Hydrobiologia 157: 161–168 (1988)

Nuisance biomass levels of periphytic algae in streams

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Received 9 July 1986; in revised form 6 January 1987; accepted 26 January 1987

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^{-2} 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 predicter of periphyton accrual on natural substrates, due to uptake and recycling of P throughout the stream and undetermined losses such as sloughing and grazing.

Introduction

Periphytic algae in streams can respond positively to the addition of phosphorus and/or nitrogen similarly to planktonic algae in lakes (Ehrlich & Slack, 1969; Stockner & Shortreed, 1978; Peterson *et al.*, 1983; and Grimm & Fisher, 1986). The question is, what biomass level(s) constitutes a nuisance water quality condition, analogous to a eutrophic state in lakes, and what is the relationship, if any, between biomass and the concentration of limiting nutrient? Grimm & Fisher (1986) hypothesized that nutrient availability ultimately does not limit standing crop, but does influence primary productivity and hence time required for accumulation of maximum biomass.

Relationships between periphytic biomass in streams and nutrient concentrations are ill-defined, compared to those in lakes. Accrual of periphytic diatom biomass on flattened rock substrates in six western Washington streams showed a strong interaction between velocity and soluble reactive phosphorus (SRP) with more biomass resulting, as velocity increased to 50 cm s^{-1}, at high (35 $\mu g\ l^{-1}$) compared to low (8 $\mu g\ l^{-1}$) SRP (Horner & Welch, 1981). Subsequently, continuous flow laboratory channel experiments were conducted in order to quantify more accurately the relationship between biomass and SRP, as well as the velocity interaction with more nuisance-prone filamentous green and blue-green algae (Horner *et al.*, 1983). Those experiments showed an average inflow SRP concentration of about 15–25 $\mu g\ l^{-1}$ to provide an apparent saturation to chlorophyll *a* (chl *a*) accrual at high and medium velocities alike. Recent experimental work with filamentous species has shown that the *in situ* concentration of SRP above which growth is saturated may be around 7 $\mu g\ l^{-1}$ (Seeley, 1986). Bothwell (1985), working with *in situ* levels and diatoms, suggested that the saturation point may be even lower (3–4 $\mu g\ l^{-1}$).

The channel results and a literature review (26 citations) suggested that a nuisance biomass of filamentous periphytic algae may be represented by a level greater than 100–150 mg chl *a* m^{-2}. A high proportion of filamentous algae in the periphyton is readily apparent and may be aesthetically displeasing and interfere with foot travel by fishermen.

While the biomass accrual on a bare area can be related to the concentration of soluble limiting nutrient (Horner & Welch, 1981), it is more important from a management standpoint to be able to predict the maximum or average seasonal biomass that ultimately develops on natural substrates. Therefore, biomass accrual on natural substrates was determined over the growing season in the six western Washington streams, and mean accrued biomass was related to ambient SRP concentration and mean cross-sectional velocity. Single, late summer observations were obtained from ten other streams. In addition, indices of nuisance conditions were determined as percent cover of periphyton biomass, dissolved oxygen (DO) content, and measures of benthic diversity, in order to evaluate the previously suggested nuisance biomass level of 100–150 mg chl *a* m^{-2}.

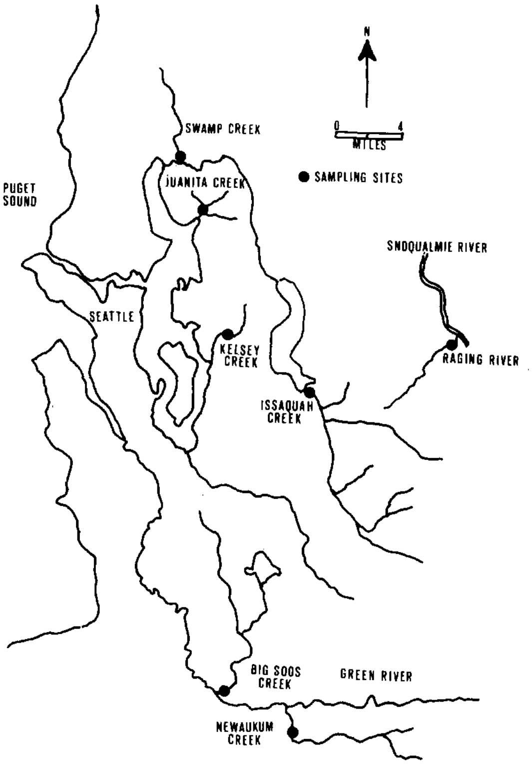

Fig. 1. Location of the stream study sites.

