that the amount of chlorophyll a on exposed, partially - shaded, and partially - exposed substrata were respectively 10-fold, 6-fold and 4-fold in comparison to the shaded substratum. The trend observed for total biovolume (Fig. 6.2) was similar to the one already described for chlorophyll a data. Increased periphytic biovolume with increased light availability was pronounced in the assemblage. This consequence was mainly associated with the arrival of certain green filamentous algae like Hyalotheca dissiliens and Zygnema gingeticum (Fig. 6.3). In the later stages, the biovolume showed a conspicuous increase due to greater abundance of Spirogyra communis and a filamentous desmid, Hyalotheca dissiliens. Table 6.4 shows biovolume contribution by the two dominant groups, namely Chlorophyta and Bacillariophyta. The increase in light intensity led to increase in share of green algae to total biovolume. Diatoms dominated the algal assemblages throughout, initially comprising more than 98% of total algal biovolume in shade condition, whereas it was 50% in exposed condition. The dominance of diatoms persisted throughout on shaded substrata. In contrast, a shift of dominance from diatoms to green

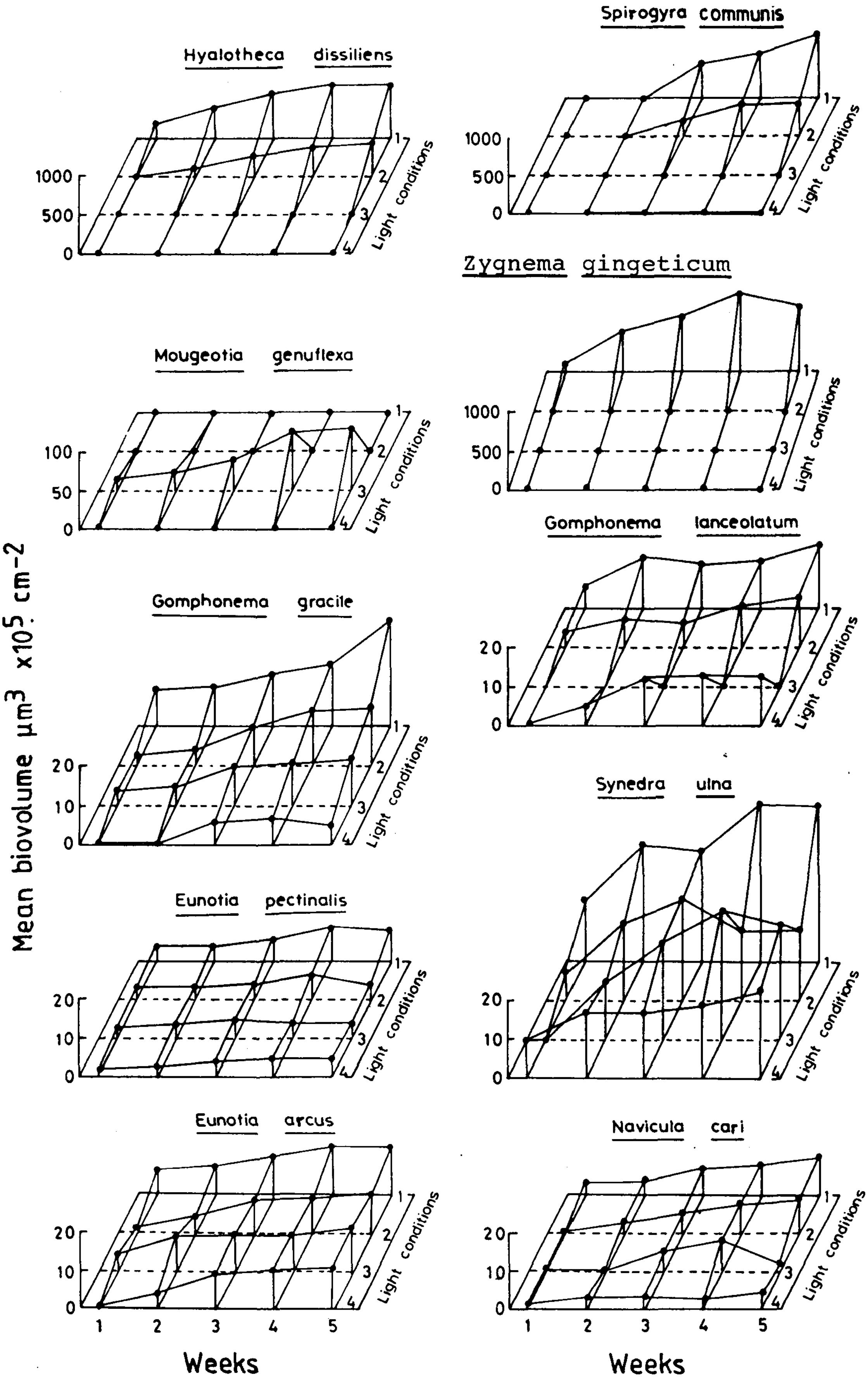

Fig. 6.3 Mean biovolume of the dominant algal species in periphytic algal assemblages developing under different light conditions: 1, exposed; 2, partially-shaded; 3, partially-exposed; 4, shaded.

Table 6.4 Biovolume ($\mu m^3 \times 10^5$ cm^{-2}) contributed by green algae and diatoms towards periphytic assemblages.

