

Aizaki, M. and K. Sakamoto. 1988. Relationships between water quality and periphyton biomass in several streams in Japan. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 23:1511-1518.

### Introduction

It is well-known that pollution by municipal sewage causes remarkable changes in both the structure and function of the periphyton on river beds. TEZUKA et al. (1974) surveyed the standing crop of periphyton from the upstream to the midstream reaches of the Tama River and reported that the biomass was changed markedly with an increase in the concentrations of nutrient and organic matter concentrations. Based upon a survey of published data, AIZAKI (1978) discussed the relationship between water qualities and amount of chlorophyll in periphyton, and showed a correlation between them. However, he also reported that the standing crop of the periphyton was alternately changed by its increase and subsequent detachment and showed a seasonal fluctuation. Therefore, in order to clarify the relationship between periphyton biomass and water quality, the current study was performed.

In this study, several streams, consisting of a wide range of nutrient and organic material concentrations, were surveyed throughout the year and the relationship between periphyton biomass and several water qualities was investigated.

Biggs, B.J. 1988. Algal proliferations in New Zealand's shallow stony foothills-fed rivers: Toward a predictive model. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 23:1405-1411.

### Introduction

The problems associated with benthic algal proliferations in rivers are widely recognised by water managers (e. g. WHARFE et al. 1984). In New Zealand, proliferations have been recorded in more than 180 rivers, with many equalling or exceeding the highest standing crops recorded in the northern hemisphere (BIGGS 1985, BIGGS & PRICE 1987.) In a survey of New Zealand's 20 regional water authorities aesthetic and recreational degradation were rated as the most significant problems caused by these growths (BIGGS 1985).

Many factors influence benthic algal growth in rivers. A low frequency of flood events so that scouring of the community does not occur, coarse-stable bed sediments to prevent physical abrasion, and moderate velocity waters to ensure nutrient replenishment are of primary importance. Other factors that determine the type of algae and rate of production include nutrient levels, temperature, light availability and invertebrate grazing (BIGGS 1987).

Although the relationship of benthic algal standing crop to one, or several, of the preceding factors has been studied (e. g. PITCAIRN & HAWKES 1973, HORNER & WELCH 1981), and models of algal development in laboratory streams (e. g. HORNER et al. 1983), a considerable gap still remains between this work and the development of predictive models suitable for use in the field by water managers. Difficulties in modelling these relationships arise due to the unpredictable nature and effects of flood events (e. g. TETT et al. 1978), and in difficulties with relating ambient nutrient levels to existing crops because of algal nutrient uptake and denitrification (e. g. MCCOLL 1974).

An approach to predicting benthic algal standing crops in rivers which may overcome these difficulties would be to: include a hydrologically based scour component in a model; trace regrowth on the falling and low-flow stages of the hydrograph; and incorporate a conservative estimator of nutrient loadings. This may then allow "algal growth potential", as opposed to actual standing crop at any one time, to be predicted for rivers where changes in their management regimes are being proposed. The objective of the following study was to attempt such model development and then test the model's predictive power.

Biggs, B.J.F. 1995. The contribution of disturbance, catchment geology and land use to the habitat template of periphyton in stream ecosystems. *Freshwater Biology* 33:419-438.

