Taxonomy and distribution of *Lemanea* and *Paralemanea* (*Lemaneaceae*, *Rhodophyta*) in the Czech Republic

Taxonomie a rozšíření ruduch rodů *Lemanea* a *Paralemanea* (*Lemaneaceae*, *Rhodophyta*) v České republice

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Traditionally, all freshwater representatives of red algae with uniaxial cartilagineous and pseudoparenchymatous thalli were placed in the genus *Lemanea*. Two subgenera of this genus were distinguished, *Lemanea* and *Paralemanea*. The recently proposed elevation of these subgenera to genera is fully justified and generally accepted. However, the increasing data from natural populations of *Lemanea* shows that not all the traditional diacritical features are reliable for distinguishing species. This paper presents the results of a research project on the morphological variability of *Lemanea* in the Czech Republic. Of the four species *Lemanea fluviatilis* and *L. torulosa* appear to be well-defined but there are no clear differences between *Paralemanea annulata* and *P. catenata*. A survey of taxa and key to species are presented.

K e y w o r d s : Czech Republic, distribution, freshwater algae, *Lemanea*, *Lemaneaceae*, *Paralemanea*, *Rhodophyta*, taxonomy

Introduction

The freshwater red algae of the family *Lemaneaceae* are characterized by an uniaxial cartilagineous and pseudoparenchymatous gametophyte thallus with internal carposporophytes (Vis & Sheath 1992). Certain authors raised the traditionally distinguished subgenera (*Lemanea* and *Paralemanea*) of the genus *Lemanea* to genera. These genera can be separated on the basis of the following characters (Vis & Sheath 1992, Sheath et al. 1996): *Paralemanea* includes plants that lack stalks and hair cells in the inner cortex. Axial filaments are surrounded by cortical filaments. Simple ray cells consist of two layers, the proximal one does not touch the outer cortex and the distal one is generally "Y" branched and connected to the cortex. Nodal spermatangial sori are arranged in rings. *Lemanea* have axial but not cortical filaments, hair cells in the inner cortex and T- or L-shaped ray cells, which are closely applied to the outer cortex. Nodal spermatangial sori are arranged in patches.

The most comprehensive taxonomic treatment of the *Lemaneaceae* worldwide, with detailed morphological descriptions of seven species of *Lemanea* and *Paralemanea*, was provided by Atkinson (1890). The recent taxonomic concept of the family is based on both morphological and ultrastructural characters (Vis & Sheath 1992, Blum 1994, Necchi & Zucchi 1995, Sheath et al. 1996, Carmona & Necchi 2002, Eloranta & Kwandrans 2002). However, identification of the species is difficult (Vis & Sheath 1992). The morphological variability and its subjective evaluation does not allow a clear delimitation of the species.

Thus, for delimiting species of *Lemaneaceae* both the morphology of vegetative and reproductive features and ultrastructural and molecular information is required (Carmona & Necchi 2002).

Five species of *Lemaneaceae* are reported from the Czech Republic: *Lemanea fluviatilis* (Linnaeus) C. Agardh 1824 is the most frequent species. *Lemanea torulosa* (Roth) Agardh 1814 is nowadays known from only one locality in the western part of the Czech Republic (Lederer et al. 2001), *Lemanea sudetica* Kützing 1843 was reported in the past from the Hrubý Jeseník Mts but not recently, *Paralemanea annulata* (Kützing) Vis et Sheath 1992 (Bas.: *Lemanea annulata* Kützing 1845) and *Paralemanea catenata* (Kützing) Vis et Sheath 1992 (Bas.: *Lemanea catenata* Kützing 1843; Syn.: *Lemanea nodosa* Kützing 1843) grow at a few localities around the country. Unfortunately, information on the morphological and reproductive characters of *Lemanea* populations and their habitats is very scarce. This paper brings together taxonomic data from several studies on *Lemanea* with the objective of strengthening the traditional diacritical features for distinguishing various species.

Material and methods

Altogether 18 localities for *Lemaneaceae* were found during 2002–2003 (Table 1). All samples were collected from running water with turbulent flow (weirs and riffles). The samples were preserved in 4% formaldehyde. The following environmental factors were measured at each site: temperature and pH (measured by WTW ph/cond.340i), flow velocity (measured by Flo-Mate, Marsh & McBirney, USA), depth (cm scale) and type of substratum, according to Wright et al. (1984).

