Current Research Trends in Limnological Studies on Periphyton

Ashok K. Pandit

Centre of Research for Development, The University of Kashmir, Srinagar – 190006, Jammu & Kashmir, India

ABSTRACT

The literature on different aspects of ecology of periphyton is quite voluminous though not as much as on plankton. The studies on the biocoenosis cover several trends. The majority of the papers deal with species composition, organization, stratification, metabolism, periodism, seasonal succession, vertical distribution, production and their role as bioindicators, besides their acting as important links in the aquatic food chain. A review of the research trends, followed in periphyton studies, are discussed by several hydrobiologists. As a comprehensive review on periphyton is extremely difficult to compile mainly due to its voluminous nature and the diffuclty in obtaining the scattered information as isolated pieces of research, an attempt has been made to review only those publications which appeared after the extensive paper "Limnological Investigation Methods for the Periphyton Community" by Sladeckova (1962). The available information pooled together in the present review is a suitable continuation of and supplement to the above paper.

Keywords: Periphyton, limnology, productivity, bioindicators, substrates, aquatic habitat.

INTRODUCTION

Periphyton or Aufwuchs, comprising the organisms living on submerged surfaces, includes both the attached forms and the organisms associated therewith. Periphyton is an extremely heterogenous and complex assocation of organisms on sub-aquatic natural and artificial substrates. The group consits of algae, zoogleal and filamentous bacteria, attached protozoans, bryozoans, rotifers and also the free swimming micro-organisms found swimming, creeping or lodging among the attached forms. Thus, the group is composed of three principal types of living organisms – producers (autotrophs), consumers (heterotrophs) and reducers. The various types of periphyton include the epiphyton on aquatic macrophytes, the epilithon on rocks, the episammon on sand grains, the epixylon on wood and sometimes the epipelon on or in mud.

Periphyton play a signficant role in the limnological process of water. These communities produce significant standing crops and hence contribute much to the productivity of freshwater ecosystems. Besides being a major contributor of carbon (energy) fixation, the periphytic algae have been found to be directly or indirectly a major source of food for the fish and waterfowl (Peter *et al*, 1968; Denny *et al*, 1978; Kaul *et al*, 1980; Pandit, 1980,84; Pandit *et al*, 1985). The periphyton is, to some extent, the life environment of invertebrates and also the commercial fish (Pandit *et al*, 1985). They are useful as biological indicators of pollution as they are mostly sessile and hence cannot avoid contact with the waste effluents.

AN OVERVIEW

The literature on different aspects of ecology of periphyton is quite voluminous though not as much as on phytoplankton. The studies on the biocoenosis cover several trends and the majority of the papers deal with species compositon, organization, stratification, metabolism, periodism, seasonal succession, vertical distribution and production. A review of the research trends followed in periphyton studies are discussed by several hydrobiologists, notable among them being Cooke (1956), Round (1956), Sladeckova (1962), Pieczynska (1964), Wetzel (1964) and Allen (1971). As a comprehensive review on periphyton is extremely difficult to compile, an attempt has been made to review extensively only those publication which appeard after the extensive paper "Limnological Investigation Methods for Periphyton Community" by Sladeckova (1962). I hope that the present review can be a suitable continuation of and supplemnt to the other paper. The entire literature on different ecological aspects of periphyton is, for the sake of convenience, reviewed under six sub-heads. These are:

I. Terminology
II. Methodology
III. Taxonomy
IV. Productivity
V. Ecological Relations
VI. Relationship to Problems of Applied Hydrobiology.

This grouping is , however, not absolute as many of the publications deal with more than one aspect of study.

I. TERMINOLOLGY

There is a great uncertainty regarding the scientific terminology concerning the group "Periphyton". The diversity of terms is great, each with subtle variations in meaning (Wetzel, 1964). With the development of special techniques for the study of aquatic organisms of certain special habitats, there arise the need for terms to describe the organisms, their mode of life and the particular association (either plant or animal) or biocoenosis (both plant or animal) in which these organisms were found (Cooke, 1956). Though detailed reviews of the heterogeneous terminology applied to periphyton are given by Naumann (1919), 31), Willer (1920), Gams (1925), Behning (1928), Roll (1939), Budde (1942), Sramek-Husek (1946). Ruttner (1952). Cooke (1956), Round (1956), Sladeckova (1962), Pieczynska (1964), Wetzel (1964), Welch (1972), Allen (1971) and Lakatos (1976), yet it becomes imperative to survey the diverse terms in a historical sequence.

Author	Year	Terminology used	Authors who adopted the terms
1	2	3	4
Moebius	1883	Basatz	Moebius (1888 a,b) & Schroder (1939)
Warmng	1895	Nerieden	Gams (1925)
Seligo	1905	Aufwuchs	Ruttner (1952), Odum (1957) & Reid (1961
Hentzschel	1916	Bewuchs	
Willer	1920	Derechtu & Unechte aufwuchs	Willer (1923)
Warming	1923	Haptobenthos	Hutchinson (1967)
Behning	1924	Periphyton	Behning (1928), Dykanov (1925, 27), Duplakov (1933), Karsinkin (1934), Karsinkin & Kusnetson (1934), Smaragdova (1937), Roll (1939), Young (1945), Welch (1948), Hunt (1952), Neel (1953) & Gumtov (1955)
Wundsch	1924	Benthos & Benthic organisms.	Budde (1928,30,32,35,42), Abdin (1930), Cholnoky (1933), Jurgenson (1935), Jaag (1938, 45), Lund (1942), Pyefinch (1947), Fjerdingstad, 1950, Litynsk (1952), Round (1956, 57,58), Lund and Talling (1957), Douglas (1958), Neumov (1961) & Reid (1961).
De Martini	1934	Slime & Slime growth	Derby (1947), Hueukelekian & Crossby (1953,55,56).
Roll	1939	Epiphyton & Lasion	

1	2	3	4
Sramek – Husek	1946	Epiphyton, Epizoan, Epidendron, Epixylon, Epilithon, Epiholon.	
Entz	1947	Coating	
Newcombe	1949	Seeded-on and attachment materials	Newcombe (1950) & Nielson (1953)
Tiffany	1951	Epiphytes and Epizoophytes	
Cooke	1956	Periphytes	
Sladeckova	1962	True Periphyton and Pseudoperiphyton.	
Wetzel	1964	Epipelic, Epilithic, Epiphytic and Epixylic periphyton	
Dussart	1965	Biotecton	Lakatos (1976)
Pieczynska	1970	Autotrophic, Autoheterotrophic and Heterotrophic periphyton.	
Lakatos	1976	Eu-biotecton, Meta-biotecton, Xeno-biotecton, Mero-biotecton, Bacteriotecton, Phytotecton and Zootecton.	
Pandit	1983	Periphytic flora and Periphytic fauna.	Pandit *et al.* (1985, 91) Pandit & Pandit, (1996), Pandit (1999,2002), Sarwar & Zutshi (1989)

To solve this terminological problem, Lakatos (1976) recommended the consistant and unequivocal use of the term "biotecton" as suggested by Dussart (1966) instead of the gramaticaly incorrect expression "periphyton". The biotecton in Dussart's interpretation is defined as a community of organisms living on under water substrata that are extraneous and well detached from the bottom. Lakatos (1976) suggests the following terminology regarding biotecton:

(i)	Eu-biotecton	-	Organism which live attached throughout their life.
(ii)	Meta-bioteton	-	Organisms which find living conditions in biotecton among sessile organisms but do not get attached themselves.
(iii)	Xeno-biotecton	-	Organisms accidentally being members of other biocoenosis like the plankton or the benthos.
(iv)	Mero-biotecton	-	The plaaktonic biotectonic organisms.

On the basis of the aspects of material circulation, energy flow and operative seasons, Lakatos (1976) suggested the classification of the biotecton biocoenosis into three categories:

(i) Bacteriotecton
(ii) Fitotecton (Phytotecton)
(iii) Zootecton

II. METHODOLOGY

The historical development of methods of analysis of periphyton from both natural and artificial substrata is reviewed in detail by Cooke (1956), Castenholz (1960), Sladeckova (1962), Wetzel (1964) and Vollenweider (1969). Despite the great significance of periphyton in the production of aquatic ecocystems, no standard procedure has been proposed for the examination of a periphytic community as a whole. This lack is chiefly due to the methodological problems of sampling which are inescapable in view of the variety of possible substrata in any given body of water (Wilbert, 1976). The general methods followed in periphyton study involve a number of steps such as sampling from substrata, preservation and analyses of samples.

