Are the freshwater rhodophytes useful bioindicators for peat mining loads?

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Abstract

During the intensive study of freshwater rhodophytes in the years 2012–2015 ca. 2100 rivers and brooks were studied including 28 river segments in drainage areas with peat mining. In August–September 2015 sampling at 159 river segments was done focusing especially to the peat mining areas. The aim was to study possible effects on occurrence and community structure of rhodophytes in the vicinity of mining areas and downstream in the drainage area. Rhodophytes occurred at 27% of studied locations at the distance of < 1 km from the mining outlet. Occurrence frequency increased evenly with the increasing distance and was 52% at the distance of > 5 km below the mining area, which corresponds the frequency in the areas without peat mining. Several ecological factors may explain the decrease of the occurrence frequency. Brook widths are smaller with lower current velocity and bottom is often organic, without suitable substrata to attach for rhodophytes. *Batrachospermum gelatinosum* was the most common taxon below the peat mining areas with 64.9% of records. Other taxa found at the distance of < 5 km were *Batrachospermum vogesiacum* and *B. keratophytum*. More far were found also *Audouinella chalybea, A. hermannii, Batrachospermum turfosum, Lemanea fluviatilis, L. fucina, Sheathia arcuata, S. confusa* and *Sirodotia suecica.*
Rhodophytes are not very suitable as indicators for peat mining effects due to low diversity and unfavourable ecological conditions for rhodophytes in peatland brooks.
Key words: freshwater Rhodophyta, peat mining, Finland

Introduction

Peatlands cover ca. 29% from Finland's land area (ca. 9.29 mill. ha) from which 65 000 ha are used for fuel peat mining in ca. 550 areas (Väyrynen et al. 2008, The Ministry of the Environment 2013). The areas of peat industry are concentrated to North Finland and to watershed areas. Nowadays there are ca.110 of peat mining areas in Central Finland, mainly concentrated to the NW part of the county. The problems caused by peat mining are related to changes in hydrology, load of nutrients and especially to load of suspended organic matter, which the waters of downpour and snow melting flush downstream from the mining areas (Sallantaus 1984, The Ministry of the Environment 2013). The effects are seen in changes in bottom sediments due to sedimentation of suspended organic material (Fig. 1), changes in organism communities (e.g. moss flora, zoobenthos, fish fauna) and water quality (TOC, COD, turbidity, nutrients).
From the primary producers aquatic mosses and diatoms have been studied in humic waters (Eloranta 1994, Muotka & Virtanen 1995), but there are not any studies on macroalgae in those habitats. Macroinvertebrates in humic streams are studied more often (e.g. Malmqvist & Mäki 1994, Vuori & Muotka 1999, Wallace & Eggert 2009). The red algae are growing on all solid substrata, rocks, stones, underwater wood and mosses (Eloranta et al. 2016). Particular organic substances released from the peat mining areas cover the solid substrata, necessary for the attachment of red algae. In the waters downstream mining areas, red algae are covered by humic particles. These suffocate thalli and cause the disappearance of algae.

The aim of the project was to study in chosen watercourses, which species (taxa) and how close to the mining areas red algae occur by going downstream until the regular occurrence. As the 'control' were small river segments located in the same areas, but without connections to the peat mining.

Material and methods

A total of 192 river segments were investigated in the western part of the county of Central Finland below 20 peat mining areas with various size and age during the years 2012–2015. The study was a subproject of the intensive study of freshwater rhodophytes, in which ca. 2100 rivers and brooks were studied. The main part of material (159 study areas) was collected in August-September 2015. Control material was 46 river segments from the same river systems but without connections with the peat mining. That material from the unimpacted sites was collected simultaneously with the material below the mining areas.
Sampling was done choosing potential growth places (places with visible current and some solid substrata) in brooks close to outlets from mining areas and then additional places downstream until larger river or lakes. Self-made viewer fitted with diver's led-pulp lamp and large pipette (ø 30 mm, length 30 cm) were used in sampling and samples were preserved in 2.5% glutaraldehyde. In the field, several habitat variables were measured (multimeter WTW Multi 3420 Set C) and recorded: water temperature, pH, conductivity, current velocity (0 = standing water, 1 = < 0.2 m s^{-1}, 2 = 0.2–0.5 m s^{-1}, 3 = 0.5–1 m s^{-1} and 4 = > 1 m s^{-1} and channel width (0 = < 1 m, 1 = 1–3 m, 2 = 3–10 m and 3 = > 10 m). Water colour (0 = clear, 1 = brownish, 2 = brown, 3 = dark brown) and turbidity (value classes 0–2: 0 = clear, 1 = slightly turbid, 2 = very turbid) were visually estimated. Abundance of the rhodophytes in the investigated river segments was estimated in the scale 0–3 (0 = absent, 1 = 1–3 thalli, 2 = several thalli but coverage < 50%, 3 = rich with thalli and coverage > 50%).
In the laboratory, samples were cleaned and pre-identified in BMS stereomicroscope and the final identification and documentation was conducted using an Olympus BX50 microscope fitted with Nikon Digital Sight DS-U1 camera.
Distance of sampling areas from the outlet of peat mining was measured using free and public website Finnish Geoportal Paikkatietoikkuna (http://www.paikkatietoikkuna.fi/web/fi/kartta).

