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Factors affecting distribution of *Nostoc* in Cascade Mountain streams of Western Oregon, U. S. A.

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With 3 tables in the text

Introduction

The presence of a nitrogen-fixing blue-green alga, *Nostoc parmeloides*, has been reported in a number of stream ecosystems in the western United States (WIRTH 1957; BROCK 1960). This species differs from other *Nostoc* species in that it can contain a dipteran larva, *Cricotopus nostocicola* (Diptera: Chironomidae), which exists within the colony during its immature stages. In this study colonies of *N. parmeloides* have been found in the northwestern states of Washington, Oregon, Idaho, and Wyoming attached to rocky substrates in rapidly flowing reaches of rivers and streams. In Oregon, *Nostoc parmeloides* is particularly abundant throughout the year in certain headwater streams in the central Cascade mountains of western Oregon. Many of the terrestrial and aquatic ecosystems in this region are nitrogen limited (THUT & HAYDU 1971; GREGORY 1980); therefore, the importance of *N. parmeloides* lies in its contribution of labile carbon and nitrogen, which is made available to the microflora and other trophic levels in the streams. It was the purpose of this study of identify factors which were most important in determining distribution of these algae, specifically focusing on their abundance and role in streams with different riparian vegetation, which affects the amount of light reaching the stream surface. Other factors which were examined included water chemistry, physical features of the streams, and relationships with the *Cricotopus* midge.

Materials and methods

Site description

Twelve sites in watersheds in or close to the H. J. Andrews Experimental Forest in the central Cascade mountains of western Oregon, U. S. A., were chosen to provide a range of streams representing an age sequence since clear-cutting for comparison with old-growth (never cut) watersheds. All were high gradient, first order, shallow streams (less than 0.25 m deep) with primarily rock and cobble substrates. Riparian vegetation in second-growth watersheds was composed mainly of *Alnus rubra* (red alder) and in old-growth watersheds, *Pseudotsuga menziesii* (Douglas-fir) and *Tsuga heterophylla* (western hemlock). Therefore, besides representing age sequences, these watersheds included streams with riparian vegetation ranging from low, shrubby plants in recently cut watersheds to deciduous vegetation in early second-growth stands to coniferous vegetation in old-growth watersheds. In addition, Nostoc Creek, a shallow second order stream in the same vicinity, was chosen as a site of an intensive annual study in which various physical, chemical and activity measurements were made. Part of the Nostoc Creek watershed (old-growth Douglas-fir and hemlock) had been experimentally thinned, thereby opening the canopy of the stream and causing soil erosion and accumulation of fine particulate matter in some sections.

Procedures

Inorganic nutrients, NO_3-N, NH_4-N, and PO_4-P were measured in filtered (GF/F Whatman glass fiber filters, 0.5 μm pore size, precombusted at 450 °C) stream water samples using a Technicon II autoanalyzer. pH was measured with a Coleman (Model 37A) pH meter and alkalinity es-

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timated by titration of stream water to pH 4.8 with 0.02 N sulfuric acid. Light intensity was measured with a Licor (Model 185B) light meter attached to quantum sensor sensitive in the photosynthetically active range (PAR) of 400 to 700 nm.

Results and discussion

The description of the twelve sites in the H. J. Andrews Experimental Forest in relation to *N. parmeloides* distribution indicated that *Nostoc* abundance was most apparent in second-growth (9—22 years since cutting) watersheds in which the canopy over the stream was still open (Table 1). It was less likely to appear in high densities in streams of recently cut watersheds (less than 4 years since cutting) or in streams of mature second-growth (35—75 years since cutting) or old-growth watersheds (450+ year old forest). Comparison of relevant water chemistry data from these same streams indicated all were low in inorganic nitrogen (NO_3-N and NH_4-N) and relatively high in inorganic phosphorus (PO_4-P), producing a dissolved inorganic nitrogen to phosphate ratio of less than 7.0 (Table 2). This ratio indicates nitrogen-limited systems, favoring development of nitrogen-fixing organisms (RUSSELL-HUNTER 1970). However, the *N. parmeloides* colonies occurred primarily only in the early second-growth streams. Therefore, increases in phosphate and decreases in inorganic nitrogen concentrations, which have been suggested as factors stimulating growth of *Nostoc* in Oregon streams (GRIMM 1977) and for blue-green algae in general (STEWART et al. 1970; STEWART & ALEXANDER 1971), were not sufficient to explain totally the distributional patterns observed here.