Methods and materials

Study area description

Six streams in western Washington were selected to verify the conclusions previously formulated using laboratory channels and observation on bare surfaces in natural streams. Stations were chosen with respect to the following criteria:

1. potential nutrient limitation (determined by soluble N/P ratios);
2. a wide range of SRP concentrations (2–55 $\mu g\ l^{-1}$);
3. substrate velocities between 5 and 75 cm s^{-1};
4. stony substrate in unshaded riffle areas; and
5. proximity to U.S.G.S. gauging stations for discharge measurements.

The six streams chosen drained catchments with different land uses (urban, agricultural and forested) and, hence, represented variable enrichment levels (SRP 5–50 $\mu g\ l^{-1}$ and inorganic N 200–2000 $\mu g\ l^{-1}$). General locations of sampling sites are shown in Fig. 1.

In addition, ten other streams in the northwestern United States and six in Sweden were sampled once each during peak summer growth to relate possible nuisance biomass levels to SRP concentrations. These streams included the Sammamish River, Swamp Creek, North Creek, and McAleer Creek in the Seattle, Washington area; the Lyre River on the Olympic Peninsula, Washington; the Spokane River in eastern Washington; and four streams in Montana: Madison River, Firehole River, Gibbon River, and Duck Creek. The six streams sampled in Sweden were in the lowlands of east-central Sweden near Stockholm and included Vendelån, Tomtaån, Jumkilsån, Erken Outlet, Funboån, and Östfora.

Experimental design and procedures

Water samples were collected every two weeks from April through September, 1984, and analyzed for total phosphorus (TP), ammonium (NH_4^+–N), SRP, and nitrate and nitrite ($NO_3^- + NO_2^-$–N) (American Public Health Association, 1981). Periphyton samples were collected from natural substrates eight times over the summer (biweekly from mid-June through September) according to a stratified random design. A known area of a rock's surface was isolated with a cylindrical plexiglass tube, scraped with brushes and blades, and washed into a collection jar (Douglas, 1958). Ten discrete periphyton samples were collected at each site on most (six out of eight) sampling occasions. Otherwise, the ten subsamples were combined in a composite sample. These samples were transported to the laboratory on ice and processed for later analysis of chl *a* (Lorenzen, 1967). Taxonomic composition was observed in preserved subsamples.

The current directly above the sampled rocks' upper surface was measured using a Marsh-McBirney current meter in order to determine the current velocity actually experienced by the periphyton community (henceforth referred to as substrate velocity).

In addition, several other water quality indices were determined to assess the effects of nuisance biomass levels of periphyton as follows:

1. Benthic macroinvertebrates were collected using a Surber sampler at six randomly selected points at each site. Macroinvertebrates were identified to genus and evaluated in terms of diversity (Shannon & Weaver, 1949; Margalef, 1968) and pollution tolerance, using the Average Score Per Taxon (ASPT) scoring system of Armitage *et al.* (1983).
2. Qualitative classifications were made of percent coverage of various phytobenthic physiognomic forms in a manner similar to Holmes & Whitton (1981).
3. The average, or equilibrium, DO level was determined during peak algal biomass in August (Slack, 1971). One-liter polyethylene bottles, which allowed diffusion of oxygen from the ambient solution into distilled water in the bottles, were submerged in the stream for three weeks. Stream maximum DO was determined by frequent mid-day (1200–1600 hours) observations during the bottle incubation. Minimum DO was estimated by assuming an equivalent difference between the average DO (at equilibrium) and determined stream maximum. This method was checked and calibrated in the laboratory by submerging the bottles in water equilibrated with the atmosphere for several days. Formalin (4% solution) was added to the distilled water to inhibit microbial growth which would alter DO levels.