In the laboratory we recorded the following morphological characters (Table 2): presence and incidence of branched plants, presence of a stalk, plant length, nodal diameter (ND), internodal diameter (ID), presence of axial cortical filaments, arrangement of spermatangial sori, length and diameter of carpospores (Vis & Sheath 1992, Necchi & Zucchi 1995, Carmona & Necchi 2002). These characters were documented photographically using BX 50 Olympus microscope equipped with Lucia Image Analysis.

Morphological analyses

Results of the morphological analyses of populations are reported in Table 2. The following red algae of the family *Lemaneaceae* occur in the Czech Republic (Fig. 1):

Genus *Lemanea* Bory de St.Vincent 1808

Structure consists of a central axis with or without cortical filaments and T- or L-shaped ray cells closely applied to the outer cortex. Thalli stalked (with definite constriction), some of them branched (15–58 %). The lengths of plants measured from 2.4 to 11.6 cm.

Typus generis: *Lemanea fucina* Bory 1808

Table 1. – Geographical characteristics of localities. The latitude and longitude were obtained using GeoBáze software. New localities (previously not reported) are marked with an asterisk. *L* = *Lemanea*, *P* = *Paralemanea*.

No.	Locality	Species	River	Latitude	Longitude	Altitude (m)
1	Čepinec	*P. catenata*	Bradlava	49°28'09"	13°29'15"	462
2	Mlynářovice	*P. catenata*	Bradlava	49°25'43"	13°27'48"	497
3	Hvížďalka	*P. catenata*	Bradava	49°36'47"	13°37'04"	427
4	Žákava	*L. torulosa*	Bradava	49°38'06"	13°31'29"	360
5	Stříbro	*L. fluviatilis*	Mže	49°44'59"	12°59'48"	360
6	Radčice	*P. catenata*	Mže	49°45'37"	13°19'47"	309
7	Plzeň–Kalikovský mlýn*	*L. fluviatilis*	Mže	49°45'02"	13°21'53"	305
8	Vranov nad Dyjí	*P. annulata*	Dyje	48°53'37"	15°48'48"	319
9	Devět Mlýnů	*P. annulata*	Dyje	48°49'01"	15°58'55"	248
10	Znojmo	*P. annulata*	Dyje	48°51'12"	16°02'36"	214
11	Valšov*	*L. fluviatilis*	Moravice	49°55'25"	17°27'03"	504
12	Annín*	*L. fluviatilis*	Hučivá Desná	50°06'52"	17°06'30"	656
13	Karlova Studánka*	*L. fluviatilis*	Bílá Opava	50°04'38"	17°17'12"	888
14	Kozlov	*L. fluviatilis*	Otava	49°17'54"	13°45'04"	411
15	Čepice	*L. fluviatilis*	Otava	49°16'02"	13°35'55"	447
16	Čeňkova pila	*L. fluviatilis*	Otava	49°06'30"	13°29'33"	644
17	Žichovice*	*L. fluviatilis*	Otava	49°16'24"	13°37'05"	443
18	Železná ruda*	*L. fluviatilis*	Řezná	49°08'07"	13°13'27"	744

Lemanea fluviatilis (Linnaeus) C. Agardh 1824

B a s . : *Conferva fluviatilis* Linnaeus 1753
S y n . : *Sacheria fluviatilis* (Linnaeus) Sirodot 1872

Plants branched (but less than 40% of the population), spermatangial sori arranged in patches (Fig. 2). It is reported to prefer non-calcareous substrates (according to Starmach 1977). Recently found at 10 localities around the Czech Republic.

Lemanea torulosa (Roth) C. Agardh 1814

B a s . : *Conferva torulosa* Roth 1797

Plants frequently branched (58% in this study), the nodal diameter less (mean = 365 μm) than that of *L. fluviatilis*, spermatangial sori arranged in patches and constricted rings, central axis with (Starmach 1977) or without cortical filaments (Fig. 3).

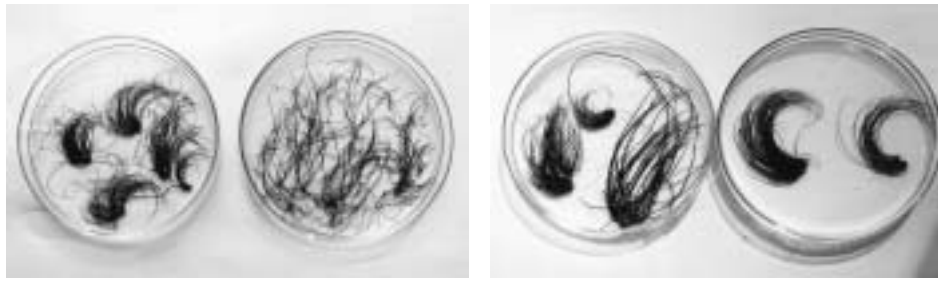
In contrast to *Paralemanea*, *L. torulosa* occurs with simple cortical filaments not arranged in fascicles (Starmach 1977, our observations). Because of the additional diacritical features, i.e. the presence of a branching and basal stalk, this species belongs to *Lemanea*. Therefore we have placed it in this genus.