The necessity for light of high enough intensity to maintain the high energy-requiring process of nitrogen fixation in lake phytoplankton (WARD & WETZEL 1980) suggested that low light intensity in streams of old-growth watersheds may decrease abundance of phototrophic, nitrogen-fixing organisms in these systems. In Nostoc Creek, annual and diurnal comparison of primary productivity rates with light intensity (WARD et al. MS) indicated daily rates of *Nostoc* photosynthesis closely paralleled incoming solar irradiance. Photosynthetically active radiation (PAR) at stream surface in Nostoc Creek ranged from maximum full sun values of 2700 $\mu E \cdot m^{-2} \cdot S^{-1}$ to 360 $\mu E \cdot m^{-2} \cdot S^{-1}$ on cloudy days (Table 3). Values in old-growth streams were usually 1 to 5 % of these values. The shading from surrounding riparian vegetation in later second-growth (primarily alder) and old-growth (Douglas-fir and hemlock) watersheds was apparently sufficient to restrict development of *N. parmeloides* in those areas. The opening of the canopy at Nostoc Creek by thinning rather than entirely clear-cutting an old-growth forest appears to be a major factor in stimulating *N. parmeloides* there.

The requirement for high light, however, does not explain the virtual absence of colonies in open-canopied streams in recently clear-cut watersheds. Several factors may be relevant here, including a combination of slightly higher NO_3-N concentrations (Table 2) and hydrologically, physically, and chemically less-stable systems. A tendency for greater movement of cobble, boulders, and logs (frequent substrates for attachment by the *Nostoc* colonies) in these physically distrupted watersheds initially after clear-cutting may retard development of *N. parmeloides* through scour and other physical means. Combined with these factors may be a minimal time period necessary for inoculation of *N. parmeloides* trichomes into these streams and development into macrocolonies.

Another observation is the occurrence of abundant *N. parmeloides* in areas with high inputs of fine particulate matter, usually resulting from soil inputs from gradual slope

Table 1. Description of 12 study sites in the H. J. Andrews Experimental Forest area. (n.s. = not significant; * = present; ** abundant; *** very abundant).

Site	Years since cutting	Vegetation	Discharge pattern	*Nostoc* abundance	Comments
WS 10	4	ground cover, open canopy	perennial	n.s.	recent clear-cut
Elk Meadow	3	ground cover, open canopy	perennial	n.s.	recent clear-cut
Q101A	9	ground cover, open canopy	perennial	*	little revegetation
WS 1	16	young alder, partially closed canopy	perennial	**	young 2nd growth
B 301	22	young alder, mostly closed canopy	perennial	**	young 2nd growth
Ennis	22	ground cover, open canopy	perennial	*** ($6.3\ g \cdot m^{-2}$)	little revegetation
Doe	28	young 2nd growth, mostly open canopy	dry in summer	n.s.	young 2nd growth
Behms	35	mature alder, nearly closed canopy	perennial	n.s.	mature 2nd growth
Quartz	35+	mature alder, nearly closed canopy	dry in summer	n.s.	mature 2nd growth
Burwell	75+	nearly mature conifer forest, closed canopy	perennial	n.s.	Nearly mature old-growth
WS 2	450+	mature douglas fir and hemlock forest, closed canopy	perennial	n.s.	old-growth
WS 9	450+	mature douglas fir and hemlock forest	perennial	n.s.	old-growth

