

Francoeur, S.N., B.J.F. Biggs, R.A. Smith, and R.L. Lowe. 1999. Nutrient limitation of algal biomass accrual in streams: seasonal patterns and a comparison of methods. *Journal of the North American Benthological Society* 18:242-260.

*Abstract.* In-situ, nutrient amendment experiments (nutrient-diffusing substrata, NDS) were conducted in 12 New Zealand gravel-bed streams to investigate seasonality of biomass accrual and nutrient limitation of benthic algal communities. Benthic algal biomass accrual rates exhibited significant ( $p = 0.019$ , repeated measures ANOVA) seasonal differences; rates were greatest in summer and least in winter. The degree of nutrient limitation also differed ( $p = 0.003$ ) seasonally; periphyton community biomass was most responsive to nutrient amendments in summer and least responsive in winter. Temperature may be the underlying cause of these patterns. The ratios of dissolved inorganic nitrogen to soluble reactive phosphorus (DIN:SRP) in streamwater and of streambed periphyton communities were of limited use for predicting which nutrient limited NDS bioassays; cellular nutrient content was weakly predictive. This study demonstrates the need to consider temporal changes (i.e., seasonality) when assessing the influence of nutrients on stream ecosystems, and indicates that the use of nutrient ratios to ascertain which nutrient may limit benthic algal biomass should be validated with field experiments.

*Key words:* benthic algae, periphyton, biomass, nutrients, seasonality, nutrient limitation, nutrient ratios, cellular nutrients.

Hill, W.R., H.L. Boston, and A.D. Steinman. 1992. Grazers and Nutrients Simultaneously Limit Lotic Primary Productivity. *Canadian Journal of Fisheries and Aquatic Sciences* 49:504-511.

Nitrate and phosphate were added to two of four flow through channels in a second-order stream in eastern Tennessee to raise nutrient concentrations to 3–4 times background, while two of four sets of colonized ceramic tiles in each channel were raised above the substratum to exclude grazing snails (*Elimia clavaeformis*). Snail grazing maintained a thin layer of periphyton dominated by *Stigeoclonium* basal cells, regardless of nutrient regime. Although nutrient effects on periphyton ash-free dry mass were statistically insignificant, nutrient additions significantly increased chlorophyll *a*, especially where snails were excluded. Snail densities were 89% higher in nutrient-enriched channels. Photosynthesis–irradiance data suggested that nutrient enrichment increased self-shading in the periphyton. Areal-specific productivity was simultaneously limited by grazing and low nutrient concentrations: snail exclusion and nutrient enrichment both increased productivity >2 times. The negative effect of snails on areal-specific productivity was due to (1) reduction in biomass by cropping and (2) depression of chlorophyll-specific productivity. The means by which *Elimia* depresses chlorophyll-specific productivity is unclear, but the depression is clearly disadvantageous to food-limited grazers. Because *Elimia* was the dominant invertebrate, our results indicate that low nutrient concentrations limit secondary as well as primary production in autumn.

Horner, R.R., and E.B. Welch. 1981. Stream Periphyton Development in Relation to Current Velocity and Nutrients. *Canadian Journal of Fisheries and Aquatic Sciences* 38:449-457.

Measurement of chlorophyll *a* accrual on flattened rock substrates placed in streams revealed that a velocity increase up to  $\sim 50 \text{ cm} \cdot \text{s}^{-1}$  enhanced periphytic algae accumulation when orthophosphate-phosphorus concentration exceeded  $40\text{--}50 \mu\text{g} \cdot \text{L}^{-1}$ . At lower P concentrations velocity increases reduced the accrual rate. The erosive effect of current was hypothesized to retard accumulation unless nutrient availability was such that the positive influence of turbulent diffusion of dissolved substances, and consequent cell growth, overcame frictional shear. Velocity increments above  $50 \text{ cm} \cdot \text{s}^{-1}$  eroded an increasingly greater proportion of the periphyton growth. The definition and use of a heterotrophic index as the ratio of adenosine triphosphate to chl *a* demonstrated that current velocity increases assisted the accumulation of the attached consumers relative to that of the primary producers. Comparison of heterotrophic indices before and after elevated storm runoff currents showed smaller reductions in the standing crop of the periphytic heterotrophs than that of the autotrophs.

*Key words:* periphyton, current velocity, nutrients, phosphorus, chlorophyll *a*, adenosine triphosphate, heterotrophs

Horner, R.R, E.B. Welch, M.R. Seeley, and J.M. Jacoby. 1990. Responses of Periphyton to changes in current velocity, suspended sediment and phosphorus concentration. *Freshwater Biology* 24:215-232.