Week	Treatments							
	Exposed		Partially-shaded		Partially-exposed		Shaded	
	Green algae	Diatoms	Green algae	Diatoms	Green algae	Diatoms	Green algae	Diatoms
1	335.5*	49.8	28.4	17.4	42.2	15.0	-	13.0
2	952.9	99.3	159.0	65.0	53.0	52.9	80.5	28.3
3	1736.0	180.0	475.4	110.7	84.4	115.4	-	75.7
4	2320.8	207.7	890.2	130.4	153.2	132.9	-	88.5
5	2418.0	257.8	930.0	120.0	-	127.5	-	112.4

*Biovolume ($\mu m^3 \times 10^5$ cm^{-2}).

N.B. Blue-green algae were represented by *Tolypothrix distorta* which occurred after the third week in exposed substrata only, and did not contribute substantially to total biovolume.

filamentous algae was noticed in substrata receiving maximum insolation under exposed condition.

Shaded substrata were not conducive to the growth of any filamentous alga throughout the course of the experiment. Algae like Eunotia arcus, E. pectinalis, Gomphonema gracile, G. lanceolatum and Navicula cari could thrive well under all light conditions. Although Synedra ulna showed its preference for high light, it thrived in other light conditions as well. The green filamentous algae Spirogyra communis, Zygnema gingeticum and Hyalotheca dissiliens showed exclusive likings for exposed and partially-shaded conditions. These algae contributed maximally to the total biovolume whenever they occurred in the assemblage. The weekly similarity of algal assemblages exposed to different light conditions is shown in Table 6.5. Similarity was calculated as described in Chapter 3. The maximum similarity was encountered between communities on exposed and partially-shaded substrata. the similarity between the communities developing under two conditions increased with time. Very less similarity existed between the following pairs: exposed and partially-exposed, exposed and shaded, and partially-shaded and partially-exposed assemblages. The algae in partially-shaded and shaded condition were initially similar, but during the later stages of colonisation their similarity was reduced to a great extent. A reverse trend was seen between the communities on partially-exposed and shaded substrata with low initial similarity followed by increased value after the 3rd week.

Table 6.5 Similarity of algal assemblages between pairs of treatments (1 = exposed, 2 = partially-shaded, 3 = partially-exposed, 4 = shaded).

Week	Pairs of treatments					
	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
1	0.15	0.01	0.07	0.02	0.26	0.03
2	0.56	0.02	0.07	0.06	0.30	0.09
3	0.59	0.01	0.03	0.01	0.08	0.25
4	0.67	0.01	0.03	0.02	0.03	0.15
5	0.78	0.05	0.02	0.07	0.02	0.55

The SEM photographs (Plate IV) show that diatoms were mainly seen during the initial stage of colonization of exposed substrata. The thin populations of diatoms were also evident on glass slides placed in shaded habitats. The growth of filamentous forms became marked in exposed habitat during the later stages of colonization. In shaded habitat the colonization of diatoms showed erect and prostrate forms, whereas the architecture on exposed substrata changed completely with erect and prostrate diatoms along with long dense entangled filamentous masses forming a systematic gradient in the assemblage.

6.4 Discussion

The present study was designed in such a way that the effect of light energy on periphytic colonization could be studied in isolation by keeping the nature of substratum and environmental conditions constant. The number of algal species constituting the periphytic assemblage is considerably lower than the number obtained by other workers using similar substrata (Muntenau & Maly 1981, Stevenson 1984 b, Chessman 1985). This may be an outcome of less diverse pool of algal species in the upstream reaches. Alternatively, many species not preferring glass substrata were perhaps unable to make their appearances. The glass substrata are muuh more smooth than natural rocks, and hence many macroalgae, particularly large filamentous forms (e.g., rhodophytes) fail to appear (Stevenson 1984 b). On the contrary, diatoms do show a liking for glass substrata (Munteanu & Maly 1981, Chessman 1985). Despite inability of many algal