Lemanea sudetica Kützing 1843 is the third species of *Lemanea* in the Czech Republic. Hansgirg (1886) found it in the Hrubý Jeseník Mts and the Krkonoše Mts in Poland. It differs from *L. fluviatilis* in irregularly distributed spermatangial sori and by having 2–9 cm long and ca 1 mm wide thalli. There are no recent findings of this species. The species seems to be dubious as a similar irregular sori distribution was observed for a plant from a *L. fluviatilis* population.

A further species of *Lemanea*, *L. fucina* Bory 1808 [syn.: *Lemanea mamillosa* (Sirodot) De Toni 1897] has not yet been reported in the Czech Republic but collected in

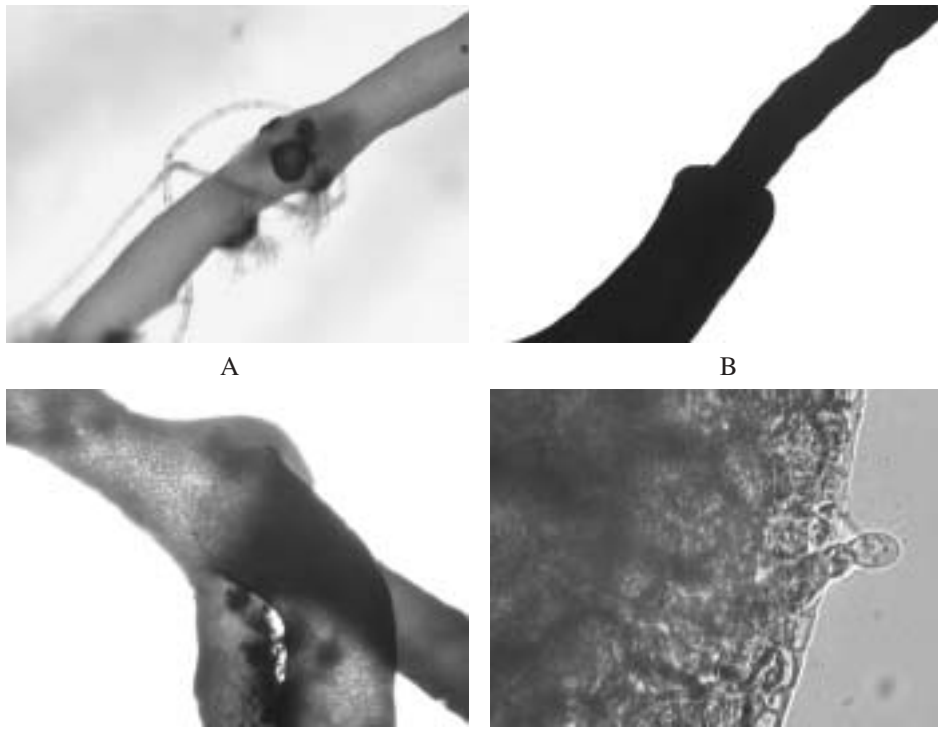
Table 2. – Characteristics of populations of *Lemaneaceae* from the Czech Republic. N – number of plants examined. Numbering of the localities correspond to those cited in Table 1.