SUMMARY. 1. Research was performed in laboratory streams to evaluate periphytic biomass accrual, export, and community composition over a range of limiting nutrient (phosphorus) concentrations with variable velocity, and suspended sediment addition, in comparison to constant velocity and no suspended sediment. In fixed-velocity treatments, velocity increase to  $60 \text{ cm s}^{-1}$  significantly enhanced biomass accrual, but further increase resulted in substantial biomass reduction. Average biomass loss rates did not change significantly over a velocity range of  $10\text{--}80 \text{ cm s}^{-1}$ . Diatoms were favoured at relatively high velocities and low phosphorus concentrations, whereas the blue-green *Phormidium* tended to dominate at higher SRP concentrations and the green *Mougeotia* seemed to prefer lower velocities.

2. Sudden increases in velocity raised instantaneous loss rates by an order of magnitude or more, but these high rates persisted only briefly. As a result, marked biomass reductions were not apparent a day after the velocity change. Dominance change from filamentous green or blue-green to diatoms immediately after the increase was reversed within 2 days. Loss rate increases due to solids addition were much smaller than those accompanying velocity increase, but simultaneous velocity elevation and solids addition produced instantaneous loss rates approximately double those with velocity increase alone.

3. The experiments demonstrated that an elevation in velocity, above that to which algae were accustomed, led to increased loss rates and temporarily reduced biomass. However, recolonization and growth after biomass reduction were apparently rapid. Substantial export of periphyton following solids addition required erosion of the protective boundary layer accompanied by a velocity increase. These results are applicable to understanding the response of lotic periphytic algae to elevated, turbid storm discharges and similar runoff or high-flow events.

4. Areal uptake rates of P by algae growing in the laboratory streams increased with soluble reactive phosphorus (SRP) concentration, up to approximately  $15 \mu\text{g l}^{-1}$  in overlying water. They also increased above  $35 \text{ cm s}^{-1}$ . Overall, uptake rate seemed to vary inversely with biomass. The ratio of areal uptake rate/biomass was significantly less where mean biomass was  $411 \pm 6 \text{ mg chl } a \text{ m}^{-2}$  compared to  $223 \pm 17 \text{ mg chl } a \text{ m}^{-2}$ .

5. The results suggested that although nutrient uptake is primarily a surface phenomenon, diffusion to interior cells can also determine the responses of attached communities. Both diffusion and uptake rate were stimulated by increasing nutrient concentration and velocity up to certain levels, but became limited by biofilm thickness and scouring.

Humphrey, K.P. and R.J. Stevenson. 1992. Responses of benthic algae to pulses in current and nutrients during simulations of subscouring spates. *Journal of the North American Benthological Society* 11:37-48.

*Abstract.* We tested the hypothesis that modest increases in discharge and nutrients, like those occurring during spates, could have a positive effect on benthic algae in streams. Patterns in orthophosphate ( $\text{PO}_4\text{-P}$ ), total phosphate (TP), nitrate ( $\text{NO}_3\text{-N}$ ), and total Kjeldahl nitrogen (TKN) concentrations in stream waters showed that nutrient concentrations could increase during and after spates. In-stream nutrient concentrations were correlated to indicators of spates in an agricultural basin more than in a forested catchment. Nutrient and current concentrations were manipulated in experimental stream channels to simulate a subscouring spate, i.e., a spate during which organisms are not removed from substrates. Increasing  $\text{PO}_4\text{-P}$  and  $\text{NO}_3\text{-N}$  concentrations in the water for 12 h had little immediate effect on algal biomass but did increase phosphorus concentrations in periphyton. This increase in periphyton-P did not stimulate algal growth. Doubling current from 10 to 20 cm/s for 24 h had no effect on benthic algal biomass during the 24-h manipulation. Increasing current increased periphyton-N in high nutrient conditions but decreased periphyton-N concentrations and algal growth rates in low nutrient conditions. Changes in periphyton chemistry provided valuable information for development of hypotheses to explain responses of algae to environmental manipulations. Our results suggest that subscouring spates will probably inhibit algal growth in nutrient-poor streams, but could stimulate algal growth in nutrient-rich streams.

*Key words:* periphyton, benthic algae, diatoms, nutrients, nitrogen, phosphorus, intracellular, current, spates.

Jones, J.R., M.M. Smart, and J.N. Burroughs. 1984. Factors related to algal biomass in Missouri Ozark streams. *Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie* 22:1867-1875.

### Introduction

In this paper we examine factors related to benthic and suspended algal biomass in selected Missouri Ozark streams. Our purpose was to describe algal biomass values in these streams and test the hypothesis that physical conditions and nutrient concentrations account for differences in algal biomass among streams and over time. In this analysis we assumed that the suspended algae in these streams originate from periphyton attached to the streambed (SWANSON & BACHMANN 1976).

Lamberti, G.A. and A.D. Steinman. 1997. A comparison of primary production in stream ecosystems. *Journal of the North American Benthological Society* 16:95-104.

The object of this paper is to identify physical, chemical, and biological variables that might help explain the wide range of primary production observed in streams from a variety of biomes and locations throughout the world. We used regression approaches to search for predictive, statistical relationships that might reveal how aquatic, riparian, and watershed variables are associated with differences in primary production among 30 streams from the original data set (see Webster and Meyer 1997) for which primary production was measured.