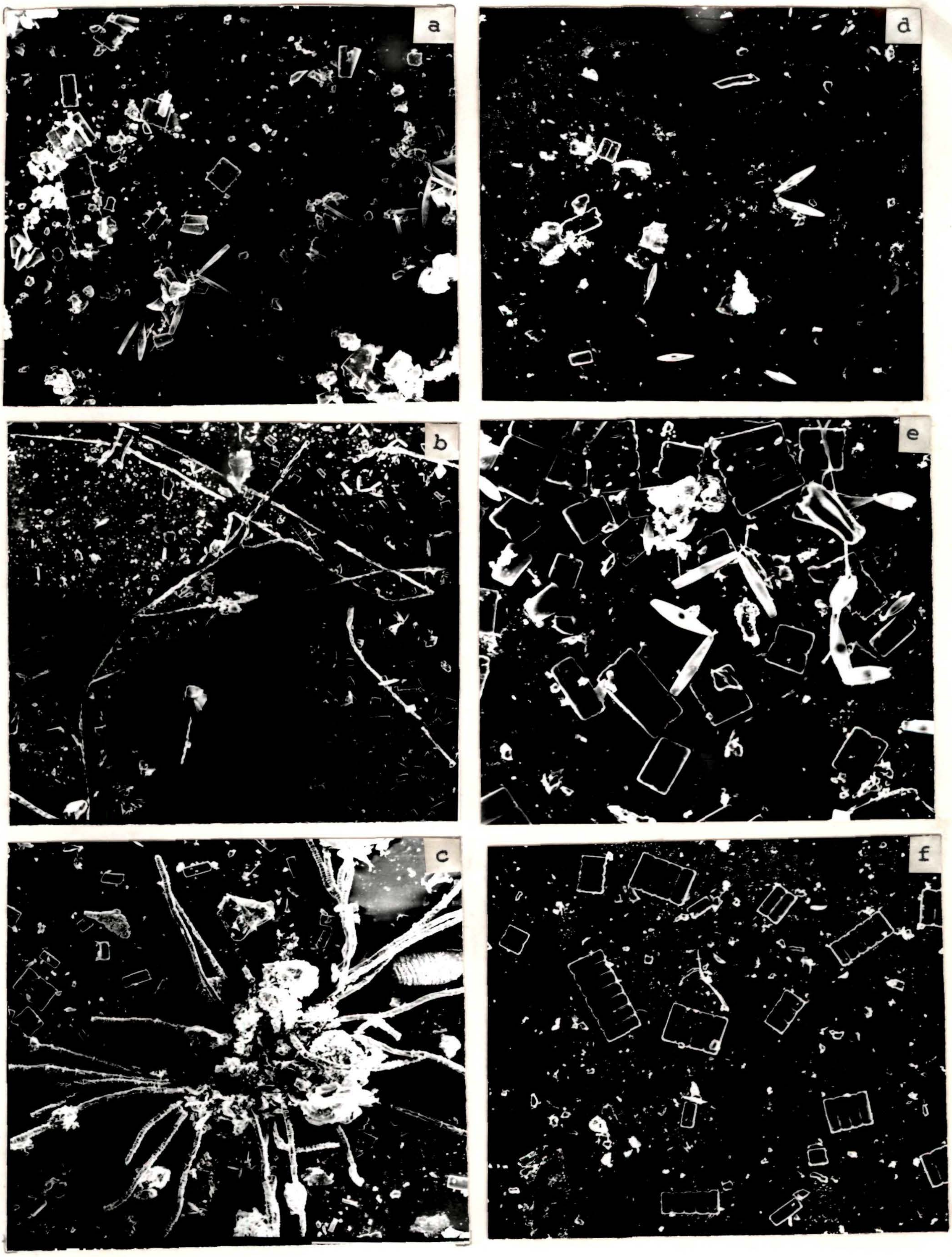

Plate IV SEM of critical point dried preparation of periphytic assemblages that developed on glass slides kept either exposed or shaded at different time periods. Exposed slides: a) 1 wk, x 300; b) 3 wk, x 117; c) 5 wk, x 480. Shaded slides: d) 1 wk, x 300; e) 3 wk, x 990; f) 5 wk, x 300. Note the abundance of filamentous algae in slides kept exposed to light.

species to colonise glass, this substratum is being increasingly used in comparative studies due to ease in sampling and reproducibility (Aloi 1990).

Notwithstanding the appearance of fewer algal species in the periphytic assemblage, the pattern of assemblage development in the present case broadly resembles the observations made by others (Stockner & Shortreed 1978, Rounick & Gregory 1981, Hamilton & Duthie 1984, Keithan & Lowe 1985, Lowe et al. 1986, Sabater 1990). Our results show increase in species number up to the 3rd week, followed by a slight decline. Nevertheless, the biomass showed a marked increase during the 2nd and the 3rd week, followed by a very slight increase during the later part of the community development. Periphytic colonization is a complex process being influenced by immigration of algae on substrata, growth, and emigration from the substrata (Stevenson & Peterson 1989). The increase in algal standing crop up to the 3rd week is on account of (i) immigration as the species richness maintained an increasing trend during this period, (ii) increase in population of different algal species. It is noteworthy that algal immigration onto glass slides took place in dark as well, although to a lesser extent. Light-dependent increase in algal biomass through time is undoubtedly due to increased photosynthesis as well as increase in number of individuals. At higher light intensities, the higher rate of photosynthesis leads to greater production of extracellular polysaccharides (Hellebust 1974), which may increase algal adhesion to surfaces and thus improve immigration efficiency of algal colonisers. Bothwell et al.

(1989) found that many diatoms emigrate from substrata under dark condition. The present work, however, did not show algal emigration from substrata kept in the dark as the species number never decreased. The substrata kept in light, however, did show a slight decline in species number after the 3rd week, due perhaps to emigration of some species which were outcompeted by others.

The algal biomass was maximum in case of substrata kept fully exposed to light. This agrees with other workers who have observed increase in periphytic biomass following increase in light intensity (Blinn et al. 1981, Steinman & McIntire 1987, Hill & Knight 1988, Steinman & McIntire 1989). Apparently high light intensity on substrata kept fully exposed was never photoinhibitory. This does not agrees with Duncan & Blinn (1989) who observed photoinhibition of periphyton growth at high light intensity. Although many diatoms responded positively to light enhancement, green algae were stimulated to a much greater extent. Specific liking of chlorophytes for high light intensities has been observed elsewhere also (Whitford & Schumacher 1963, McIntire 1968, Steinman & McIntire 1986, 1987, Duncan & Blinn 1989). In many of the earlier studies on streams, green algae increased in abundance following the thinning or removal of riparian vegetation (Lyford & Gregory 1975, Gregory 1980, Shortreed & Stockner 1983, Lowe et al. 1986). The requirement of higher light intensities by green algae as compared to diatoms has been related with low pigment diversity in the former (Round 1965).

In conclusion, the patchy distribution of periphytic algae in the bottom of streams traversing forested areas is due inter alia to highly variable light conditions.

