



Catalogue of Croatian Freshwater Rhodophytes

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Abstract

This paper summarises all available data on the flora of freshwater rhodophytes in Croatia, comprising 18 species from 13 genera—*Audouinella*, *Bangia*, *Batrachospermum*, *Chroodactylon*, *Compsopogon*, *Hildenbrandia*, *Lemanea*, *Paralemanea*, *Pneophyllum*, *Polysiphonia*, *Porphyridium*, *Sirodotia* and *Thorea*. Presented data are mostly a result of a comprehensive survey undertaken from 2009 to 2019 and including more than 600 freshwater locations—channels, streams, rivers, natural and artificial lakes. Additionally, all available published historical data, dating from 1890 onwards, as well as herbarium material from the ZA collection was overviewed and included in this study.

Keywords: checklist, macroalgae, systematics, taxonomy

Introduction

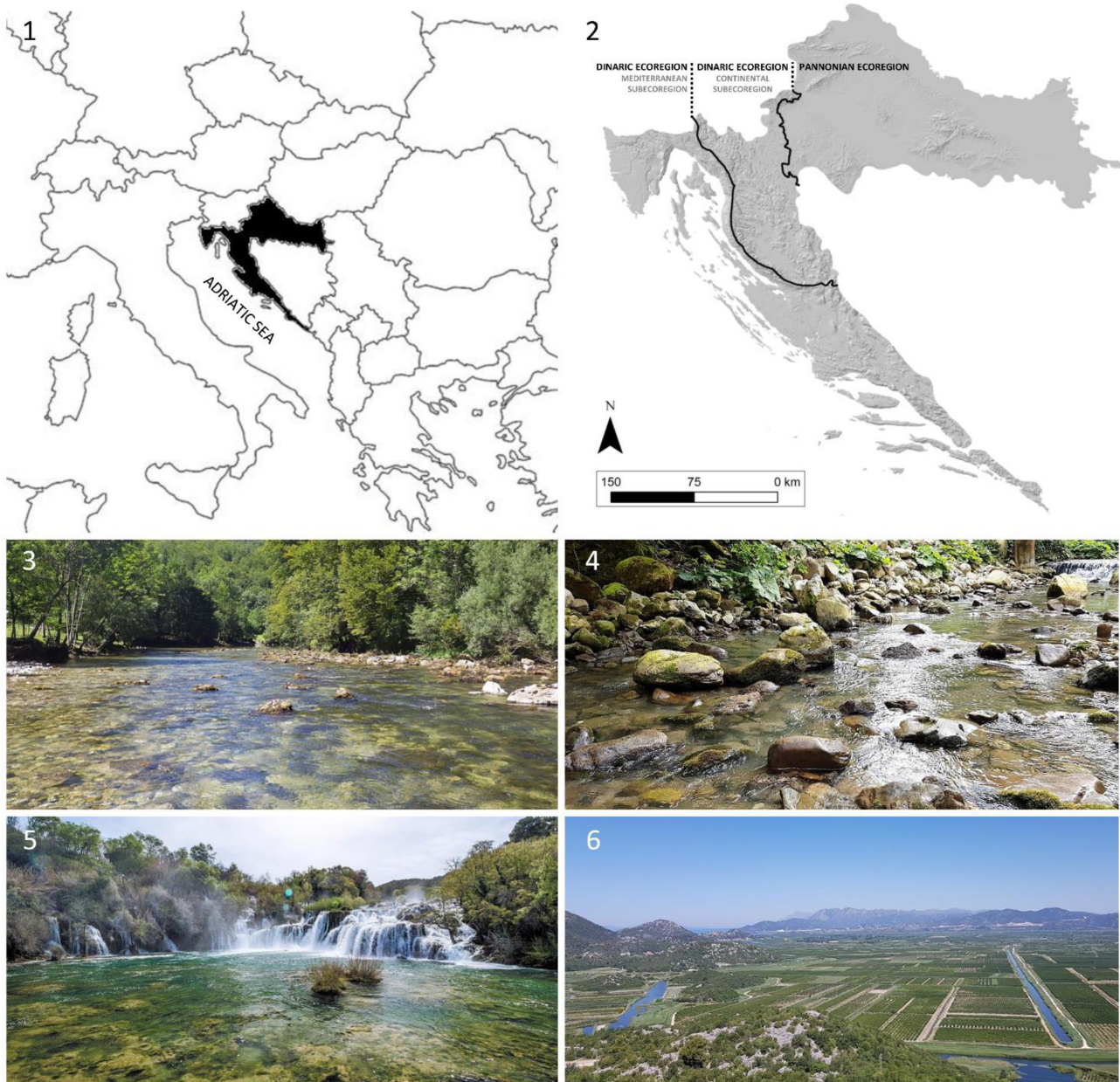
The finding of chrysophycean alga *Hydrurus penicillatus* C. Agardh (1827: 630) (= *H. foetidus* (Villars) Trevisan (1848: 75)), incidentally mentioned as a member of aquatic vegetation in the Plitvica Stream by Reichardt (1867), marked the first record of any macroalgal taxon in Croatian freshwaters. At the end of the 19th century, Hansgirg (1890) published a contribution to the algal flora of Istria and Dalmatia regions. This work mostly focused on the Krka River, with few details about the Neretva and Rijeka Dubrovačka Rivers. While describing four new rhodophyte species, the author provided the first information about the distribution of freshwater rhodophytes in Croatia.

During the mid-20th century, there was a major breakthrough in the field of freshwater algology in Croatia, with a large number of papers documenting the occurrence and abundance of the algal flora in Croatian watercourses. These papers primarily focused on the algal flora from specific geographic localities, such as the Krka River (Golubić 1957) and the Plitvice Lakes (Marčenko 1958), or the karst rivers in general (Matoničkin & Pavletić 1959, 1960, 1961, 1962, 1963, 1964, 1966, 1967a, b, Pavletić & Matoničkin 1965, Viličić 1980). Many of these papers were published as offprints in the national language and in local journals, most of which are still only available in printed form (Koletić *et al.* 2018b). Pevalek (1916) published a list of algae of northern Croatia and provided their geographic distribution in the area, while the complete overview including historical records of freshwater rhodophytes for the whole Yugoslavia was provided by Vouk (1953), but this only included a checklist of taxa without any locality information.

More recent studies focused on the Characeae S.F. Gray (1821: 1, 27) due to local expertise in this group (Blaženčić & Randelović 1994, Blaženčić & Blaženčić 2002, Blaženčić *et al.* 2006). The Characeae were also studied as a part of a surface waters monitoring program (Alegro *et al.* 2016a, b), conducted according to the Water Framework Directive (WFD) (European Community 2000). Systematic papers with summarised literature were published for freshwater Cyanophyceae Schaffner (1909: 446) (Plenković-Moraj 1996) and Chlorophyceae Wille in Warming (1884: 22) (Plenković-Moraj 1997), covering the microalgal component of the Croatian flora. Finally, at the beginning of the 21st century, papers focused specifically on chrysophycean, phaeophycean and rhodophycean macroalgae (Stanković & Leitner 2016, Žuljević *et al.* 2016, Koletić *et al.* 2017, 2018a, 2019a). These contributions provided new insights into the macroalgal flora; however, no systematic overview has been presented to date.

Currently, only a few checklists with freshwater rhodophytes have been published for Southeastern European countries, e.g. Bulgaria (Temniskova *et al.* 2008), Romania (Carauș 2002, 2012, 2017) and Serbia (Cvijan *et al.* 2003).