1. Substrata

Both for qualitative and quantitative analyses, periphyton samples have been collected from natural as well as submerged substrata by a host of workers as enumerated below:

(a) ***Natural substrata***

(i) Aquatic Plants- Ende and Linkskens, 1962; Ende and Oorschot, 1963; Kowalczewski,1965, Bownik, 1970; Govrilla, 1970, Szczepanska, 1970; Hickman, 1971, Allen, 1971; Tell, 1972,73; Moshkova and Vodop'yan, 1973; Luchini, 1973, 74; Allanson, 1973; Brown, 1974; Hansak-Schmager, 1974; Hickman and Klarer, 1975; Klarer and Hickman, 1975; Mason and Bryant, 1975; Dekhtyar, 1976; Gough and Woelkerling, 1976; Mols, 1976; Brown, 1976; Roos and Trueba, 1976; Fry and Ramsay, 1977; Sullivan, 1977; Denny *et al*, 1978; Finke and Seelay, 1978; Gough, 1978; Eminson, 1978; Howard-Williams *et al*, 1978; Lakatos, 1978; Luscinska, 1978; Eminson and Moss, 1980; Pandit, 1983; Pandit *et al*, 1985, Sarwar and Zutshi, 1989.

(ii) Molluscs - St. Clair *et al*, 1978; Kaul *et al*, 1980; Pandit, 1980.

(iii) Siliceous Foraminifera – Very and Bronnimann, 1968.

(iv) Rocks – Olive, 1971; Sherman and Phiney, 1971; Tett *et al*, 1975; Perkins and Kapalan, 1978; Neves, 1979; Moore, 1981.

(v) Stones – Dor, 1970; Chierici-Magnetii, 1971; Luchini, 1974b, Jones, 1974; Légier and Talin, 1976.

(vi) Sand grains – Meadows and Anderson, 1966.

(b) ***Artificial substrata***

i. Glass slides – King and Ball, 1966; Wilbert, 1969, 1976; Dumont, 1969; Dor, 1970; Nusch, 1970; Szeczepanska, 1970; Stockner and Armstrong, 1971; Olive, 1971; Tilley, 1972; Ertl *et al*, 1972; Stickney and Campbell, 1972; Brown, 1973; Dickman, 1973; Ertl and Tomajka, 1973; Patsch, 1974; Brettum, 1974; Luchini, 1974; Levadnaya, 1975; Liaw and Macrimmon, 1978; Sarwar and Zutshi, 1987, 1989.

(ii) Glass plates – Oltean, 1968; Legier and Talin, 1976.

(iii) Glass rods – Vollenweider and Saman, 1972; Mason and Bryant, 1975.

(iv) Plexiglass plates – Cooper and Wilhm, 1975; Gemelli and Zullini, 1976; Wilhm *et al*, 1978.

(v) Pressed massonite borad – Arthur and Horning, 1969.

(vi) Cellophane strips – Huk, 1973.
(vii) Cellulose –acetate substrate- Hooper and Robinson, 1978.
viii. Plastic petridishes – Kuesters, 1974.
(ix) Plastic plants – Cattaneo and Kalff, 1978

2. Sampling

Collection of quantitative samples from varied substrata has received the attention of many workers not only in the past but also in recent years and many variations in sampling methods have been noticed. (Davies and Gee, 1993; Szlauer, 1996)

Ertl (1971) has made a device that allows quantitative sampling of periphyton growing on rough surfaces without losses of released organisms from the sampling area. It is an improvement over that of Douglas (1958). The sampler consists of two metal or plastic cylinders, one fitting into the other, with the space between the cylinders fitted with plasticine or some similar material. The sampler is pressed firmly against the substrate to be sampled and the plasticine is forced down onto the substrate to isolate the known sampling area of the inner cylinder. The periphyton in the area is removed by a brush with stiff bristles or by a small battery-powered mixer fitted with a small circular brush.

A design of a simple and inexpensive woodfloat periphyton sampler has been given by Anderson and Paulson (1972) and it has been modified by Stern and Stern (1975) for use under harsh river conditions.

A method of rapid and reliable scrapping of periphyton slides has been given by Tilley (1972) while Czarnecki *et al* (1973) has described a technique employing ultrasonic vibrations for the removal of diatoms from microscope slide substrate. The latter authors have also discussed the application of the technique for chlorophyll analysis and certain microscopical mounting procedures. Cattaneo (1978) has used a new peel-off technique for comparing the micro-distribution of diatoms and green algae on the leaves of *Potamogeton richardsonii* and on those of plastic aquarium plants.

Dickinson *et al* (1974) has given an impression method for examining epiphytic micro-organisms and discussed its application in phylloplane studies.

3. Time of Attachment

Brown (1974) used a new method to compare communities of attached algae on several species of macrophytes. Land forms of these plants were removed from shore, planted in plastic or glass enclosures and directly submerged in water. Rapid colonization by algal epiphytes followed, which interpolated on time scale, made it possible to find the time of attachment of communities on naturally growing macrophytes.

4. Fixation and Staining

Trembley (1960) developed a staining procedure using acid fuchsin and methylene blue for the preparation of whole mounts of periphyton grown on microscope slides. Owen (1973) and Owen *et al* (1978) have given a modification of this procedure. The preserved samples are stained with acid fuchsin, dehydrated and then prepared for microscope counts. The procedure provides a single preparation for periphyton or phytoplankton samples and also permits the investigator to distinguish between live and dead diatoms, based on cell counts.

Wilbert (1976) described the protargol impregnation method for fixation and differentiation of autotrophic and heterotrophic forms in a periphyton population. Here a substrate of known area and compostion (a glass slide) is exposed to colonization by periphyton in a body of water. At the end of exposure time, the periphyton is fixed while still on the slide and impregnated with protargol. The method preserves the shapes of organisms and stains all the cell nuclei. Cross *et al* (1977) described a preservative technique of critical point drying for use with scanning electron microscopy.

5. Counting

A procedure for direct observation and enumeration of microscophic epilithic algae on stone surfaces is given by Jones (1974). The method involves the use of incident light fluorescence microscopy and provides a rapid estimate of total numbers as well as the information on the distribution of organisms. The method accounts for the serious underestimates of the algal propulation produced by the conventional procedures involving the scrapping of stone surfaces. Procedures on the removal and quantification of algal aufwuchs from macrophyte hosts are given by Gough and Woelkerling (1976) and Pandit (1983).

6. Productivity

A detailed account of glass slide method for the determination of the periphyton production is given by Sladececk and Sladeckova (1964). Kavern *et al* (1966) has further discussed, by the use of artificial substrate, the estimation of production of periphyton.

Some notes on the chlorophyll method of estimating the photosynthetic capacity of stream periphyton are given by Waters (1961). Tell *et al* (1975) described a method for the measurement of chl-a and phaeophytin-a of the periphyton on rocks and in soft sediments. The method involves successive extractions directly from frozen samples with boiling methanol and estimation of pigments by optical density measurements before and after acidification.

A technique for assessing the *in situ* productivity of periphyton, utilizing C^{14} as a tracer, is given by Wetzel (1963). Vollenweider and Saman (1972) has further described a technique for measuring C-assimilation through C^{14} technique and chlorophyll content from glass rod artifical substrates submerged in water.

Hickman and Klarer (1973) gave a method for quantitative measurement of primary production, utilizing liquid scintillation counting technique and standing crops (as chl.-a content and cell counts) of the epiphytic algal community attached to *Scirpus validus*. Further Hickmann (1974) has described a method for determding the standing crop and primary productivity of the epiphyton attached to *Chiloscyphus* sp. on a quantitative basis.

Gonyea (1969), while comparing the dichromate oxidation and the ashing methods, found the two methods giving similar results in measuring organic matter of periphyton and net plankton. Armstrong *et al* (1971) gave a rapid method for the estimation of microgram amounts of organic carbon in seston and periphyton samples with an IR analyser after combustion in an induction furnance.

7. Water Pollution Surveillance

Dickman (1969) has given a method of assess the toxic effect of water soluble substances released in lakes and streams on the basis of changes in periphyton community structure. A set of slides, coated with a suspected toxicant, are exposed to the water column of a lake or stream. A second set of slides identical to the first but lacking the suspected toxicant is suspended nearby for comparison. Significant differences in the species composition at regular intervals are attributed to the presence of the substance impregnated on the slides. Weber and Raschke (1970) have discussed the use of a floating periphyton sampler for water pollution surveillance.

III. TAXONOMIC SURVEY

Taxonomic survey of periphytic organisms are oriented more botanically and zoologically than ecologically and often pertain to recording of species and reporting of new species. The work in the field has been referred by Sladeckova (1962) and the publications appearing thereafter are reviewed here.

