ALGAL ECOLOGY OF TWO STREAMS DRAINING DEFORESTED CATCHMENTS AT SHILLONG

By

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I certify that the thesis entitled "Algal Ecology of Two Streams Draining Deforested catchments at Shillong", submitted by Miss Mita Ghosh Hazra, 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.

Signature of the Supervisor

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Preface

Algae contribute significantly towards primary production of streams. Unfortunately, stream algae have not been studied as extensively as the phytoplankton of lakes. The poor state of knowledge on stream algae is due inter alia to unstable nature of the habitat, difficulties in sampling due to extremely patchy distribution, and unavailability of proper methods for the sampling and study of stream algal communities. During the last two decades, substantial progress has been made in refining the methods for the sampling and study of stream algae. Improvements in methodologies have led to a surge in interest on stream algae. Although streams of North America and Europe have been studied in some detail, similar efforts in the tropical region are virtually insignificant. The present work was prompted by the consideration that algal ecology of Indian streams has remained a neglected area of research till now.

This dissertation has been divided into eight chapters. The current status of the subject and the justification of the present work are given in 'General Introduction' (Chapter 1). The second chapter describes the study area. Detailed studies on algal epilithon in relation to physico-chemical characteristics of stream water carried out for a period of two years are presented in Chapter 3. The next chapter deals with similar studies on epipelic and epiphytic algal assemblages. Chapter 5 describes laboratory bioassays carried out to identify nutrient limitation in selected streams. Short-term studies were performed to assess the impact of water current on structural characteristics of periphytic algal assemblages (Chapter 6). Chapter 7 describes experiments carried out in situ to see the response of periphytic community to nutrient enrichment. 'General Discussion' constitutes the last chapter of this dissertation, and is followed by a Summary and list of references cited in the text.

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Mita Ghosh Hazra
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Chapter 1

GENERAL INTRODUCTION

The mention of streams conjures up the vision of tumbling, turbulent ribbons of crystal clear water ruled by trout (Cummins 1977). All streams belong to rivers. The large network of small streams coalesce to larger and larger streams that are, in turn, collected by rivers. This arrangement can be described by a numerical ordering system: the smallest streams are of order 1, the streams receiving first order tributaries are assigned order 2, the streams formed by the confluence of second order streams represent order 3, and so on (Hynes 1970). Depending on stream size, Vannote et al. (1980) have grouped lotic waters into headwaters (orders 1-3), medium-sized streams (4-6), and large rivers (order>6). A variety of aquatic organisms find in streams a healthy life support system. Streams serve as a source of water for various human demands. They provide harvestable fish populations, maintain biological and genetic diversity for future generation and help control the flux of nutrients from lands to lakes and seas (Peterson 1987). In hilly regions, streams are a major source of potable water to inhabiting human populations. In many parts of the world where water is surplus, the overwhelming view of streams has been simply as conduits to either remove water from agricultural lands, to carry away effluents, or to impound for hydroelectric power.

The last two decades have witnessed a surge in ecological studies on lotic waters (Lock & Williams 1981, Barnes & Minshall 1983, Fontaine & Bartell 1983, Statzner 1987, Winterbourn 1987). These studies have been mainly carried out in headwater streams and small rivers due to ease in sampling and lesser influence of man on these systems (Cummins 1975). Although monitoring type studies on larger rivers have increased due to their ever-increasing contamination with anthropogenic chemicals, basic research has remained confined to smaller streams. Advancements in streams ecology have led to the propagation of many new concepts, the most important of which regards streams as organic processing systems (Cummins 1974, Boling et al. 1974). A lot of interest has been generated regarding the processing of terrestrial litter (allochthonous organic matter) in stream ecosystems (Minshall et al. 1985). Moreover, the significance of stream-land linkage has also been realized (Hynes 1975). In any river system a continuous gradient of physical conditions could be seen from headwaters to mouth. In all probabilities, this gradient elicits a series of responses within the constituent populations resulting in continuum of biotic adjustments and regular patterns of loading, transport and utilization of organic matter along the length of a river.