As for other European countries, the literature suggests that relevant data are outdated (Kwandrans & Eloranta 2010). Therefore, the purpose of this study was to survey the literature, herbarium and recent field records of freshwater rhodophytes in Croatia from 1890 onward to update all relevant data in the form of a catalogue.

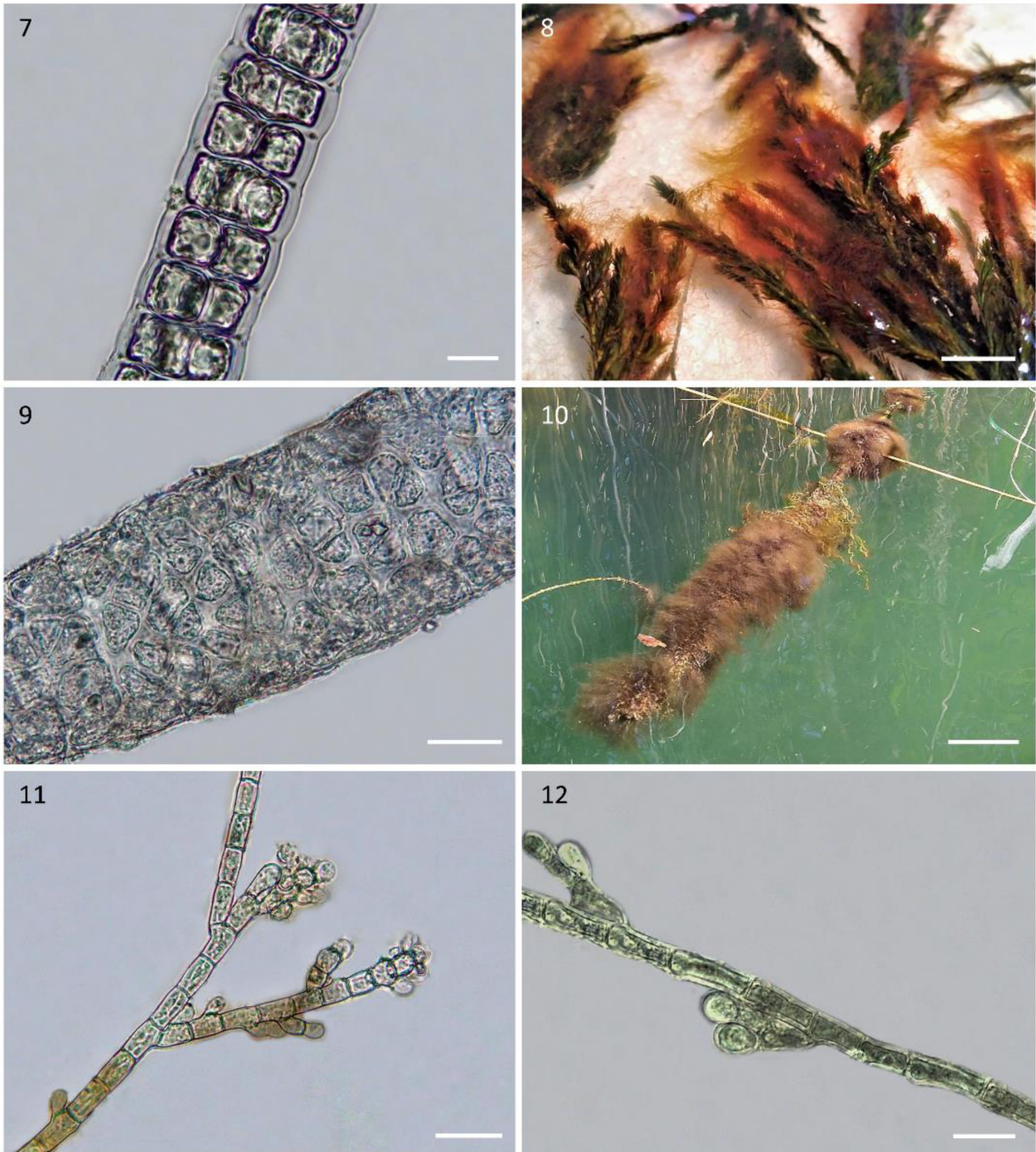


FIGURES 1–2. Map of Croatia in context of Southeast Europe with defined biogeographical regions. **FIGURES 3–5.** Partly shaded karst rivers with mesolithal stones in the river bed were mostly in the focus of the research. **FIGURE 3.** Kupa River. **FIGURE 4.** Curak Stream. **FIGURE 5.** Krka River. **FIGURE 6.** Neretva River Valley.

Materials and methods

Study area

The Republic of Croatia is a Southeastern European country (Fig. 1), covering an area of 56 594 km². Geographic relief for the country is very diverse with three main relief types as follows: (1) alluvial lowlands and isolated low mountains in the SW part of the Pannonian Basin, (2) the Dinaric Alps with karst plateaus and karst fields and (3) the Adriatic coast with more than a thousand islands, islets and isolated rocks (Fig. 2). The Dinaric Alps and adjacent Adriatic coast are classified as world biodiversity hotspots (Myers *et al.* 2000). More generally, Croatia officially comprises three European biogeographic regions: Continental, Alpine and Mediterranean (European Environmental Agency 2016).