Experimental control

The six western Washington sites sampled during the summer of 1984 exhibited comparable light, temperature, and discharge patterns. With the exception of Kelsey Creek, which had substantial areal shading (about 50%) due to riparian vegetation, the sites were open (90% or more unshaded) and well-lit. Mid-day temperatures ranged from 15 to 18 °C at all sites. Discharges were quite uniform (mean coefficient of variation = 0.38) during the periphyton collection period, due to a lack of significant precipitation during the July through September period. The stability of flows and optimal conditions present over the growing season permitted evaluation of periphyton development in relation to nutrient content and velocity without the presence of confounding meteorological conditions.

Results

Biomass versus phosphorus and velocity

Phosphorus was potentially limiting in all streams with N/P ratios ranging from 30–70, except in Kelsey Creek where the mean N/P ratio was 12. A simple relationship between average (or maximum) summer chl *a* density and average SRP content at the six western Washington stream sites was not apparent (Table 1, Fig. 2). For example, biomass was lowest in Big Soos Creek even though SRP averaged 20 $\mu g\ l^{-1}$. Kelsey Creek SRP averaged 51 $\mu g\ l^{-1}$ and chl *a* was relatively high (100 mg chl *a* m^{-2}), but the composition was predominantly diatoms. Issaquah Creek maintained high diatom biomass (mean 166 mg chl *a* m^{-2}) with moderate SRP content (15 $\mu g\ l^{-1}$). The other three streams conformed to expectations; Raging River supported only diatoms, and at rather low biomass (55 mg

Table 1. Values (mean ± 1 SD) for SRP, TP, NH_4^+-N, NO_3^- + NO_2^--N, chl *a*, and velocity in six western Washington streams. Nutrients were measured biweekly from April through September, 1984. Mean chl *a* and substrate velocity represent the average of eight biweekly measurements during June through September. Maximum chl *a* is shown as the mean of 10 discrete subsamples across a transect.

Constituent	Raging River	Issaquah River	Big Soos	Newaukum Creek	Juanita Creek	Kelsey Creek
SRP, $\mu g\ l^{-1}$ (n = 12)	5 ± 2	15 ± 7	20 ± 7	26 ± 13	27 ± 5	51 ± 7
TP, $\mu g\ l^{-1}$ (n = 12)	16 ± 4	33 ± 11	43 ± 11	138 ± 147	42 ± 9	88 ± 11
NH_4^+-N, $\mu g\ l^{-1}$ (n = 12)	12 ± 18	28 ± 34	36 ± 20	21 ± 15	20 ± 11	30 ± 10
NO_3^- + NO_2^--N, $\mu g\ l^{-1}$ (n = 12)	144 ± 62	756 ± 97	673 ± 251	1768 ± 272	1388 ± 163	556 ± 158
chl *a*, mg m^{-2} (n = 8)	55 ± 9	166 ± 22	23 ± 6	131 ± 32	164 ± 94	97 ± 14
Max. chl *a*, mg m^{-2} (n = 10)	92 ± 57	267 ± 57	54 ± 3	190 ± 178	805 ± 1504	145 ± 54
Substrate velocity cm s^{-1} (n = 8)	9 ± 4	21 ± 8	36 ± 11	18 ± 14	22 ± 14	14 ± 6

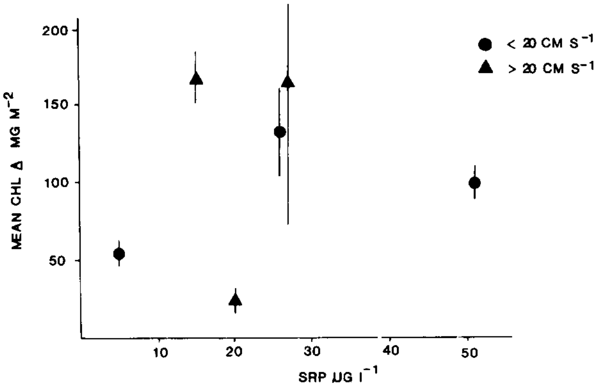

Fig. 2. Mean summer chl *a* versus SRP at six western Washington stream sites for two velocity ranges.