Chapter 7

RESPONSE OF STREAM ALGAE TO DESICCATION AND REWETTING

7.1 Introduction

All streams are disturbed to some degree. Disturbance and recovery may be the normal state of affairs in streams where habitats are highly heterogeneous with substrate-specific associations of organisms (Reice 1980). The effect of perturbation will vary from species to species, from one patch to another, and from time to time. Chemical and biological changes accompany due to the changes in water level. At times of low water level, the volume of flow and current rate decline, nutrient depletion is increased, and nutrient replacement is decreased. At certain times, some streams stop flowing, and become converted into a series of pools, and either death or dormancy is imposed on the riffle biota.

During flood the water level rises, its interface and average speed are greatly increased, local currents or riffles change their orientation, and attached algae and other organisms are torn away from substrata. Numerous rocks are transported short distances downstream, and smaller mineral particles are carried in greater abundance. Turbidity increases greatly and water chemistry undergoes marked changes. Although both drying and flooding phenomenon occur frequently in streams, drying as a disturbance has received far less attention from stream researchers than flooding. But similar disruptions of the function, structure and dynamics of stream ecosystems during drought conditions may be envisaged.

A survey of literature reveals that the effect of desiccation has been studied in detail mainly in case of seaweeds (Darley 1982). This aspect has been investigated to some extent in soil algae also (Jones 1977, Trainor 1982, Coxson & Kershaw 1983, Scherer et al. 1984, 1986). Freshwater algae have been, however, studied to a very limited extent with regard to their ability to tolerate drought (Round 1981). Evans (1958, 1959) investigated the survival of pond algae during dry periods. Peterson (1987) compared the desiccation response of lotic diatom communities in sheltered and direct current habitats. He found algae in sheltered habitats to be less resistant to desiccation than those in rigorous flow conditions. Morison & Sheath (1985) found increase in cell wall thickening and shifts in carbon metabolism of a stream alga Klebsormidium rivulare after drying.

This chapter reconnoitres the ability of stream periphyton to withstand short-term desiccation.

7.2 Materials and Methods

The experiment was conducted using algal assemblages on glass slides. The glass substrata (5 replicates for each treatment) were kept in the stream bottom at St. 2 in Apr '91 under identical conditions for a period of four weeks. This duration of exposure has been found to be sufficient for periphytic colonization by different workers (See Aloi 1990), and also observed by us in the preceding experiment (see Chapter 6). After four weeks, the periphytic algae colonised on the glass substrata, as well as the water samples, were brought to the laboratory. Due care was taken so that the algal samples did not dry out during transportation to laboratory. These algal assemblages were used for desiccation experiments. Various physico-chemical analyses of water samples were done according to the methodologies described in Chapter 3. One set of glass slides containing four-week old periphytic assemblages were analysed immediately for various characteristics and another set was kept in sterilised nutrient medium for three days. The four-week old assemblages were desiccated for 6 h, 24 h and 74 h by keeping them in a B.O.D. incubator at 24±1°C and 70 μE m^{-2} s^{-1} light intensity. After which five replicate substrata for each desiccation treatment were utilized for various estimations, and the remainder five replicates were transferred to sterilized nutrient medium (see Chapter 5 for composition of nutrient medium) and kept in optimum condition (24±1°C, PAR 70

$\mu E \ m^{-2} \ s^{-1}$, 14 h light and 10 h dark cycle) to study the recovery of desiccated algae. Periphytic algal growths on glass slides of desiccated as well as rewetted replicates were scrapped from 4.5 cm^2 area and diluted with known amount of sterilized medium. Photosynthetic oxygen evolution of periphytic algae was measured using a Clark-type oxygen electrode (Rank Brothers, Bottisham, Cambridge). The temperature inside the electrode chamber was controlled to 24±0.1°C with a circulating water bath. The reaction vessel received 500 $\mu E \ m^{-2} \ s^{-1}$ illumination at its outer surface. Five ml of algal suspension was taken in the reaction chamber and continuously stirred with a magnetic stirrer. The chlorophyll a and phaeopigment contents were estimated according to Strickland & Parsons (1968) (see Chapter 3). For algal identification and enumeration the methodologies followed are exactly similar to those in Chapter 3. The protein content of periphytic algal samples was determined by the Lowry's method (see Price 1965). Bovin serum albumin was taken as the standard. Carbohydrate content was estimated by the phenol-sulphuric acid method described by Kochert (1978). The standard curve was prepared with known concentrations of glucose solution.

7.3 Results and Discussion

Table 7.1 shows physico-chemical characteristics of stream water during the colonisation experiment. The levels of various nutrients and other characteristics of water were

Table 7.1 Physico-chemical characteristics of stream water during colonization of artificial substrata.

Parameter	Mean ± SD	
Temperature (°C)	14	± 0.0
pH	6.42	± 0.12
Flow rate (cm s^{-1})	26.0	± 2.1
Conductivity (µS cm^{-1})	686.67	± 11.55
NH_4-N (µg l^{-1})	99.33	± 9.87
NO_3-N (mg l^{-1})	0.77	± 0.12
SRP (µg l^{-1})	14.43	± 0.75
TP (µg l^{-1})	27.40	± 0.69
Si (mg l^{-1})	13.53	± 0.12

broadly similar to the data obtained in two year study already discussed in Chapter 3.