Author	Year	Location	Substrate	Periphyton organisms	No. of taxa reported
1	2	3	4	5	6
Dumont	1968	Lake Donk, Eastern Flanders, Belgium		Rotifers	82,41 as periphyton
Oltean	1968	Lake Poru, Denube delta	Glass plates	Periphyton	105
Very and Bronnimann	1968	Red sea, Sea of Antiles and Mediteranean sea	Shells of Foraminifera	Diatoms	
Olive	1971	Scioto River Basin, Ohio	Glass slides and rocks	Diatoms	43-126
Sherman and Phinney	1971	Metolius River Oregan	Rocks	Algae	51
Vander Boen	1971	French coast of Mediterranean Sea	Leaves of *Psidonia oceanica*	Epiphytes	
Cornejo	1972	Marine waters of Philippines	Plant, sandy and rocky substrata	Algae	35
Parker *et al*	1972	South River, Virginia	Rooted plants, rocky sediments etc	Algae	65
Tell *et al*	1972	Continental water of Argentina	Plants	Algae	Record of 19 new species to Argentina
Tell	1973	Ponds and lakes of Argentina	Submerged plants	Cyanophyta	Records 8 new species to Argentina
Caretta	1973	Ticini River and some pools, Italy	General	Algae and Mycotic flora	

1	2	3	4	5	6
Daemus and Dumont	1973	Central Belgium	-	Flosculatiids (Rotifers)	
Moskkova and Vedop`yan	1973	Uhort River, Bolotnista River in the territory of Polosyne reservation, USSR.	Plants	Algae	98 species with 119 varieties and forms
Rivera	1973	Chilean Coast	*Gracillaria verrucosa*	Diatoms	
Luchini	1973	Mascardi Lake, Argentinia	*Scirpus californicus, Myriophyllum, elatinoides, Isoetes* sp and bottom-pebble surface	Diatoms	118
Luchini	1973	Lake Situacin, Argentina	*Nitella flexilis, Scirpus californicus*		119
Bosva	1974	Lake Krasnoya, Karebian Isthmus, USSR	General and bottom	Algae	244
Hamak-Schmager	1974	Rifer Vistula and River Bzemsza, Poland		Epiphytic forms, phytoseston and zooplankton	374
Koch and Reisser	1974	Spring fed streams	Leaf detritus	Algae	
Luscinska	1974	Lakes of Byszewo Channel, Poland		Algae	151
Tassen	1974	Espegrand, W. Norway	*Dumontia incrassata*	Diatoms	

1	2	3	4	5	6
Dickman and Kralina	1975	Gatineau Park Lakes, Quebec	-	Periphyton	368
Jankovia	1975			Chronomids	25
Gough and Woelkerling	1976	Soft water and hard water lakes, calcareous springs, ponds, Wisconsin, USA.		Plankton and aufwuchs	
Mols	1976	A ditch and other field stations near Tienhoven, Netherlands	Macrophytes	Diatoms	119
Tokar *et al*	1976	Tiszamentivergyi nuvak, Szolnok, Hungary	Surface of the elements of cooling water system.	Biotecton	-
Roos and Trueba	1977		Submerged roots of *Phragmites australis*	Protozoa	-
Bowker and Denny	1978	Nyumba ya Mungo Reservior, Africa	Artificial and natural	Periphyton	192
Gough	1978	Hard water lakes and spring ponds, South Wisconsin		Desmid Aufwuchs	-
Lakatos	1978	Waters of different trophic status, Hungary	*Typha latifolia*	Biotecton	
St. Clair *et al*	1978	A warm spring-fed pond near Goshen, Utah	Snail shells, macrophytes and rocks.	Diatoms	60
Sheath and Hellebust	1978	Tundra pond near Toktoyaktuk, N.W.T.		Algae	166 species with 109 species as periphyton

1	2	3	4	5	6
Luscinska	1979	Lobelia-lakes in the area Bory Tuchlskie, Poland	Reeds	Algae	104
Kaul *et al*	1980	Haigam wetland, Kashmir, India	Snails (Gastropoda)	Algae Protozoa	21
Pandit	(1983 c.f. 1993)	Dal and Nilnag lakes in Kashmir, India	*Potamogeton lucens*	Algae	264 species 84 genera
				Invertebrates	126 species 80 genera
			Myriphyllum spicatum	Algae	239 species 77 genera
				Invertebrates	112 species 83 genera
Pandit *et al*	1985	Dal and Nilnag lakes in Kashmir, India	Six submerged macrophytes	Epifaunal invertebrates	6 animal groups
Sarwar and Zutshi	1987	Dal, Anchar and Waskur lakes in Kashmir, India	Artificial and natural substrates	Six classes of algae	214 taxa
Shachenko	1996	Reservoirs, Ukraine	Soil inorganic substrate	Algae	197 taxa
Sarwar	1999	Anchar Lake, Kashmir	Natural substrates (6 macrophytes)	Six classes of Algae	154 taxa

IV. PRODUCTIVITY

Studies on the role of periphyton in regard to biological productivity of aquatic ecosystems have been conducted by a host of workers and Sladeckova (1962) has reviewed some of the earlier works. The present review hence gives only resume of some of the works carried out during the past four decades, noteworthy among these being those of Wetzel (1964,68), Mc Intire (1966), Kowalczewski (1965,75), Pieczynska (1965,68), King and Bal (1966), Szczepanski and Szczepanska (1966), Cushing 11967), Szczpanska (1968,70), Cooper and Wilham (1970), Dor (1970), Hickman (1971,74), Allen (1971), Stockner and Armstrong (1971), Ertl *et al* (1972), Hillbright-Ilkowska *et al* (1972), Elwood and Nelson 1972), Stickney and Campbell (1972), Welch (1972), Mc Intire (1973), Ertl and Tomajka (1973), Ertl (1974), Koch and Risser (1974), Levadnaya (1975), Bohr and Luscinska (1975), Mason and Bryant (1975), Sheldon and Boylen (1975), Spondniewska *et al* (1975), Tilley and Haushid (1975), Hooper and Robinson (1976), Ho (1976), Seyfer (1976), Seyfer and Wilhm (1977), Sommer (1977), Bowker and Denny (1978), Liaw and Maccrimmon (1978), Perkins and Kaplan (1978), Cattaneo and Kalff (1978,79,80), Vass *et al* (1978), Wilm *et al* (1978), Hooper and Robinson (1978), Moore (1979), Neves (1979), Adamczak *et al* (1978), Luscinska (1979), Pandit (1983), Pandit *et al* (1985), Sarwar and Zutshi (1987,89), Kostikora (1989) and Melormick *et al* (1998). Some of the estimates of periphyton biomass and productivity on varied substrata in different types of waterbodies are given in Table 1.

V. ECOLOGICAL RELATIONS

The literature concerning the ecological relations of periphyton with various environmental factors is the most extensive and it is impossible to review all the relevant works in the field. Hence only some of the important publications appearing during the last forty years are cited in the paper.

1. Substrate Type

The relationship between the substrate and the peripyton has received increasing attention and speculation in recent years (Hansson, 1992; Cattaneo *et al*, 1997). However, the interpretation of the literature is complicated by a frequent lack of clear statement of the criteria for comparison and of quantitative estimates.