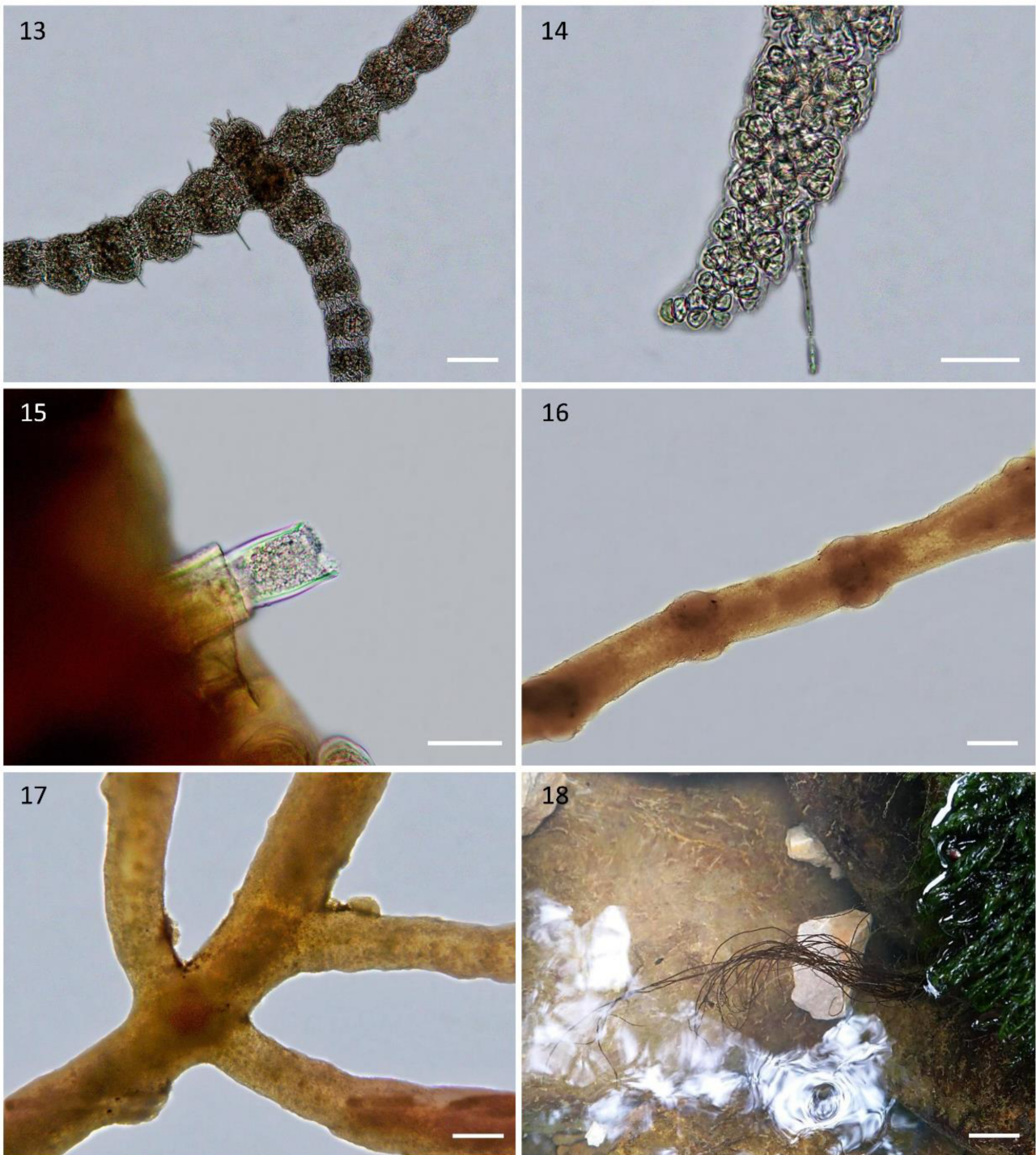


FIGURES 7–8. *Bangia atropurpurea*. **FIGURE 7.** multiseriate thread. Scale bar = 20 μm . **FIGURE 8.** filaments on aquatic moss *Cinclidotus aquaticus* from Krka River. Scale bar = 1 cm. **FIGURES 9–10.** *Compsopogon caeruleus*. **FIGURE 9.** detail of the thallus. Scale bar = 20 μm . **FIGURE 10.** tufts covering submerged reeds in Neretva River Valley. Scale bar = 10 cm. **FIGURE 11.** *Audouinella hermannii*, part of the plant with branching filaments showing terminal monospores. Scale bar = 50 μm . **FIGURE 12.** *Audouinella chalybea*, part of the plant with monosporangia. Scale bar = 20 μm .

Sampling methods, specimen conservation and identification

More than 600 localities were surveyed from 2009 to 2019, including streams, rivers, and channels, natural and artificial lakes. The majority of localities (altogether 501), were surveyed within the WFD biomonitoring, during which the periphyton and macroalgal samples were collected (Figs. 3–4). In addition, 105 localities were surveyed as a part of other projects as follows: 15 in the Krka River National Park (Fig. 5), 40 in the Plitvice Lakes National Park and 50 in

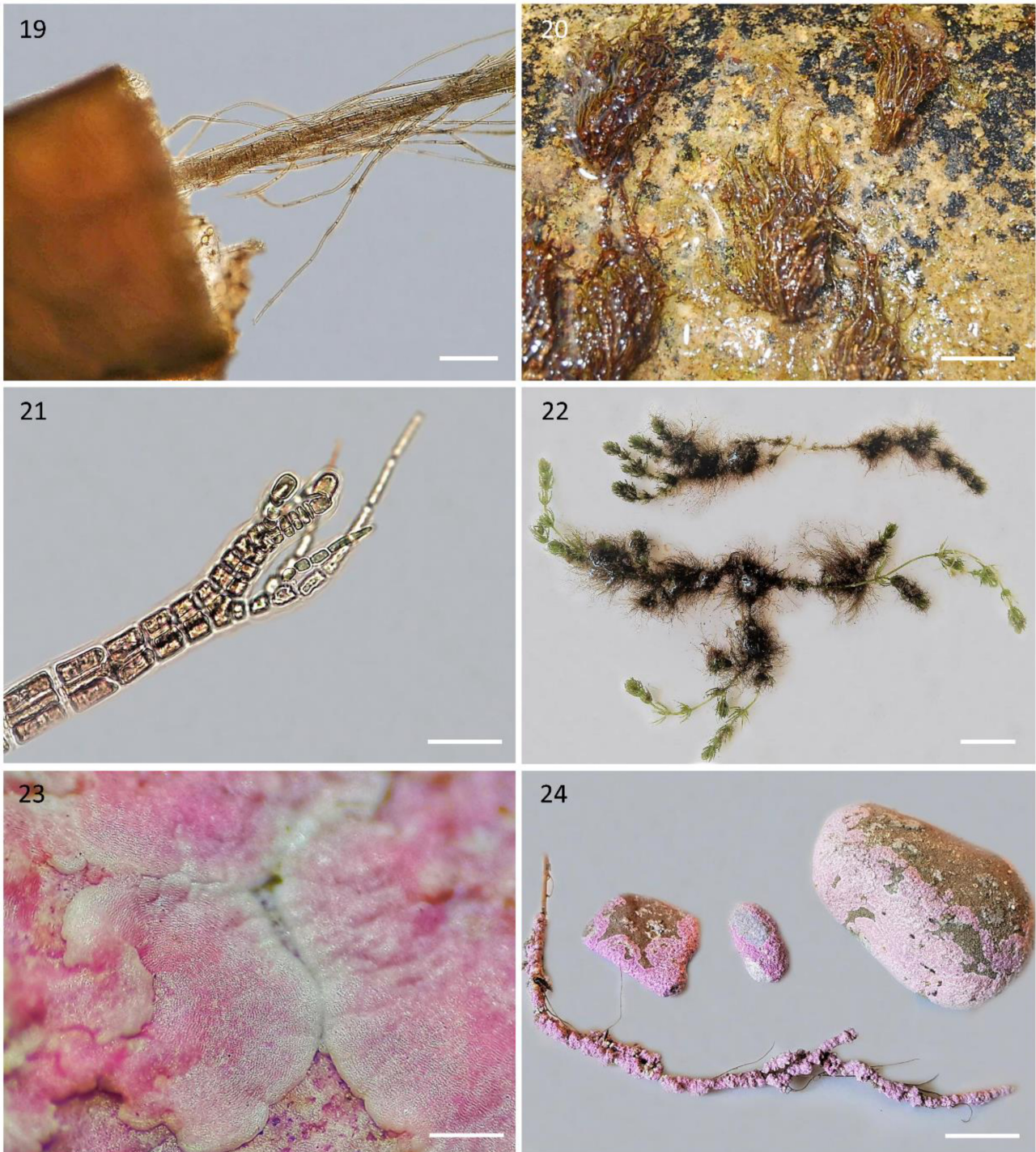
the Neretva River Valley (Fig. 6). Out of the 600 locations, around 50 were characterized as standing waters which are generally unsuitable habitat for freshwater red algae growth.



FIGURES 13–14. *Sirodotia suecica*. **FIGURE 13.** axes with dense confluent whorls. Scale bar = 200 μ m. **FIGURE 14.** apex of young branch. Scale bar = 100 μ m. **FIGURE 15.** *Lemanea fluviatilis*, lateral cross section showing single axial filament. Scale bar = 20 μ m. **FIGURE 16.** *Lemanea fucina*, part of the plant with two nodes showing spermatangial papillae. Scale bar = 100 μ m. **FIGURE 17.** *Lemanea mamillosa*, part of the plant with rich ramification. Scale bar = 50 μ m. **FIGURE 18.** *Lemanea rigida* attached on stone in Curak Stream. Scale bar = 20 cm.