Locality number	N	Branched plants (%)	Plant length (cm)		Nodal Diameter (μm)		Internodal Diameter (μm)		Axial cortical filaments	Spermatangial sori arrangement	Carpospores			
											Length		Diameter	
			Range	Mean ±S.D.	Range	Mean ±S.D.	Range	Mean ±S.D.			Range	Mean ±S.D.	Range	Mean ±S.D.
1	24	0	3.5–13.5	10.1±1.2	355–890	754±91	221–750	580±102	yes	rings	25.2–44.8	32.8±6.5	10.5–27.6	18.5±2.1
2	45	0	2.8-12.6	9.7±1.8	487–915	785±110	260–621	415±84	yes	rings	24.0–41.6	35.1±3.7	12.5–25.2	19.9±3.5
3	52	0	5.3–13.1	11.5±0.7	650–1105	737±156	310–650	517±110	yes	rings	21.8–40.6	33.5±6.2	10.6–20.1	16.8±2.2
4	51	58	2.4–10.2	6.5±1.6	283–492	365±106	170–486	321±70	no	patches/rings	23.3–45.3	30.3±7.0	8.2–24.9	17.9±4.3
5	36	26	3.1–8.8	7.5±1.0	480–897	604±156	180–760	590±104	no	patches	19.6–46.2	32.2±6.2	8.5–21.8	16.4±2.0
6	21	0	2.1–13.5	10.2±1.3	516–1179	859±124	320–760	585±120	yes	rings	24.0–48.8	37.2±9.3	12.6–25.8	18.4±3.2
7	12	37	2.8–8.5	6.6±0.4	429–607	468±103	280–686	395±80	no	patches	20.1–42.6	35.0±4.4	8.4–21.8	16.0±3.1
8	20	0	4.2–8,6	7,1±0.8	362–871	697±100	311–731	520±91	yes	rings	24.2–42.8	34.7±5.5	9.5–24.3	19.4±3.7
9	42	0	3.5–9,1	7,3±0.6	390–725	520±158	350–790	421±52	yes	rings	22.8–51.2	36.9±7.6	16.2–26.9	22.1±1.5
10	32	0	2.9–9,5	8,1±1,1	411–779	658±80	251–705	486±80	yes	rings	20.6–52.5	39.4±4.3	17.4–25.0	20.1±2.1
11	36	25	3.5–9.8	8.4±1.0	318–794	615±154	210–760	443±50	no	patches	32.3–51.2	38.7±6.6	10.2–26.3	18.5±3.3
12	40	35	2.7–8.6	6.5±1.6	206–810	627±102	150–592	430±103	no	patches	26.1–44.5	32.0±7.5	7.6–21.9	18.5±2.0
13	25	10	3.5–10.4	8.8±1.1	287–560	471±94	201–421	350±46	no	patches	20.5–44.3	30.7±5.6	12.3–24.8	18.5±2.4
14	35	15	2.8–11.6	8.5±2.0	390–861	730±76	143–611	461±60	no	patches	24.9–51.1	37.4±9.2	15.0–26.7	21.3±2.1
15	25	20	4.3–9.9	8.1±0.5	400–852	711±103	150–520	318±108	no	patches	20.5–43.2	31.7±5.0	9.4–21.8	18.1±2.6
16	36	20	4.1–11.5	8.6±0.4	391–796	610±150	184–601	403±50	no	patches	21.3–39.1	30.4±6.9	10.1–26.0	21.5±2.2
17	26	15	3.9–10.4	7.7±0.5	420–735	571±130	206–598	384±45	no	patches	24.9–48.6	36.8±9.1	8.7–23.4	17.5±3.1
18	24	25	3.5–10.1	7.9±1.0	281–710	526±114	186–572	370±105	no	patches	21.1–49.0	35.5±4.2	7.6–22.9	17.8±3.5



A B C D

Fig. 1. – General view of *Lemaneaceae*: A. *Lemanea fluviatilis* (Stříbro); B. *Lemanea torulosa* (Žákava); C. *Paralemanea catenata* (Hvížďalka); D. *Paralemanea* "*annulata*" (Znojmo).



A B C D

Fig. 2. – Morphological features of *Lemanea fluviatilis* (locality Kozlov and Plzeň – Kalikovský mlýn): A. arrangement of spermatangial sori (scale bar 0.8 mm); B. stalk with definite constriction (scale bar 0.8 mm); C. branching (scale bar 0.6 mm); D. carpogon (scale bar 0.1 mm).

Austria (Rott et al. 1999) in Salzach bei Schwarzach, region Pongau. It resembles *L. fluviatilis*, but has very long (up to more than 20 cm) and freely branched thalli.