## SUMMARY

1. Periphyton chlorophyll *a* (chl *a*), ash-free dry mass, taxonomic composition, and cellular and water-column nutrients were analysed every 4 weeks for a year at sixteen stream sites in New Zealand. The hypothesis was investigated that broad-scale differences in mean monthly periphyton development are defined primarily by the frequency of flood disturbances and the periphyton's interaction with the nutrient status of the streams as determined by catchment geology and land use.
2. Overall, mean monthly chl *a* concentration declined with increasing flood frequency ( $r = -0.711$ ,  $P < 0.001$ ), and seasonality in chl *a* was better defined at sites with a low frequency of floods. Chlorophyll *a* concentration was generally low throughout the year at sites with frequent floods ( $> 15 \text{ yr}^{-1}$ ).
3. No relationship existed between inorganic nutrient concentrations and catchment geology or land development. However, conductivity declined significantly as a function of the percentage of the catchment underlain by nutrient-poor, hard rocks (plutonic and fine-grained metamorphic rocks) ( $r = -0.515$ ,  $P < 0.05$ ), but increased significantly with the percentage of the catchment in intensive agricultural land use ( $r = 0.799$ ,  $P < 0.001$ ).
4. Cellular nutrient concentrations suggested that nitrogen was the nutrient most commonly limiting periphyton production. In turn, cellular N concentrations declined significantly with increasing percentage of the catchment in hard rock ( $r = -0.561$ ,  $P < 0.05$ ) and increased with percentage of the catchments in intensive agricultural land use ( $r = 0.948$ ,  $P < 0.001$ ).
5. The sites were classified into three enrichment groups (high, moderate and low) based on their land use and underlying geology. Cellular N concentrations varied significantly among these enrichment groups (ANOVA  $F = 14.661$ ,  $P < 0.001$ ).
6. Log chl *a* decreased significantly with increases in the annual 80th percentile velocity. However, the relationship was significantly different among the enrichment groups.
7. A stepwise multiple regression on the full dataset identified that the frequency of floods, proportion of the catchment in high-intensity agricultural land use and proportion in alkaline rocks were the most significant factors explaining variation in mean monthly chl *a* among the sites ( $r^2 = 89\%$ ).
8. Overall, the results showed that flood disturbance and catchment enrichment regimes are probably the principal axes of the habitat template of periphyton among the study streams, and could be used to explain and predict broad-scale differences in periphyton development among other temperate stream ecosystems.

Biggs., B.J.F. 1996. Patterns in Benthic Algae of Streams. *in* "Algal Ecology, Freshwater Benthic Ecosystems" R.J. Stevenson, M.L. Bothwell, and R.L. Lower (eds.). Academic Press, New York.

No abstract available.

Biggs, B.J.F. 2000. Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. *Journal of the North American Benthological Society* 19:17-31.

*Abstract.* Statistical models for predicting the effects on algal biomass of eutrophication are much better developed for lentic systems than for lotic systems, partly because of the dynamic physical nature of streams as controlled by flood regimes. I analyzed data from 30 sites in 25 runoff-fed streams and rivers to develop statistical models for mean monthly and maximum chlorophyll *a* as a function of soluble nutrient concentrations and days of accrual (reflecting the frequency of flood disturbance events). Variation in stream-water nutrients explained 12–22.6% of the variation in mean monthly chlorophyll *a* and 29.5–32.5% of the variation in maximum chlorophyll *a* among sites. Days of accrual explained 39.7% and 61.8 % of the variation in mean monthly and maximum chlorophyll *a*, respectively. Multiple regression models combining dissolved nutrient data and days of accrual explained 43.7–48.8% of the variation in mean monthly chlorophyll *a* and 72.1–74.1% of the variation in maximum chlorophyll *a* among sites. In streams with infrequent floods and long accrual periods (e.g., >100 d), a relatively small increase in dissolved nutrients greatly increased the frequency of high biomass events. However, as could be anticipated, this result did not occur in more flood-prone streams. A nomograph to predict oligo-, meso-, and eutrophic conditions as a function of nutrient concentrations and days of accrual is presented based on the regression models for maximum chlorophyll *a*. The models need further testing, but might be useful for predicting the effects of changes in nutrients on benthic algal biomass in other temperate streams and rivers. I suggest that variable nutrient criteria for the prevention of benthic algal proliferations could be set in streams in relation to regimes of local flood frequency and expected time available for biomass accrual. The present analysis suggests that managing nutrient supply could not only reduce the magnitude of maximum biomass, but also reduce the frequency and duration of benthic algal proliferations in streams.

*Key words:* stream ecology, eutrophication, enrichment, nutrients, nitrogen, phosphorus, flooding, disturbance, algae, periphyton, water resources management.

Biggs, B.J.F., and M.E. Close. 1989. Periphyton biomass dynamics in gravel bed rivers: the relative effects of flows and nutrients. *Freshwater Biology* 22:209-231.

SUMMARY. 1. Periphyton chlorophyll *a* and ash free dry weight (AFDW) were monitored in nine rivers to examine the relative importance of flows and nutrients for regulating periphyton biomass in gravel bed rivers.