Algal material was collected at depths ranging from 0 to 50 cm, from a variety of substrata and submerged material, as well as from aquatic and helophytic vegetation. Collected material was mostly preserved with 4% formaldehyde or 70% ethanol, while some samples were pressed and dried, or desiccated with silica gel. All samples are deposited in the Herbarium collection of the Faculty of Science of University of Zagreb (ZA) (Thiers 2019). Algal material was analysed using a microscope with 40–1000 \times magnification, photographed and identified according to Athanasiadis

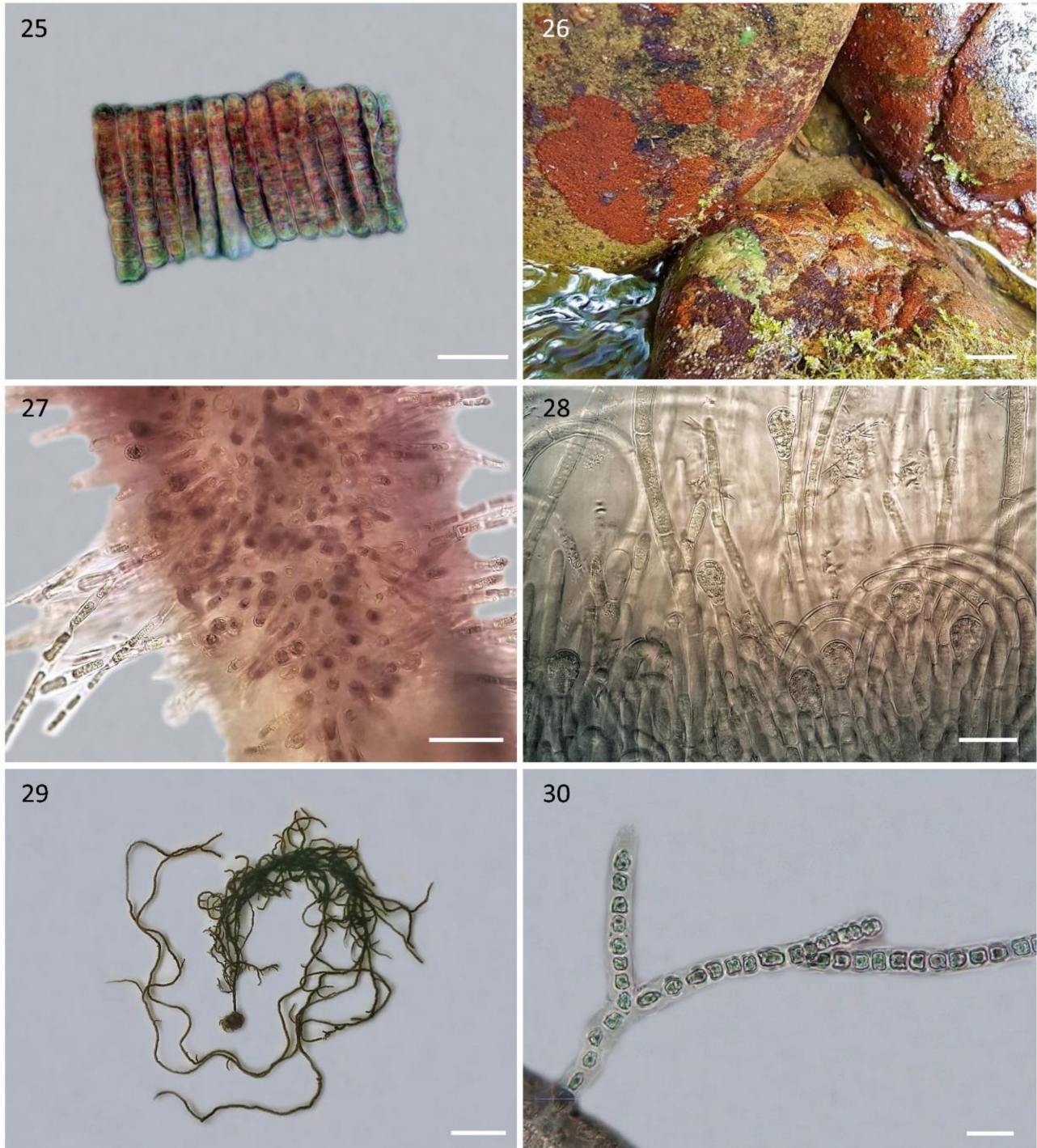
(1996), Eloranta *et al.* (2011), John *et al.* (2011) and Necchi Jr. (2016). The nomenclature follows AlgaeBase (Guiry & Guiry 2019).



FIGURES 19–20. *Paralemanea torulosa*. **FIGURE 19.** lateral cross section showing multiple axial filaments. Scale bar = 20 μ m. **FIGURE 20.** plants attached on stones in Kupa River. Scale bar = 1 cm. **FIGURES 21–22.** *Polysiphonia subtilissima*. **FIGURE 21.** uncompressed part of erect axis with two pericentral cells in each section and branch arising in axils of trichoblasts. Scale bar = 20 μ m. **FIGURE 22.** plants growing on *Chara aspera* from the Zrmanja River. Scale bar = 2 cm. **FIGURES 23–24.** *Pneophyllum cetinaensis*. **FIGURE 23.** detail of the crusty coralligenous thallus. Scale bar = 0,2 cm. **FIGURE 24.** alga covering the stones and branch from the Cetina River. Scale bar = 2 cm.

Literature and herbarium examination

Relevant literature on Croatian freshwater algae, such as floristic, taxonomic and ecological papers published since the mid-19th century, were gathered and reviewed. Additionally, herbarium material of freshwater rhodophytes from the ZA collection was reviewed, and taxa are presented using the currently accepted names.



FIGURES 25–26. *Hildenbrandia rivularis*. **FIGURE 25.** erect filaments shown in side view. Scale bar = 20 μ m. **FIGURE 26.** crustaceous patches of plant on stones in Curak Stream. Scale bar = 2 cm. **FIGURES 27–29.** *Thorea hispida*. **FIGURE 27.** part of sporophyte tuft with numerous monosporangia. Scale bar = 20 μ m. **FIGURE 28.** gametophyte monosporangia on basal cells of assimilatory filaments. Scale bar = 20 μ m. **FIGURE 29.** plant attached on aquatic gastropod from the Kupa River. Scale bar = 2 cm. **FIGURE 30.** *Chroodactylon ornatum*, pseudofilaments surrounded by thick gelatinous matrix. Scale bar = 20 μ m.

Results

This comprehensive study revealed a total of 18 freshwater rhodophyte species in the Croatian flora, classified to 13 genera and 11 families.