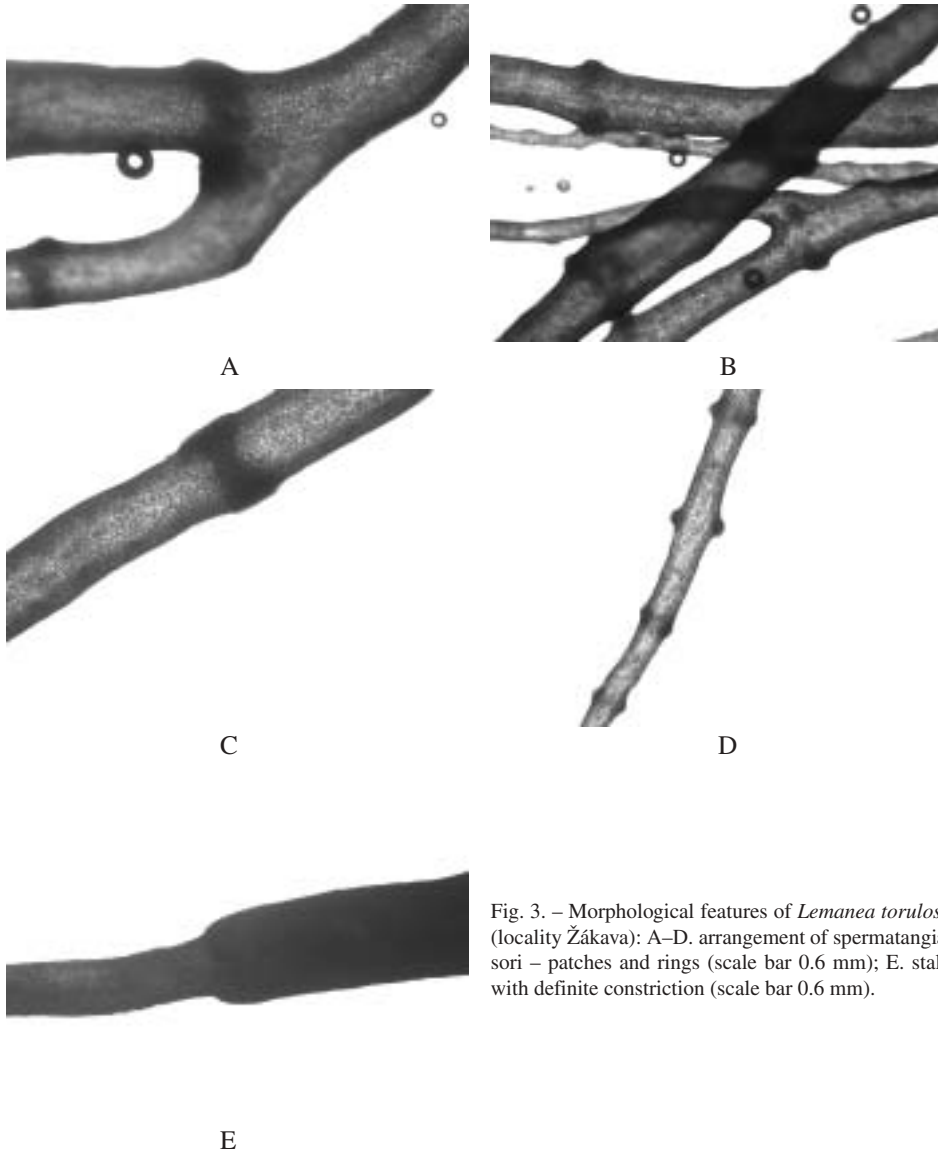


Fig. 3. – Morphological features of *Lemanea torulosa* (locality Žákava): A–D. arrangement of spermatangial sori – patches and rings (scale bar 0.6 mm); E. stalk with definite constriction (scale bar 0.6 mm).

Genus *Paralemanea* (P. C. Silva) Vis et Sheath 1992

The internal structure of thalli consists of a central axis with cortical filaments and simple ray cell not reaching the outer cortex. Thalli lacks stalks (without definite constriction). Spermatangial sori are arranged in rings on nodes. The lengths of plants ranged from 2.1 to 13.5 cm. The length and diameter of the carpospores did not differ from those of *Lemanea*.