2. Mean annual flows in the rivers ranged from 0.94 to 169 m<sup>3</sup> s<sup>-1</sup>, mean dissolved reactive phosphorus (DRP) from 1.3 to 68 μg l<sup>-1</sup>, periphytic chlorophyll *a* from 4.6 to 73 mg m<sup>-2</sup>, and AFDW from 2.8 to 16 g m<sup>-2</sup>.

3. For eight of the nine rivers NH<sub>4</sub>-N, DRP, total Kjeldahl nitrogen, total phosphorus and total suspended solids were correlated ( $P < 0.01$ ) with flow, and for seven rivers conductivity was inversely correlated ( $P < 0.05$ ) with flow.

4. There was a hyperbolic relationship between flows and biomass, with chlorophyll *a* >100 mg m<sup>-2</sup> and AFDW >20 g m<sup>-2</sup> occurring most frequently in flows of <20 m<sup>3</sup> s<sup>-1</sup>.

5. Floods prevented the development of medium term (i.e. up to 2 months) maxima in biomass in five of the rivers, but maxima occurred over summer–autumn and winter–spring in the three rivers where floods were absent.

6. Chlorophyll *a* biomass was more resistant to flooding than AFDW. Only 59% of the forty-six recorded floods caused chlorophyll *a* scouring, whereas 74% of the floods caused AFDW scouring. The efficiency of scour was more influenced by the pre-flood biomass than the magnitude of the event.

7. Biomass maxima were significantly correlated ( $P < 0.01$ ) with mean DRP concentration during the accrual period. Overall, up to 53% of the mean annual biomass difference between rivers was explained by the mean annual DRP concentrations. However, the high correlations between nutrient concentrations and flow indicated that the nutrient data were also carrying hydrological information and that simple causal relationships between nutrients and biomass are difficult to establish in rivers.

8. It is concluded that hydrological factors contribute at least equally with nutrients to the differences in periphyton biomass between the gravel-bed study rivers. They combined to explain up to 63.3% of the variance in biomass, compared with 57.6% for nutrients. It is recommended that periphyton data from gravel-bed rivers should always be viewed within the context of the flow history of the site, and not just as a function of nutrient concentrations.

Biggs, B.J.F., C. Kilroy and R.L. Lowe. 1998a. Periphyton development in three valley segments of a New Zealand grassland river: test of a habitat matrix conceptual model within a catchment. *Arch. Hydrobiol.* 143 2 147-177.

**Abstract:** We monitored water nutrient concentrations, periphyton biomass, and periphyton cellular nutrient concentrations in run and riffle habitats at sites representative of headwater, mid-catchment and lowland valley segments of a grassland river for two years, and community composition on four occasions during this period, to determine how these communities varied spatially and temporally as a function of downstream changes in hydraulic conditions, flood disturbance regimes and enrichment. Predictions of community biomass and structure were tested under a proposed habitat matrix conceptual model for periphyton. Discharge increased and valley segment slope decreased in a downstream direction as expected from geomorphic models of catchment processes. However, site-specific depths and velocities did not change systematically down the river. Water nutrient concentrations suggested a change from nitrogen limitation of primary production at the headwater site to phosphorus limitation at the lowland site. This was associated with a downstream increase in stream nitrate concentrations, but not phosphorus. However, cellular nutrient concentrations and instream nutrient bioassays suggested either N limitation, or weak N and P limitation, at all sites. In runs, mean monthly chlorophyll-a did not vary significantly ( $P > 0.05$ ) among the three sites, but it did in riffles. The differences in community biomass between run and riffle habitats were more significant than differences among sites. Periphyton community structure in the runs was similar among valley segments during a period of frequent flood disturbances, but during a period of infrequent disturbances communities in the headwater sites were dominated by filamentous cyanobacteria whereas in the mid-catchment and lowland sites they were dominated by nitrogen-fixing cyanobacteria and diatoms. Major differences in community structure occurred in riffles among the sites. Riffle communities at the headwater site were dominated by filamentous cyanobacteria and diatoms, whereas at the mid-catchment and lowland sites filamentous green algae and diatoms were dominant, possibly a result of increased nitrate concentrations progressing downstream. Overall, a downstream gradient in nitrate enrichment appeared to control biomass and community composition of the riffle communities, but not the run communities. Strong grazer activity in runs during more hydrologically stable periods at the lowland site appeared to override any response to nutrients and maintained biomass at low levels. Periphyton biomass and community composition was predicted more accurately from the habitat matrix conceptual model based on local habitat factors than by expected downstream gradients in hydraulic conditions and enrichment.