Primary production may be defined generally as the conversion of solar energy to reduced chemical energy, or specifically as the amount of organic matter formed from inorganic carbon by photosynthetic organisms during a specified time interval (Bott 1996). The total amount of carbon fixed during the interval is the gross primary production (GPP). Common intervals used to describe GPP are a day or a year. Because plants also respire to drive their cellular metabolism, some of this fixed energy is lost as CO<sub>2</sub>; this process is termed autotrophic respiration (R<sub>a</sub>). The remaining fixed carbon allocated to biomass represents the net primary production (NPP).

Leland, H.V. 1995. Distribution of phytobenthos in the Yakima River basin, Washington, in relation to geology, land use, and other environmental factors. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1108-1129.

**Abstract:** Benthic-algal distributions in the Yakima River, Washington, basin were examined in relation to geology, land use, water chemistry, and stream habitat using indicator-species classification (TWINSpan) and canonical correspondence analysis (CCA). Algal assemblages identified by TWINSpan were each associated with a narrow range of water-quality conditions. In the Cascade geologic province, where timber harvest and grazing are the dominant land uses, differences in community structure (CCA site scores) and concentrations of major ions (Ca and Mg) and nutrients (solute P, SiO<sub>2</sub> and inorganic N) varied with dominant rock type of the basin. In agricultural areas of the Columbia Plateau province, differences in phytobenthos structure were based primarily on the degree of enrichment of dissolved solids, inorganic N, and solute P from irrigation-return flows and subsurface drainage. Habitat characteristics strongly correlated with community structure included reach altitude, turbidity, substratum embeddedness (Columbia Plateau), large woody-debris density (Cascade Range), and composition and density of the riparian vegetation. Algal biomass (AFDM) correlated with composition and density of the riparian vegetation but not with measured chemical-constituent concentrations. Nitrogen limitation in streams of the Cascade Range favored nitrogen-fixing blue-green algae and diatoms with endosymbiotic blue-greens, whereas nitrogen heterotrophs were abundant in agricultural areas of the Columbia Plateau.

Lohman, K., J.R. Jones, and B.D. Perkins. 1992. Effects of Nutrient Enrichment and Flood Frequency on Periphyton Biomass in Northern Ozark Streams. *Canadian Journal of Fisheries and Aquatic Sciences* 49:1198-1205.

Ambient nutrient concentrations (TN and TP) and periphyton biomass (Chl a) were measured every 2 wk during March–November in 1985 and 1986 at 22 sites on 12 streams in the northern Ozarks, Missouri. Benthic Chl a was positively correlated in both years with log TN ( $R^2 = 0.58, 0.60$ ) and with log TP ( $R^2 = 0.47, 0.60$ ). When sites were grouped by the degree of enrichment and plotted over time, benthic Chl a decreased at all sites after flood events, but rebounded more rapidly at highly enriched sites. Differences in recovery following flooding were most obvious in fall 1986, when both high and moderately enriched sites exhibited similar biomass accrual patterns, reaching mean benthic Chl a of 397.4 and 321.1  $\text{mg}\cdot\text{m}^{-2}$ , respectively, within 42 d after a catastrophic flood. In contrast, average benthic Chl a at nutrient-poor sites reached a maximum level of 76.8  $\text{mg}\cdot\text{m}^{-2}$  within 28 d after flooding, suggesting that maximum standing crops are influenced by both nutrient supply and the length of the flood-free period.

Lowe, R.L., S.W. Golladay, and J.R. Webster. 1986. Periphyton response to nutrient manipulation in streams draining clearcut and forested watersheds. *Journal of the North American Benthological Society* 5:221-229.

*Abstract.* Nutrient-releasing artificial substrata were deployed in streams draining clearcut and forested watersheds to evaluate resources potentially limiting to populations of benthic algae. Nitrogen, phosphorus, and calcium were released singly and in combination in the two streams that differed primarily in light availability. Periphyton were harvested after one- and two-month exposure periods and analyzed for chlorophyll. The two-month substrata were additionally analyzed for algal community structure. Algal periphyton in the clearcut stream accumulated more chlorophyll and biovolume than in the forested stream across all nutrient treatments. Algal community structure was significantly different between streams but not between nutrient treatments. Algal physiognomies were also significantly different between streams with filamentous green algae dominating the clearcut stream and erect diatoms dominating the forested stream. Light appears to limit algal accumulation in the forested stream and there is evidence that some populations in the clearcut stream may be nutrient limited. Adequate light also resulted in a more architecturally diverse community.

*Key words:* periphyton, algae, benthos, nutrients, micro-architecture, streams, productivity.

McCormick, P.V. and J. Cairns, Jr. 1994. Algae as indicators of environmental change. *Journal of Applied Phycology* 6: 509-526.