Many of the thoughts given in the preceding paragraph have been synthesized into the 'River Continuum Concept' (abbrev. RCC) which was first proposed by Vannote et al. (1980). This concept views streams as longitudinally-linked systems in which the physical variables (e.g., width, depth, velocity, etc.) display a continuum of gradient. In headwaters, shading from a closed tree canopy coupled with large inputs of allochthonous (dissolved and particulate) organic matter form a system in which respiration exceeds photosynthesis. As the stream channel widens several changes take place: the tree canopy separates, allochthonous input decreases and light availability and temperature of stream water increase. A shift in metabolism from heterotrophy to autotrophy occurs, producing systems in which photosynthesis predominates.

The movement of various nutrients in a stream is related to their downstream transport. Nutrients regenerated at one point in a stream are transported downstream before subsequent reutilization. Webster (1975) introduced the term 'spiraling' to describe the joint processes of cycling and transport. The nutrient atom while moving downstream cycles several times through the same component of the ecosystem, each time being displaced downstream from the last, thus tracing a spiral or a helical pathway through the ecosystem. Nutrient spiraling in streams has been studied with regard to phosphorus using its radioactive isotope (^{32}P) (Ball & Hooper 1963, Elwood & Nelson 1972, Newbold et al. 1981). Carbon spiraling is however difficult to measure because cabon dioxide is directly exchanged across the air-water interface. It may be released to the atmosphere instead of spiraling downstream. The organic carbon may be produced within the system or may enter from terrestrial sources. From the time of its entry, organic matter moves downstream through a number of ecosystem compartments before becoming oxidized. For example, carbon atom in an inorganic form in the water column may be assimilated by a sessile alga through photosynthesis, released and transported downstream as dissolved organic carbon and reincorporated heterotrophically by an attached bacterium. In doing so, the path of the atom may be linkened to a spiral (Webster & Pattern 1979).

Deviations in regional and local conditions such as climate and geology, tributaries and related influences, and geomorphology suggest that adjustments need to be made in RCC if it is to be applied across biomes, and when environmental extremes or unusual situations are involved. Winterbourn et al. (1981) could not find macroinvertebrate shredders in some headwater streams of New Zealand and questioned the validity of the RCC. However, the processing of organic matter cannot be viewed in isolation. The macroinvertebrate shredders are absent if coarse particulate organic matter is inadequate, and they are often replaced by other size-reducing mechanisms like microbes, beaver, physical fragmentation (see Minshall et al. 1985). Abnormal factors, such as, the entrance of geothermal waters or acid rains may eliminate certain components of the community. Since stream ecosystem dynamics is closely linked to the fluvial geomorphic conditions, these should also be considered. Therefore, samples should be taken in such a manner that the mean of characteristic geomorphic conditions are represented. Despite minor discrepancies, enough evidences are lacking to invalidate the RCC, and these variations can be regarded as exceptions on a larger scale.

Prior to surge in interests on allochthonous organic matter processing in streams, considerable emphasis had been laid on algae and other primary producers (Butcher 1932, 1933, 1940, 1946, Gumtow 1955, Blum 1957, Douglas 1958), and their role in stream food chains (Percival & Whitehead 1929, Jones 1950). However, emphasis on the dynamics of allochthonous carbon had become so great that the significance of autotrophy in stream ecosystems had been virtually ignored. By mid-1970's, ecologists started studying streams outside forested areas (Minshall et al. 1985), and the significance of algae and other autotrophic organisms was once again realized. In general, heavily-shaded streams are heterotrophic, with the ratio of gross primary productivity (P) to community respiration (R) $<$ 1. Under these conditions the main source of organic carbon is allochthonous. Autochthonous organic matter produced by algae and other photosynthetic organisms does not play an important role in streams heavily shaded with riparian vegetation. All streams shift from heterotrophy to autotrophy with reduction in shading (Minshall 1978). In deciduous forests and some coniferous forests the transition occurs at order 3. At higher elevations or in xeric condition this shift may occur at order 1. Even in the absence of riparian vegetation, streams may show heterotrophy due to side slope ("canyon") shading (see Minshall et al. 1985).

The production of autochthonous organic carbon in fast-flowing streams is mainly carried out by algae, though other primary producers (e.g., bryophytes, angiosperms) also make small contributions. In streams, attached algae predominante because continuous flow of water normally does not allow a true phytoplankton, i.e., community to thrive.