Biggs, B.J.F., Stevenson, and R.L. Lowe. 1998b. A habitat matrix conceptual model for stream periphyton. *Archiv. Fur hydrobiologie*. 143:25-56.

**Abstract:** In this paper we suggest a conceptual model for the evaluation of periphyton communities in unshaded temperate streams based on the primary habitat variables of flood disturbance, nutrient resource supply and invertebrate grazing. The core of this model is a classification of 35 periphyton taxa into four main functional groups based on the *C-S-R* life history strategies of Grime. Possible successional trajectories following system-wide disturbances under different nutrient supply regimes are also discussed. The interaction of disturbance and nutrient supply on species membership, productivity and accrual time results in a predicted gradient from low biomass in frequently disturbed, unenriched habitats to high biomass in infrequently disturbed, enriched habitats. This prediction is verified empirically using literature data. Herbivory can strongly modify such periphyton responses to disturbance and resource supply. However, these grazing effects could vary greatly depending on the dominant invertebrate grazer and their total abundance, which in turn, is also sensitive to changes in disturbance and nutrient resource supply. This interaction is also discussed. The conceptual model complements other more general habitat templet and dynamic equilibrium concepts in ecology.

Biggs, B.J.F., A. Smith, and M.J. Duncan. 1999. Velocity and sediment disturbance of periphyton in headwater streams: biomass and metabolism. *Journal of the North American Benthological Society* 18:222-241.

*Abstract.* Disturbance by floods is believed to be 1 of the fundamental controllers of temporal and spatial patterns in stream periphyton. However, the exact causes of biomass losses are still poorly understood and discharge measures of disturbance often only explain limited variance in periphyton development. We investigated the effects of 2 of the main mechanisms of flood disturbance to periphyton—frequency of high-velocity events and frequency of bed sediment movement—in an effort to better understand disturbance processes and improve the quantification of flood disturbance regimes for studies of stream periphyton. Three sites were selected in headwater streams in each of 4 groups according to a 2-way factorial design of frequency of high-velocity events and sediment stability, giving a total of 12 sites. Periphyton were sampled monthly for 15 mo and analyzed for chlorophyll *a*. Maximum photosynthetic rates ( $P_{max}$ ), chlorophyll-specific  $P_{max}$ , community respiration (CR), and  $P_{max}$ :CR ratios were determined seasonally. Nutrient concentrations were generally low and did not vary as a function of disturbance regime.

Peaks in chlorophyll *a* were usually low reflecting the low nutrients. Chlorophyll was 2–10× higher where bed sediments moved <15×/y and with seasonal maxima most often in autumn. Frequency of bed movement, soluble reactive P, and the frequency of velocity perturbations were significant predictors of mean monthly chlorophyll *a* ( $r^2 = 0.88$ ).

Chlorophyll *a* and water temperature were major correlates of  $P_{max}$ , specific  $P_{max}$ , and CR, and thus the metabolic variables partly reflected changes in biomass among the disturbance regimes. With chlorophyll and temperature removed as covariates, the main factor influencing all metabolic parameters was season.  $P_{max}$  was 7× higher in summer than in spring when minima occurred, chlorophyll-specific  $P_{max}$  was 10× higher in summer than in spring, and CR was 4× higher in autumn than in spring.  $P_{max}$ :CR ratios indicated that the communities were generally autotrophic at times of maximum photosynthesis with the highest ratios in summer (3× higher than winter). The frequency of velocity perturbations also had a significant effect on  $P_{max}$ :CR ratios with highest ratios at sites where there was a low frequency of high-velocity events. Our results suggest that sediment instability greatly increases disturbance intensity for periphyton. It is therefore essential to assess not just the frequency of floods, but also the degree of bed movement when quantifying disturbance regimes for periphyton in headwater streams.