### Abstract

Despite an increased awareness by governments and the general public of the need for protecting all types of aquatic habitats, human impacts continue to impair the services that these ecosystems provide. Increased monitoring activities that focus on all major biological compartments are needed to quantify the present condition of Earth's aquatic resources and to evaluate the effectiveness of regulations designed to rehabilitate damaged ecosystems. Algae are an ecologically important group in most aquatic ecosystems but are often ignored as indicators of aquatic ecosystem change. We attribute this situation both to an underappreciation of the utility of algal indicators among non- phycologists and to a lack of standardized methods for monitoring with algae.

Because of their nutritional needs and their position at the base of aquatic foodwebs, algal indicators provide relatively unique information concerning ecosystem condition compared with commonly used animal indicators. Algae respond rapidly and predictably to a wide range of pollutants and, thus, provide potentially useful early warning signals of deteriorating conditions and the possible causes. Algal assemblages provide one of the few benchmarks for establishing historical water quality conditions and for characterizing the minimally impacted biological condition of many disturbed ecosystems. Preliminary comparisons suggest that algal indicators are a cost-effective monitoring tool as well.

Based on available evidence from field studies, we recommend development of taxonomic indicators based on diatoms (Bacillariophyceae) as a standardized protocol for monitoring ecosystem change. Both population- and community-level indices have inherent strengths, and limitations and information from both levels of biological organization should be utilized in tandem. However, further information concerning species tolerances to a variety of anthropogenic stressors is needed if autecological indices are to be used routinely for monitoring purposes. While functional measures (e.g. productivity) may also prove useful as monitoring tools, further investigation is required to characterize the reliability of alternative methodologies and to assess the consistency of these indicators under varying field conditions.

Miltner, R.J. and E.T. Rankin. 1998. Primary nutrients and the biotic integrity of rivers and streams. *Freshwater Biology* 40:145-158.

### SUMMARY

1. Controls to reduce loadings of primary nutrients to maintain biotic integrity in rivers and streams have not been widely implemented because the relation between nutrients and chlorophyll, and its consequences for higher trophic levels, is confounded in lotic ecosystems by their openness, the variable degree of nutrient limitation and by the effect of physical factors.
2. The relationship between primary nutrients and biotic integrity in rivers and streams was tested using biological, physical and chemical information collected since 1982 from similar locations in streams throughout Ohio using standard procedures.
3. There was a negative correlation between nutrients, especially total phosphorus, and biotic integrity. The deleterious effect of increasing nutrient concentration on fish communities in low order streams was detectable when nutrient concentrations exceeded background conditions (total inorganic nitrogen and phosphorus  $> 0.61 \text{ mg L}^{-1}$  and  $0.06 \text{ mg L}^{-1}$ , respectively).
4. These results suggest that the control of release of toxins and oxygen-demanding wastes to rivers is insufficient to protect aquatic life, and confirm the importance of non-point sources of pollution in catchment planning as well as the combined effect of habitat and riparian quality on nutrient assimilation.

Mulholland, P.J., E.R. Marzolf, S.P. Hendricks, and R.V. Wilkerson. 1995. Longitudinal patterns of nutrient cycling and periphyton characteristics in streams, a test of upstream-downstream linkage. *Journal of the North American Benthological Society* 14:357-370.

*Abstract.* Longitudinal gradients in streamwater nutrient concentrations in Walker Branch are generated as a result of instream nutrient uptake and spatially confined groundwater inputs during the period from November to May. The response of the stream periphyton community to these longitudinal nutrient reductions was determined by measuring periphyton biomass, productivity, species composition, and phosphorus (P) cycling indices at four stations along a longitudinal transect in the stream. Phosphorus cycling indices (chlorophyll-specific phosphatase activity, phosphorus content of periphyton) exhibited significant changes along the longitudinal transect during those times of the year when streamwater soluble reactive phosphorus (SRP) concentrations also decreased along the transect. During the period from June to October, however, neither streamwater phosphorus concentrations nor phosphorus cycling characteristics exhibited longitudinal trends. Regressions between phosphatase activity and streamwater SRP concentration and between phosphorus content and streamwater SRP were highly significant for all data combined, with SRP explaining  $\geq 74\%$  of the variation in phosphatase activity and P content.

Measures of periphyton biomass (chlorophyll *a*, total biovolume), and productivity (areal carbon fixation rate, chlorophyll-specific carbon fixation rate) exhibited no consistent longitudinal patterns, even during the period of longitudinal streamwater phosphorus depletion. Regressions between productivity measures and streamwater SRP concentration for all data combined were significant, but SRP explained  $\leq 56\%$  of the variation in productivity. Periphyton biomass and productivity at all stations along the longitudinal transect appear to be maintained at low levels by high and longitudinally uniform rates of herbivory throughout the year. Algal species composition exhibited some response to longitudinal nutrient depletion. The biovolume and percentage of the blue-green alga *Chamaesiphon investiens* increased and the percentage of the chlorophyte *Stigeoclonium* sp. declined longitudinally when nutrients also declined.