Both for qualitative and quantitative analyses periphyton are generally taken by scrapping submerged objects, which are natural or artificial. The artificial substrata, most frequently glass or plastic slides, are simply used to overcome the problem of sampling. These are easy to sample and can produce results of high precision. How accurate a picture the results give of the ecology of natural periphyton communities is, however, subject to much debate. Several authors have shown reasonable correspondence of the communities on artifical substrata with those on inert surfaces such as rocks, stones and piling (Pieczynska and Spondniewska, 1963; Whitford and Schumacher, 1963; Brown and Austin, 1971, 73) and some have claimed similar matching with those on aquatic plants (Cattaneo and Kalff, 1978, 79). Whitford and Schumacher (1963) found that colonization on glass slides was similar to that of rock substrates, although it was somewhat different from colonization observed on living plants. With some quantifications Dor (1970) found the species composition of attached communities similar on glass slides and natural substrates in Lake Taberias. The author reports the algae which attached to slides generally

Table 1. Periphyton biomass and productivity on varied substrata in different types of waterbodies

Author	Year	Site location	Substrata	Biomass and productivity values
I. LAKES				
Szczepanski	1970	6 lakes of Mazurian Lakesland	Reed	Amount of Chl. on last years reed = 3.6 $\mu g\ cm^{-2}$ and on 2 years old reed = 16.5 $\mu g\ cm^{-2}$.
Allan	1971	A small temperate lake	Macrophytes	Mean productivity of epiphytic algae: (i) emergent plants = 336 $mg\ cm^{-2}\ day^{-1}$ and (ii) on submerged plants = 258 $mg\ cm^{-2}\ day^{-1}$ Mean productivity / unit area of littoral zone: (i) 195 $mgC\ m^{-2}\ day^{-1}$ in *Scirpus* dominated site (ii) 180.7 $mgC\ m^{-2}\ day^{-1}$ in *Najas-Chara* site Total annual production of algal epiphytes: (i) 2.86 $g\ cm^{-2}\ day^{-1}$ of lake surface in *Scirpus* dominated site (ii) 35.00 $mg\ cm^{-2}\ day^{-1}$ of lake surface yr^{-1} *Najas-Chara* site. Amount of chl. a = 7.3 $g\ m^{-2}$ (Highest record in literature)
Stockner and Armstrong	1971	4 experimental Lakes, Area Lakes N. W Ontario	Glass slides	Periphyton growth: (i) during initial colonization = 27 mg org. matter $m^{-2}\ day^{-1}$ (ii) during the period of max. growth = 250 mg org. matter $m^{-2}\ day^{-1}$
Hillbrich Ilkowska	1972	A Polish lake	*Potamogeton perfoliatus*	Average algal growth (biomass) = 0.09 $mg\ cm^{-2}$
Stickney and Campbell	1972	2 acid and 2 alkaline stripmine lakes, Central Missouri.	Vertical glass slides	Mean rate of accumulation of organic matter: (i) in alkaline lakes = 2.28 $mg\ day^{-1}\ dm^{-2}$ (ii) in acid lakes = 0.65 $mg\ day^{-1}\ dm^{-2}$
Kowalczewski	1974	Mikolajskie Lake, Poland	4 macrophytes	Average periphyton dry mass for all plants = 0.37 g 100 cm^{-2} Average chl. content = 80 μg 100 cm^{-2} of plant surface Average chl. content = 334 μg 100 cm^{-2} on *Myriophyllum spicatum* Average gross primary production =2.2 mg 100 cm^{-2} of plant surface hr^{-1} Average photosynthetic activity = 42 mg O_2 /mg chl. /24 hr. Yearly gross primary production = 363 g $O_2\ m^{-2}$ of the littoral.

Table 1. contd

Author	Year	Site location	Substrata	Biomass and productivity values
Bohr and Luscinska.	1975	Lakes Jeziorak and Tynwald	...	Net production during the vegetation season of 240 days = 857 k cal m^{-2}. P/B = 15. Turn over = 16 days.
Mason and Bryant	1975	Alderfen Broad, Norfolk, Britain	Dead *Typha* stems and glass rods	Standing crop on (i) *Typha* stem = 0 – 1.8 mg cm^{-2} (ii) glass rods = 1.6 – 1.94 mg cm^{-2} (Peak value) Net primary production = 70 mg dry wt. m^{-2} day^{-1}
Scheldon and Boylen	1975	Lake George, New York		Max. photosynthetic capacity of epiphytes= 0.60 mg of Carbon fixed m^{-2} of macrophytic surface area per hour
Adamczak *et al*	1979	Tynwald Lake, Ilowa Lake District	Reed and glass slides	Mean values of biomass on (i) glass slides 1973 = 24. 6 k cal m^{-2}; 1974 = 0.99 k cal m^{-2}; (ii) on reeds 1973 = 70. 23 k cal m^{-2}; 1974 = 9.0? k cal m^{-2}. Annual total Pr.production of periphyton = 4.6% of total annual Pr.production of 1881.3 k cal m^{-2} for whole lake
Luscinska	1979	5 Lobelia lakes in the area of Borry Tucholskie	Reed *Phragmites*	Max. value of biomass = 68.9 k cal m^{-2}; Max. value of GPP = 3. 22 k cal m^{-2}; Max. value of NPP = 0. 84 k cal m^{-2}; Turn over = 48 – 163 days
Sarwar and Zutshi	1989	Dal, Waskur & Anchar lakes of Kashmir	*Myriophyllum* *Phagmites*	Biomass = 26 – 1325 µg / 10 mg dry wt. = 2.4 – 62 µg / 10 mg dry wt.
II PONDS AND POOLS				
Hooper and Robinson	1976	A marsh pond Manitoba, USA	Cellulose acetate substrate	Annual Production of epiphytic algae = 26.8 mg C cm^{-2} of pond surface = 32. 2 g C m^{-2} on *Scirpus acutus* = 1700 kg C m^{-2} on *Potamogeton pectinatus*
Vass *et al*	1978	Brakish water ponds at Kaladwip, W. Bengal, India	Sterlized roughened glass slides	Mean dry matter production = 4 - 275 mg m^{-2} day^{-1}; Mean value = 165 mg m^{-2} day^{-1}

Table 1 contd

Author	Year	Site location	Substrata	Biomass and productivity values
III. RESERVOIRS				
Levadnaya	1975	Novosibirsk Reservoir, USSR	Glass slides	Max. biomass = 1580 mg 10 cm $^{-2}$ Max. Photosynthetic activity = 6.2 mg O_2 10 cm $^{-2}$ P/B = 012, Turn over = 8.5 days.
Bowker and Denny	1978	Nymba Ya Mungo Reservoir, Tanzania	Macrophytes and glass	Mean net production rate of periphyton : (i) on shoots = 140 mg org. matter dry wt. m^{-2} day^{-1} (ii) on glass = 820 mg org. matter dry wt. m^{-2} day^{-1}
IV. RIVERS				
King and Ball	1966	Red Cedar River, Michigan	Glass slides	Biomass = 1.0 to 3.8 g m^{-2}
Cushing	1967	Columbia River, Washington, USA		Biomass = 4.09 g m^{-2} Chlorophyll = 3.6 – 50.9 mg m^{-2}
Ertl and Tomajka	1973	River Denube	Rough glass	Average primary production of periphyton = 5.1 – 54.8 mg O_2 dm^{-2} day^{-1} Annual production = 0.94 – 9.20 g O_2 dm^{-2} for different depth zones Max. annual production = 14.74 gO_2 dm^{-2} Average efficiency of gross photosynthesis in one zone = 1.72%.
Ertl	1974	River Denube	Rough glass	Gross production = 0-176 mg O_2 dm^{-2} day^{-1} Average gross production for different depth zones = 22.5 – 53.7 mg O_2 dm^{-2} day^{-1} Average net production for different depth zones 12.3 – 41.2 mg o_2 dm^{-2} day^{-1} Average net production = 2.88 – 8.63g O_2 dm^{-2}
Koch and Risser	1974	Wilkes Branch, Tennesse	Rocks	Ash free weight of periphyton = 0.19-0.0.66 g m^{-2}
Liaw and Maccrimmon	1978	Down River riffle of Grand River, S. Ontario Canada	Concrete block glass slide sampler	Average ash free wt. of periphyton = 266.2 mg m^{-2} day^{-1} Average chl. a = 2.95 mg m^{-2} Standing biomass = 21.9 – 201.6 g m^{-2} (Mean = 66.1 g m^{-2})
V. STREAMS AND CANALS				
Elwood and Welson	1972	A wooland sream, S USA		Periphyton standing crop = 198 – 658mg ash free dry wt. m^{-2} Periphyton net production rate = 14 – 24 mg ash free dry wt. m^{-2} day^{-1}

Table 1. contd.

