Oceanological and Hydrobiological Studies
International Journal of Oceanography and Hydrobiology
Vol. XXXIII, No.1

Institute of Oceanography (47-54) University of Gdańsk
ISSN 1730-413X 2004 eISSN 1897-3191

Original research paper

Indicator value of freshwater red algae in running waters for water quality assessment[1]

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Key words: Rhodophyta, water quality, indicators

Abstract

Freshwater red algae (Rhodophyta) occur mainly in running waters. They are generally indicators of good water quality (oligotrophic, oligosaprobic). Many of them are also included on lists of threatened algae. According to the literature, the range of occurrence of red algae at the group level is wide for current velocity, water conductivity and pH. At the genus level, some genera seem to prefer or need hard water and an alkaline environment (*Compsopogon, Hildenbrandia, Thorea*), whereas others prefer soft water (conductivity < 100 μS m^{-1}). They may also occur in acid water (*Audouinella, Batrachospermum, Lemanea, Sirodotia* and *Tuomeya*). With the exception of those living in hard waters, most species also have a rather wide ecological tolerance as measured by common water quality variables. Trophic and saprobic classifications seem to depend rather on geographical conditions than on the real ecological preferences of red algal taxa.

[1] Results of this paper were presented on an 5th International Symposium "Use of Algae for Monitoring Rivers" Cracow, 2-6 September 2003, Poland.
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INTRODUCTION

Freshwater red algae (Rhodophyta) appears to be a threatened algal group in many European countries. However, in the Nordic countries (Finland and Sweden) and in northwestern Russia the group occurs with rather high diversity (25 – 30 taxa; Israelson 1942, Eloranta and Kwandrans 1966, 2002, Kwandrans et al. 2002), whereas, for example, 20 taxa have been recorded in Poland (Sieminska 1992) and 22 taxa in Austria (Rott et al. 1997, 1999). With only a few exceptions (e.g., *Batrachospermum gelatinosum* (L.) DC. (syn. *B. moniliforme* Roth), *B. keratophytum* Bory de Saint Vincent (syn. *B. vagum* (Roth) C. Agardh var. *keratophytum* Bory de Saint Vincent), *B. turfosum* Bory de Saint Vincent (syn. *B. vagum* (Roth) C. Agardh), *Hildenbrandia rivularis* Libmann (Ag.), most of the freshwater red algal taxa occur in running waters (e.g., Sheath 1984). Many taxa have been recorded only occasionally and without measurements describing their ecological environments. Therefore, knowledge of their ecological needs is poor. In general, freshwater red algae favor soft, clear waters, but their ecological amplitude is rather wide (Sheath 1984, Sheath and Hambrook 1990, Eloranta and Kwandrans 1996). The use of this group for water quality assessment is limited because it occurs occasionally in rivers which have suitable water quality. The objective of this paper is to evaluate and discuss the usefulness of freshwater red algae as indicators of river water quality, especially the trophic state and the level of saprobity. The paper is based on information found in the literature and our own published (Eloranta and Kwandrans 1996, 2002, Kwandrans et al. 2002) and unpublished records from Finnish waters.

RESULTS AND DISCUSSION

Approximately 200 rhodophyte taxa belonging to 28 genera occur in fresh waters (Skuja 1938; Sheath 1984). Many of these genera occur only in tropical areas, while others live in the temperate zone but are rare or not reported in Europe (e.g., *Ballia, Boldia, Caloglossa, Nemalionopsis, Nothocladus, Ptilothamnion* and *Sterrocladia*). Rare freshwater rhodophyte genera in Europe include *Balbiania, Bostrychia, Kyliniella* and *Laurencia*. However, knowledge of their ecological relationships is very sparse.