*Key words:* disturbance ecology, stream ecology, stream metabolism, autotrophic biomass, habitat template, bed sediments, sediment stability, habitat hydraulics, disturbance resilience.

Borchardt, M.A. 1996. Nutrients in "Algal Ecology, Freshwater Benthic Ecosystems" R.J. Stevenson, M.L. Bothwell, and R.L. Lower (eds.). Academic Press, New York.

No abstract available.

Bothwell, M.L. 1989. Phosphorus - Limited Growth Dynamics of Lotic Periphytic Diatom Communities: Areal Biomass and Cellular Growth Rate Responses. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1293-1301.

Three long-term phosphate enrichment experiments were conducted at the Experimental Troughs Apparatus (EXTRA), South Thompson River, British Columbia to determine the relationship between external orthophosphate ( $\text{PO}_4^{3-}$ ) concentration and peak areal biomass (PB) of periphytic diatom communities. Levels of  $\text{PO}_4^{3-}$  which saturated PB were two orders of magnitude greater than those required to saturate specific growth rates in thin film periphyton communities of similar taxonomic composition. With  $\text{PO}_4^{3-}$  additions between 0.1 to 1.0  $\mu\text{g P}\cdot\text{L}^{-1}$ , PB responded in a hyperbolic fashion, initially increasing rapidly, then showing signs of saturation. PB continued to increase in a slow, linear manner above 1.0  $\mu\text{g P}\cdot\text{L}^{-1}$ . Maximum PB ( $\text{PB}_{\text{max}}$ ) was calculated to occur at ca. 28  $\mu\text{g P}\cdot\text{L}^{-1}$ . At higher  $\text{PO}_4^{3-}$  concentrations (>30–50  $\mu\text{g P}\cdot\text{L}^{-1}$ ) PB was no longer P limited. Below the saturation point, PB was approximated by a log-linear function of  $\text{PO}_4^{3-}$ .

Bourassa, N. and A. Cattaneo. 1998. Control of periphyton biomass in Laurentian streams (Quebec). *Journal of the North American Benthological Society* 17:420-429.

*Abstract.* Hypotheses concerning the factors controlling periphyton biomass are mostly based on experimental evidence. To examine their application under natural conditions, we sampled periphyton and invertebrate biomass in 12 Laurentian streams (Québec) covering a range of total phosphorus from 5 to 60  $\mu\text{g/L}$ . We sampled at open and shaded sites to explore light limitation by canopy cover. Periphyton biomass measured as chlorophyll *a* or ash-free dry mass was not related to nutrient concentration or canopy cover. Only current velocity and depth explained a significant but relatively small fraction (10% and 20% respectively) of periphyton variation among sites. Grazer biomass and mean grazer size were positively correlated with phosphorus concentration, which explained 48% and 45% of their variation respectively; canopy cover was not significant. These results indicate that, at least in summer under stable flow, grazer biomass rather than periphyton biomass would increase along a nutrient gradient typical in Laurentian streams. The results suggest top-down control of periphyton biomass.

*Key words:* periphyton, invertebrates, herbivory, nutrients, canopy, streams.



Burton, T.M., M.P. Oemke, and J.M. Molloy. 1991. Contrasting effects of nitrogen and phosphorus additions on epilithic algae in a hardwater and a softwater stream in Northern Michigan. *Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie* 24:1644-1653.

## Introduction

Hardwater, high alkalinity streams are generally thought to have greater production of fish and invertebrates than do softwater, low alkalinity streams (ARNOLD et al. 1981, EGGLESHAW 1968, KRUEGER & WATERS 1983, TARZWELL 1938). A possible reason for this difference, if it exists, may be that primary production is lower in softwater streams. LAY & WARD (1987), however, found no substantial differences in patterns of primary productivity in a softwater and a hardwater stream in Alabama in the Southern USA. They attributed this lack of difference to possible inhibition by low orthophosphate concentrations in both streams. Thus, any relationship that might exist between primary productivity and stream hardness is likely to be strongly influenced by response of periphyton populations to ambient nutrient levels and, perhaps, to differential responses of algal populations to nutrient additions.