Typus generis: *Lemanea catenata* Kützing 1843

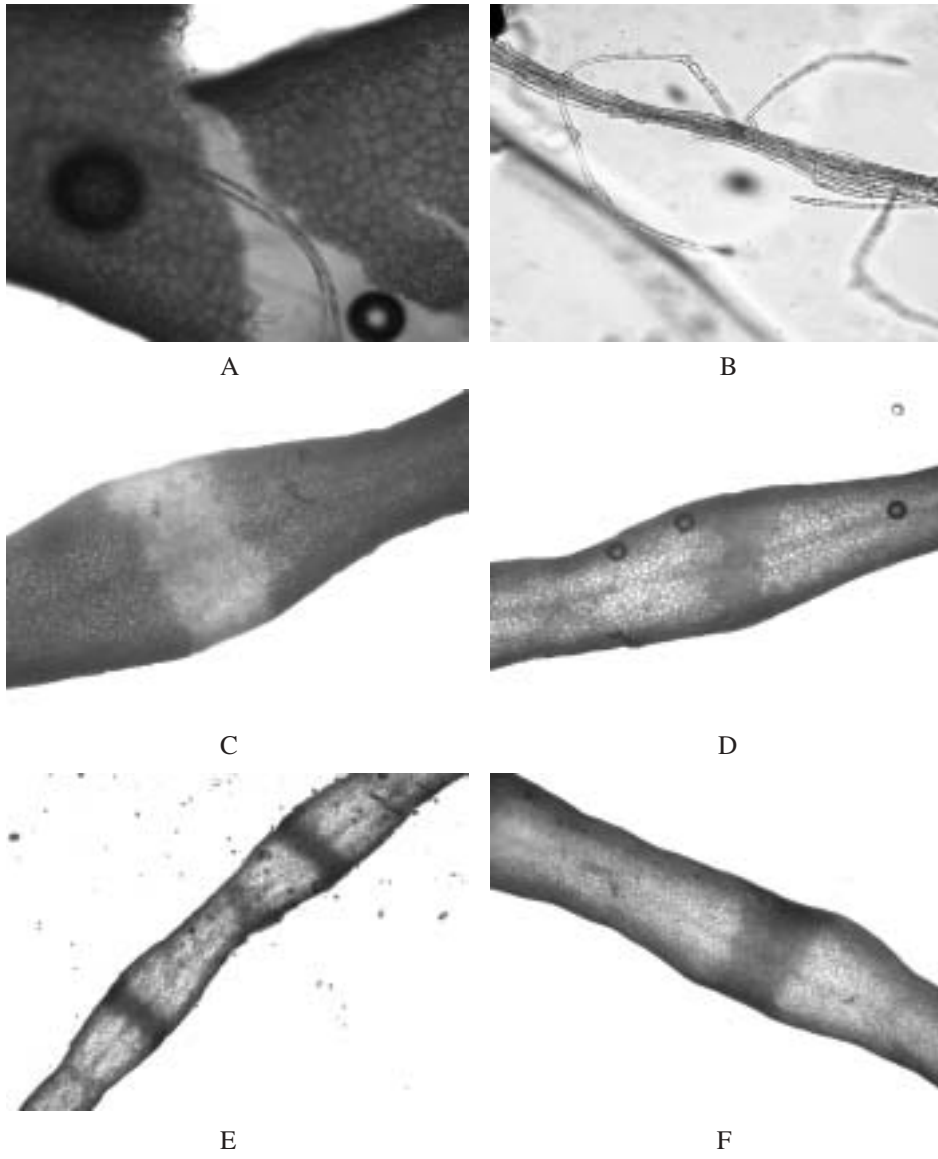
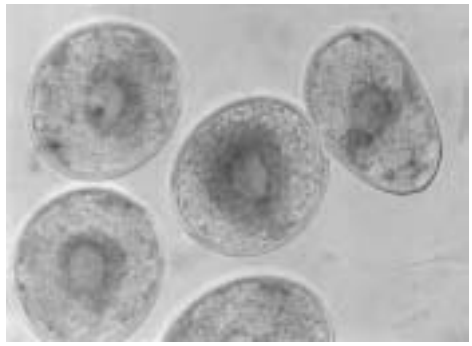


Fig. 4. – Morphological features of *Paralemanea catenata* (incl. *P.* "*annulata*"): *P. catenata* (A–E): A. cortical filaments in the middle of the thallus, locality Radčice (scale bar 0.3 mm); B. internal structure consisting of a central axis with cortical filaments and simple ray cells (scale bar 0.1 mm); C–F. nodal ring of spermatangia: C. locality Hvížďalka, D. locality Mlynářovice, E. locality Radčice (scale bars 0.6 mm). *P.* "*annulata*" (F): nodal ring of spermatangia, locality Znojmo (scale bar 0.6 mm).

Paralemanea catenata (Kützing) Vis et Sheath 1992

B a s . : *Lemanea catenata* Kützing 1843
S y n . : *Lemanea annulata* Kützing 1843; *Lemanea nodosa* Kützing 1843; *Lemanea pleocarpa* Atkinson 1931



A

B

C

Fig. 5. – *Paralemanea catenata*, locality Mlynářovice. A–C. detail of carpospores (scale bars 0.1 mm).

Differences between *Paralemanea annulata* and *P. catenata* recorded by Vis & Sheath (1992) for North American populations are not present in our material (Fig. 4, 5). The mean length of the thalli should be less than 6 cm for *P. annulata* and more than 8 cm for *P. catenata*. Plants from the Czech Republic, corresponding to *P. annulata*, measured 7.1–8.1 cm and those to *P. catenata* 10.1–11.1 cm. Plant length evidently depends on sample size, season and environmental conditions, especially flow velocity and illumination (P. Kučera & P. Marvan, unpublished data). None of the features mentioned by Starmach (1977), namely the arrangement of spermatangial sori, can be used for delimiting these species. The regularity of the ring varies with age and the magnification used (Lederer & Lhotský 2001). Plants of *P. annulata* have both types of ring. It was therefore assumed that they belong to *P. catenata*.