These algae can characterize their environments in many ways and are connected to their different preferences for physical, chemical and biological variables. For example, some algae occur during winter in cold water and at low light conditions, whereas others prefer high illumination and warm water (Sheath and Hambrook 1990). Similarly, preferences can be found for standing or running waters, water pH, conductivity and different nutrient concentrations

(Sheath and Hambrook 1990). These last variables are often connected with indicators of trophic degree (e.g., oligotrophy, eutrophy). All of these preferences have some physiological background. In applied limnology studies, organisms are also used to indicate the degree of organic wastewater loads associated with different degrees of saprobity (e.g., Fjerdingstad 1964, 1965; Sladecek 1973).

Taxa indicating general ecological variables

The main ecological factor dividing freshwater red algae is current velocity. Most species live in running waters and prefer current velocity >16 cm s^{-1} (Sheath 1984). Others, such as *Batrachospermum turfosum*, but sometimes also *B. keratophytum, B. gelatinosum*, *Compsopogon* spp. and *Hildenbrandia rivularis* (Starmach 1977), live mainly in lakes and ponds.

The need for adequate light exposure is poorly known, but many taxa favor the reduced light intensity occurring in small rivers under a tree canopy or in brown waters. According to Kremer (1983), species within the genera *Compsopogon* and *Lemanea* can also grow when exposed to higher irradiance, whereas *Batrachospermum* spp. and especially *Hildenbrandia* spp. favor lower irradiance values.

Water conductivity is represented by the total concentration of inorganic ions in the water and is connected to water pH and its buffering capacity (alkalinity). Inland waters with high conductivity also possess a higher content of calcium, and the pH is usually neutral or alkaline. Many common red algal genera have a rather wide tolerance over the conductivity range from soft to hard waters. However, species of *Compsopogon, Hildenbrandia* and *Thorea* are limited to alkaline and hard waters (e.g., Israelson 1942, Sheath and Hambrook 1990, Necchi Jr. et al. 2000). Rott et al. (1999) report that *Hildenbrandia rivularis* is alkaliphilic but prefers Ca-poor rocks, whereas other researchers recorded it in Ca-rich waters on rock substratum (Israelson 1942, Luther 1954). Water pH is strongly connected with water hardness and conductivity. Thus, species living in hard waters are those which also typically live in waters with pH > 7.

The genus *Bangia* is mainly a brackish water taxon, but has been found in larger rivers, channels and lakes with high conductivity (e.g., *B. atropurpurea* (Roth) Ag.) (Sheath and Hymes 1980, Sheath 1984, Eloranta and Kwandrans 2002, Sheath and Sherwood 2002).

Taxa indicating trophic degree of waters – oligotrophy vs. eutrophy

Algal biomass or primary productivity is often used to evaluate the trophic state of lakes. Various algae have also been associated with different trophic

conditions. However, most red algae prefer rather oligotrophic waters with low turbidity and an environment with clean, free substrata for attachment. In eutrophic rivers the solid substrata (mainly rocks) are often covered by silt or filamentous green or blue-green algae. Rott et al. (1999) developed a classification for the trophic preferences of running water red algae (Table 1). In this classification several taxa are named as eutrophic or meso-eutrophic. These include: *Audouinella hermannii* (Roth) Duby (me-eu); *Bangia atropurpurea* (me-eu); *Batrachospermum gelatinosum* (eu); *Lemanea fucina* Bory (eu); *Thorea hispida* (Thore) Desvaux (eu). *Audouinella pygmaea* (Kützing) Weber Van-Bosse is mesotrophic. All the others are classified as oligotrophic or ultra-oligotrophic. In the Nordic countries *Audouinella* spp. live in a wide ecological spectrum, including oligotrophic and eutrophic waters (Eloranta and Kwandrans 1996). Similarly, *Batrachospermum gelatinosum* and *Lemanea fucina* are the most common taxa in their genera in the Finnish waters and live mostly in oligotrophic waters, whereas *B. helminthosum* Bory De Saint Vincent (syn. *B. virgatum* Sirodot nom. illeg.) and *Lemanea mamillosa* (Sirodot) De Toni are found only in eutrophic rivers and creeks on the southern coast of Finland. Rott et al. (1999) classify *B. helminthosum* as ultra-oligotrophic.