Attached algae have been variously referred to as the periphyton, or by a German word 'Aufwuchs', often used without capital A (Hynes 1970). The periphytic assemblages of streams consist of microscopic algae as well as large filaments and other kinds of macroalgae. Microalgal flora of streams consists of diatoms, desmids, and coccoidal algae. Stream macroalgae belong to Rhodophyta (e.g. *Lemanea*, *Hildenbrandia*, *Batrachospermum*), Chlorophyta (e.g. *Stigeoclonium*, *Cladophora*, *Oedogonium*), Chrysophyta (*Vaucheria* and *Hydrurus*) and Cyanophyta (*Oscillatoria*, *Phormidium*) (see Hynes 1970, Round 1981). A large number of commoner species appear to be world-wide in distribution (see Hynes 1970). Nevertheless, large areas of earth still remain unexplored, and according to Statzner (1987) no lotic system exists for which a complete list of species has been elaborated. Gessner (1955) postulated that many algal species are probably confined to the tropical region. Hynes (1970) suggested that most of the species are available at all times; they flourish when conditions are favourable, and many are simple opportunists.

Stream algae are firmly attached to various kinds of substrata: rocks (epilithic algae), other plants (epiphytic algae), and sand particles lying in the upper layer of sediment (epipsammic algae). The sediment also contains unattached and generally motile algae referred to as the epipelon. Some algae are found attached to the surfaces of animals; such forms are referred to as the epizoon. In general, the ecological significance of epilithic algae is much more than of any other type of stream algae.

Stream algae are subjected to a constant flow of water. The continuous flow of water not only maintains a regular supply of nutrients, but ensures the removal of algal extra-cellular products. Downstream movement of water moves algae laterally, whilst turbulent mixing results in vertical movements. Flow around substrata is seen to be turbulent throughout most of the boundary layer, but a laminar sublayer exists immediately adjacent to the substratum (Curle & Davies 1968). The dome-shaped substrata cause a laminar flow on the upstream side of the rock. It is assumed that laminar flow causes a greater shearing force than the turbulent flow. Watershed geology including the riparian vegetation also exert profound influence on stream communities. Duffer & Dorris (1966) compared streams in different geological regions, but few have tried to correlate geology with mineral content of water and algal community dynamics (Marker 1976, Neel 1963). Size and shape of rocks have a strong bearing on species richness in epilithic assemblages (Hart 1978, Sousa 1979). Increased size is thought to enhance the habitat diversity (Minshall 1984). The direct shearing force on the flat substrata is less than on dome-shaped ones (Tuchman & Stevenson 1980). The specific densities of substrata determine their movement in stream bottom. Exposure of the substratum to water forces is an important factor that determines the rate of periphyton development and its composition which is due to differences in the strength of the adhesion of the various periphytic components (Otten & Willemse 1988).

Attached algae of streams have received far less attention than the phytoplanktons of lakes (Round 1972, Wetzel 1975). The difficulties involved in describing algal communities of flowing waters, particularly streams, are well known. The communities often consist of many species and show marked spatial heterogeneity and rapid temporal changes (Holms & Whitton 1981). The quantitative methods which have been used to sample and study lotic periphyton include laying 10 m long transect (Descy 1973) and estimating percent cover of algae. Likewise, point-intercept method can also be used if time is the major constrain (Rout & Gaur 1990). The relative amounts of different species can be recorded on a 5-degree scale (Kawecka 1971, Wasylik 1971, Holmes & Whitton 1981): these estimates can be made quantitative, if time permitted. Most investigators sample epilithon by scraping them with a scalpel or a brush from a known area (Moore 1977a, Blinn et al. 1980). This technique is not perfect; it may underestimate species diversity since many loosely-attached forms are of missed. Lay & Ward (1987) submerged the entire rock substrata in organic solvents to avoid missing loosely attached species. A syringe sampler was developed by Stockner & Amstrong (1971) which helped replicate sampling of epilithon without the removal of rock substrata from water. However, these syringes could be used only in shallow waters. The modified sampler of Loeb (1981) facilitates sample collection from shallow and deep waters without removing substrata from water. This method helps in efficient sampling of periphyton, but draws in a small amount of the surrounding water. Gale (1975) developed a bar-clamp sampler which prevents any loss of periphyton. On the other hand, macroalgae are relatively easier to sample. The epiphyton can be removed by scraping, but their removal from finely divided macrophytes is extremely difficult. However, shaking or stirring the plant can easily dislodge the epiphytic algae from their hosts (Carignan & Kalff 1982, Jones & Adams 1982). The FAA (two parts formalin, 10 parts 95% ethyl alcohol, one part glacial acetic acid, seven parts water) completely removes epiphytic algae from their hosts by hydrolyzing polysaccharide of mucilage. When the researcher is interested in only diatoms, the entire plant may be chemically oxidized, leaving cleaned diatom frustules (O'Quinn & Sullivan 1983). The epipelon can be sampled by an aspirator (Moore 1980).