Distribution

The *Lemanea* and *Paralemanea* species are rare in the Czech Republic (Gardavský et al. 1995), as they are sensitive to levels of pollution. *Lemaneaceae* inhabit fast flowing and turbulent water. They can grow even in currents exceeding 5 $m \cdot s^{-1}$ (Israelson 1942). *Lemaneaceae* are common in Europe and North America, but uncommon in South America,

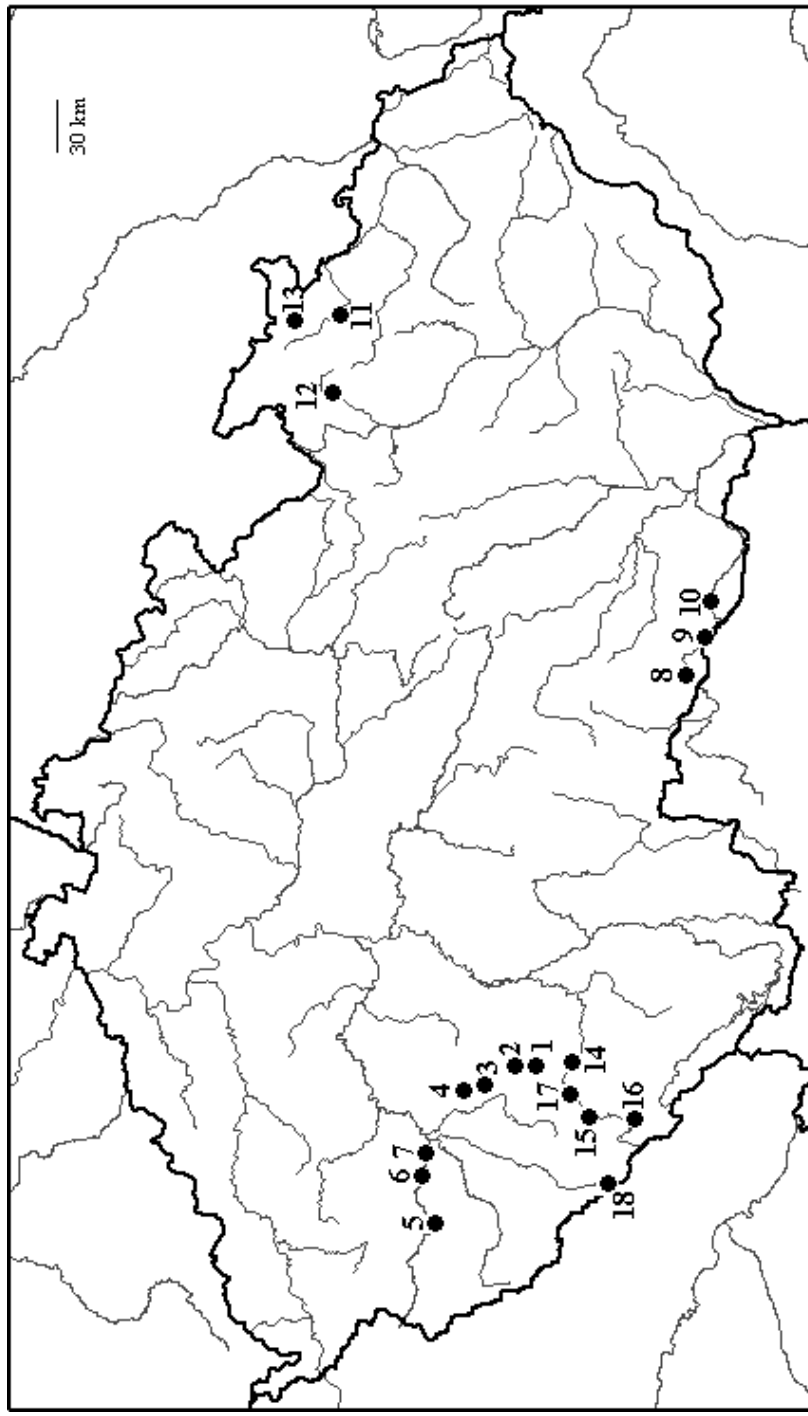


Fig. 6. – Map of the localities of *Lemaneaceae* in the Czech Republic. The numbers of the localities corresponds with that in Table 1.

with *L. fluviatilis* the most frequent species (Starmach 1977, Sheath & Hambrook 1990). Israelson (1942) made a detailed study of the altitudinal distribution of *Lemaneaceae* and only found *Lemanea condensata* above 1000 m. The genus *Lemanea* is also reported in mountainous regions in North America (Palmer 1941) and Europe (Starmach 1977, Rott et al. 1999).