The response of periphytic assemblage to desiccation and the process of recovery after rewetting in basal medium have been summarised in Table 7.2. Desiccation led to the decline in number of healthy individuals. With increased duration of desiccation, the number of healthy individuals proportionately decreased. Maximum decline was evident in case of the assemblage desiccated for 72 h. Rehydration of desiccated assemblages led to some recovery. Whereas maximum recovery was seen in case of the substrata desiccated for 6 h, the recovery was rather slight for assemblages air dried for a longer duration. Thus the present study showing the ability of stream algae to withstand desiccation is in consonance with the observations of Evans (1958, 1959) and Hostetter & Hoshaw (1970) for ponds, and Morison & Sheath (1985) and Peterson (1987) for streams. It has been further suggested that the formation of thick-walled spores (akinetes) may enable many algae to withstand drought (Morison & Sheath 1985). The present work however revealed that no spore forming alga colonized glass slide, and those present were able to tolerate the dry period in vegetative phase only. This was obviously the reason why little or no recovery took place in assemblages desiccated for an extended duration.

The concentration of chlorophyll a on the surface of glass substrata declined after desiccation (Table 7.3). However, the

Table 7. 2 Total number of healthy individuals in algal periphyton after various treatments.

S.No.	Treatment	Total number of healthy individuals (x 10^3 cm^{-2})
1.	Four-week old assemblage	62.0±8.5 *
2.	Four-week old assemblage after 6 h desiccation	36.0±6.7
3.	Four-week old assemblage desiccated for 6 h and subsequently kept insterilized nutrient medium for three days	46.0±6.3
4.	Four-week old assemblage after 24 h desiccation	26.0±3.4
5.	Four-week old assemblage desiccated for 24 h and subsequently kept in sterilized nutrient medium for three days	28.0±4.9
6.	Four-week old assemblage after 72 h desiccation	18.0±2.9
7.	Four-week old assemblage desiccated for 72 h and subsequently kept in sterilized nutrient medium for three days.	18.4±2.3

* Mean ± SD.

Table 7.3 Chlorophyll a and phaeopigment concentration, and the rate of photosynthesis of periphytic assemblages after various treatments.

S. No.	Details of algal assemblage/ treatment	Chlorophyll a ($mg\ m^{-2}$)	Phaeopigments ($mg\ m^{-2}$)	Photosynthesis ($\mu M O_2$ evolved mg^{-1} chlorophyll a h^{-1})
1.	Four-week old assemblage	5.1±0.06*	0.33±0.03	434±14.1
2.	Four-week old assemblage after 6 h desiccation	4.8±0.05	0.41±0.01	410±9.9
3.	Four-week old assemblage desiccated for 6 h and subsequently kept in sterilized nutrient medium for three days	5.3±0.04	0.53±0.02	430±7.1
4.	Four-week old assemblage after 24 h desiccation	4.0±0.07	0.42±0.02	388±17.7
5.	Four-week old assemblage desiccated for 24 h subsequently kept in sterilized nutrient medium for three days	4.3±0.06	0.45±0.04	397±13.4
6.	Four-week old assemblage after 72 h desiccation	3.7±0.05	0.48±0.05	233±9.9
7.	Four-week old assemblage desiccated for 72 h and subsequently kept in sterilized nutrient medium for three days	3.6±0.05	0.40±0.03	201±9.9

* Mean ± SD.

assemblages were able to recover when transferred to sterilized nutrient solution. The recovery was maximum for the assemblage desiccated for 6 h. Another important change occurring in desiccated assemblage was increase in level of phaeopigments an indication that desiccation is causing degradation of chlorophyll a. Numerous investigations have found increased levels of phaeopigments in natural algal assemblages, particularly in phytoplankton, under stressed environment (see Round 1981). Decreased levels of chlorophyll have been similarly observed in algal cells after drying (Morison & Sheath 1985). Desiccation lowered the rate of photosynthesis as determined by oxygen evolution method (see Table 7.3). The rate of photosynthesis in periphytic assemblage measured immediately after 6 h desiccation was slightly less than the control. However, when the same assemblage was kept in nutrient solution for three days substantial recovery occurred, and now it showed a photosynthetic rate almost equal to the control. Prolonged desiccation caused greater inhibition of photosynthetic rate. These assemblages did not show pronounced recovery of photosynthetic rate after rewetting. The decline in rate of photosynthesis in periphytic algae subjected to prolonged desiccation could be due to distortion of chloroplasts and disruption of thylakoids (McLean 1968a & b, Poljakoff-Mayber 1981, Morison & Sheath 1985), and/or degradation of water-splitting system and parts of the photosynthetic electron transport (Wiltens et al. 1978).

Desiccation of periphytic assemblage also caused decline in protein content (see Table 7.4). The decrease in the level of protein was related to the duration of desiccation; greater the desiccation period greater was the decrease in protein content. Carbohydrate content slightly rose in case of assemblages subjected to drought. However, after rewetting the concentrations declined reaching the level of the control. In *Klebsormidium rivulare*, Morison & Sheath (1985) similarly observed decline in protein and increase in carbohydrate under drought conditions. They also found increased level of lipids. These changes undoubtedly reflect shifts in metabolic characteristics of desiccated algae. Lipid accumulation has been suggested as one of the mechanisms of drought tolerance in algae (Evans 1958, Poljakoff-Mayber 1981, Morison & Sheath 1985). However, lipid estimation could not be carried out in the present work due to methodological problems.