chl *a* m^{-2}), with a mean SRP of 5 $\mu g\ l^{-1}$, while Juanita and Newaukum Creeks had filamentous green algal biomass around the 150–200 mg chl *a* m^{-2} range, associated with SRP content between 25 and 30 $\mu g\ l^{-1}$.

Similarly, periphyton biomass was not consistently related to NO_2^-+ NO_3^-–N concentration in the streams (Table 1). Ammonium was relatively low in all six streams (<40 $\mu g\ l^{-1}$), as expected in well-aerated systems with little organic loading. TP content was proportional to that of SRP levels in the six streams and, thus, also did not demonstrate a positive relationship with periphytic algal biomass (Table 1).

Velocity was positively related to both maximum and mean chl *a* during the summer period for five of the six stream sites (Fig. 3). Big Soos Creek, with the highest average velocity (and intermediate SRP content), produced the lowest biomass level. The stimulatory effect of velocity was also observed among and within four of the six Swedish streams.

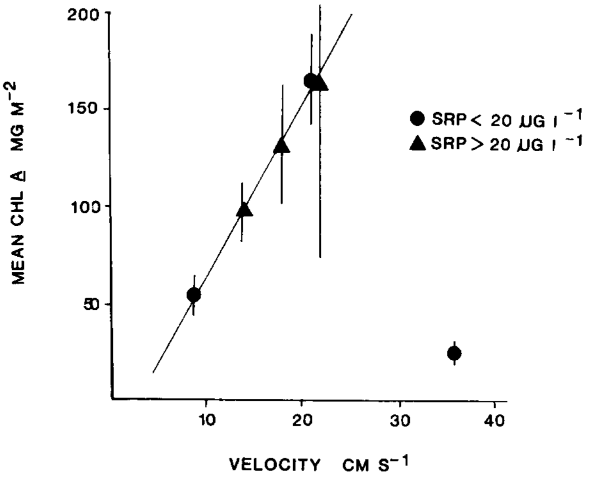

Fig. 3. Mean summer chl *a* versus velocity at six western Washington stream sites for two SRP ranges.

Indicators of water quality

Tables 2 and 3 present the results of investigating water quality indicators that may be affected by nuisance periphyton growth. Not surprisingly, percent coverage by filamentous algae generally increased with biomass (Fig. 4). The coverage by filamentous algae was less than 20 percent if chl *a* was less than the earlier suggested criterion of 100 mg m^{-2}.

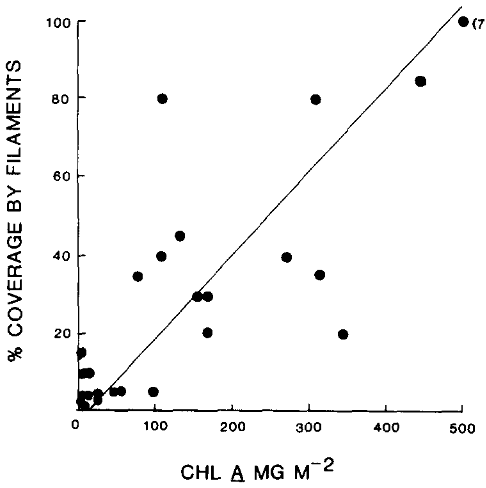

Fig. 4. Coverage by filamentous algae versus chl *a* biomass at all 25 stream sites (r = 0.78).

Table 2. SRP, chl *a* biomass, and coverage by filamentous species measured once during late summer 1984 at 12 sites in Washington and Montana and 6 sites in Sweden during 1983.