Taxa indicating saprobity of waters

Fjerdingstad (1964, 1965) named some freshwater red algae as indicators to his saprobity zone classification. These are:

A) gamma-mesosaprobic zone: *Batrachospermum gelatinosum, Lemanea fluviatilis*;
B) oligosaprobic zone: *Batrachospermum turfosum, Hildenbrandia rivularis, Paralemanea annulata* (syn. *Lemanea annulata* Kützing);
C) katharobic zone: *Audouinella chalybea, Hildenbrandia rivularis.*

Backhaus (1968) grouped acid and soft water rivers in southwestern Germany and characterized them using microphytes. Red algae occurred only in one of six river types, i.e., katharobic, or oligosaprobic according to the classification of Liebmann (1962). These rivers were fast-flowing, clearwater creeks with low nutrient content and without organic loads. The red algal taxa living in these creeks were *Batrachospermum anatinum* Sirodot (syn. *B. ectocarpum* Sirodot) and *Audouinella hermannii* (syn. *A. violacea* (Kützing) Hammel).

According to Sládeček (1973), all listed red algae are xeno- to oligosaprobic, with *Batrachospermum turfosum* and *Hildenbrandia rivularis* having the lowest saprobic value (≤0.4). The other taxa recorded (*Audouinella chalybe, Bangia atropurpurea, Batrachospermum moniliforme, Lemanea annulata, L. fluviatilis, L. nodosa* Kützing (= *Paralemanea catenata* Kützing),

Table 1

Ecological classifications of some freshwater red algae in relation to trophic state and pH (Rott et al. 1999), saprobity (Sládeček 1973; Rott et al. 1997), water hardness (Israelson 1942) and ecological type of waters (Eloranta and Kwandrans 1996, 2002).

Species	Trophy, pH gr. Rott et al. (1999)		Saprobity		Ecology	
			Sládeček (1973)	Rott et al. (1997)	Israelson (1942)	Elor.&Kwandr. (1996, 2002)
Audouinella hermannii	me-eu	ind.	-	2.7	-	olig.-eu.
A. chalybea	-	-	ol	2.4	-	-
A. pygmaea	me	alkf	-	1.5	hard water	olig.
Balbiania investiens	olig.	ind.	-	1.1	-	-
Bangia atropurpurea	me-eu	alkf	ol	2.0	-	eu
Batrachospermum anatinum	ul-ol	alkf	-	-	hard water	soft, brown
B. arcuatum	olig.	alkf	-	1.3	-	-
B. atrum	olig.	alkf	ol	1.4	hard water	hard water
B. boryanum	ul-ol	alkf	-	1.4	hard water	olig.
B. gelatinosum	eu	alkf	x-bm	1.8	-	hard w., eu
B. helminthosum	ul-ol	ind.	-	1.2	hard water	soft, brown
B. skujae	ul-ol	alkf	-	-	-	soft water
B. turfosum	ul-ol	acid	x-ol	1.4	soft water	
Compsopogon coeruleus	-	-	-	-	-	-
Hildenbrandia rivularis	eu	alkf	x-ol	1.8	hard water	hard water
Lemanea borealis	-	-	-	-	-	small riv., olig.
L. condensata	-	-	-	-	alpine	Nordic alpine
L. fluviatilis	olig.	circ.	ol	1.6	-	larger open riv.
L. fucina	eu	circ.	-	1.4	-	olig.
L. mamillosa	-	-	-	1.5	-	eu
L. rigida	-	-	-	-	-	olig.
Paralemanea annulata	olig.	acf	x-ol	1.5	-	-
P. catenata	olig.	acf	-	1.3	-	-
Sirodotia suecica	-	-	-	-	soft	soft, olig.
S. tenuissima	-	-	-	-	-	soft, olig.
Thorea hispida	eu	ind.	ol	-	-	-
Tuomeya americana	-	-	-	-	-	soft, olig.