Our results demonstrate an upstream-downstream biotic linkage in Walker Branch. We show that instream nutrient uptake can reduce the concentrations of nutrients in stream water and thereby influence the structure and functioning of downstream periphyton communities. However, increases in nutrient cycling in response to lower streamwater concentrations can partially compensate for nutrient depletion by upstream organisms, thereby buffering primary productivity in downstream periphyton communities from changes in nutrient supply.

*Key words:* stream periphyton, nutrients, phosphorus, phosphatase, primary productivity, upstream-downstream linkage, longitudinal gradients.



Munn, M.D., L.L. Osborne, and M.J. Wiley. 1989. Factors influencing periphyton growth in agricultural streams of Central Illinois. *Hydrobiologia* 174:89-179.

#### Abstract

Factors limiting periphyton accrual in east-central Illinois agricultural streams were investigated. Nutrient-diffusing substrata were used to examine periphyton macronutrient limitation in streams in two agricultural watersheds. Substrata consisted of sand-agar mixtures with one of six experimental treatments. Macronutrients included carbon, nitrate, phosphate and combinations of the three. Substrata were collected after a 5 and 9 day period and analyzed for chlorophyll *a*. None of the treatments were significantly greater than the controls at any of the seven stations, thus we conclude that periphyton in these streams was not nutrient limited. Highest periphyton colonization/growth rates were associated with the smaller upstream reaches, while lower rates occurred in the larger downstream reaches. Multiple regression showed that most of the variance in the rate of chlorophyll *a* accrual after five days was explained through water temperature and turbidity ( $r^2 = 0.91$ ); whereas, stream nitrate and phosphate concentrations accounted for no significant portion of the variance. We conclude that instream primary production in agricultural streams of central Illinois is limited by temperature and light.

Perrin, C.J., M.L. Bothwell, and P.A. Slaney. 1987. Experimental Enrichment of a Coastal Stream in British Columbia: Effects of Organic and Inorganic Additions on Autotrophic Periphyton Production. *Canadian Journal of Fisheries and Aquatic Sciences* 44:1247-1256.

Periphyton accumulation rates and alkaline phosphatase activity were examined in reaches of the Keogh River, British Columbia, following additions of grain and inorganic fertilizer as separate treatments during spring–summer 1981. Two different levels of N and P addition were used: one to attain ambient N and P concentrations of 200 and 15  $\mu\text{g}\cdot\text{L}^{-1}$ , respectively, and the other to attain 400 and 20  $\mu\text{g}\cdot\text{L}^{-1}$ , respectively. Grain (rolled barley) was added monthly at 280  $\text{g}\cdot\text{m}^{-2}$ . N and P additions increased chlorophyll *a* accrual rates by more than an order of magnitude. Diatoms dominated the periphyton community until midsummer. In July and most of August, the relative importance of chlorophytes increased and biomass levels declined markedly in spite of continued nutrient additions. Grain additions resulted in no detectable change in periphyton accrual, but alkaline phosphatase activity increased by 35% over control levels. These results suggest that additions of labile organic matter to nutrient-deficient coastal streams can increase autotrophic P deficiency. Based on responses of juvenile salmonids, additions of inorganic nutrients to increase autotrophic production can maximize trophic enhancement in nutrient-deficient streams.

**Abstract.** Using stream-side, flow-through channels, I tested for the effects of nutrients (NU) (nitrogen plus phosphorus), irradiance (L), and snail grazing (G) on a benthic algal community in a small, forested stream. Grazed communities were dominated by a chlorophyte (basal cells of *Stigeoclonium*) and a cyanophyte (*Chamaesiphon investiens*), whereas ungrazed communities were comprised almost entirely of diatoms, regardless of nutrient and light levels. Snails maintained low algal biomass in all grazed treatments, presumably by consuming increased algal production in treatments to which L and NU were increased. When nutrients were increased, cellular nutrient content increased under ambient conditions (shaded, grazed) and biomass and productivity increased when snails were removed and light was increased. Together, nutrients and light had positive effects and grazing had negative effects on biomass (chlorophyll *a*, AFDM, algal biovolume) and chlorophyll- and areal-specific productivity in ANOVAs. However, in most cases, only means from treatments in which all three factors were manipulated (ungrazed, + NU&L treatments) were significantly different from controls; effects of single factors were generally undetectable. These results indicate that all three factors simultaneously limited algal biomass and productivity in this stream during the summer months. Additionally, the effects of these factors in combination were in some cases different from the effects of single factors. For example, light had slight negative effects on some biomass parameters when added at ambient snail densities and nutrient concentrations, but had strong positive effects in conjunction with nutrient addition and snail removal. This study demonstrates that algal biomass and productivity can be under multiple constraints by irradiance, nutrients, and herbivores and indicates the need to employ multifactor experiments to test for such interactive effects.

**Key words:** Periphyton – Nutrients – Irradiance – Grazing – Stream

Rosemond, A.D. 1994. Multiple factors limit seasonal variation in periphyton in a forest stream. *Journal of the North American Benthological Society* 13:333-344.