erosion or massive slope failure (sluice-outs). In contrast to the streams in recently clear-cut watersheds, this may represent a disturbance factor in second-growth watersheds which actually promotes distribution and growth of *N. parmeloides* colonies. Of the sites examined, Ennis Creek and Nostoc Creek had the highest densities of colonies and also visually apparent accumulations of fine sediment material which became trapped around the colonies and were retained in small pools. The potential mechanism of stimulation is not clear, but may result directly from nutrient or trace metal enhancement of growth or indirectly, for example, from chelation by organic matter, which makes certain nutrients more available for utilization by algae. Soil extracts have been used frequently in algal studies to enhance growth of laboratory cultures of algae, and several species of *Nostoc* thrive in terrestrial soils (Stewart 1973). Also, blue-green algae have been reported dominant in benthic littoral regions of oligotrophic alpine lakes in California and Oregon, but

Table 2. Concentration of inorganic N and P in 12 streams in the vicinity of the H. J. Andrews Experimental Forest.

Site	Stand age (yrs.)	[1] NO_3-N ($mg \cdot l^{-1}$)	[1] NH_4-N ($mg \cdot l^{-1}$)	[2] DIN ($mg \cdot l^{-1}$)	[1] Ortho-P ($mg \cdot l^{-1}$)	[3] DIN / Ortho-P
WS 10	4	0.021	0.013	0.034	0.030	1.20
Elk Meadow	3	0.027	0.022	0.049	0.009	5.78
Q101A	9	0.005	0.019	0.024	0.009	2.77
WS 1	16	0.003	0.029	0.032	0.024	1.38
B 301	22	0.004	0.011	0.015	0.011	1.27
Ennis	22	0.003	0.020	0.023	0.016	1.44
Doe	28	0.003	0.014	0.017	0.017	1.06
Behms	35	0.008	0.035	0.043	0.011	1.83
Quartz	35+	0.003	0.025	0.028	0.011	2.64
Burwell	75+	0.008	0.029	0.037	0.020	1.80
WS 2	450+	0.002	0.013	0.015	0.022	0.68
WS 9	450+	0.002	0.024	0.026	0.017	1.25

1: Average of 13 sample dates during 1978–1979.
2: Sum of annual mean of NO_3-N and NH_4-N.
3: Ratio of annual mean of dissolved inorganic N and ortho-P.

Table 3. Summary of physical, chemical, and biological properties of Nostoc Creek. Annual range of 1981.

Temperature	3–15.8 °C
Light ($\mu E \cdot S^{-1} \cdot m^{-2}$)—	390–2700*
pH	5.81–7.37
Alkalinity ($meq \cdot l^{-1}$)	0.29–0.58
NO_3-N ($mg \cdot l^{-1}$)	N.D.–0.003**
NH_4-N ($mg \cdot l^{-1}$)	N.D.–0.024
PO_4-P ($mg \cdot l^{-1}$)	0.015–0.061

* Mid-day values in open section; light sensor held at stream surface.
** N.D. = non-detectable.

were not numerous in the phytoplankton (Loeb & Reuter 1981), suggesting a sediment stimulatory factor for benthic blue-green algae in both lakes and streams in the northwest.

Finally, the distributional pattern of the *N. parmeloides* colonies may be linked to life cycle characteristics and distributional patterns of the *Cricotopus* midge. The close mutualistic relationship between the midge and the *N. parmeloides* colonies suggest that the colonization of one may be dependent on the other. If so, length of life cycle, timing and site of egg deposition, distribution of adult midges as well as other life history properties may affect the degree of colonization and growth of *N. parmeloides* colonies in any given stream.