Phylum Rhodophyta Wettstein, 1901

Class Bangiophyceae Wettstein, 1901

Order Bangiales Nägeli, 1847

Family Bangiaceae Duby, 1830

Genus *Bangia* Lyngbye, 1819

1. *Bangia atropurpurea* (Mertens ex Roth) C.Agardh 1824: 76

(Figs. 7–8, 34, 36)

- Jadro River, on branches, 43°32'2.73" N, 16°29'25.20" E, August 2019, leg. A. Rimac, N. Vuković, det. N. Koletić
- Krka River, Roški slap Waterfall, on bryophytes, 43°54'18.0" N, 15°58'30.5" E, July 2018, leg. A. Alegro & A. Rimac, det. N. Koletić (Koletić *et al.* 2019c)
- Krka River, Manojlovac Waterfall, on stones, 44°00'54.9" N, 16°01'30.4" E, July 2018, leg. A. Alegro & A. Rimac, det. N. Koletić (Koletić *et al.* 2019c)
- Curak Stream, Zeleni Vir, on stones, 45°25'35.4" N, 14°53'33.2" E, June 2018, leg. N. Koletić & N. Vuković, det. N. Koletić (Koletić *et al.* 2019c)
- Drava River, near Botovo Village, on sunken branches, 46°14'13.3" N, 16°56'22.3" E, January 2018, leg. N. Hanžek & I. Stanković, det. N. Koletić (Koletić *et al.* 2019c)
- Butižnica Stream, downstream from the Power Plant Golubić, on stones, 44°05'20.5" N, 16°13'11.4" E, July 2017, leg. A. Alegro & N. Koletić, det. N. Koletić (Koletić *et al.* 2019c)
- spring of the Rijeka Dubrovačka River, 42°40'32.71" N, 18° 8'11.94" E, (Matoničkin & Pavletić 1961, 1967b)
- Krka River, Roški slap Waterfall, 43°54'16.78" N, 15°58'27.31" E, (Matoničkin & Pavletić 1962)
- Trebež River, 45°21'37.57" N, 16°46'52.96" E, (Matoničkin & Pavletić 1961)
- Plitvice Lakes, Milka Trnina Waterfalls, 44°54'0.03" N, 15°36'40.21" E, (Marčenko 1958, Matoničkin & Pavletić 1967a)
- Krka River, Bilušića buk Waterfall, 44° 0'47.33" N, 16° 4'6.72" E, (Golubić 1957)
- mills in the mountain streams of Zagreb City surroundings, 45°49'33.57" N, 15°52'36.36" E, (Vouk 1953*)
- Krka River, Roški slap Waterfall, 43°54'24.63" N, 15°58'36.52" E, (Vouk 1953); as *B. atropurpurea* ssp. *coccinea*
- *Podsused, 27-XI-1937, leg. V. Vouk (ZA)
- Dolje Stream, St. Šimun, Bliznec Stream near Podsused City, 45°49'19.15" N, 15°50'1.19" E, (Pevalek 1916)

Class Compsopogonophyceae G.W.Saunders & Hommersand, 2004

Order Compsopogonales Skuja, 1939

Family Compsopogonaceae F.Schmitz, 1896

Genus *Compsopogon* Montagne, 1846

2. *Compsopogon caeruleus* (Balbis ex C.Agardh) Montagne 1846: 154 (as „*caeruleus*“)

(Figs. 9–10, 36)

- Crna Rika River, Neretva River Valley, on submerged parts of reed, 43°03'08.6" N, 17°31'10.5" E, August 2018, leg. N. Vuković & N. Koletić, det. N. Koletić (Koletić *et al.* 2019c)
- Orepak, irrigation system near Rogotin Village, Neretva River Valley, on aquatic plants, August 2018, 43°02'29.9" N, 17°27'40.9" E, leg. N. Vuković & N. Koletić, det. N. Koletić (Koletić *et al.* 2019c)

Class Florideophyceae Cronquist, 1960

Order Acrochaetiales Feldmann, 1953

Family Acrochaetiaceae Fritsch ex W.R. Taylor, 1957

Genus *Audouinella* Bory, 1823, nom. cons.

3. *Audouinella hermannii* (Roth) Duby 1830: 972

(Figs. 11, 36)

- Butižnica Stream downstream from the Power Plant Golubić, on *Lemanea fucina*, 44°05'20.5" N, 16°13'11.4" E, July 2017, leg. A. Alegro & N. Koletić, det. N. Koletić (Koletić *et al.* 2019c)
- Krka River, 43°49'51.16" N, 15°59'12.86" E, (Hansgirg 1890); as *Chantransia violacea*

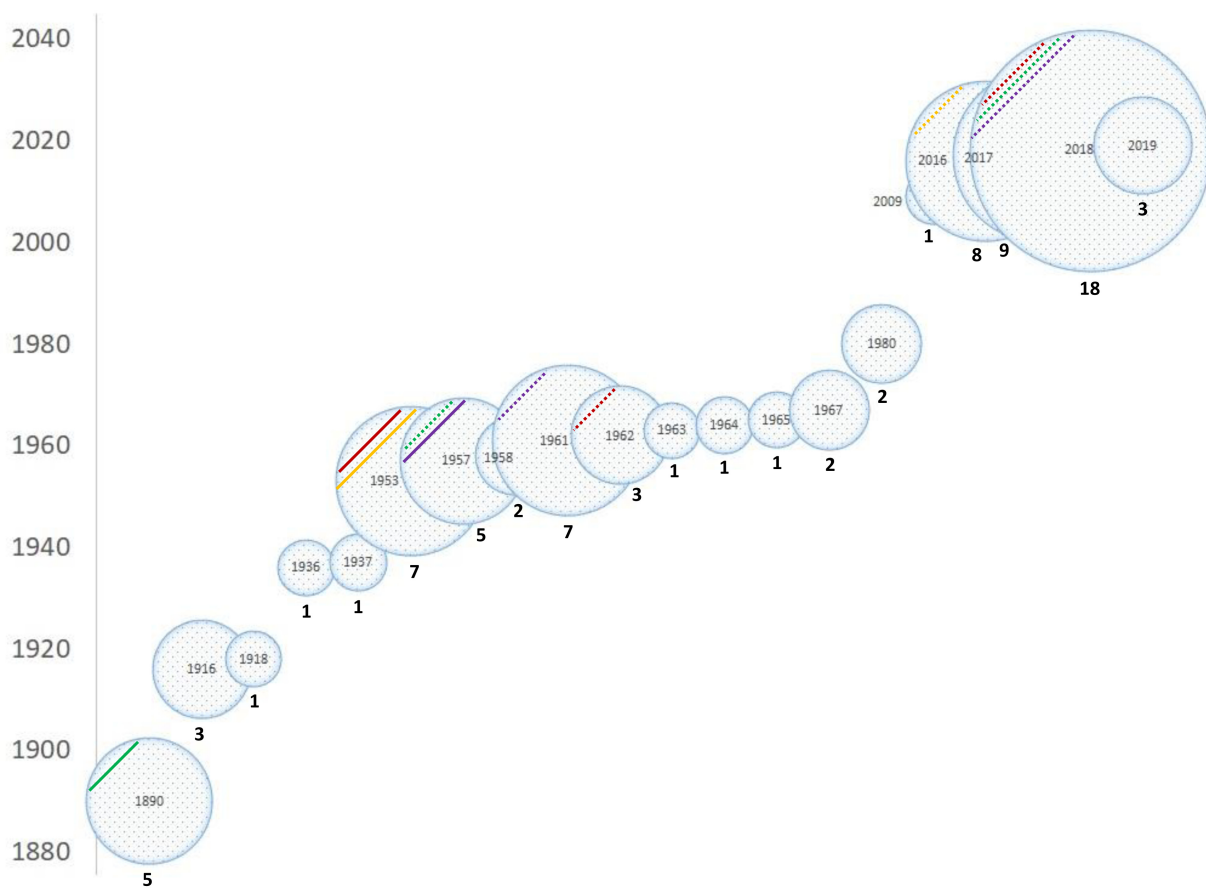


FIGURE 35. Number of freshwater rhodophyte records per year is indicated by the size of the circle with the exact number of described/ found species below the circle. Reconfirmed records of the same species on the same locations are indicated by coloured lines in circles: full line—first record, dotted line—reconfirmed record (red: *Bangia atropurpurea*, green: *Lemanea fluviatilis*, purple: *L. fucina*, orange: *L. mamillosa*).