L. torulosa Kützing and *Thorea ramosissima* Bory) have saprobic values ranging from 0.5 to 1.15, with their main occurrence in oligosaprobic environments. They are also in beta-mesosaprobic waters; *Audouinella chalybea* is tolerant of alfa-mesosaprobity.

Rott et al. (1997) provides the saprobity classification for 24 red algal taxa. They listed four taxa as saprophobic (saprobic value S <1.3) - *Balbiania investiens* (Lenorm.) Sirodot, *Batrachospermum helminthosum, Chroothece richteriana* Hansgirg and *Lemanea catenata* (= *Paralemanea c.). Audouinella hermannii* (incl. synonym *A. violacea*) and *A. chalybea* were classified as saprophilous (S = 2.2 – 2.5). All the others were slightly or moderately tolerant (S = 1.4 – 2.1) of organic load.

CONCLUSIONS

Evaluating the ecological preferences of many freshwater red algal taxa is difficult due to the low number of records, especially those with good ecological background data. The older ecological literature contains little information concerning freshwater red algae. The most common taxa are the most adaptable to a range of ecological conditions. These include *Batrachospermum gelatinosum* (*B. moniliforme*), *B. turfosum* (*B. vagum*), *Lemanea annulata, L. fluviatilis* and *Hildenbrandia rivularis*. *L. annulata* belongs to the subgenus *Paralemanea*, which does not occur in Nordic countries. This is in contrast with the genus *Sirodotia*, which is rather common, although it is absent from Central Europe. Sometimes *B. gelatinosum* (*B. moniliforme*) and *Lemanea fluviatilis* are used without proper taxonomical identification as 'general names' for all *Batrachsopermum* spp. and *Lemanea* spp.

Generally, freshwater red algae indicate "good water quality", which means waters without heavier loads from human activities. General ecological factors (light, current, space, ice erosion) have a strong impact on the occurrence of the group and also on individual species. Most taxa, however, have a rather wide tolerance of physical and chemical variables. Thus, the range of ecological values reported in papers regarding different geographical areas refers mainly to the characteristics of water in the studied area. Most of the taxa recorded in the Finnish material occurred almost throughout the range of the measured variables (pH 5.6 – 7.5, current velocity, water color 10 – 320 mg l^{-1} Pt, conductivity 2.5 – 5.7 mS m^{-1}, total P 5 – 60 µg l^{-1} and COD 5 – 38 mg l^{-1}) (Eloranta and Kwandrans 1996). Although red algae occur in Finnish waters often without clear preferences for water quality, these waters are generally soft, slightly acid, brown and have a low nutrient concentration. On the other hand, the frequency of occurrence of red algae is rather low, and there are many rare taxa. Red algae have been found in only approximately 40-50% of the river sections and most often with only one taxon in each. Although several rhodophyte taxa are characteristic for some types of water, they are not as good

indicators of water quality as, for example, diatoms which occur in running waters practically everywhere and continuously.

Red algae have a complex, long life cycle (e.g., Lee 1980; van den Hoek et al. 1995). Therefore, they need a hydrologically stable environment (e.g., places without seasonal drying). They are also weak competitors for space, so they are either sparse or absent from rivers with strong growths of aquatic mosses. Among the genera in the temperate zone, *Lemanea* is known to favor, or at least tolerate, strong light (Kremer 1983). However, many *Lemanea* spp. grow in Finland in brown water rivers or in places with a tree canopy (Eloranta and Kwandrans 1996). Some genera are epiphytic with a connection to particular host species (e.g., Starmach 1977). *Audouinella* spp. often grows on *Lemanea thallus*, mosses or man-made substrata. *Balbiania* grows on *Batrachospermum* thalli (Starmach 1977), and *Sirodotia* can also grow on stones as well as on *Batrachospermum* thalli (Eloranta and Kwandrans 2002).

Few of the recent studies of freshwater red algae include reasonable ecological background information. More studies are needed to understand and explain the occurrence and disappearance of red algae in rivers and the status of any threatened species among this group.

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