Stream	SRP ($\mu g\ l^{-1}$)	Chl *a* (mg m^{-2})	Filament coverage (%)
Lyre R., WA	2	345	20
Sammamish R., WA	3	108	80
Spokane R., WA			
site 1	17	14	<5
site 2	14	108	40
site 3	31	307	80
Duck Cr., MT	21	442	85
Gibbon R., MT	23	1	<5
Madison R., MT	50	25	5
Firehole R., MT	75	12	10
Swamp Cr., WA	45	45	5
North Cr., WA	71	276	40
McAleer Cr., WA	236	706	100
Erken Outlet, Sweden	5	156	30
Vendelån, Sweden	18	3	15
Jumkilsån, Sweden	19	73	35
Funboån, Sweden	20	312	35
Tomtaån, Sweden	26	6	0
Östfora, Sweden	70	6	10

No consistency was seen between DO and macroinvertebrate indices and periphyton biomass or the filamentous algal component (Table 3). However, there was a negative relationship between chl *a* and

Table 3. Indices used to evaluate nuisance conditions or water quality impairment in six western Washington streams during June – August, 1984.

Stream	Filament coverage (%)	Minimum D.O. (mg l^{-1})	No. macroinvertebrate genera	Macroinvertebrate density (no. m^{-2})	Macroinvertebrate diversity (H')[a]	Macroinvertebrate diversity ($\bar{d}$)[b]	ASPT[c]
Raging River	5	4.2	23	1216	2.1	3.1	6.0
Issaquah Creek	20	3.8	21	4745	1.1	2.4	6.4
Big Soos Creek	<5	4.5	14	872	2.3	2.1	6.1
Newaukum Creek	45	2.9	26	3734	2.2	3.0	5.8
Juanita Creek	30	4.8	8	463	1.7	1.1	4.7
Kelsey Creek	5	3.8	9	538	2.6	1.3	4.1

[a] $H' = \sum_{i=1}^{s} \frac{Ni}{N} \log_2 \frac{Ni}{N}$ Shannon and Weaver (1949) (H' = 3 – 4 indicates clean water streams.

[b] $\bar{d} = \frac{s-1}{\ln N}$ (Margalef, 1968)

[c] ASPT = Average score per taxon using scoring system of Armitage *et al.* (1983) (ASPT = 5 – 6 indicates unpolluted sites).

macroinvertebrate diversity as measured by the Shannon & Weaver (1949) index ($r = -0.657$), although it was not statistically significant ($0.05 < P < 0.10$). Minimum DO was lowest in Newaukum Creek, but the macroinvertebrate community showed no evidence of stress. While percent coverage of filamentous algae was highest there, biomass was not as high as other streams that had higher minimum DO. The minimum DO in Newaukum Creek may have been related to access by cattle.

The two streams that had the lowest ASPT (Juanita and Kelsey Creeks) and significantly ($P < 0.05$) fewer genera and lower densities of macroinvertebrates than other streams, did not show consistency with the other indices. Macroinvertebrate diversity, as measured by H', was inexplicably high in Kelsey Creek despite the low numbers of genera, density and ASPT. The evenness of the organism distribution among genera may account for the deceptively high H'. Juanita Creek had high periphyton biomass and percent filamentous algae, but Kelsey Creek was intermediate in those characteristics. These two creeks are the most urbanized of the six and are severely affected by high flows and scouring, as well as high suspended sediment loads following rains. Thus, the generally low invertebrate indices are probably a reflection of those physical factors; such has been the case for Kelsey Creek (Pedersen, 1980).

Discussion

Periphyton biomass in these natural streams was not related to ambient SRP concentration, but was related to increased velocity and to increased coverage by filamentous species. Diatom-dominated assemblages were not readily apparent and were not associated with high biomass (>200 mg chl *a* m^{-2}). More than 20 percent coverage could be expected if biomass exceeded 100 mg chl *a* m^{-2}. A level of 100 mg chl *a* m^{-2} was demonstrated, however, to be the quantity of periphyton biomass above which filamentous species tended to dominate and have a noticeable effect on the aesthetic quality in these streams.