Fig. 1. 1. Typical peat mining area, 2. draining ditches, 3. particular peat material deposits in outflow stream, 4. typical outflow brook (photo 1 - A. Isomäki, 2–4 - Centre for Economic Development, Transport and the Environment of Central Finland).

Results

The peat mining areas are typically in the headwater areas. The average width and current velocity of channels became bigger with the increase of drainage area in the lower reaches. However, the markedly narrower in the nearest category when compared with the unimpacted rivers, but the difference was not significant in the whole material (Table 1). The average current velocity was significantly lower and water colour significantly higher in the impacted rivers when compared with those in the unimpacted ones (Table 1).

Table 1. Average and standard deviation values of some brook/ river characteristics measured and recorded at sampling stations with different distance from the peat mining areas.

Distance (km)	N	Brook/ river width (0–3)	Current (0–4)	Colour (0–3)	Turbidity (0–2)	Temper. (°C)	Conduct. (µS cm^{-1})	pH
< 1	25	0.69 ± 0.40	1.19 ± 0.55	1.62 ± 0.58	0.81 ± 0.41	11.6 ± 2.2	58.4 ± 24.5	6.50 ± 0.39
1–2	20	1.00 ± 0.54	1.36 ± 0.41	2.08 ± 0.63	0.53 ± 0.39	11.3 ± 2.5	39.6 ± 14.3	6.33 ± 0.59
2–3	14	1.13 ± 0.50	1.57 ± 0.47	1.87 ± 0.62	0.67 ± 0.32	12.2 ± 3.3	40.3 ± 16.9	6.23 ± 0.40
3–5	21	1.25 ± 0.41	1.64 ± 0.57	1.92 ± 0.47	0.58 ± 0.44	12.1 ± 1.8	37.3 ± 14.2	6.29 ± 0.52
>5	33	1.60 ± 0.62	1.82 ± 0.48	1.87 ± 0.42	0.37 ± 0.34	12.4 ± 2.9	31.8 ± 12.3	6.12 ± 0.40
Impacted	113	1.17 ± 0.60	1.53 ± 0.54	1.87 ± 0.54	0.57 ± 0.40	12.0 ± 2.6	40.8 ± 18.7	6.28 ± 0.46
Unimpacted	46	1.30 ± 0.78	1.73 ± 0.55	1.24 ± 0.71	0.56 ± 0.48	14.5 ± 4.2	30.9 ± 12.0	6.25 ± 0.41
Difference	t-value	1.16 n.s.	2.49 p > 0.02	-4.36 p > 0.001	-1.03 n.s.	3.07 p > 0.01	-4.68 p > 0.001	-1.05 n.s.

The soil and peat quality vary between mining areas, making irregular variation also in the studied waters. However, maximum turbidity was recorded in the closest river segments in the water outlets. The study period in Autumn 2015 was dry without rainy days, which explains rather even and low turbidity values in all sampling spots. Difference ranges of water temperature, conductivity and the water pH are not significant for the occurrence of rhodophytes.

Red algae was found in 81 locations (50.9%). The occurrence frequency of red algae increased from 27% at the distance < 1 km downstream from the mining area (Fig. 3). At the distance over 5 km the ocurrence frequency reached typical value (ca. 50%) for the region without influences of peat mining. In some streams with rocky bottom and good growth of rhodophytes, thalli was seen covered by particular humic matter from upstream mining area at 2 km distance (Fig. 2).