First references to the occurrence of *Lemaneaceae* in the Czech Republic were published by Hansgirg (1886, 1892) and Lhotský & Rosa (1955). All four species recorded from the Czech Republic were found in unpolluted rivers in non-calcareous areas. The distribution of *Lemaneaceae* in the Czech Republic (18 localities investigated) is shown on the map in Fig. 6.

Lemanea fluviatilis is the most frequently found species in the Czech Republic. This species occurs in mountain rivers and streams (Kubečková 1997, Lederer & Soukupová 2002). In this investigation, it was found at altitudes ranging from 305 to 888 m, where the pH was 6.6–7.8, temperature 6.8–12.3 °C, and depth of the water 2–15 cm. The species was observed on stony substrates (boulders and cobbles) in riffles (localities Žichovice, Čepice, Čeňkova pila, Annín, Karlova Studánka, Železná ruda) or weirs (Kozlov, Valšov, Stříbro, Plzeň–Kalikovský mlýn), which were partly shaded or well illuminated. At certain localities, it was found growing with *P. catenata* (Stříbro, Plzeň–Kalikovský mlýn).

Lemanea torulosa was found recently only at one locality in the Czech Republic – Žákava, a stony weir shaded by trees at an altitude of 360 m in river Bradava (Lederer et al. 2001). The flow velocity was not higher than 0.3 $m \cdot s^{-1}$; pH 6.7–7.4; temperature 7–22 °C; depth 2–6 cm. In the past, this species was found in the Šumava Mountains (Gardavský et al. 1995).

The genus *Paralemanea* was found at localities at altitudes up to 497 m; pH 6.8–8.1; temperature 8–24 °C; depth 2–45 cm. At Vranov nad Dyjí and Devět mlýnů (river Dyje) the plants grow on stony weirs together with mosses and *Cladophora glomerata*. The community structure and the presence of *Paralemanea* are influenced by the flow of water from the Vranov dam (Kučera & Komárek 2004). Below the dam at Znojmo (river Dyje) it occurs on boulders in riffles. *Paralemanea* occurs in shaded (localities Čepinec, Mlynářovice, Hvížďalka) and well illuminated areas (Vranov nad Dyjí, Devět mlýnů, Znojmo).

All localities have the same characteristics as reported in the literature (e.g. Israelson 1942, Eloranta & Kwandrans 2002). The *Lemaneaceae* were found on stony substrates in running turbulent waters or on weirs. *L. fluviatilis* was found at a wide range of altitudes including lowland areas. Other species were found only in the lowlands or uplands (up to altitudes of 497 m).

A synoptic key of the *Lemaneaceae* in the Czech Republic

1a Plants stalked, branched or unbranched; central axis with or without cortical filaments; ray cells T- or L-shaped, closely applied to the outer cortex; spermatangia in patches or constricted rings on nodes ..... ***Lemanea* (2)**

1b Plants unstalked and unbranched; central axis with cortical filaments; ray cells simple, not abutting the outer cortex; spermatangia in rings on nodes ..... ***Paralemanea catenata***

2a Spermatangia in patches or in constricted rings on nodes; central axis with or without cortical filaments; high frequence of branching (> 40%) ..... ***Lemanea torulosa***

2b Spermatangia in patches on nodes; central axis without cortical filaments; frequence of branching is low (< 40%) ..... ***Lemanea fluviatilis***

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Souhrn

Tradiční systém ruduch (*Rhodophyta*) řadí všechny sladkovodní zástupce s monoaxiální pseudoparenchymatickou stélkou do rodu *Lemanea*. Odlišeny byly dva podrody: *Lemanea* a *Paralemanea*. V současnosti došlo k povýšení těchto podrodů na rodovou úroveň, což je zcela oprávněně uznáváno. Na druhou stranu získání dalších dat z přírodních populací *Lemanea* ukazuje, že ne všechny determinační znaky tradičně používané pro determinaci do druhové úrovně jsou správně používány pro rozlišení druhů. Tento článek přináší první výsledky výzkumného projektu, jehož úkolem bylo zjistit více informací o morfologické variabilitě rodu *Lemanea* v České republice. Ze čtyř pozorovaných druhů jsou *Lemanea fluviatilis* a *L. torulosa* dobře definovatelnými druhy. Rozdíly mezi *Paralemanea annulata* a *P. catenata* nebyly nalezeny. Přehled taxonů a determinační klíč jsou připojeny.

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