Artificial substrata have been widely used to study periphytic algae because these substrata reduce the heterogeneity generally associated with naturally occurring substrata (Schindler et al. 1973). An ideal artificial substratum should bear resemblance to naturally occurring substrata so that it develops a similar community. Moreover, the colonization time must be short enough to satisfy the design of the experiment. The methodologies pertaining to the use of artificial substrata have been recently discussed by Aloi (1990). Glass slides have been commonly used for periphyton colonization (Marcus 1980, Chessman 1985). The orientation of glass slides determines the pattern of colonization (Muteanu & Maly 1981, Oemke & Burton 1986). However, due to textural uniqueness glass slides do not harbour communities exactly similar to those on natural substrata. Naturally-occurring rocks have been cleaned and used in a few studies (Horner & Welch 1981, Lock et al. 1984). Huntsinger & Maslin (1976) and Tuchman & Stevenson (1980) have popularized the use of clay tiles in periphyton studies. Lamberti & Resh (1985) evaluated clay tiles, sterilized rocks and naturally occurring rocks as substrata for colonization by bacteria, algae and macroinvertebrates and obtained mixed results. Flint et al. (1977), Bothwell (1985) and Perrin et al. (1987) used anchored styrofoam sheets as substrata for algal colonization. Aluminium SEM stubs have been used by Blinn et al. (1980) to investigate community structure and development. Fairchild & Lowe (1984), Pringle & Bowers (1984) and Fairchild et al. (1985) described nutrient diffusing clay pots for assessing the response of periphytic algae to in situ nutrient enrichment. Some researchers are skeptical about the use of aritificial substrata for studying algal aufwuchs (see Aloi 1990). They believe that algal assemblages on artificial substrata are not similar to those on naturally-occurring substrata.

Ecological studies on stream algae have followed two general approaches, one concerning metabolic or functional mechanisms and, a second examining structural aspects. Studies pertaining to structural aspects have provided insight into the complexities of stream communities (Patrick 1970). The functional aspects of running water ecosystems gained momentum in the 1960's and 1970's from which emerged a consistent picture of headwater streams (Teal 1957, Nelson & Scott 1962, Minshall 1967, Tilly 1968, Hall 1972, Fisher & Likens 1972, 1973, Boling et al. 1974, Fisher 1977). Individualistic effects of many physico-chemical parameters like water current, light, temperature, pH, nutrients suspended particles, etc., on community dynamics have been taken up (McIntire & Phinney 1965, Patrick et al. 1969, Stockner & Shortreed 1976, Welch 1981, Antoine & Benson Evans 1982, Lowe et al. 1986, Pringle et al. 1986, Maurice et al. 1987, Peterson 1987, Keithan et al. 1988). Taxonomic changes during periphytic colonization have been well described (Patrick 1967, 1977, Hudon & Bourget 1981, 1983, Kaufman 1982, Steinman & McIntire 1986). For better reproductibility of results, artificial substrata have been employed extensively for studying colonization, succession, productivity dynamics and taxonomic survey (Brown 1976, Tuchman & Blinn 1979, Tuchman & Stevenson 1980).

Efforts have been made to relate seasonal changes in stream algae with variations in physico-chemical characteristics of the environment. The studies conducted in Europe, Japan and North America have shown clear cut seasonal changes (Squires et al. 1973, Homes & Whitton 1981, Wehr 1981, Sheath & Burkholder 1985, Duncan & Blinn 1989). Some of the winter forms in streams include Achnanthes, Meridion, Gomphonema, Navicula, Diatoma, Ulothrix, Phormidium and Batrachospermum. During spring, Cocconeis, Synedra and Navicula are joined by Cymbella, Melosira and a great variety of green algae. Some of the autumn genera are Diatoma, Synedra, Navicula, Cocconeis and Melosira. Gumtow (1955) found that the scouring action of floods in May and June almost cleaned the stones, and recovery took place after late July. During recolonization a build-up of diatoms and other algae, mainly Tetraspora and Oscillatoria, took place in August through September. Navicula was the most abundant diatom at this time, but was replaced by Diatoma in early winter. Wehr (1981) observed Zygnema insigne and Klebsormidium mucosum to predominate in late spring. During late winter and early spring, the blue-green alga Tolypothrix penicillata reached its peak.