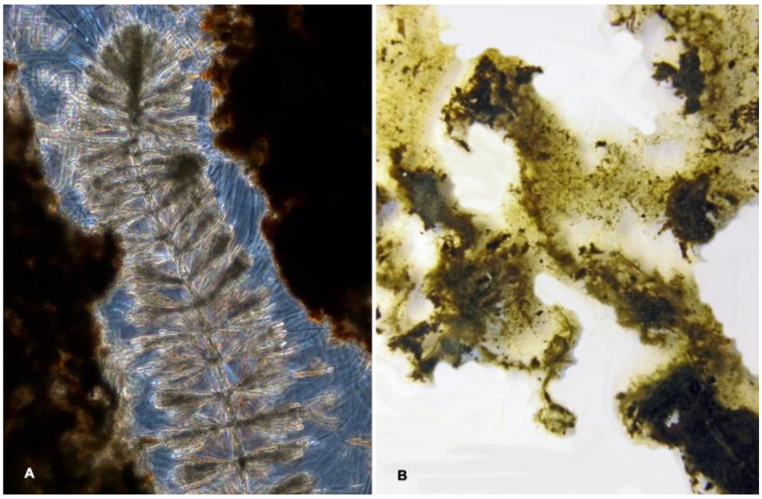

Fig. 2. A. *Batrachospermum* thallus between peat material, B. Dead thalli mixed with colloid and particular humic material.

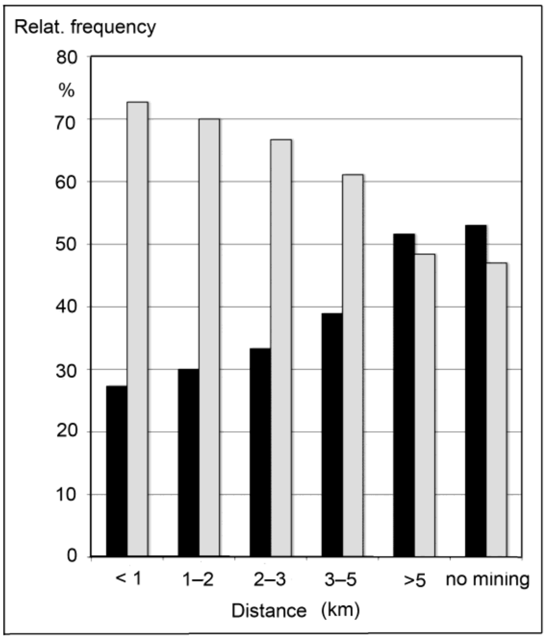

Fig. 3. The relative frequencies of river segments with and without red algae in the different investigated distance groups.

A total of 12 taxa were observed (Table 2), but the highest diversity was at the distance > 5 km from peat mining areas and in the unimpacted rivers in the same region. The most common taxon was *Batrachospermum gelatinosum* (64.9% of records), which is the most common freshwater red alga in the whole Finland. The number of taxa in locations < 5 km from peat mining outlets was 1–4, but higher (7–9), when influence of peat mining waters decreased along increasing distance and also the water current came more favourable for rhodophytes.

Table 2. Occurrence of different red algal taxa in the different investigated distance groups.

Taxon	N	%	>1 km	1–2 km	2–3 km	3–5 km	> 5 km	Unim-pacted
Audouinella chalybea	1	1.4				1		
A. hermannii	2	2.7					1	1
Batrachospermum gelatinosum	48	64.9	5	5	4	4	12	18
B. keratophytum	2	2.7			1	1		2
B. turfosum	2	2.7						1
B. vogesiacum	5	6.8		1		2	1	1
Sheathia arcuata	4	5.4						4
S. confusa	3	4.1					2	1
Lemanea fluviatilis	1	1.4					1	
L. fucina	3	4.1						3
Sirodotia suecica	5	6.8					1	4
unidentified remains	5	6.8					1	4
Number of taxa			1	2	2	4	7	9
Average abund. (0–3)			1.50	1.25	1.30	1.07	1.66	1.89

Batrachospermum keratophytum, *B. turfosum* and *B. vogesiacum* were found in the smallest brooks, slowest current velocities and lowest pH (Table 3), whereas *Audouinella* spp., *Lemanea* spp., *Sheathia* spp. and *Sirodotia suecica* were found in rivers with higher current velocity and wider channel width. *Batrachospermum gelatinosum* has very wide ecological tolerance to many environmental factors and did not show any preference for measured river characters.

The algae grew on stones or gravel (89.8%), only in few cases on submerged wood (3.6%) or metal (3.6%) and especially *Audouinella* spp. and *Sirodotia suecica* also on water mosses (2.9%). The average abundance of red algae in records from unimpacted river segments was 1.89 ± 0.81 (n = 30) and in records from the impacted areas 1.44 ± 0.58 (n = 40). The difference is significant at P > 0.01 level (t = 3.20, df = 59).

Table 3. The average values of characteristics in river segments where different taxa were recorded.