Table 7.5 shows the response of algae constituting the periphytic assemblage to desiccation. Leaving aside a few exceptions, the diatoms seemed to be more tolerant to drought as compared to green algae. Due to the presence of thicker and more rigid cell wall, diatoms were better able to tolerate desiccation than green algae. Thickened rigid cell walls due to high elastic modulus (ϵ) may confer some desiccation tolerance by allowing smaller changes in cell water content through turgor regulation (Zimmerman 1978). The better ability of diatoms to tolerate drought seems to be one of the reasons

Table 7.4 Protein and carbohydrate content of periphytic algae after various treatments.

S.No.	Treatment	Protein (μg cm^{-2})	Carbohydrate (μg cm^{-2})
1.	Four-week old assemblage	9.31±0.2*	36.9±4.0
2.	Four-week old assemblage after 6 h desiccation	8.5±0.3	40.0±6.0
3.	Four-week old assemblage desiccated for 6 h and subsequently kept in sterilized nutrient medium for three days	9.0±0.2	36.4±2.0
4.	Four-week old assemblage after 24 h desiccation	7.5±0.3	41.3±4.0
5.	Four-week old assemblage desiccated for 24 h and subsequently kept in sterilized nutrient medium for three days	7.9±0.3	38.7±4.0
6.	Four-week old assemblage after 72 h desiccation	5.9±0.3	50.2±6.0
7.	Four-week old assemblage desiccated for 72 h and subsequently kept in sterilized nutrient medium for three days	6.2±0.4	41.3±2.0

*Mean ± SD.

Table 7.5 Response of periphytic algae to desiccation and subsequent recovery.

Species	Relative abundance (%) before desiccation	% decrease in number of healthy individuals after desiccation for different time periods (% recovery after rewetting)		
		6 h	24 h	72 h
Closterium acerosum	3.2	100 (0)	-	-
Cymbella cymbiliformis	4.8	33.3 (0)	66.7 (0)	100 (0)
C. hungarica	3.2	100 (0)	-	-
Eunotia pectinalis	6.5	12.5 (0)	25.0 (0)	100 (0)
Gomphonema gracile	13.0	31.3 (120.0)	50.0 (12.5)	56.3 (12.5)
G. intricatum	4.8	16.7 (200.0)	33.3 (50.0)	66.7 (25.0)
G. lanceolatum	6.5	37.5 (33.3)	50.0 (0)	75.0 (0)
Hormidium subtile	4.8	66.7 (0)	100 (0)	-
Microspora stagnorum	1.6	100 (0)	-	-
Navicula cari	11.3	28.6 (100)	42.9 (33.3)	42.9 (0)
N. cryptocephala	9.7	50.0 (16.7)	58.3 (12.5)	66.7 (0)
N. exigua	3.2	25.0 (200.0)	50.0 (100.0)	50.0 (50.0)
N. gracilis	4.8	16.7 (0)	66.7 (0)	66.7 (0)
Oedegonium curtum	1.6	100 (0)	-	-
Pinnularia gibba	8.1	40.0 (75.0)	50.0 (20.0)	50.0 (0)
P. interrupta	3.2	100 (0)	-	-
Spirogyra communis	3.2	50 (0)	100 (0)	-
Synedra ulna	6.5	25.0 (200.0)	25.0 (50.0)	50.0 (25.0)

N.B. The recovery of desiccated *G. gracile*, *G. intricatum*, *N. exigua* and *S. ulna* after rewetting increased their populations more than the levels before desiccation. Hence, the percent recovery values exceeded 100%.

for their abundance in streams which show tremendous fluctuations in water level on short as well as long-term basis.

Although the present study demonstrates the ability of stream periphyton to withstand desiccation, more efforts are needed to elucidate the mechanisms of tolerance to drought in different algal groups. The periods of desiccation and recovery longer than the ones taken for the present work and extending several weeks or months should be taken to have a more clear understanding of this important aspect of stream algae.

Chapter 8 GENERAL DISCUSSION

The present study involved the measurements of structural characteristics of epilithic and epipelic algal communities in relation to physico-chemical characteristics of water in two streams traversing forested areas. These streams were found to be mildly acidic, softwater due to low concentrationsof calcium and magnesium, and have low concentrations of nitrogen and phosphorus. These characteristics seem to be on account of the presence of highly leached and nutrient impoverished lateritic soil in the catchment (Singh 1990). The persistence of high levels of silica in stream water is due to the predominance of silica-rich rocks in the stream bottom. The concentrations of nutrient ions generally showed inverse relationships with flow rate, a trend matching with the observations of other workers (Mosley & Rowe 1981, Howard-

Williams et al. 1986, Biggs & Close 1989). During the spring, the concentration of nutrient ions slightly increased due to extremely low flow rate.

The epilithic and epipelic algal assemblages of the selected streams show broad compositional similarity with similar assemblages of temperate streams. Both of the assemblages were dominated by diatoms (121 spp. in the epilithon and 102 spp. in the epipelon). The members of Chlorophyta, Cyanophyta and Rhodophyta were also important to the epilithon, whereas the last division was poorly represented in the epipelon. Most of the algal species observed by us have been reported from streams at other places (Marker 1976, Moore 1977a, Ennis & Albright 1982, Rushforth et al. 1986, Hamilton & Duthie 1987, Steinman & Lamberti 1988). Whereas the epilithon was dominated by algae firmly attached to rock surfaces, the epipelon was dominated by motile species. Motility offers a distinct advantage to epipelic algae in better utilization of solar radiation for photosynthesis, and avoiding burial in continuing sediment deposition (Darley 1982). Surirella species, well known for their movement capabilities (Round 1964), were restricted to the epipelon. It should however not be taken that motile algae were restricted to the epipelon. The epilithic assemblage often contained a good representation of motile forms which seem to have been possibly derived from the epipelon. The presence of large number of taxa common to epipelic and epilithic assemblages suggests a lot of intermixing between the two assemblages.