Biomass and filamentous coverage were not related to minimum DO or macroinvertebrate community indices. Therefore, 100 mg chl *a* m^{-2} (or any other specific biomass) was not demonstrated to be a level that definitely depletes stream oxygen resources through respiration and suppresses benthic invertebrate communities. Effects of physical factors, such as scouring from high stormwater runoff rates, in urbanized streams (e.g., Juanita & Kelsey) may have overshadowed possible effects from periphyton abundance.

Streams that did not support biomass levels expected from the SRP content may have had other limiting controls. For example, Kelsey Creek was relatively shaded and also may have been N-limited, because soluble inorganic N/P ratios ranged from 12 to 16 by weight. A shaded N-limited stream would explain the lower than expected biomass with such a high P content and the absence of filamentous species. Grazing is suspected to have been important in Big Soos Creek, because grazers comprised about 45% (by numbers) of the benthic collections. Velocity was neither high nor variable enough (36 ± 11 cm s^{-1}) to cause significant scouring. Horner & Welch (1981) found that velocity did not reduce biomass on flattened rock surfaces in these streams unless it exceeded 50 cm s^{-1}.

The time required for maximum biomass development was longest for Raging River and Big Soos Creek (mid August) among the five streams that were potentially P-limited. These streams were subjected to heavy grazing pressure, especially during July when the caddisfly larva *Dicosmoecus gilvipes* was abundant. Maximum biomass accrual in Kelsey Creek did not occur until mid September and may have been related to limitation by light or N. Maximum biomass in the other high nutrient streams (Juanita and Newaukum Creeks) occurred by mid to late July. If increased nutrient availability stimulates primary productivity, the time required to achieve the maximum biomass should decrease. This hypothesis is partially supported here where streams did not reach biomass levels expected from the SRP content had other limiting controls (e.g., grazing losses, or for Kelsey Creek, light and/or N limitation).

This work indicates that firm criteria, such as a critical SRP concentration(s) for nuisance periphytic biomass levels in natural streams may be very difficult to identify from correlation analysis. Periphyton biomass accrual on natural surfaces in a wide range of streams, either as an average or maximum density, was not related to SRP content. Jones *et al.* (1984) have also observed poor relationships between ambient nutrient content and periphytic biomass. Ambient, as well as inflow SRP, has been related positively to periphyton biomass in laboratory channels (Horner *et al.*, 1983; Seeley, 1986) and on artificial substrates (Horner & Welch, 1981). However, SRP in the channels was maintained in proportion to inflow enrichment levels because residence time was only 16 minutes. Even in experiments in four of the same six natural streams (Horner & Welch, 1981), growth on the small, bare, flattened surfaces could not affect the ambient SRP content during the two-week growth period. This is not the case in a long stream course, however, where sufficient time exists for nutrient depletion and the persistence of conditions of high biomass and low levels of available, limiting nutrient.

Therefore, to evaluate nutrient-biomass relationships in streams, a dynamic modelling approach may be necessary. In a model, such as proposed by Horner *et al.* (1983), nutrient uptake is controlled by ambient concentration and mass transport-velocity considerations and biomass losses result from scouring. Constants for uptake kinetics may vary among different algal types, such as filamentous greens and diatoms. While biomass in lakes is restricted by the concentration of limiting nutrient (Dillon & Rigler, 1974; Smith, 1982), because that concentration represents the supply, the supply to areal biomass in streams is not restricted to the mass of nutrients per volume of water passing over the substrate. Therefore, concentration of limiting nutrient in streams may be related to the total biomass throughout a downstream reach until depletion occurs. Where streams are fed by enriched groundwater (Biggs, 1985), the inflow nutrient concentration from that source, as well as the in-stream residual, may represent the available supply. High grazing rates, such as observed in Erken outlet (Jacoby, 1985) and Raging River during 1985 (Jacoby, 1986), could still result in lower than expected biomass predicted by such a dynamic model.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. CEE-8304731 and the Valle Exchange Scholarship Fund, University of Washington.

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