Taxon	N	Brook/ stream width (0–3)	Current (0–4)	Colour (0–3)	Turbidity (0–2)	Temper. (°C)	Conduct. ($\mu S\ cm^{-1}$)	pH
Audouinella chalybea	1	2.50	2.45	1.27	0.50	14.8	34.5	6.2
A. hermannii	2	2.43	2.50	1.29	0.43	14.5	37.1	6.2
Batrachospermum gelatinosum	48	1.48	1.79	1.40	0.52	13.5	38.6	6.3

B. keratophytum	2	1.38	1.88	1.75	0.63	12.1	35.7	6.2
B. turfosum	2	1.00	1.50	1.50	1.00	13.9	30.0	6.1
B. vogesiacum	5	1.20	1.80	1.60	0.40	11.5	29.4	6.1
Sheathia arcuata	4	1.43	2.07	1.36	0.64	12.4	28.6	6.3
S. confusa	3	1.43	2.12	1.75	0.25	12.1	45.7	6.4
Lemanea fluviatilis	1	2.33	2.42	1.66	0.75	15.7	40.6	6.3
L. fucina	3	2.83	2.33	1.00	0.67	18.7	31.7	6.2
Sirodotia suecica	5	2.21	2.04	1.54	0.67	16.2	29.8	5.9

Discussion

The structure of the riverine benthic algal communities depends on many geographical, climatical, physical, chemical and biological factors. Some algae are typically epiphytic, epipelic or epilithic and occur on those substrata (e.g. Round 1964). Diatoms, green algae and cyanobacteria are found in many substrata, but the most freshwater red algae occur on solid substrata like on stones, rocks, gravel or on submerged wood (Eloranta et al. 2016). The same situation was in this study, too. This type of substrata are found in moderate water current. Many red algal taxa occur in a wide range of current velocity (Sheath & Hambrook 1990, Eloranta & Kwandrans 1996). However, current velocity in smaller brooks may vary and change in rather short intervals e.g. after downpours. According to Sheath & Hambrook (1990) the range of mean current velocities at which red algae occur is 29–57 cm s^{-1}. This reduces weakly attached competitors (Whitton 1975) and sedimentation of particular matter on the substrata. This current velocity equals with the current velocity class 2 in this study, but in the study areas, especially near the peat mining areas current velocity is markedly lower.

Peat mining areas locate typically in watershed areas. Draining brooks and small streams are narrow with slow current and typically with organic bottom. Water is humic with acid pH, brown colour, low conductivity and in the most cases poor with nutrients (e.g. Kortelainen 1999). Intensive draining action by peat mining changes drastically hydrology of outflowing brooks and rivers (Sallantaus 1984, Seuna in Mustonen 1986) causing short term high runoff peaks. During those flood peaks large amounts of dissolved and suspended particular organic matter flushes downstream (Sallantaus 1984) and gradually sedimentates. This loose, organic layer makes attachment on substratum unavailable for macroalgae like rhodophytes and for mosses. According to the river continuum concept the ratio production/respiration (decomposition) is < 1 in the river headwaters due to low amount of primary producers. The main energy source for consumers is particular organic matter (Vannote et al. 1980). In humic streams diatoms often play the major role of primary production with aquatic mosses (Vuori & Muotka 1999).

During the summer months in 2015 peat mining activity was low due to rainy weather, which also reduced load of particular organic matter. However, water colour and turbidity values were higher than in those areas without peat mining. Frequency and diversity of rhodophytes were clearly lower close to the mining areas and reached typical values of this type of waters at the distance of 5 km. This can be explained with lack of suitable substrata, like stones and gravel or submerged wood material, but also with the low current velocity in flat watershed areas. The most common taxon *Batrachospermum gelatinosum* occurs in very wide range of ecological measures. According to the large-scale Finnish study of rhodophytes *B. gelatinosum* occurred in water pH 3.6–7.8 and conductivity 16–690 µS cm^{-1} (Eloranta et al. 2016). The other three taxa found in brooks closer to peat mining areas *Batrachospermum*

keratophytum, *B. turfosum* and *B. vogesiacum* are known to favour soft, acid and humic waters (e.g. Kylin 1912, Israelson 1942, Compere 1991, Eloranta & Kwandrans 1996, 2002, Knappe & Huth 2014, SLU-Artdatabanken 2015, Eloranta et al. 2016). The rhodophyte diversity increased with the increasing drainage area, stream size and current velocity, which also supported more suitable habitats for rhodophytes.
The aim of this research was to study the usefulness of rhodophytes as bioindicators of effects by peat mining industry. In the flat headwater areas most streams are naturally typified with organic bottom, slow current and narrow channels. Therefore, it is difficult to explain the scarsity and low diversity of rhodophytes by the effects of peat mining. However, the loads of particular matter prevents attaching of possible propagulas and new growth.
In the future the studies should be done simultaneously when some new area is taken under mining and in the preinvestigated outlet rivers segments, which are known to have rhodophytes.

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