Moore (1976) noticed best growth of *Achnanthes minutissima*, *A. lanceolatum* and *Nitzschia palea* in an eutrophic stream in Southern England. Duncan & Blinn (1989) found light, temperature and stream discharge to be mainly responsible for seasonality in epilithic algae in a highly shaded canyon stream. During autumn and winter *Cladophora glomerata* and *Chaetophora attenuata* were the common non-diatom algae. *Navicula cryptocephala*, *Nitzschia dissipata*, *Fragilaria vaucheriae*, *Meridion circulare*, *Achnanthes minutissima* were numerically important diatoms during the winter months, and *Cymbella affinis*, *Gomphonema clevei*, *Melosira varians*, *Cocconeis placentula* during summer months. In an eutrophic farmland stream, Moore (1977b,c) observed *Navicula viridula* and *Surirella ovata* reaching maximum numbers during spring bloom. Unshaded streams have been shown to exhibit little seasonality. While studying macro-algal communities in Rhode Island, Sheath and Burkholder (1985) observed *Stigeoclonium lubricum*, *Batrachospermum boryanum*, *Tuomeya americana* and *Tetrasporoposis perforata* to be primarily winter/spring species while *Stigeoclonium subsecundum* and *Spirogyra* sp. were summer forms. Therefore, the fluctuating light, temperature, flow and nutrient levels have been considered to be the major variables in determining the seasonal changes in stream algal communities.

Some work has been carried out on the physiology of periphytic algae and their adaptation to environmental conditions. In a fully-developed periphytic assemblage a stratified organization of individual species has been frequently observed. This kind of physical arrangement of the community possibly produces a gradient of growing condition within the assemblage (Sand-Jensen 1983, Lock et al. 1984). Filamentous and other kinds of algae constituting the upper strata experience high light intensities and rapid renewal of nutrient supply from water flowing above them, conversely, algae occupying the lower strata are exposed to low light and nutrient levels. It has been found that algae in the understory have more of photosynthetic accessory pigments (Hudon et al. 1987). This perhaps enables them to adapt to lower light regimes. Due to light limitation, the algae of lower strata show lower rate of photosynthesis than the algae in the overstory (Paul & Duthie 1989). Jasper & Bothwell (1986) gave definitive evidences for self-shading of periphyton growing on styrofoam substrata. Photoinhibition of epilithon has been reported at light intensities greater than 250 $\mu E\ m^{-2}.s^{-1}$ (Paul & Duthie 1989). Other reports showing inhibitory effect of high light intensities on photosynthetic carbon fixation are also available (Hunding 1971, Eichenberger & Wuhrmann 1975).

Hamilton & Duthie (1984) suggested that close-linked elemental cycle within the attached community parallels the development of an algal-microbial-detrital microcosm. Sand-Jensen (1983) demonstrated that when nutrients were removed from water, a bidirectional exchange of metabolic products occurred between the components of a cyanophycean mat. He concluded that internal processes become more important with the advancement in age of attached algal community. Paul & Duthie (1989) speculated that the understory helps in recycling nutrients as organic complexes within the periphyton, whereas the overstory extracts nutrients from overlying water. Clearly, more work is needed to elucidate the interaction of epilithon with nutrients in the water column (Corning et al. 1989).

The structure and function of periphyton are influenced by the activities of algal grazers (Gregory 1983, Lamberti & Moore 1984). Snails, the chydorid Cladocera, chrironomid larvae and caddisfly are the common algal grazers in streams. Like terrestrial ecosystems, the primary productivity of streams and other aquatic ecosystems could be accelerated by algal grazing. Grazers tend to keep periphyton communities in a relatively productive, early successional stage. Lamberti & Resh (1983) observed in ungrazed stream periphyton change from a diatom film to a dense turf of filaments. This kind of shift was not observed in case of grazed periphyton where monolayer of diatoms persisted. According to them herbivory prevented the development of filamentous algae which were more liked by the herbivores. The high turnover rate of grazed periphyton could be due to the following reasons (Lamberti & Resh 1983): (i) waste products of grazers serve as a source of nutrients to algae, (ii) grazers consume and thereby remove senescent cells that reduce the overall productivity of algal mat, and (iii) grazers reduce the thickness of algal mats thereby increasing the availability of nutrients and light to algae. Despite great significance of algal grazers, very little amount of work has been done on this aspect in stream ecosystems.