Rainy season was most unfavourable to a majority of epilithic and epipelic algal species due to prevailing fast water current. However, some algae (*Cylindrocapsa conferta*, *Synedra ulna*, *Navicula mutica*, *Frustulia jogensis*, *Nitzschia angustatum*, *Gomphonema intricatum*, *Pinnularia major*) were particularly resistant to high flow rates. Water current has been found to be extremely important to stream algae as it continuously replenishes nutrient supply around stream algae besides maintaining a high level of gases (oxygen, carbon dioxide) needed for the metabolic machinery of these organisms (Hynes 1970). In fact, many freshwater rhodophytes show highly specific requirements for flow condition (Sheath 1984). The periods of high flow rate were characterised by algal assemblages with low species richness, diversity and biomass due mainly to abrasive action of water current (see Gumtow 1955, Moore 1977a, Biggs & Close 1989, Duncan & Blinn 1989). Both assemblages were equally susceptible to high water current. Whereas high flow rate stressed the epilithic algae in a rather direct manner, the epipelic algae were hampered due mainly to displacement/transportation of sediment particles. As the rainy season came to an end, water current declined and regrowth of algal epilithon took place. Although the effect of water current on stream algae has not been studied in the present case, limited efforts were made to assess the ability of stream periphyton to withstand desiccation as water current fluctuates tremendously in streams particularly during the rainy season. The periphytic community was capable of tolerating short-term desiccation; however, greater the period of desiccation, lesser was the extent of recovery. In comparison to green algae, diatoms were found to be more tolerant to desiccation due mainly to the fact that they have thickened rigid cell wall which allows only minor changes in cell water content through turgor regulation (Zimmerman 1978).

Of the various nutrients, silica occurred at concentrations high enough to saturate the growth of diatoms (Kilham 1975). The high atomic ratio of nitrogen:phosphorus in stream water is suggestive of phosphorus limitation of epilithic algae. This is obviously one of the reasons for the presence of low epilithic biomass (5-54 mg chlorophyll a m^{-2}) which is much below the level (100-150 mg chlorophyll a m^{-2}, Welch et al. 1980) considered to be a nuisance. Laboratory bioassay of stream water with Selenastrum capricornutum as the test organism reconfirmed phosphorus limiting condition as addition of this particular nutrient to stream water much more effectively increased the final standing crop in comparison to nitrogen or trace element supplementation. In the present work sediment was not analysed for various nutrients, hence it is difficult to elaborate nutrient-epipelon relationships since epipelic algae are known to derive their nutrients from sediment as well as water (Darley 1982).

The growth of periphytic algae in streams passing through forested areas is often limited due to low availability of light. Augmentation of light level has been found to considerably increase periphytic growth in laboratory streams (Bothwell et al. 1989), and natural streams after thinning or removal of forest cover (Hansman & Phinney 1973 , Lyford & Gregory 1975, Gregory 1980, Lowe et al. 1986). The present study showed greater species richness, total algal biovolume in the epilithon as well as in the epipelon at St. 2 and 4 in comparison to St. 1 and 3, respectively, due mainly to greater amount of solar radiation. Moreover, the contribution of green algae, well known for their high light requirement (McIntire 1968, Steinman & McIntire 1987, Duncan & Blinn 1989), to algal biovolume was considerably higher at St. 2 and 4 than St. 1 and 3, respectively. The spring maxima of stream algae could also be explained in terms of increased light intensity as well as photoperiod. Short-term experiments on the effect of light did show stimulatory effect of higher intensities of light. Although stream ecologists have often found difficulty in distinguishing the effect of light from the effect of temperature (see Hynes 1970), the short-term experiment did explicitly demonstrate stimulation of periphytic colonization on substrata kept in full light than the substrata shaded to different degrees under similar temperature condition. Contrary to Duncan & Blinn (1989), no photoinhibitory effect of high light intensity was evident on algae of the selected streams.

A majority of dominant species in the epipelon and the epilithon existed throughout the year, although their population size showed temporal changes. Very rarely did the commoner species disappear from the community. This particular tendency is unlike phytoplankton where species build up and disappear during succession (Hutchinson 1967, Round 1971). Vannote et al. (1980) believe that the term "biological succession" with its sequence of discrete successional stages may be obsolete for lotic systems. They further suggest the existence of a "continuous heritage" of species where the total absence of a population is rare, and the abundances of species merely shift along a temporal or spatial axis. The present study thus supports the hypothesis of Vannote et al. (1980). The seasonal cycle of algae in selected streams could be summarised as the best development during late winter/spring and least during the rainy season. Undoubtedly, the rainy season was most inimical to stream algae as it led to very high flow rate. With the advancement of rainy season, species richness, biomass and diversity declined and the algal assemblages showed poor structural organisation. Improvements in structural characteristics of algal assemblages took place in the autumn reaching peak during late winter/spring period. The late winter/spring maxima of algal biomass is similar to temperate streams (Marker 1976, Moore 1977a, Holmes & Whitton 1981, Duncan & Blinn 1989, Sabater 1990), however, the winter minima often seen in temperate streams (Flemer 1970, Lyford & Gregory 1975, Rounick & Gregory 1981, Stockner & Shortreed 1976) did not occur in selected streams as winter temperature here are much higher than the temperate streams.