4. *Audouinella chalybea* (Roth) Bory 1823: 340 (Figs. 12, 36)

- Raminac Stream at confluence into the Pakra River, on stream substrate, 45°25'01.7" N, 17°08'28.9" E, August 2017, leg. A. Rimac, det. N. Koletić (Koletić *et al.* 2019c)
- Garešnica Stream, upstream from Garešnica City, on stream substrate, 45°35'47.4" N, 16°55'51.5" E, July 2017, leg./det. N. Koletić (Koletić *et al.* 2019c)
- Gliboki Stream, near Poganac Village, on stream substrate, 46°09'05.6" N, 16°36'01.9" E, April 2017, leg./det. N. Koletić (Koletić *et al.* 2019c)
- Bistrec Rakovica Stream near Čakovec City, on stream substrate, 46°25'20.61" N, 16°28'23.94" E, June 2016, leg./det. N. Koletić
- Jalošovec Stream near Čakovec City, on stream substrate, 46°24'28.33" N, 16°23'44.46" E, June 2016, leg./det. N. Koletić
- Tomašica Stream near Tomašica Village, on stream substrate, 45°36'13.86" N, 16°59'29.01" E, June 2016, leg./det. N. Koletić
- Kupa River, 45°27'22.53" N, 15°18'57.84" E, (Viličić 1980); as *Chantransia chalybea*
- St. Helena Village near Samobor City, 45°49'1.62" N, 15°42'19.94" E, (Vouk 1953); as *C. chalybea*
- urban streams in Zagreb City, 45°47'39.97" N, 15°56'10.55" E, (Vouk 1953); as *C. chalybea*
- Neretva River near Metković City, 43°2'48.76" N, 17°38'25.71" E, (Hansgirg 1890); as *C. chalybea*
- Rijeka Dubrovačka River, 42°40'18.30" N, 18°7'42.42" E, (Hansgirg 1890); as *C. chalybea*

Order Batrachospermales Pueschel & K.M.Cole, 1982

Family Batrachospermaceae C.Agardh, 1824

Genus *Batrachospermum* Roth, 1797

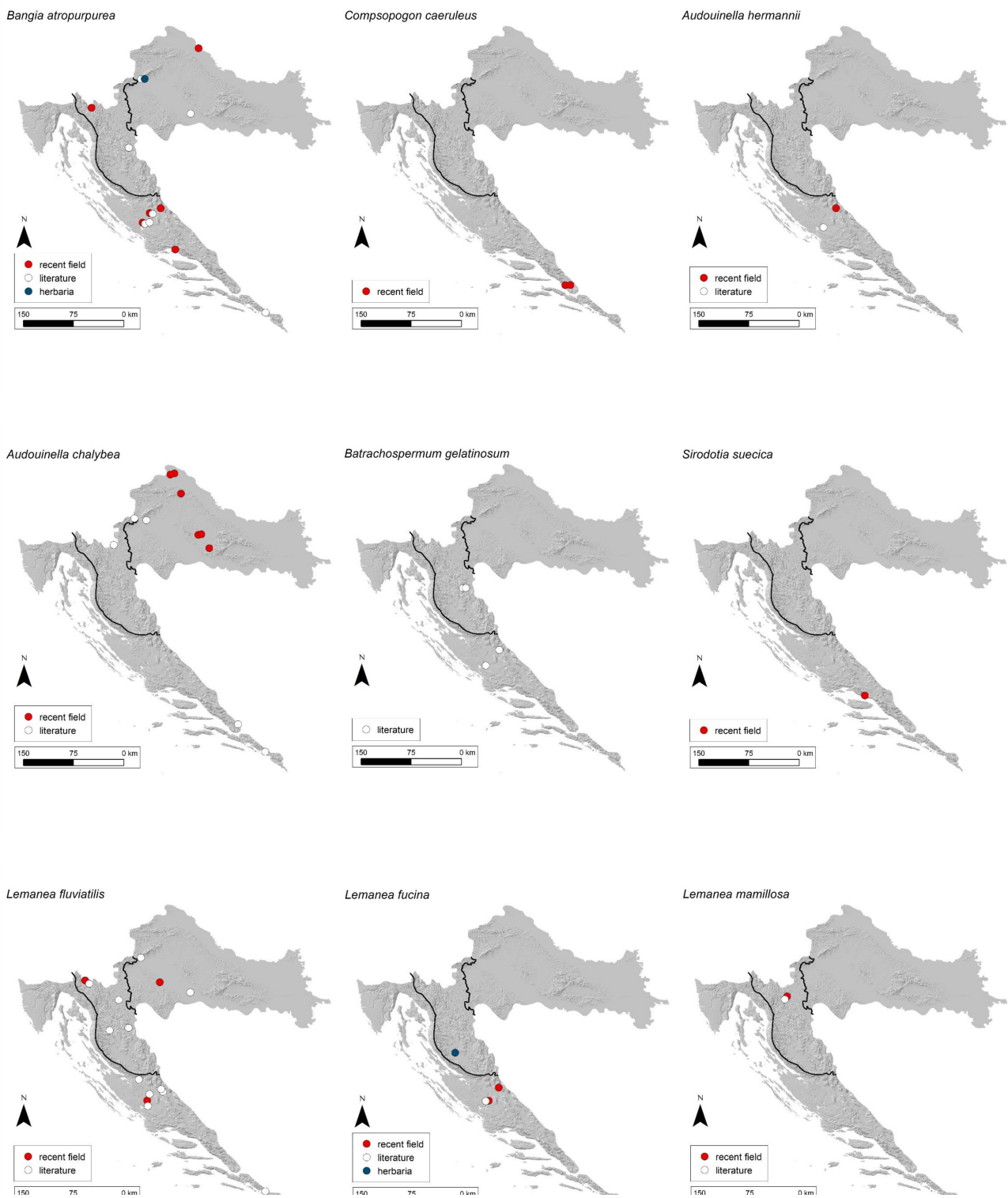


FIGURE 36. Geographic distribution of *Bangia atropurpurea*, *Compsopogon caeruleus*, *Audouinella hermannii*, *A. chalybea*, *Batrachospermum gelatinosum*, *Sirodotia suecica*, *Lemanea fluviatilis*, *L. fucina* and *L. mamillosa* in Croatia.

5. *Batrachospermum gelatinosum* (Linnaeus) De Candolle 1801: 21
(Fig. 36)

- Plitvice Lakes, on tuffa barriers and waterfalls, 44°52'40.94" N, 15°36'52.00" E, (Matoničkin & Pavletić 1961, 1967a); as *B. moniliforme*
- Plitvice Lakes, Lake Okrugljak and Lake Prošće, 44°52'13.56" N, 15°35'52.48" E, (Marčenko 1958); as *B. moniliforme*

- Krka River, Veliki buk Waterfall, 44°2'31.24" N, 16°14'6.82" E, (Matoničkin & Pavletić 1961); as *B. moniliforme*
- Krka River, 43°49'51.16" N, 15°59'12.86" E, (Hansgrig 1890); as *B. moniliforme*

Genus *Sirodotia* Kylin, 1912

6. *Sirodotia suecica* Kylin 1912: 38, figs 3, 16 a-f
(Figs. 13–14, 36)

- Cetina River, Radmanove mlinice, on sunken branches, 43°26'21.1" N, 16°45'05.4" E, July 2018, leg. A. Rimac & N. Vuković, det. N. Koletić (Koletić *et al.* 2019c)

Family Lemnaceae C.Agardh, 1828

Genus *Lemanea* Bory, 1808, nom. cons.

