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Donald Kaczmarczyk and Robert G. Sheath*: Pigment content and carbon to nitrogen ratios of freshwater red algae growing at different light levels

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Donald Kaczmarczyk and Robert G. Sheath, Department of Biology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1B 3X9

Rhodophyta growing in streams are frequently subjected to shading by riparian vegetation which results in significant seasonal variations in light quantity and quality. It has been suggested that there is a relationship between this photoregime and the predominance of phycocyanin in freshwater red algae (Sheath 1984). However, there is little evidence to support this suggestion (Kaczmarczyk and Sheath 1991; Raven 1992). Pigment content and phycobiliprotein to chlorophyll *a* ratios can also change in response to variations in nitrogen metabolism (Maccoll and Guard-Friar 1987). In order to examine the combined effects of light and nitrogen content on photosynthetic pigments in freshwater red algae, a survey was conducted in April of 1987. The study examined phycobiliprotein and chlorophyll *a* content as well as carbon to nitrogen (C/N) ratios in different rhodophyte taxa growing in streams which were subjected to varying degrees of shading.

Light measurements were taken at eleven stream sites in southern and western Rhode Island (U.S.A.). These readings were taken within two hours of noon at the stream surface using a LICOR quantum meter (Model LI-185B). By combining meteorological data (% cloudiness and daylength, National Weather Service—Warwick, R. I., U.S.A.) with the light measurements at the stream, it was possible to obtain estimates of the mean energy received by the plants (in mol m^{-2} d^{-1}) at each site.

The total list of Rhodophyte taxa collected included the following: *Audouinella hermannii*, (ROTH) DUBY [=*A. violacea* (KÜTZ.) HAMEL], *Batrachospermum boryanum* SIROD., *B. gelatinosum* (L.) DC. (=*B. moniliforme* ROTH), *B. sirodotii* SKUJA ex REIS [=*B. virgatum* (KÜTZ.) SIROD.], *Lemanea fluviatilis* (L.) C. AG., *Sirodotia suecica* KYLIN and *Tuomeya americana* (KÜTZ.) PAPENFUSS. Algal populations were collected in triplicate and returned to the laboratory for pigment and carbon-nitrogen analysis. Epiphytes and debris were mechanically removed from the samples upon microscopic examination. The samples were then uniformly blotted to remove excess water and divided in half. One half was used for pigment analysis and the other half was subjected to carbon-nitrogen analysis. Fresh weights were obtained for all subsamples with a Mettler AE-200 balance. Pigment analysis was performed as outlined in Kaczmarczyk and Sheath (1991). For determination of carbon and nitrogen content, algal samples were ground and then resuspended in distilled water. They were dried by boiling off the water in a microwave oven. Portions of the dried samples were then weighed on a Cahn Electro Balance and carbon to nitrogen ratios were obtained from standard curves after combustion in an Elemental Analyzer (Carl Erba Model 1106).

Differences in means among populations were calculated based on the following: total pigment, phycobiliprotein to chlorophyll *a* ratio (PBP/chl *a*), phycocyanin to phycoerythrin (PC/PE) and carbon to nitrogen (C/N). To test differences among samples, a one-way analysis of variance (ANOVA) was performed using the Minitab computing system

* Author for correspondence

Table 1. Total pigment content (mg g^{-1} fw), phycobiliprotein to chlorophyll *a* (PBP/chl *a*), phycocyanin to phycoerythrin (PC/PE) and carbon to nitrogen (C/N) ratios of freshwater red algae collected from Rhode Island streams with varying degrees of shading (Light energy estimates in mol m^{-2} d^{-1}).

Species	Energy	Total Pigment	PBP/chl *a*	PC/PE	C/N
Audouinella					
A. hermannii	21	0.510	0.304	0.494	9.4
	35	0.125	0.572	0.494	11.8
	39	0.386	0.315	0.654	9.0
Batrachospermum					
B. boryanum	15	0.110	1.520	1.433	7.5
	16	0.158	0.982	0.848	6.1
	29	0.084	0.982	0.933	7.1
	33	0.054	1.141	0.767	7.4
	35	0.111	1.192	0.764	9.0
	39	0.124	1.489	0.642	7.8
	44	0.193	1.151	0.914	6.9
B. gelatinosum	29	0.059	0.772	0.744	10.0
	35	0.099	0.782	1.000	9.3
B. sirodotii	21	0.174	0.465	1.938	8.8
	29	0.082	0.695	1.944	8.2
	33	0.066	0.616	1.389	11.5
	35	0.086	1.008	2.611	8.1
Lamanea					
L. fluviatilis	21	0.062	0.469	1.733	11.6
	39	0.070	0.839	1.162	13.5
Sirodotia					
S. suecica	15	0.053	0.441	0.914	8.3
	29	0.157	0.490	1.750	8.8
	33	0.053	0.481	3.000	8.8
Tuomeya					
T. americana	21	0.138	0.272	1.857	10.1
	33	0.092	0.335	1.286	9.1
	34	0.094	0.362	1.000	9.3