Author	Year	Site location	Substrata	Biomass and productivity values
Ho	1976	Renggam streams	Glass substrate	Production rate (i) ash free dry wt. = 41-104 mg m^{-2} day^{-1} (ii) chl. a = 0.88 – 2.80 mg m^{-2} Turn over rate once a month Projected annual production = 10.95 – 33.58 g m^{-2} yr^{-1}
Seyfer	1976	Otter Creek, Oklahoma, USA		Ash free wt. = 0.25-6.20 g m^{-2} Chl.a – 0.09 – 31.84 mg m^{-2}
Seyfer and Wilhm	1977	Different order streams in Otter Creek, Oklahoma, USA		Chl.a – 0.21 – 15.34 mg m^{-2} Phaeophytin – 0 -2.62 mg m^{-2} Ash free wt. – 0.31 – 3.51 mg m^{-2}
Perkins and Kaplan	1978	Ward Creek, (within lake Tahoe basin) California, USA		Mean total carbon content – 0.508 ± 0.263 mg C cm^{-2} Live biomass (ATP measurement) – 0.121 ± 0.115 mg C cm^{-2}
Wilhm *et al.*	1979	3 streams in Oklahoma, USA	Plexiglass plates	Mean ash free wt. – 60 – 5020 mg m^{-2} Ash free wt. – 1.0 – 64.2 mg m^{-2} Chlorophyll a – Non detectable levels to 308 mg m^{-2}
VI. ESTUARIES				
Welch *et al.*	1972	Duwamish Estuary, Washington	Floating substrates	Net primary productivity rate – 100 mg m^{-2} $week^{-1}$
Tilley and Haushid	1975	Intertidal zone of Duwamish Estuary, S.Seatle, Washington, USA	Fixed glass slides	Net primary productivity – 0.11 mg m^{-2} Chl. a / week

represented the natural periphytic population of stones found in the lake, although quantitatively stony substrates possessed higher degree of colonization. When sheets of basalt and limestone made from stones of Lake Taberias were exposed with glass slides, the glass slides supported only 73% of the periphyton which basalt and limestone did. Hodgkiss and Tai (1976) found that the seasonal compositions of the characteristic diatom assemblages in Plover Cove reservoir, Hongkong (the epilithon, epiphyton, epipelon, and epipsammon) were not totally restricted to specific environments, and it was concluded that the different surfaces exerted little qualitative effect on the diatom communities. This view point has also been supported by Pieczynska and Spondiniewska (1963) who noted few instances of substratum specificity of diatoms in European lakes. However, Cattaneo and Kalff (1978) found the same epiphytic species and the same seasonal trend on natural and plastic plants. Moreover the relative importance of the species was found to be affected by the substrate. The loosely attached communities developed best on natural plants while the tightly attached communities developed best on artificial plants. Both the diversity differences and the differences in the community structure appeared to be the result of the summer accumulation of $CaCO_3$ observed only on the upper surface of the natural plants. In another study, Cattaneo and Kalff (1979) found similar productivities (biomass as chl. and primary production per unit area) of epiphytes on *Potamogeton richardsonii* (Denn) Rydb, and on a plastic analogue but found some evidence of nutrient transfer from the host to the epiphytes as the alkaline phosphatase activity, an indicator of P limitation, was always higher for epiphytes than on artificial substrates.

Many investigators have found great differences between the communities on slides and on natural substrata both in community composition and seasonal occurrence. Dillard (1966) reported glass to have higher diatom poupulation at both high and low temperatures. Foerster and Schlichting (1965) showed that in an eutrophic and an oligotrophic lake glass slides supported a smaller diversity of speices of diatoms, chlorophycean and cyanophycean algae compared to natural substrata. Many of the genera found on aquatic macrophytes were found to be absent on glass. They also reported that a peak in attached algae occurred on slides before it was found on plants in the oligotrophic Lake Opeongo, Ontario, Canada. A more detailed study by Tippet (1969) showed that in an eutrophic and an oligotrophic lake, and some streams, the seasonal succession of diatom species on both the natural substrata and the glass slides differed considerably. The diversity of diatom species found on the glass slides was smaller than on natural substrates, while the growth cycle of several diatom species either lengthened or shortened. Tippet (1970) found that population peaks of attached diatoms on glass did not correspond to those on *Elodea canadensis* during a two year study in Abbott's pond, England. He also reports differences in propositions of some attached species, in seasonal variation of species and in the number of species present on natural vegetation and glass slides. Twice as many diatom species were generally found attached to the natural vegetation as on slides. Thus, Tippett (1970) has questioned the ability of the artificial substrates to represent natural communities. According to the author, the use of artificial substrata could easily produce upredictable results and is an unreliable ecological indicator of changes occurring within the natural community. Luchini (1973, 74), while discussing the probable relation between substrate and diatom population, showed different percentage of microscopic slides and quartz stones (natural substrate). The presence of main species and their growth time were also shown to be different on the two types of substrates. Gemelli and Zullini (1976) in their study on the periphytic fauna living in a stretch of Po River near Piacenza (Italy) found higher number of species on artificial substrata (plexiglass slides). The data collected by Brown (1976)in lake Mize, Florida appears to support some of the findings of Tippet (1970). In open areas of the lake where current exposure was a factor, more species were found on *Eleocharis baldwinii* than on slides. Also, differences in proportions of attached species on glass and *E. baldwinii* were observed somewhat paralleling another Tippet's finding. Whereas Tippet (1970) as well as Foerster and Schlichting (1965) sometimes found higher total algal densities on glass than on aquatic macrophytes, total algal densities in Lake Mize were higher on *E. baldwinii* than on glass for all conditions tested. The abundance of many filamentous and metaphytonic algae on *E. baldwinii* and their rarity or infrequences on glass indicated that some growth forms among attached algae have difficulty in making an initial adherence (colonization) and remaining attached to glass. According to Brown (1976), it is possible that either the narrow, slender form of *E.baldwinii* or its rougher surface, as constrated with glass, promotes the development of the more weakly attaching forms in its flora i.e., filamentous and meta-phytonic species. Since both filamentous and the metaphyton were sometimes found abundant on broad-leaved macrophyte *Pancium hemitomon*, it implied that a rough surface is the more important factor in facilitating attachment. Further Brown (1976) found that the vertical range of most algal species varied with the two substrates, generally extending deeper on *E. baldwinii* than on glass. This was attributed to the presumably greater loss of algae from slides and to the decreasing photosynthesis, occurring below the lake's surface which was insufficient to maintain an increase in algal population and replace losses occurring on slides. In view of the tendency to show differential colonization rates, growth rates, turnover rates, rates of consumption and taxonomic compositions of periphyton associated with artificial as compared with natural substrata, the use of artificially submerged surfaces to measure net production rates of periphyton has especially been criticized (Foerster and Schilichting, 1965, Tippet, 1970, Mason and Bryant, 1975).

Few authors have discussed the influence of the substratum on the nature of the periphyton communities. The importance of the nature of substrate upon the structure of aufwuchs has been emphasized by Ruttner (1953). Mols (1976) found a slight relationship between the diatom composition and the kind of substrate, though environmental factors of the surrounding water seemed to be more important. St. Clair *et al.* (1978) found that the rock and macrophytic substrates had fewer total diatom species and lower density than in the plankton or on the snail shells. The lowest diversity was found on the vegetable substrate. It also had the least similarity to other habitats. The higher density and total number of species in the plankton and snail samples were found to be due to the instability of these habitats. Benzhitskii and Polikarpov (1971) found that in different regions of the surface layers of Atlantic, southern and Indian Oceans, the neuston periphyton on the contaminants (oil aggregates) differed in compostion, depending upon the degree of mineralization of substratum, geographical position and biocoenographic conditions.

Attemps so far, to detrmine any specificity of the periphyton community for different macrophytes species, have given conflicting results. Hutchinson (1967), in a review, found a general lack of specificity. Gough (1978) found no obvious specificity of epiphytic desmid taxa for a particular macrophyte. Soszka (1975) considers aquatic plants as a natural substrate for attached organisms. This view point has been well supported by Pandit (1983,93) and Pandit *et al.* (1985). However, according to Eminson and Moss (1980) the active nature of macrophyte surfaces makes this an unexpected conclusion. There is every reason to expect some influence of a live aquatic macrophytes on its periphyton flora. The encrusting algae are associated with many bacteria, inorganic deposits and mucus (Allanson, 1973) and the community must itself be metabolically quite active so that a very different environment might be expected at the macrophyte surface compared with only a few mm distant. Submerged macrophytes secrete organic compounds (Wetzel 1969) which may be taken up by the periphyton complex (Allen, 1971). Harlin (1975) and Mc Roy and Georing (1975) have also reported a transfer of nutrients from macrophytes to epiphytes. In some cases a two way movement of substances such as P has been demonstrated (Linsken, 1963, Harlin 1975, Mc Roy and Georing 1975). Fitzgerald (1969) reported inhibition of the epiphytes by plants and observed nutrient competition between macrophytes and epiphytes. Soszka (1975) and Wetzel (1975) suggested a form of symbiosis between the two. However, at present not much is known about the physiological relationship between the host plants and the epiphytes, nor is it known what determines which species of epiphyte shall develop. In considering the specificity of the periphyton communities for different macrophytes in the past, little attention has been given by most authors to the additional interaction of the external environment e.g., water chemistry and the fertility, and the way it might modify host-periphyton specificity (Eminson and Moss, 1980). Eminson and Moss (1980) found very high host specificity in the periphyton communities of an infertile lake and the specificity was found to break down even at moderately fertile waterbodies when the periphyton community composition was determined largely by external factors. Gough and Woelkerling (1976) have presented the aufwuchs data for several hosts and also the comparison of population densities among hosts within a given lake and between the same host in dfferent lakes in Wisconsin.