*Abstract.* This study was conducted to characterize periphyton biomass, productivity, and algal species composition, and to examine how these parameters changed seasonally over the course of two years in Walker Branch, a temperate forest stream. Seasonal variations in several factors potentially controlling periphyton (irradiance, streamwater nutrient concentrations, temperature, and the incidence of severe storms) were large. However, there was no consistent seasonal variation in herbivore (snail) density, which was high ( $>1000$  animals/m<sup>2</sup>). Regression analysis was conducted to determine the influence of potential controlling factors on periphyton biomass and productivity. Seasonal changes in periphyton biomass were small and only weakly related to irradiance (–), snail density (–), and temperature (+). Biomass was lowest in early spring and highest in summer in 1989; but during the following year, biomass was similar year-round. Seasonal variation in primary productivity was also relatively small, but was positively related to inorganic nitrogen concentration and was highest during summer. Although there were some small seasonal changes in algal species composition, more striking was the fact that *Stigeoclonium* sp. (primarily grazer-resistant basal cells) dominated year-round, forming  $>45\%$  of total algal biovolume. The lack of strong seasonal variation in periphyton biomass and productivity and the observed dominance by a grazer-resistant alga appeared to be primarily the result of the high and relatively constant density of snails. The lack of a relationship between periphyton biomass and productivity also suggested an overriding effect of snails, which can consume increases in productivity when they occur. These findings suggest that in streams where herbivore density is high, periphyton productivity and biomass may remain relatively constant, despite seasonal fluctuations in potentially limiting physical and chemical variables. Although high densities of snails were probably the primary cause of the lack of large seasonal variation in periphyton biomass, productivity, and species composition, strong asynchrony in several growth-limiting factors, such as nutrients and irradiance, may also have limited seasonal changes in periphyton, implying that multiple factors were important.

*Key words:* periphyton, algae, seasonality, limitation, stream, herbivory, nutrients, irradiance, snails, temperature, discharge.

Schanz, F. and H. Juon. 1983. Two different methods of evaluating nutrient limitations of periphyton bioassays, using water from the River Rhine and eight of its tributaries. *Hydrobiologia* 102:187-195.

Abstract

An investigation was undertaken to evaluate the nutrient status of the River Rhine (two stations) and eight of its tributaries (total of ten samplings). Determinations of the following inorganic substances were made:  $\text{PO}_4^{3-}\text{-P}$ ;  $\text{NO}_3^- \text{-N}$ ;  $\text{NO}_2^- \text{-N}$ ;  $\text{NH}_4^+ \text{-N}$ ; and  $\text{C}^{1-}$ . In addition, pH and carbonate alkalinity were measured. Bioassays to obtain the algal growth potential (AGP) were carried out using periphyton from the River Rhine. A linear relationship could be established between  $\text{NO}_3^- \text{-N}$  and the AGP, while the AGP showed a non-linear dependence on the  $\text{PO}_4^{3-}\text{-P}$  concentration. The critical N/P ratio for N or P limitation of the algal growth in bioassays was evaluated graphically and by calculation. The results of the two methods were in good agreement; N is the limiting factor at  $\text{NO}_3^- \text{-N} / \text{PO}_4^{3-}\text{-P}$  ratios less than 10, while P is limiting at ratios greater than 20. At values between 10 and 20 neither N nor P can be supposed with certainty to be limiting.

Sumner, W.T. and S.G. Fisher. 1979. Periphyton production in Fort River, Massachusetts. *Freshwater Biology* 9:205-212.

**SUMMARY.** The primary production and general ecology of a periphyton community of a New England, lowland stream were studied over a seventeen-month period. Temperature, light, periphyton chlorophyll-*a*, and community structure were monitored regularly. Seasonally distinct chlorophyll peaks coincided with the light maximum in early May, just prior to the appearance of leaves of riparian trees, and again in autumn after terrestrial leaf fall. During midwinter, despite low light and temperature levels and high stream discharge, mean chlorophyll concentrations remained similar to summer values.

A mathematical expression relating periphyton photosynthesis per unit chlorophyll-*a* to temperature, light and periphyton density was established with submersible light-dark chambers *in situ*. Survey data collected over the study period were employed in the empirical equation to estimate seasonal variations in periphyton primary production. Weekly mean daily estimates of periphyton gross production ranged from  $< 0.1 \text{ g O}_2 \text{ m}^{-2}$ , during midwinter, to  $6.5 \text{ g O}_2 \text{ m}^{-2}$  during early May. Estimated annual periphyton gross production and respiration were 0.58 and  $1.27 \text{ kg O}_2 \text{ m}^{-2}$ , respectively. Factors influencing seasonal variations of Fort River periphyton standing crop are discussed.

Van Niewenhuyse, E.E. and J.R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. *Canadian Journal of Fisheries and Aquatic Sciences* 53:99-105.