Nutrient limitation of periphyton in streams has been demonstrated for several streams with either nitrogen (GRIMM et al. 1981), or phosphorus (ELWOOD et al. 1981, HORNER & WELCH 1981, PETERSON et al. 1985, PRINGLE & BOWERS 1984, STOCKNER & SHORTREED 1978) or both nutrients (JONES et al. 1984, TRISKA et al. 1983) implicated as limiting growth of periphytic algae. The ratio between these two nutrients has also been shown to be an important factor in determining responses of periphytic algae to nutrient enrichment (PRINGLE 1987). Other studies have demonstrated that physical or chemical factors may be more important than limitation by N and P in determining algal accumulation in many streams with light, temperature, current velocity, and inorganic carbon most often cited as important determinants of periphyton dynamics in streams (e.g. GREGORY 1980, HORNER & WELCH 1981, HORNICK et al. 1981, LOWE et al. 1986, STEVENSON 1983, SUMNER & FISHER 1979). Based on this literature, we suggest that nutrient limitation is most likely to occur in streams that are either in non-forested land use or are wide enough to make shading by riparian vegetation of limited importance and that nutrient limitation will be of greatest importance during long periods of baseflow during summer months.

We decided to investigate the effects of nutrient limitation in unshaded reaches of a softwater and a hardwater river in Michigan's upper peninsula during the summer

of 1987. We assessed the effects of additions of  $\text{NO}_3$  and  $\text{PO}_4$  added singly and in combination on chlorophyll *a* production and algal community composition. The objective of this research was to determine the effects of N and P additions on the algal community in a hardwater versus a softwater stream and to compare the algal communities on nutrient enriched substrates in each of these rivers to communities that occurred on non-enriched substrates. Our hypotheses were that:

- 1) the benthic algal community of the softwater stream would be characterized by fewer cells per unit area and by a different species composition than would the algal community of the hardwater stream; and
- 2) that nutrient additions would have differential effects on the algal communities of the two streams with the algae of the hardwater stream responding most favorably to N and P addition because of less likelihood of carbon limitation.

Carrick, J.H., R.L. Lowe, and J.T. Rotenberry. 1988. Guilds of benthic algae along nutrient gradients: relationships to algal community diversity. *Journal of the North American Benthological Society* 7:117-128.

*Abstract.* We attempt to define groups of functionally related benthic algal species or guilds to assess if the species richness of such guilds varies across experimentally manipulated nutrient gradients, and to determine the relative contribution of these guilds to total community diversity. Nutrient gradients were established using nutrient-releasing substrata; treatments consisted of Si, N+P, Si+N+P, and controls. Nutrient enrichment significantly altered the biovolume of 27 species (out of a total of 141). Results from one-way ANOVA tests coupled with multiple means range tests categorized these species into four major guilds: three guilds of species which achieved their highest abundance on either Si, N+P, or Si+N+P treatments, and a guild that grew best on controls. This pattern of structuring was corroborated by cluster analysis and principal components analysis. Total community diversity and the relative contribution of guilds to total community diversity was less on N+P and Si+N+P substrata compared with that on Si and the control substrata. This suggests that nutrient enrichment may narrow the conditions amenable to many algal species (nutrient generalists), creating a niche occupied by those taxa sufficiently equipped to benefit under such conditions (nutrient specialists).

*Key words:* benthic algae, nutrients, guilds, community structure.

Chessman, B.C., P.E. Hutton, and J.M. Burch. 1992. Limiting nutrients for periphyton growth in sub-alpine, forest, agricultural, and urban streams. *Freshwater Biology* 28:349-361.

## SUMMARY

1. Nutrient-diffusing artificial substrata were used in summer and autumn to assess limiting nutrients for periphytic algal growth in streams draining sub-alpine, forested, agricultural and urban catchments in eastern Victoria, Australia.
2. Chlorophyll *a* density was primarily limited by nitrogen in most cases; often phosphorus was secondarily limiting. One sub-alpine, one forest and one agricultural stream were primarily phosphorus limited in at least one season. Added trace elements and vitamins did not increase chlorophyll density.
3. The dominant filamentous algal genera did not differ greatly between various nutrient enrichments. However, the relative abundance of *Stigeoclonium* spp. was sometimes increased on substrata containing the limiting nutrient.
4. The results suggest that nutrient limitation is a widespread phenomenon in Victorian streams, and that limiting nutrients can be inferred from stream-water nitrogen to phosphorus ratios in many instances.