Distribution of periphyton in relation to the age and part of the macrophyte colonized has received some attention. Govrilla (1970) found that the qualitative and quantitative compostion of the periphyton varied not only in regard to macrophytic host type but even from one plant organ to another indicating the existence of complex allelopathic relationships between the algae and their substrate. Bownik (1970) found the dependence of density and the abundance of periphyton organisms on the life cycle of aquatic plants forming their substratum and of periphyton development on the biomass changes of the plants.

The periphyton is apparently disadvantageous to its macrophyte host because it absorbs much light that would otherwise reach the plant surface (Sand - Jensen, 1977) especially when light is a major facor limiting submerged aquatic plant growth. Further their disadvantage is because of the ability of many aquatic plants to absorb mineral nutrients from the generally nutrient rich sediments (Eminson and Moss, 1980). Thus some aquatic plants and filamentous algae such as Conjugales have evolved anti-periphyton mechanism like slimy surfaces. Other plants have a high rate of production of new leaves and discard older periphyton-clogged ones, but many tolerate quite dense periphyton growths. The later suggests that grazing invertebrates such as snails and Ephemeroptera nymphs may be diverted by such easily available food from the growth tips of the host plant so that, on balance, the periphyton conveys some advantage to the host (c.f. Eminson and Moss, 1980). Thus Wetzel (1975) suggests a form of symbiosis between epiphytes and their macrophytic substratum.

Work on the fine structure of periphyton community is restricted. Gray (1967) described the appearance of microbial flora on soil particles using SEM and Meadow and Anderson (1966) detailed the arrangement of periphyton components on the surface of sand grains. Allanson (1973) studied the structural minutial of macrophyton periphyton by SEM and gained some insight into the fine structure. Howard-Williams *et al.* (1978) studied the influence of periphyton on the surface structure of *Potamogeton pectinatus* leaves by SEM. Leaves showed a distinct succession of microflora. After 6 weeks of leaf growth prosthecate bacteria developed and were associated with cuticular erosion and epidermal pitting. 14 week old sensecent leaves showed extensive peeling and epidermal cell wall rupture which could well prepare the leaf for rapid leaching to take place immediately after death.

Wetzel and Allen (1970) and Allen (1971) have proposed a model which explains the metabolic interactions between various periphytic components and the submerged host plants and the role this littoral community plays in freshwater ecosystems.

2. Hydrological Factors

Many investigators have found that the species composition, species diversity, succession, vertical distribution, N, P, chl-a etc. of periphyton are related to different physical and chemical factors in varied types of waterbodies like lakes (Stockner and Armstrong, 1971; Gough and Woelkerling, 1976; Gough, 1978), ponds (Gough and Woelkerling, 1976; Gough, 1978), ditches (Mols, 1976), bogs (Woelkerling, 1976), creeks (Squires *et al.* 1973) and estuaries (Welch, 1972).

Brown (1973) found a positive correlation between the statistically significant increase in total cell populations and increasing length of slide exposure, pH, temperature, nitrates, nitrites and a negative correlation with oxygen, orthophosphates and hardness (Mg and total) in littoral periphyton communities sampled at different stations in Elke Lake, British Columbia.

a. *Slope:* Littoral slope has been found to determine the chemical compostion of periphyton through its effect on accumulation and suspension of organic poor benthic detritus which adheres to periphytic filamentous algae. Amounts of protein, organic matter and algae in PDA (periphytic detrital aggregate) are positively correlated with the slope of the littoral bottom (Bowen, 1979).

b. *Current:* While studying the effect of current velocity on periphyton communities in laboratory streams, Mc Intire (1966) found that in faster current periphyton consisted of diatoms and in slower current it consisted of loose, long and filamentous algae. Jones (1978) found that higher flow caused instability and scouring of stones in a small stream resulting in a decrease in standing crop of *Cocconeis* sp. and an increase in the variability between and within the stones. Dekhtyar (1976) found that the distribution and the level of the quantitative development of Testacea, Nematoda, and Crustacea on higher aquatic plants in Kie Reservoir were dependant on the degree of flowage of shallow water besides their position on floodplain and character of vegetation. Disturbances by floods are belived to be one of the fundamental controllers of temporal and spatial pattern in stream periphyton (Biggs *et al.*, 1999). Momo (1995) further opined that above a critical current velocity, development of periphyton is not stable.

Nutrients: The effect of nutrient loading in freshwaters of different fertilities has been studied by Eminson (1978), Hill and Harvey (1990), Pandit and Pandit (1996), Dude and Culp (1997), Biggs *et al.* (1999) and Pizarro (1999). They found that the increased nutrients increase the epiphytic density. With increasing stream order, an increase in the number of taxa, species diversity and equitability and a decrease in chl.a and ash-free weight values was observed by Seyfer and Wilhm (1977) while as in another study made by Wilhm *et al.* (1978) there was observed an increase in the number of taxa and decrease in densities and species diversity.

The effects os various tertiary treatment nutrient removal schemes on periphyton communities in laboratory streams have been studied by Smrcheck *et al.* (1976). Saks *et al.* (1976) has worked on the autotrophic and heterotrophic nutritional budget of salt marsh epiphytic algae.

d. *Light :* The influence of light on periphyton has been studied only in a few investigations (Wellnitz *et al*, 1996; Kutka and Richards, 1997).Welch *et al.* (1972) found an increase in the accumulation of periphyton (as µg chl. a cm^{-2} $week^{-1}$) being related to incident light.

e. *Temperature:* The effects of temperature, either direct or indirect by influencing the other environmental factors, on the growth of periphytic communities and the periphyton species individually have been studied by Phinney and Mc Intire (1965), Hutchinson (1967), Stockner (1967), Patrick (1969), Brettum (1974), Hickman (1974), and Bottrell (1975).

Phinney and Mc Intire (1965) found that atleast for temperatures, ranging not widely from the maintenance temperature of the periphyton communities developed in laboratory streams, Q_{10} of approximately 2 is applicable to rates of community respiration in lotic streams. Brettum (1974) found an important influence of water temperature on the colonization activity and efficiency of periphytic diatoms. Bottrell (1975) has discussed the relationship between temperature and duration of egg development in some epiphytic Cladocera and Coperpoda from the River Thames.

f. *DOM*: The relationship between dissolved organic matter (DOM) concentration and the character of CPM (communities of periphytic micro-organisms) metabolism in sea waters has been delineated by Khailoo and Goerbenko (1967, 69). These authors in the latter study found the concentration of organic matter at which the system is in a steady state and the limits of its fluctuation under the described experimental conditions. A model of the regulating mechanism is also suggested.

g. *Radioactivity*: Distinct periods of maximum beta-radioactivity of periphyton have been found to coincide with those of increased radioactivity of water in certain man-made reservoirs in Poland by Kwapulinskii (1972,73).

3. Relationship with Other Ecological Groups

Interactions between the periphytic algae and other ecological groups like phytoplankton and microbenthic algal associations, on the basis of quantitative evaluation of speices, have been worked out by Govrilla (1971) and Brown and Austin (1973). A decrease in cell numbers and percent abundance of some common species in planktonic populations was found to coincide with their increase in periphyton (Brown and Austin, 1973). Similarly Pandit (1980) also noticed a decrease in phytoplankton populations during winter months to be followed with an remarkable increase in the density of epipelic algae.

The ecological relations between vertebrates and submerged macrophyters are reciprocal and manifold. The macrophytes are believed to act as suitable breeding (as a place of egg-laying) and sheltering (as wintering place, as mining place, as material for building cases and substrate) places for epifaunal organisms, besides acting as food. The relation between inverebrates and macrophytes can be indirect due to the utilization of periphyton colonizing the plants (Soszka, 1974). Periphyton, as an indication of food source, is to some extent the life environment of invertebrates as the macrophytes are. The food habits of majority of the dominant epifaunal organisms (snails and chironomids) indicate macrophytes alongwith periphyton being more preferred over macrophytes without periphyton as also the dead or partly decomposed plants (Mc Gaha, 1952; Rosine, 1955; Stranczykowska, 1960; Gaevskaja, 1966; Pieczńska, 1970; Soszka, 1974; Soszka, 1975; Pandit, 1983 and Pandit *et al.* (1985). Pandit (1983 c.f. Pandit 1993) opined that the maximum development of periphytic algal community in Himalayan lakes (Dal and Nilnag) during autumn is particularly due to the death and partial decay of macrophytes, improving the trophic conditions as the decomposers release minerals for the growth of algal blooms. The growth gets restricted due to the high water level and siltation in summer.