**Abstract:** Regression analysis of a data set compiled from the literature ( $n = 292$ ) showed that summer mean chlorophyll concentration (Chl) among temperate streams bore a strong ( $R^2 = 0.67$ ) curvilinear relationship with summer mean total phosphorus concentration (TP). The predicted slope of the TP-Chl relationship (Chl:TP) ranged between 0.22 at  $TP = 50 \text{ mg}\cdot\text{m}^{-3}$  and 0.08 at  $TP = 1030 \text{ mg}\cdot\text{m}^{-3}$ , the highest value of TP in our data set. A bivariate model indicated that stream catchment area had a significant effect on Chl at all levels of TP and predicted a 2.3-fold increase in Chl:TP as the stream catchment area increased from 100 to 100 000  $\text{km}^2$ . We suggest that TP may provide a reliable basis for predicting Chl in small and large temperate streams worldwide.

Walton, S.P., E.B. Welch, and R.R. Horner. 1995. Stream periphyton response to grazing and changes in phosphorus concentration. *Hydrobiologia* 302:31-46.

#### Abstract

Grazing by the large caddisfly larva, *Dicosmoecus gilvipes* (Trichoptera; Limnephilidae), drastically reduced periphyton biomass in laboratory channels at a current velocity of  $20 \text{ cm s}^{-1}$ . Reduction in biomass as chl *a* and AFDW ranged from 88 to 93% and 82 to 85%, respectively. On average, grazing rate increased with in-channel SRP (soluble reactive phosphorus) content from 6 to  $10 \mu\text{g l}^{-1}$ . Grazing rates averaged  $25.9\text{--}29.3 \mu\text{g chl } a \text{ m}^{-2} \text{ d}^{-1}$  and  $10.8\text{--}12.2 \mu\text{g chl } a \text{ mg}^{-1} \text{ d}^{-1}$  based on area and grazer biomass, respectively, with most variability among treatments being due to the grazing effect. Grazing tended to shift the algal community increasingly to filamentous blue-green algae regardless of enrichment. After three weeks, *Phormidium* comprised over 61% of the community in grazed treatments but only 35% in ungrazed treatments. The stalked diatom *Gomphonema* comprised only 4% of the grazed community, but 11% in the three ungrazed channels with similar values for *Scenedesmus*. A model that includes grazing was calibrated to the data and produced a reasonable expectation of periphyton biomass over a range in SRP concentrations. While the model with constant grazer abundance predicts a gradually increasing grazed biomass as SRP increases, grazer production in natural streams may actually increase to accommodate the increased food production.

Welch, E.B., J.M. Quinn and C.W Hickey. 1992. Periphyton Biomass Related to Point-Source Nutrient Enrichment in Seven New Zealand Streams. *Water Research* 26:669-675.

**Abstract**—Periphyton biomass on natural substrata at 26 sites above and below point source discharges in 7 New Zealand streams was compared with maximum potential values predicted by a laboratory calibrated model to determine the extent to which biomass was controlled by nutrients. Point-source enrichment, which increased dissolved reactive phosphorus (DRP) from 6 to 100 times the saturation level (about 25  $\mu\text{g/l}$ ) in five streams, was found to substantially increase biomass at all enriched sites in four streams. In two of these streams, biomass below the enrichment inputs was about 1200 mg chl *a*/m<sup>2</sup>. Overall, biomass averaged only  $35 \pm 44\%$  of that predicted from phosphorus, velocity and temperature using the model. Furthermore, aesthetically nuisance biomass levels (i.e. > 200 mg chl *a*/m<sup>2</sup>) were observed at only 7 of the 19 downstream sites. In many cases, the lower than expected biomass levels were associated with high macroinvertebrate grazer densities, riparian shading or unsuitable attachment surfaces. These factors, therefore, appear to have exercised more control on periphyton biomass than nutrients, and may offer more effective alternatives for biomass control in enriched streams than lowering DRP below biomass saturating levels.

**Key words**—periphyton, nutrients, point source

Welch, E.B., J.M. Jacoby, R.R. Horner, and M.R. Seeley. 1988. Nuisance biomass levels of periphytic algae in streams. *Hydrobiologia*. 157:161-168.

**Abstract**

Relative coverage of filamentous periphytic algae increased with chlorophyll *a* (chl *a*) biomass on natural substrata in 22 northwestern United States and Swedish streams. A biomass range of 100–150 mg chl *a* m<sup>-2</sup> may represent a critical level for an aesthetic nuisance; below those levels, filamentous coverage was less than 20%. Other indices of water quality (dissolved oxygen content and measures of benthic macroinvertebrate diversity) were apparently unaffected by periphytic biomass or filamentous coverage in these streams. Neither was biomass related to limiting nutrient content (soluble reactive phosphorus, SRP), as has been observed in previous experiments using bare rocks in streams and slides in artificial channels. Ambient SRP concentration may not be a useful predictor of periphyton accrual on natural substrates, due to uptake and recycling of P throughout the stream and undetermined losses such as sloughing and grazing.