Chetelat, J., F.R. Pick, and A. Morin. 1999. Periphyton biomass and community composition in rivers of different nutrient status. *Canadian Journal of Fisheries and Aquatic Sciences* 56:560-569.

**Abstract:** Epilithic periphyton was investigated in riffle zones of 13 rivers in southern Ontario and western Quebec to describe how algal biomass and community composition vary with nutrient concentration and water velocity during summer. Algal biomass (milligrams chlorophyll *a* (Chl *a*) per square metre) was strongly correlated with total phosphorus concentration ( $r^2 = 0.56$ ,  $p < 0.001$ ) and conductivity ( $r^2 = 0.71$ ,  $p < 0.001$ ) of the overlying water but unrelated to water velocity over the range of 10–107 cm·s<sup>-1</sup>. Differences in periphyton Chl *a* were associated with changes in biomass of Chlorophyta ( $r^2 = 0.51$ ,  $p = 0.001$ ) and Bacillariophyta ( $r^2 = 0.64$ ,  $p < 0.001$ ) and were not related to Rhodophyta and Cyanophyta biomass ( $p > 0.10$ ). The relative proportions of taxonomic divisions varied with total standing stock. Percent Chlorophyta biomass increased with periphyton Chl *a* and was the largest fraction at moderately eutrophic sites. Rhodophyta contributed the most biomass at sites with the lowest Chl *a*. *Cladophora*, *Melosira*, and *Audouinella* biomasses were positively correlated with total phosphorus concentration over the range of 6–82 µg·L<sup>-1</sup> ( $r^2 = 0.39$ – $0.64$ ,  $p < 0.005$ ), and these genera were dominant at sites with the highest nutrient concentrations.

## Conclusions

Many factors can regulate primary producers in streams, including nutrient availability, hydrodynamics, grazing, turbidity, riparian shading, and human impacts (e.g., addition of toxic compounds, global change, introduced species, watershed development). However, nutrient inputs are usually the most effectively managed factor. Factors in addition to nutrients need to be considered mainly because they can lead to cases of low algal biomass with high nutrients. Although these additional factors may decouple nutrient enrichment from algal biomass, most of these (e.g., flooding, grazing, turbidity) are not easily controlled at most sites. Thus, we are left with setting nutrient criteria as the primary way to mitigate problems of excessive algae.

Developing a single value that can be used for nutrient criteria in streams and rivers will be difficult, given the variety of reasons for setting the criteria (Table 1). To protect human health, no more than 10 mg/L  $\text{NO}_3^-$ -N should be present. To avoid chronic toxicity by  $\text{NH}_3$ , no more than 0.02 mg/L  $\text{NH}_3$ -N should be present. If the concern is eutrophication, then setting criteria for TN and TP is most reasonable.

If streams are not turbid, preventing maximum benthic chlorophyll levels from exceeding 200 mg/m<sup>2</sup> is reasonable because streams with higher levels are not aesthetically pleasing, and their recreational uses may be compromised. For benthic chlorophyll to remain below 200 mg/m<sup>2</sup> at the very least, TN should remain below 3 mg/L, and TP below 0.4 mg/L. Based on cumulative frequency distributions of nutrients, and assuming that ~½ the systems in the US have been impaired by excessive nutrients, levels of TN and TP would be set at 0.9 and 0.4 mg/L, respectively. If a mean of 50 mg/m<sup>2</sup> chlorophyll is the target (thus ensuring chloro-

phyll is <100 mg/m<sup>2</sup> most of the time), TN should be 0.47 and TP 0.06 mg/L. Lower levels for nutrient criteria should be considered for regions with more pristine systems (e.g., TN and TP levels of 0.3 and 0.02 mg/L, respectively, were chosen for the Clark Fork River in Montana, Table 1). If systems downstream are to be protected, even lower stream nutrient concentrations will be necessary in some situations.