7. *Lemanea fluviatilis* (Linnaeus) C.Agardh 1811: 25
(Figs. 15, 36)

- Kupa River near Nebojan Village, on stones, 45°29'44.3" N, 16°12'03.4" E, August 2018, leg. A. Rimac, det. N. Koletić (Koletić *et al.* 2019c)
- Krka River, Roški slap Waterfall, on stones, 43°54'18.0" N, 15°58'30.5" E, July 2018, leg. A. Alegro, A. Rimac & V. Šegota, det. N. Koletić (Koletić *et al.* 2019c)
- Kupa River near Gašparci Village, on stones, 45°30'26.6" N, 14°46'27.6" E, August 2016, leg. A. Alegro & V. Šegota, det. N. Koletić (Koletić *et al.* 2019c)
- Kupa River near Brod na Kupi Village, 45°27'49.21 N, 14°51'10.60" E, (Viličić 1980)
- spring of the Rijeka Dubrovačka River, 42°40'32.71" N, 18° 8'11.94" E, (Matoničkin & Pavletić 1967b)
- tributary waters of the Plitvice Lakes: Crna rijeka Stream, Bijela rijeka Stream, Plitvica Stream and Rječica Stream, 44°52'49.86" N, 15°36'45.88" E, (Matoničkin & Pavletić 1965)
- Gacka River, 44°50'36.65" N, 15°15'18.25" E, (Matoničkin & Pavletić 1961, 1965)
- Mrežnica River, 45°15'14.75" N, 15°25'14.90" E, (Matoničkin & Pavletić 1961, 1965)
- Zrmanja River with its tributary the Krupa River, 44°11'9.34" N, 15°48'54.09" E, (Matoničkin & Pavletić 1964)
- Krka River, Veliki buk Waterfall, 44°2'31.24" N, 16°14'6.82" E, (Matoničkin & Pavletić 1962)
- Trebež River, 45°21'37.57" N, 16°46'52.96" E, (Matoničkin & Pavletić 1961)
- Krčić Stream, 44°2'31.86" N, 16°14'49.43" E, (Golubić 1957)
- Krka River, downstream from the Power Plant Miljacka, 43°59'30.03" N, 16°0'58.11" E, (Golubić 1957)
- Dolje Stream, St. Šimun, Bliznec Stream near Podsused City, 45°49'19.15" N, 15°50'1.19" E, (Pevalek 1916)
- Krka River, 43°49'51.16" N, 15°59'12.86" E, (Hansgirg 1890)

8. *Lemanea fucina* Bory 1808: 185, pl. 21: fig. 3
(Figs. 16, 32, 36)

- Krka River, Roški slap Waterfall, on stones, 43°54'18.0" N, 15°58'30.5" E, July 2018, leg. A. Alegro, A. Rimac & V. Šegota, det. N. Koletić (Koletić *et al.* 2019c)
- Butišnica Stream, downstream from the Power Plant Golubić, 44°05'20.5" N, 16°13'11.4" E, July 2017, leg. A. Alegro & N. Koletić, det. N. Koletić (Koletić *et al.* 2019c)
- Lika River near Gospić City, 44°33'10.18" N, 15°23'47.23" E, (Vouk 1953*)
- Krka River, Roški slap Waterfall (Golubić 1957) and numerous unnamed waterfalls, 43°54'25.45" N, 15°58'36.70" E, (Matoničkin & Pavletić 1961)
- *Gospić, 1916, leg. V. Vouk (ZA)

9. *Lemanea mamillosa* Kützing 1845: 261
(Figs. 17, 36)

- Dobra River near Goljak Village, on stones, 45°17'56.2" N, 15°15'51.6" E, September 2016, leg. V. Šegota, det. N. Koletić
- Dobra River, Đulin ponor Abyss near Ogulin City, 45°16'0.03" N, 15°13'26.43" E, (Vouk 1953)

10. *Lemanea rigida* (Sirodot) De Toni 1897: 42
(Figs. 18, 37)

- Curak Stream, Zeleni Vir, near Skrad City, on stones, 45°25'35.4" N, 14°53'33.2" E, June 2018, August 2019, leg. N. Koletić & N. Vuković, det. N. Koletić (Koletić *et al.* 2019c)
- Krkić River near Topolje Village, 44° 2'29.98" N, 16°14'5.68" E, (Vouk 1953)