The occurrence of high densities of *N. parmeloides* streams of early second-growth watersheds in the Cascade mountains of western Oregon appears to be the result of a complex of factors including well-known influences on blue-green algal growth such as inorganic P and N concentrations and light regime as well as more subtle factors such as distribution and nutrient stimulatory capacity of sediment inputs, stability of substrate, and the interaction with the dipteran larva which inhabits the colony. The role of the nitrogen-fixing algae in these types of streams parallels the role of alder in the terrestrial environment in second-growth watersheds in this region (Newton et al. 1968) in that both replenish nitrogen to ecosystems which have been previously stripped of large amounts of total N by the process of clear-cutting. The presence of alder increases nitrogen content of the soil, thereby improving growth of several associated trees (Tarrant 1968). Large amounts of woody debris left after clear-cutting in streams would enhance retention of new nitrogen inputs, maintaining it in the watershed in which nitrogen-fixing organisms occur (Sedell & Triska 1974). Therefore, the replenishment and maintenance of nitrogen in stream ecosystems with *N. parmeloides* undoubtedly influence development of future stream communities as they recover from the clear-cutting process. The extensive practice of clear-cutting for economic purposes in this region will increase the number of streams undergoing this recovery sequence and, also the probability of increased abundance of *Nostoc* in Cascade streams.

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References

Brock, E. M., 1960: Mutualism between the midge *Cricotopus* and the alga *Nostoc*. — *Ecology* **41:** 474—483.

Gregory, S. V., 1980: Effects of light, nutrients, and grazing on periphyton communities in streams. — Ph. D. dissertation, Oregon State Univ., 151 pp.

Grimm, N., 1977: Factors regulating *Nostoc* abundance in Oregon mountain streams. — Senior Honors thesis, Hampshire College, Amherst, Massachusetts.

Loeb, S. L. & Reuter, J. E., 1981: The epilithic periphyton community: a five-lake comparative study of community productivity, nitrogen metabolism, and depth-distribution of standing crop. — *Verh. Internat. Verein. Limnol.* **21:** 346—352.

Newton, M., El Hassan, B. A. & Zavitokovski, J., 1968: Role of red alder in western Oregon forest succession. — In: *Proc. Symp. on Biology of Alder*: 73—84. J. M. Trappe, J. F. Franklin, R. F. Tarrant & G. M. Hansen (eds.). Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Russell-Hunter, W. D., 1970: *Productivity: an introduction to some basic aspects of biological oceanography and limnology*. — Macmillan Co., London, 306 pp.

Sedell, J. R. & Triska, F., 1975: Biological consequences of large organic debris in northwest streams. — In: *Logging debris in streams*: 21 pp. Oregon State Univ., School of Forestry.

Stewart, W. D. P., 1973: Nitrogen Fixation. — In: N. G. Carr & B. A. Whitton (eds.), *The Biology of Blue-green Algae*: 676 pp. Univ. of California Press, Berkeley/Los Angeles.

Stewart, W. D. P. & Alexander, G., 1971: Phosphorus availability and nitrogen activity in aquatic blue-green algae. — *Freshwat. Biol.* **1:** 389—404.

Stewart, W. D. P., Fitzgerald, G. P. & Burris, R. H., 1970: Acetylene reduction assay for determination of phosphorus availability in Wisconsin lakes. — *Proc. Nat. Acad. Sci.* **66:** 1104—1111.

Tarrant, R. F., 1968: Some effects of alder on the forest environment. — In: *Proc. Symp. on Biology of Alder*: p. 193, J. M. Trappe, J. F. Franklin, R. F. Tarrant & G. M. Hansen (eds.). Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Thut, R. N. & Haydu, E. P., 1971: Effects of forest chemicals on aquatic life. — In: *Proc. Symp. on Forest Land uses and stream environment*: 159—171. Oregon State Univ.

Ward, A. K. & Wetzel, R. G., 1980: Interactions of light and nitrogen source among planktonic blue-green algae. — *Arch. Hydrobiol.* **90:** 1—25.

WIRTH, W. W., 1957: The species of *Cricotopus* midges living in the blue-green alga *Nostoc* in California (Diptera: Tendipedidae). — *The Pan-Pacific Entomol.* 33: 121—126.

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