Krull (1970) found an average of 1 g of animal material in association with 100 g of plant matrial, the results are somewhat comparable to those of Pandit *et al.* (1985).

4. Grazing

The effects of grazing by snails on the community structure of periphyton in laboratory streams have been studied by Kehde and Wilhm (1972) and Doremus and Harman (1977). They found that grazing by snails decreased the periphyton standing crop. Kehde and Wilhm (1972) further found that grazing caused a significant increase in chl a concentration, reduction in pigment diversity and no effect on species diversity. The role of reed periphyton as a source of food for chironomids has been discussed by Mason and Bryant (1975) and that of periphyton diatoms as food of lacustrine amphids is pointed by Luchini (1975). Gemmelli and Zullini (1976) have worked out the main food chain as organic sediment → *Tubifex tubifex* → *Leucisus cephalus* and *Chondrostoma soetta*, in a stretch of Po River (Italy) while Denny and Bowker (1978) found epiphyton → commercial fish food chain predominant in a reservoir in Tanzania. More recently Pandit (1983) and Pandit *et al.* (1985) constructd a typical food web of Dal lake in Kashmir Himalaya delineating the trophic relations of periphyton. The immediate consumers of periphytic algae in the complex food web were Protozoa, Rotifera, Cladocera, Ostracoda, Nematoda, Gastropoda (Mollusca), Chironomidae, Rhagonoidae, Zygoptera (nymphs), *Coraxia* sp., *Barbus conchonius*, Hydraenidae, *Hydrophilus* sp., *Schizothrax* sp (snow fish) and *Cyprinus carpio* (carp), which in turn are consumed by consumers of successive trophic levels. Studies of grazing on periphyton in the recent past have also been made by a number of workers (Hansson, 1992; Wellnitz *et al.* 1996; Charlebois and Lamberli, 1996; Bourassa and Anonella, 1998; Grahem and Vinebrooki, 1998., Greenwood *et al.* 1999 and Norberg, 1999).

5.Succession

The studies on the seasonal succession of periphyton mostly pertain to algal communities growing on substrata other than macrophytes while those concerning the epiphytic algae and the periphytic fauna are limited in number except that the data on the seasonal trends of both the periphytic flora and fauna is based on both the density and biomass of these communities in Dal and Nilnag lakes of Kashmir (Pandit, 1983).

Some of the papers which deal with the seasonal succession of different types of periphyton in diverse types of waterbodies are reviewed as under:

Author	Year	Location	Substrate	Type of periphyton
1	2	3	4	5
I. Lakes				
Oltean	1968	Lake Poru (Denube delta)	Glass plates	Algae including diatoms.
Stockner and Armstrong	1971	Experimental Lakes, Area Lakes, W. W. Ontario	Glass slides and rocks	Diatoms
Brown and Austin	1973	Elke Lake, British Columbia, Canada	Glass slides	Diatoms
Bosva	1974	Lake Krasnoye (Karebian Isthmus)		Algal groups
Ross and Trueba	1977	Lake Abcouderweer, Holland	*Phragmites australis*	Algae
Cattaneo and Kalff	1978	A shallow bay of lake Memphremagog	*Potamogeton richardsoni* and plastic analogue	Algae
Fernandes and Esteves	1996	Lagoon, Brazil	*Typha dominguenis*	Filamentous algae
II. Ponds and Pools				
Markosova	1974	Two fish ponds in south water, Bohemia		Macro fauna
Philipose *et al.*	1976	A perennial pond, Cuttak (India)	Glass slides	Algae and fauna
III. Reservoirs				
Tai and Hodgkiss	1977	Cove Reservoir, Hong Kong	Plants, rocks mud and sand	Algae including diatoms

1	2	3	4	5
IV. Wetlands				
Chierici Magnetti	1971	A strech of low river marshland, Po, Italy.	Stones	Algae and fauna
V. Streams & Canals				
Brettum	1974	An Arbuckle mountain	Glass slides	Diatoms
Reisen	1976	An Arbuckle Mountain limestone streams, Oklahoma, USA.		Tavertine periphyton
Moore	1977	A canal in sourthern England	Macrophytes	Algae
Jones	1978	Wilfin Bech, English Lake District	Stones	Algae including diatoms
Aliva and Arce	1989	Fnesno California	Stones	Cyanophyceae in summer and diatoms in spring and winter.

Philipose *et al.* (1976) while studying the periphyton on glass slides in a perennial pond at Cuttack, tropical part of India revealed the maximum development of algae during January-May and November-December and animalcules during July – September and January – March. Algae generally decreased from surface to bottom whereas the animalcules were more at the bottom or middle than at surface except during October – December. In contrast, the sub-temperate lakes of Kashmir, India evinced a unimodal growth curve for periphytic algae, with autumn as the period of enormous growth, winter and summer as periods of moderate growth and spring as the period of poor or limited growth. The investigations of Pandit (1983) further indicated mass bursts of epifaunal organisms both in summer and autumn and thus registered a long growth period.

6. Vertical distribution

The vertical distribution of littoral periphytic diatoms in relation to possible regulating mechanism has been studied by Stockner and Armstrong (1971) in one of the lakes in experimental Lakes area Lakes, N. W. Ontaria. Philipose *et al.* (1976) while studying the periphyton on glass slides fixed at 3 levels in a perennial pond at Cutack, India have found that algae generally decreased from surface to bottom whereas the animalcules were more at bottom or middle than at surface.

7. Chemical composition

The chemical compostion of PDA (periphytic detrital aggregate) on submerged *Potamogeton* species in a tropical lakes, Lake Kalercia (Venezuela) investigated by Bowen (1979) showed that samples of PDA averaged 42.2% organic matter, and the organic matter averaged 17.40% carbohydrate, 15.6% lipid, 2.6% protein and 65.2 humic substances and 2 – 2.8% of algae as a fraction of organic dry weight. Amounts of protein, organic matter and algae in PDA were positively correlated with the slope of the littoral bottom.

The fatty acid spectra of periphytic communities, developed in laboratory streams at different combinations of light intensity and current velocity, have been studied by Mc Intire (1966). He found that the communities dominated by blue-green algae exhibited relatively high proportion of Oleic, linoleic and linolenic acids and low proportion of palmitoleic acid and a $C_{20:5}$ acid as compared to communities consisting primarily of diatoms. It was observed that the species composition of the communities has no striking effect on the proportions of palmitic acid and stearic acid.

8. N_2- fixation

Invesigations on nitrogen fixation by epiphytes have been conducted by Georing and Parker (1974) in sea grass communities and by Finke and Seelay (1978) in a freshwater pond. The later workers found that the epiphytes were capable of adding 7.5 to 12.5 μg of N/mg of plant per year to the pond.

VI. RELATIONSHIP TO PROBLEMS OF APPLIED HYDROBIOLOGY

The publications dealing with the relation of periphyton to various problems of applied hydrobiology, during the last forty years, are reviewed under the following heads:

1. Role of Periphyton as Indicators of Water Quality

Periphyton communities are extremely sensitive to changes in water chemistry and are, therefore, often used in assessing the quality of water and the degree of pollution in lakes (Szczepanski, 1968; Luscinska, 1974; Pandit, 1983, 1993; Smoot *et al*, 1998), reservoirs (Sladeckova and Sladececk, 1963; Kyselowa and Krzeczkowska - Woloszyn, 1974), ponds (Philipose *et al*, 1976; Lakatos, 1977), wells (Sladeckova, 1972), rivers (Olive, 1971; Golowin, 1971; Hanak-Schmager, 1974; Furuta *et al*, 1977) and streams (Cooper and Wilhm, 1975). Besides the periphyton analysis has been used even in evaluating the ground water quality (Sladeckova, 1969).

Szczepanski (1968) established a relationship between the types of lake and the periphyton from reeds and recognized three groups of lakes with different kind of periphyton in Suwalki Lake-land.

(i) Oligotrophic lakes – with periphyton of low chlorophyll content and a low biomass.

(ii) α - mestrophic lake – with periphyton of low chlorophyll content and a high biomass.

(iii) β- mesotrophic and eutrophic lakes – with a high amount of chlorophyll in the periphyton and a high biomass.

Sladeckova (1972) has recognized four types of periphyton indicating different quality of wells.

(i) Periphyton composed entirely of iron bacteria indicating the real ground water rich in dissolved ferrous compounds.