(Ryan *et al.* 1976). Pearson-product moment correlations were calculated between light energy and both pigmentation (total pigment, PBP/chl *a* and PC/PE) and the C/N ratio.

There were no significant differences among pigment amounts and ratios in populations of the seven rhodophyte species despite the variations in light energy at the stream sites (Table 1). The following trends were observed in pigment differences between species: 1) all samples of *Audouinella hermannii* had a significantly higher total pigment content than that of other species except *Batrachospermum boryanum*; and 2) samples of *B. boryanum* had a significantly higher PBP/chl *a* ratio than that of *Sirodotia suecica* and *Tuomeya americana*.

There was a significant negative correlation between mean total pigment and light energy in *T. americana*. However, no other significant correlations were observed between light energy and pigment content or ratios of the other taxa.

There were no significant differences in the C/N ratio among any of the species in the survey (Table 1). Likewise, there was no significant correlation between light energy and the C/N ratios among populations of any of the species examined. The C/N

values ranged from 6.1 (*B. boryanum* at 16 mol $m^{-2} d^{-1}$) to 13.5 (*Lemanea fluviatilis* at 39 mol $m^{-2} d^{-1}$).

All seven of the taxa analyzed in this study were found in streams with varying light energy levels and hence occurrence did not appear to be significantly affected by light regime. This agrees with the findings of Sheath and Burkholder (1985) who did not observe a relationship between freshwater rhodophyte distribution and stream shading. The results contrast with the predictive model of Vannote *et al.* (1980); namely, freshwater macroalgae are expected to be localized where light penetration is maximum.

The lack of significant differences among populations at varying light regimes was notable. The one exception was the negative correlation between total pigments in *Tuomeya americana* and light energy. The lack of correlation between total pigment and light in other species is in accord with the findings of Rider and Wagner (1972), who observed little change in the pigment content of two *Batrachospermum* species grown under different light levels.

Mean C/N ratios in this survey were in the range of 7.0 to 11.0 given for *Lemanea mamillosa* by Raven (1992) and close to the 12.0 average ratio reported for marine macroalgae (Lobban *et al.* 1985) and for autochthonous organic matter within freshwater systems (Wetzel 1983). However, for most populations, the C/N ratios fell below the latter value.

Phycobiliproteins can act as storage pools of nitrogen in red and blue-green algae (Bird *et al.* 1982, Lapointe 1985, Maccoll and Guard-Friar 1987). In the Rhodophyta, nitrogen-enriched plants of *Gracilaria tikvahiae* increased total pigment content (Bird *et al.* 1982). In this study, however, the lack of significant differences in C/N ratios among species suggested that the pigment differences did not result from nitrogen availability.

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D. Kaczmarczyk and R. G. Sheath：異なる光条件下で生育した淡水産紅藻の色素含量と C/N 比

淡水産紅藻において，光条件とフィコシアニン量との間にはある関係が既に示唆されている。また，フィコビリン蛋白量及びその Chl a 量に対する比が窒素代謝の変化に応じて変化し得ること，フィコビリン蛋白は紅藻や藍藻において，窒素の貯蔵プールの役割をもち得ることも既に示されている。

そこで，川の異なった光量下に生育する淡水産紅藻（5 属 7 種）について，平均日中光量が，フィコビリン色素 (PBP)［フィコシアニン (PC) とフィコエリスリン (PE)］の含量，PC と PE の含量比，炭素と窒素の含量比（C/N 比）及び Chl a と PBP の含量比に及ぼす影響について調べた。しかし，生育場所の光量，色素含量及び上記の比率の間には有意の相関は認められなかった。(Department of Biology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1B 3X9)