Stream algae have been studied primarily in the North America and Europe (Moore 1977a,b,c, Round 1981). The focus on the earlier 1930's was more on general limnological studies including the taxonomical aspects (Budde 1928, Fritsch 1929, 1931, Bucher 1932, 1933, 1940, 1946). Ruttner (1926) studied habitat factors affecting stream algae. Pioneering work on the ecology of streams was taken up by Fjerdingstad (1950) and Luther (1954). In the past several years there has been a resurgence of interests on the general ecology of algae in streams of arctic and subarctic (Johansson 1980, 1982, Ennis & Albright 1982), temperate (Stockner & Shortreed 1976, Wehr 1981, Round 1981), antarctic (Hirano 1979, Seaburg et al. 1981, Broady 1982, Howard-Williams et al. 1986, Tilzer et al. 1986), and deserts (Fisher et al. 1982, Whitton et al. 1986).

Mountain streams have been studied mainly in Europe and North America (Parker et al. 1973, Kann 1978, Johansson 1980, Kawecka 1981). Frequent acid rains may cause perceptible damage to streams and other freshwater systems by altering the species composition at every trophic level, and this was cited as an important aspect in the 1970's (Almer et al. 1974, Beamish 1974, Leivenstad et al. 1976, Schofield 1976, Rosenquist 1978, Seip & Tollan 1978). The ecological problems related to deforestation have aroused considerable concern in almost every part of the earth. Deforestation results in immediate and massive efflux of dissolved nutrients, however, reorganizations take place in nutrient cycling with the passage of time. These changes have been monitored in detail by Gene E. Likens and associates in the Hubbard Brook experimental area (Likens et al. 1977, Bormann & Likens 1979). Shifts in algal biomass and community structure have been reported, although it is difficult to relate these changes to deforestation due to multiplicity of the parameters involved, such as, increased light, altered water chemistry and temperature (Hansmann & Phinney 1973, Murphy & Hall 1981, Webster et al. 1983).

Lotic algae have been used extensively for biomonitoring purposes because of ubiquity, small size and high multiplication rate. Biomonitoring of aquatic systems with algae is inexpensive and moreover algae react sensitively to various types of contaminants. The quality of water is reflected by the algae growing therein since these organisms derive their nutrition from chemicals dissolved in the ambient water (Patrick 1973). Phycologists and ecotoxicologists have attempted to judge the degree and severity of pollution by analyzing the changes in structure and function of algal communities. Because of fixed position, epilithic algae accurately reflect the prevailing environmental conditions (Patrick 1973). Patrick (1973) and Lowe (1974) recommended the use of diatoms for water quality assessment.

The researches on stream ecosystems have been carried out mainly in temperate regions (North America and Europe), and streams of tropical regions have been virtually ignored. In the entire Indian subcontinent nothing worthwhile has been contributed to understand the basic ecology of stream algae. Among the lotic systems only rivers have been studied in some detail with regard to biomass, species composition and seasonal succession of phytoplankton (Lakshminarayana 1958, 1965a,b, Venkateswarlu 1969a,b,c, 1970). Tiwari (1983), Senger et al. (1985) and Singh (1988) used phytoplankton to assess water quality of rivers.

Present Study

Lack of information on stream algae was the main consideration for taking up the present work. I have carried out a detailed study of algae in two streams draining deforested catchments because in forested streams low light condition often limits algal growth. Epilithic algal communities of selected streams were studied with regard to biomass, species composition, and diversity. Temporal variations in community composition have been related to physico-chemical characteristics of water using the latest technique of multivariate analysis, namely, the canonical correspondence analysis or CCA (ter Braak 1986). Similarly, epipelic and epiphytic communities of selected streams were also studied.

Laboratory-based bioassay experiments have been performed with the test alga *Selenastrum capricornutum* to define nutrient limitation of algal growth in selected sites of two streams. Water current has been considered extremely important to stream periphyton; however, effects of water flow on natural periphytic assemblages have not been subjected to a thorough investigation. Hence, this aspect was studied in detail by 'fixed substratum' and 'substrata inversion' experiments. In addition, combined effects of nutrient enrichment and flow conditions on the development of periphytic assemblage was also investigated under in situ condition.