(ii) Periphyton with abundant colourless sulphur bacteria indicating the absence of organic contaminants.

(iii) Periphyton composed of both the iron and the sulphur bacteria indicating the conditions resembling mineral springs.

(iv) Periphyton consisting of felted mats of *Sphaerotilus* filaments indicating a warming evidence of contamination due to seepage of organically enriched river water.

Luscinska (1974) considers the occurrence of epiphytic assocaiton of *Oedogonio – Epithemictum* in some Polish lakes pointing to high purity of littoral waters. Further the occurrence of great number of filamentous Chlorophyceae at relatively considerable depths showed the moderate eutrophication of the lakes. The occurrence of *Meridion circulare* and *Gongrosira schmidler* also pointed to the cleanliness and oxygenation of the littoral of the lakes.

A high species diversity and more varied periphyton indicate an improvement of water quality in enriched streams (Cooper and Wilhm, 1975). A high species diversity also represents meso-eutrophic conditions and smaller number of epiphytic algal species and individuals represent oligotrophic state of ponds (Lakatos, 1977).

On the basis of list of species and numerical data of the Pantle-Buck index, Hanak-Schmager (1974) found high values of saprobe index for a sector of River Vistula (Poland) and characterized it as alpha-mesosaprobic.

Rurtura *et al.* (1977) assessed the water pollution level of Chickuma and Kakuma rivers in Japan by means of attached diatoms and found them to be β -meso saprobic and α –mesosaprobic respectively.

Recently Pandit (1983, 1993) made use of indicator speeis, species compostion and biomass of periphytic flora and fauna to assess the trophic status of Himalayan lakes. The studies pointed out that the valley lakes, as typified by the Dal Lake, with greater species number and biomass besides the predominance of eutrophic forms, has higher trophic status and enjoy eutrophication compared to less eutrophic forest lake (Nilnag) which is almost in a transitional stage between mesotrophic and eutrophic conditions.

2. Effect of Commercial Wastes on Periphyton

Dickman (1969) found that germanium dioxide inhibited the natural diatom growth on slides and brought about changes in species composition and diversity of periphyton. In another study, Dickman (1974) found that germanium caused a significant decrease in standing crop and species diversity and a change in successional pattern. Dickman (1973) has also studied the effect of total dissolved electrolytes on periphyton above and below a sulphite and paper mill. Dickman (1973) found that additions of less than 50 mg/l of $NaHCO_3$ was sufficient to stimulate a dense standing crop of periphytic algae in a small bog lake outlet. Further the species compostion did not differ appreciably between treated and control slides. A slight shift in species composition towards Cyanophyceae was also observed on bicarbonate treated slides. Dickman and Gochnaur (1978) have also studied the impact of addition of sodium chloride to a small stream (in order to simulate roadsalt loading) on the periphyton collected on slate tiles. The results showed a reduction in algal density and algal diversity and an increase in bacterial density. Further the algal and bacterial grazers were found to be noticeably less abundant at the salt enriched station. While studying the effect of discharge of inorganic compounds from a chemical company on the epiphytic diatoms of the lower Weeland River, Ontario, Dickman *et al.* (1980) found that *Nitzschia dissipata* being replaced by *N.palea* and the filamentous green algae being replaced by blue-green algae such as *Oscillatoria* and *Lyngbya*.

Cooper and Wilhm (1975) has studied tne effect of sugar mill effluents on the periphyton of Skeletal Creek, Oklahoma and found that the pollution increased the periphyton saprobity and periphyton productivity. Hillebust *et al.* (1975) studied the effect of crude oil, leaking from pipes, on the periphyton of subarctic Hanna Lake in the Mackenzie Valley and found that crude oil had marked inhibitory effect on most of the members of the periphyton growing on periphyton traps. A definite species difference in crude oil tolerance of the periphyton was also observed. Crude oil was seen to stimulate the growth of *Oedogonium angustissima* and inhibiting the growth of *Mougeotia, Cosmarium* and *Tabellaria* species. Chrost and Sikorska (1976) studied the effect of pollution with commercial wastes on periphyton and found that the heavily polluted environments effect the inhibition of the photosynthetic activity of periphyton. Stainslawska- Swiatkowska and Rankerybicha (1976) studied the effect of the insecticides, Dichlorofos and Nogas-G, on periphyton. Nogas-G was found to cause reduction in the number of organisms and had the strongest effect on certain dominant plant and animal species during the first three days and with the passing time a gradual regeneration of the periphytic communities was observed. Fry and Ramsay (1977) have studied the changes in the activity of epiphytic bacteria following treatment with herbicide paraquat. Amblard *et al.* (1996) and Dube and Culp(1996) studied the effects of pulp on the structure and metabolism of periphytic algae and chronomids in their studies respectively.

3. Effect of Sewge Effluent on Periphyton

Muncipal sewage on phyco-periphyton has been studied by Schlichting and Gearhart (1966) in the Lake Murray, Oklahama and on ciliates by Kuesters (1974) in marine areas in Konigshaften, W. Germany. Furuta *et al.* (1977) found that the domestic discharge increased the periphyton biomass in Chickuma and Kakuma rivers in Japan.

4. Effect of Thermal Effluents on Periphyton

The effect of thermal stress, mainly due to the inflow of the treated waters or heated waters from power stations or nuclear generating stations, on periphyton communities have been studied by Owen (1971) in Columbia River, Taylor (1973) in Green River, Hickman and Klarer (1974,75) and Klarer and Hickman (1975) in Lake Wabamun, Edmonton, Alberta, Andrzejezak – Czechowska and Wisniewski (1976) in Narew River, Poland and Hein and Koppen (1979) in Forked River, New Jersey. It has been found that the heated water keeps the waterbodies free of ice during winter and thus extending the period of open water conditions (Hickman and Klarer, 1974; Klarer and Hickman, 1975). Such conditions increase the growing season of macrophytes and hence an increase in the mean yearly standing crop size (Klarer and Hickman, 1975) and the primary productivity of epiphyton (Hickman and Klarer, 1975). Besides, the longer growing season has been found to be responsible for early development and extended spring maxima of some algal species (Hickman and Klarer, 1974). Heated waters have also been found to effect the growth of certain species adversely (Hickman and Klarer, 1974) besides causing a change in species composition and a shift of dominance from diatoms to chlorophycean species (Klarer and Hickman, 1975; Hickman and Klarer, 1975). The general pattern of seasonal succession is not altered by heated waters (Klarer and Hickman, 1975). According to the authors, the thermal effluent has been found to act as a pollutant causing a decrease in the number of species and corresponding increase in the relative importance of few species. A decrease in photosynthetic efficiency of algae and a decrease in photosynthetic index due to the inflow of heated waters has been observed by Hickman and Klarer (1975). Heated waters causing a decrease in the density of periphytic algae and the number of diatom species and an increase in the ratio of the indicator forms of α-mesosaprobity have been observed by Andrezejezak-Czechowska and Wisniewski (1976). Hein and Koppen (1979) observed that the heated effluents cause a decrease in the species number and diversity and an increase in redundancy of periphyton diatom assemblages developed on Styrofoam balls. Further they found that the thermal stress above a critical temperature for short periods is detrimental to the structure of the assemblages.

5. Role of Periphyton in the Treatment of Industrial Wastes

Kasmov *et al.* (1972) found that in a waste water treatment plant the periphyton had a greater affinity for P_{32} and accumulated larger quantities than did the corresponding biomass of plankton. The average gross uptake rate per hour (R_1) of periphyton was found to be six times greater than that of the plankton community and the average activity uptake rate (R_2) was noted as 147 for the periphyton and only 6.4 for the plankton.

Berzins and Lundqvist (1973) found the replacement of saprobic organisms by eutrophic and indifferent organisms of the periphyton populations in Ybbarpsam River, Sweden, after a factory began treating its effluents. Huk (1973) also reported the observations on the development of epiphytic microphytes on a synthetic medium (bunches of cellophane strips) in a pond filled with undiluted beet sugar factory wastes. The results showed full mineralisation of waste waters within 8 months from the time the wastewaters were released into the pond. The individual stages of self-purification were found to be characterized by a different composition of periphyton and different numbers of particular taxons. This was found to correspond with the biochemical changes recorded in the examined pond.

6 Periphyton of Cooling Towers

While aiming at preventing the formation of biotecton on the surface of elements of the cooling water system in Tiszamenti Vegyimuvek, Szolnok (Hungary), Tokar *et al.* (1976) has investigated the species compostion, structure and succession of the formation of biotecton besides finding out the ecological demands of different species.

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