SUMMARY

Studies on epilithic algae and physico-chemical characteristics of water were carried out for a period of two years in two third-order streams draining forested catchments. Two stations, one upstream and the other downstream, approximately 1 km apart, were selected for regular sampling. The up- and downstream stations of Wah Dienglieng stream have been referred to as St. 1 and St. 2, respectively, whereas St. 3 and St. 4 are the up- and downstream reaches of Wah Risa. In spite of a well developed riparian vegetation, nearly 30-40% and 75-80% area of the stream bed is exposed at St. 1 and St. 2, respectively. Similarly, St. 3 is exposed 40-45%, whereas nearly 80-90% of the streambed is exposed at St. 4. The streams were found to be softwater due to low levels of calcium and magnesium and slightly acidic as pH always remained <7. The level of silica in stream water always remained markedly high. The high concentration of silica is on account of predominance of silica-rich rocks in the stream bottom. Excepting silica, all other nutrients occurred at low concentrations indicating oligotrophic nature of streams. However, their concentrations were slightly greater in the spring as compared to other time periods. Three physiognomic forms, namely, encrusting, filamentous flocs and filaments, of epilithic algal assemblages were evident of which the encrusting form was the most abundant. The epilithic community was composed of 97-108 algal species at different stations. Diatoms were found to be dominant in the epilithon of studied streams when species number was considered. On the other hand, when biovolume values were taken into account the filamentous algae were found to contribute maximally. Among diatoms, species like *Caloneis silicula*, *Eunotia pectinalis*, *Gomphonema gracile*, *G. lanceolatum*, *Navicula cari*, *N. complanatula*, *N. gracilis*, *Pinnularia gibba*, *P. interrupta*, *Synedra acus* and *S. ulna* were abundantly found in these streams. Blue-green algae occurred abundantly at upstream stations (St. 1 and St. 3), whereas the profuse growth of chlorophytes occurred at St. 2 and St. 4. This shift from blue-green to green algae was found to be associated with augmentation of light availability at St. 2 and St. 4. The rhodophyte *Audouinella violacea* occurred more abundantly at shaded sites (St. 1 and 3) than other stations. The period late winter/spring was the most favourable time for algal growth. The number of epilithic algal species, their number of individuals as well as the biomass showed increase during the spring. The algal epilithon was found to be more diverse during the spring months. In order to understand species-environment relationships, the most recent method of multivariate analysis called canonical correspondence analysis (CCA) was employed. CCA showed that water current is the most important variable regulating the structure of the epilithon in streams. Majority of ions were found to be negatively correlated with flow. CCA showed that most of the green algae were stimulated by increased level of phosphorus. Seasonal changes in the epilithic assemblage of the streams sampled seem to have been caused mainly by the variations in flow rate and changes in other factors had exerted a relatively minor influence.

The study of epipelic algal assemblages was conducted for a period of one year only. The algal composition was found to be broadly similar to epilithic assemblages. Diatoms dominated the assemblage. The dominant genera observed at various stations are Caloneis, Eunotia, Gomphonema, Navicula, Nitzschia, Pinnularia and Synedra. The algal abundance was affected by variations in flow conditions. During rainy season the reduced epipelic algal flora in the stream bottom was quite evident. The species diversity and evenness were maximum in the spring months. Cluster analysis based on similarity (SIMI) index showed the winter and spring samples to be more similar. The higher biovolume during the autumn was mainly associated with the availability of certain filamentous algae in the assemblage. Another peak of epipelic biovolume obtained in the spring is similar to temperate streams. The presence of some large-sized diatoms like Surirella spp. and Stauroneis phoenicenteron sometimes enhanced the algal biovolume to a great extent. CCA showed that flow is the most important factor controlling the abundance of epipelic algae in these streams.

Laboratory bioassay of stream water showed that the supplementation of phosphorus singly or in combination with nitrogen enhanced the growth of test alga, Selenastrum capricornutum, to a significant extent. This reflects phosphorus limitation of algal growth in these streams.

The effect of various light conditions on the growth of periphytic algae revealed that higher light intensities supported higher algal abundance. The number of algal taxa was found to be significantly different among various light conditions (26, on exposed; 20, on partially-shaded; 17, on partially-exposed, and 11 on shaded substrata). Chlorophyll a and mean algal biovolume were substantially greater in the exposed condition than others. The growths of green filamentous algae were more pronounced at high light intensity than in low light or shaded habitats. Algae like *Hyalotheca dissiliens*, *Spirogyra communis*, *Zygnema gingeticum* and *Synedra ulna* responded positively to high light intensity.

A short-term experiment on desiccation showed the tolerance of some periphytic algae, particularly diatoms, to desiccation. During desiccation, periphytic algae showed a decline in level of chlorophyll a and protein, whereas carbohydrates and phaeopigments showed an increase. Rewetting of desiccated algae led to recovery which depended on the duration of desiccation period.

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APPENDIX

List of Papers Published

Rout, J. & J.P. Gaur, 1990. Comparative assessment of line transect and point intercept methods for stream periphyton. Arch. Hydrobiol. 119: 293-298.

Rout, J. & J.P. Gaur, 1990. Identification of nutrient-limited algal growth in two streams of Shillong (India). Acta Oecologica 11: 1-14.