A significant amount of monitoring data are necessary to refine recommendations for nutrient criteria. Some regions and agencies have data that can be used for this purpose. Data that would be useful to collect or glean from existing sources for many more systems include seasonal means and maxima for benthic and planktonic chlorophyll, associated water column nutrients, and diurnal DO concentrations for a variety of stream types. Such data should be collected in a way that avoids sampling bias. Data on macrophyte abundance related to nutrients, reference streams with acceptable algal and macrophyte biomass, and factors related to dominance by nuisance algal and macrophyte species also are sorely lacking for many regions.

Establishing rational criteria will require bridging the gap between managers and scientists. The managers will provide the realistic assessment of what needs to be accomplished, whereas the scientists can suggest the best available means to reach the management goals. Continued interplay between applied and basic approaches will be necessary if eutrophication in streams is to be controlled in an efficient manner.

Dodds, W.K., V.H. Smith, and B. Zander. 1997. Developing nutrient targets to control benthic chlorophyll levels in streams: a case study of the Clark Fork River. *Water Research* 31:1738-1750.

**Abstract**—Approaches for assessing the effects of lowering nutrients on periphyton biomass in streams and rivers are poorly developed in contrast to those for lakes. Here we present two complementary approaches to assess target nutrient concentrations in streams, given desired mean and maximum standing crops of benthic algal chlorophyll. In the first approach, a reference portion or reach of the river that typically exhibits acceptable levels of benthic chlorophyll is identified (i.e. seasonal mean and maximum values do not exceed desirable levels), and the target levels for instream nutrient concentrations are defined by mean nutrient levels in the reference region. In the second approach, regression and graphical analyses of a large stream database are used to identify acceptable levels of instream total N and total P. The first approach supplies site-specific nutrient targets, whereas the second places nutrient control into a broader, more comparative perspective. In order to link these target concentrations to specific nutrient control measures, we describe a spreadsheet model that can be used to translate changes in external loading by point sources into predicted new instream nutrient concentrations. These quantitative methods are applied here to the control of nuisance algal growth in the Clark Fork River, Montana. We suggest that, in general, maintenance of mean instream total N concentrations below  $350 \mu\text{g l}^{-1}$  and total P below  $30 \mu\text{g l}^{-1}$  will result in mean benthic algal chlorophyll *a* density below nuisance levels of  $100 \text{ mg m}^{-2}$  in most streams. © 1997 Elsevier Science Ltd

*Key words*—eutrophication, periphyton, streams, rivers, nitrogen, phosphorus, benthic algae

Dodds, W.K., J.R. Jones, and E.B. Welch. 1998. Suggested Classification of Stream Trophic State: Distributions of Temperate Stream Types by Chlorophyll, Total Nitrogen, and Phosphorus. *Water Research* 32:1455-1462

**Abstract**—Aquatic scientists and managers have no conventional mechanism with which to characterize and compare nutrients and algal biomass in streams within a broader context analogous to trophic state categorization in lakes by chlorophyll (chl) and nutrients. We analyzed published data for a large number of distinct, temperate, stream sites for mean benthic chl ( $n = 286$ ), maximum benthic chl ( $n = 176$ ), sestonic chl ( $n = 292$ ), total nitrogen ( $n = 1070$ ), and total phosphorus ( $n = 1366$ ) as a first effort to establish criteria for trophic boundaries. Two classification systems are proposed. In the first system, the boundary between oligotrophic and mesotrophic categories is defined by the lower third of the cumulative distribution of the values. The mesotrophic–eutrophic boundary is defined by the upper third of the distribution. In the second system, individual streams are placed more precisely in a broad geographic context by assessing the proportion of streams that have greater or lesser nutrient and chl values. The proposed relationships for streams were compared to trophic criteria published for lakes. The proposed trophic boundaries for streams generally include a broader range of values in the mesotrophic range than conventional criteria for lakes. The ratio of maximum to mean benthic chl for streams was significantly higher than that found for planktonic chl in lakes, reflecting the greater variance in streams. This high variance in streams suggests that the proposed stream trophic criteria should be viewed only as a general first approach to categorizing stream ecosystems. © 1998 Elsevier Science Ltd. All rights reserved

*Key words*—chlorophyll, eutrophic, mesotrophic, nitrogen, nutrients, oligotrophic, periphyton, phosphorus, rivers, streams