Welch, E.B., R.R. Horner, and C.R. Patmont. 1989. Prediction of Nuisance Periphytic Biomass: A Management Approach. *Water Research* 23:401-405.

**Abstract**—Model predictions of periphyton biomass, as a function of ambient SRP concentration, were compared against observed biomass accrual on natural and artificial substrates in the Spokane River, Washington. A range in biomass was predicted based on uncertainties due to temperature, velocity, accumulation period and an empirical growth constant. Only 8 of 47 observed biomass values exceed the lowest biomass predictions, which supports the contention that the model represents the maximum potential biomass. Using the SRP concentration that would produce a threshold nuisance biomass (150–200 mg chl *a*/m<sup>2</sup>), an approach is proposed for controlling the stream distance for which periphytic biomass exceeds the nuisance level. For the Spokane River, critical distance with biomass exceeding 200 mg chl *a*/m<sup>2</sup> may exceed 10 km unless SRP is held below 10 µg/l.

**Key words**—periphyton, phosphorus, management

Wharfe, J.R., K.S. Taylor, and H.A.C. Montgomery. 1984. The Growth of *Cladophora* Glomerata in a River Receiving Sewage Effluent. *Water Research* 18:971-979.

**Abstract**—A considerable improvement in the natural flora of the River Great Stour has occurred since the mid-1960s when dense growths of *Cladophora glomerata* dominated sections of the river with the disappearance of some rooted macrophytes. *Cladophora* growths in the river in response to changing river conditions and sewage treatment operations during a thirty year period are reviewed. A vegetation mapping programme undertaken from 1978 to 1982 to assess the influence of a sewage treatment works discharge on the growth of the filamentous alga has shown that previous recommendations to reduce dissolved phosphorus concentrations in the final effluent need not be implemented.

**Key words**—*Cladophora*, filamentous alga, macrophytes, nutrients, dissolved phosphorus, sewage treatment

Wold, A.P. and A.E. Hershy. 1999. Spatial temporal variability of nutrient limitation in 6 north shore tributaries to Lake Superior. *Journal of the North American Benthological Society* 18:2-14.

*Abstract.* Nutrient availability varies both spatially and temporally in temperate systems because of timing of seasonal and hydrological events (e.g., spring snowmelt). Most studies have found either N or P to be primarily limiting. A nutrient-diffusing bioassay was used to determine if N, P, neither nutrient, or both nutrients were limiting to periphyton growth (measured by chlorophyll *a*) in 6 tributaries to Lake Superior during the ice-free season of 1994. Molar ratios of dissolved inorganic nitrogen to soluble reactive phosphorus (DIN:SRP) were also calculated to predict potential limitation conditions and determine agreement with bioassay results. Co-limitation predominated (N + P > all other treatments). No limitation was also common during the late portion of the ice-free season. DIN:SRP ratios were not useful in predicting nutrient-limitation conditions. Results showed that nutrient limitation of periphyton biomass varied over space and time on a relatively small regional scale. This result is significant because many studies extrapolate results from a single stream or time period to a much larger spatial or temporal scale.

*Key words:* nutrient limitation, DIN:SRP, spatial and temporal variability, co-limitation, bioassays, Lake Superior tributaries.

Yang, J-R, B.K. Basu, P.B. Hamilton and F. R. Pick. 1997. The development of a true riverine phytoplankton assemblage along a lake-fed lowland river. *Arch. Hydrobiol.* 140:243-260.

**Abstract:** Phytoplankton biomass, taxonomic composition and size structure were estimated at intervals along a lake-fed lowland river (Rideau River, Canada). Phytoplankton biomass decreased sharply from the headwater lake to the first riverine sampling site (at 14 km), and then increased downstream reaching a maximum at the last sampling station (90 km). At the upstream sites, the biomass was dominated by nanoplankton algae (<22  $\mu\text{m}$ ), which were gradually replaced by larger netplankton algae (>64  $\mu\text{m}$ ) at subsequent downstream sites. The downstream increase in total algal biomass was due primarily to an increase in abundance of netplankton which may have been favoured by the higher nutrient concentrations and longer water residence time. Diatoms usually dominated at all sites and the specific composition of the assemblages was influenced by water residence time, water depth and nutrient concentration. Although planktonic diatoms always dominated the diatom assemblage, non-planktonic diatoms were observed in shallow waters or in fast flow conditions. Lacustrine diatom species such as *Fragilaria crotonensis*, *Tabellaria fenestrata* and *Cyclotella bodanica* abundant at the headwater lake site, decreased sharply downstream where true riverine assemblages developed. At the first riverine sites, diatom assemblages were dominated by *Aulacoseira italica*, *Cocconeis placentula*, *Cyclotella atomus* and *C. pseudostelligera*. With increasing nutrient concentrations downstream, these species were replaced by taxa more typical of eutrophic conditions such as *Aulacoseira granulata*, *Stephanodiscus parvus*, and *S. hantzschii*. The latter taxa appear characteristic of large nutrient enriched temperature rivers.