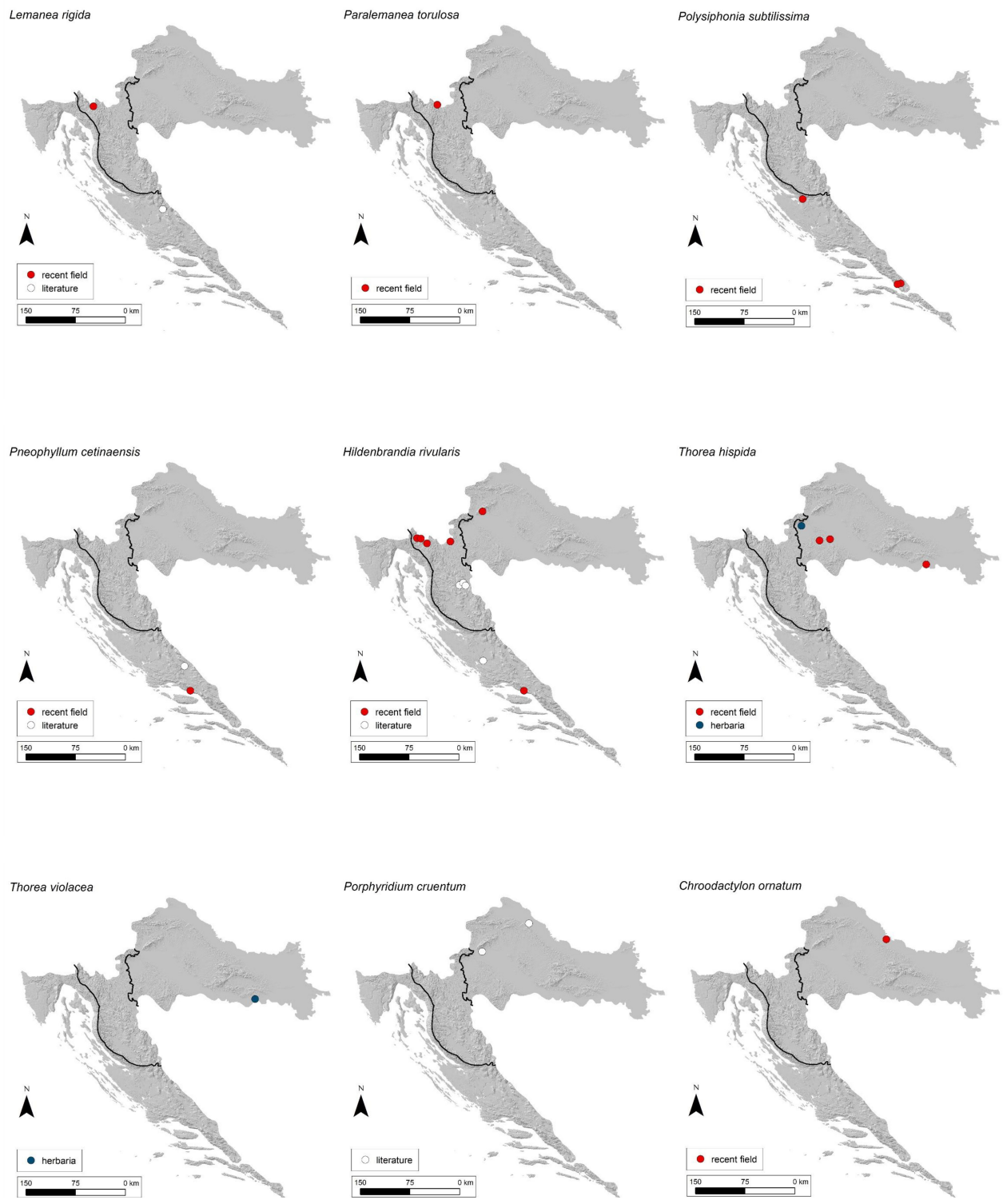


FIGURE 37. Geographic distribution of *Lemanea rigida*, *Paralemanea torulosa*, *Polysiphonia subtilissima*, *Pneophyllum cetinaensis*, *Hildenbrandia rivularis*, *Thorea hispida*, *T. violacea*, *Porphyridium cruentum* and *Chroodactylon ornatum* in Croatia.

Genus *Paralemanea* (P.C.Silva) M.L.Vis & Sheath, 1992

11. *Paralemanea torulosa* (Roth) Sheath & A.R.Sherwood 2002: 137
(Figs. 19–20, 37)

- Kupa River, near Blaževci Village, on stones, 45°29'03.7" N, 15°04'30.8" E, August 2016, leg. A. Alegro, N. Koletić & V. Šegota, det. N. Koletić (Koletić *et al.* 2019c)

Order Ceramiales Nägeli, 1947

Family Rhodomelaceae Horaninow, 1847

Genus *Polysiphonia* Greville, 1823, nom. et typ. cons.

12. *Polysiphonia subtilissima* Montagne 1840: 199

(Figs. 21–22, 37)

- Zrmanja River, near Obrovac City, 44°11'54.5" N, 15°41'26.9" E, August 2018, leg./det. N. Koletić (Koletić *et al.* 2019b, 2019c)
- Crna Rika River, Neretva River Valley, on submerged part of reed, 43°03'08.6" N, 17°31'10.5" E, August 2018, leg. N. Vuković & N. Koletić, det. N. Koletić (Koletić *et al.* 2019b, 2019c)
- Orepak, irrigation system near Rogotin Village, Neretva River Valley, on aquatic plants, August 2018, 43°02'29.9" N, 17°27'40.9" E, August 2018, leg. N. Vuković & N. Koletić, det. N. Koletić (Koletić *et al.* 2019b, 2019c)

Order Corallinales P.C.Silva & H.W.Johansen, 1986

Family Hydrolithaceae R.A.Townsend & Huisman, 2018

Genus *Pneophyllum* Kützing, 1843

13. *Pneophyllum cetinaensis* Kaleb, Zuljevic & Peña 2016: 2, fig. 2a-e, 3 a-f, 4

(Figs. 23–24, 37)

- Cetina River near Radmanove mlinice, on sunken branches and stones, 43°26'21.1" N, 16°45'05.4" E, July 2018, leg. A. Rimac & N. Vuković, det. N. Koletić (Koletić *et al.* 2019c)
- Cetina River and its tributary Rumin Veliki, 43°46'21.41" N, 16°38'41.50" E, (Žuljević *et al.* 2016)

Order Hildenbrandiales Pueschel & K.M.Cole, 1982

Family Hildenbrandiaceae Rabenhorst, 1868

Genus *Hildenbrandia* Nardo, 1834, nom. cons.

14. *Hildenbrandia rivularis* (Liebmann) J.Agardh 1851: 379, 495

(Figs. 25–26, 37)

- stream on Medvednica Mountain near Zagreb City, on stones, 45°52'19.6" N, 15°57'31.9" E, September, 2019, leg./det. N. Koletić
- Curak Stream, Zeleni Vir, on stones, 45°25'35.4" N, 14°53'33.2" E, June 2018 (Koletić *et al.* 2019c), August 2019, leg. N. Koletić & N. Vuković, det. N. Koletić
- Kupa River, Kupari Spring, on stones, 45°29'41.2" N, 14°41'52.4" E, November 2017; leg./det. N. Koletić (Koletić *et al.* 2018a, 2019c)
- Kupa River near Vukova Gorica Village, on stones, 45°27'24.4" N, 15°20'33.0" E, July 2017, leg. A. Alegro, det. N. Koletić (Koletić *et al.* 2018a, 2019c)
- Kupa River near Gašparci Village, on bryophytes, 45°30'26.6" N, 14°46'27.6" E, August 2016, leg. A. Alegro, N. Koletić & V. Šegota, det. N. Koletić (Koletić *et al.* 2019c)
- Cetina River near Radmanove mlinice, 43°26'21.1" N, 16°45'05.4" E, May 2009, leg. A. Rimac & N. Vuković, det. N. Koletić (Koletić *et al.* 2018a, 2019c)
- Plitvica Stream Spring, 44°54'4.72" N, 15°34'26.28" E, (Matoničkin & Pavletić 1967a)
- Plitvica Stream, 44°54'0.39" N, 15°35'57.03" E, (Matoničkin & Pavletić 1963)
- Veliki buk Waterfall, 44°52'13.56" N, 15°35'52.48" E, (Matoničkin & Pavletić 1962)
- Krka River, tuffa waterfalls, 44°52'13.56" N, 15°35'52.48" E, (Matoničkin & Pavletić 1961)
- Krčić River, beneath the waterfall, 43°50'40.22" N, 15°59'17.71" E, (Golubić 1957); as *Hildenbrandia rivularis*

Order Thorealess K.M.Müller, Sheath, A.R.Sherwood & Pueschel 2002

Family Thoreaceae Hassall, 1845

Genus *Thorea* Bory, 1808

15. *Thorea hispida* (Thore) Desvaux 1818: 16

(Figs. 27–29, 33, 37)

- Sava River near Slavonski Brod City, 45°8'28.32" N, 18°2'46.80" E, August 2019, leg. M. Srebočan, det. N. Koletić
- Kupa River near Nebojan Village, on stones and gastropods, 45°29'44.3" N, 16°12'03.4" E, August 2018, leg. A. Rimac, det. N.

- Koletić (Koletić *et al.* 2019a, 2019c)
- Kupa River near Pokupsko Village, on stones, 45°28'33.8" N, 15°59'50.9" E, July 2017, leg. V. Elez, det. M. L. Vis, conf. N. Koletić (Koletić *et al.* 2019c)
- stream Toplica near St. Jana Village, Jastrebarsko City, 45°40'23.81" N, 15°38'40.90" E, (Vouk 1953*); as *T. ramosissima*
- *In rivreto Toplica ad Sv. Jana prope Jaska in Croatia, 17.V.1918., leg. V. Vouk (ZA)

16. *Thorea violacea* Bory 1808: 133, pl. 18: fig. 2
(Figs. 31, 37)

- Sava River near Slavonski Brod City, 45°9'7.85" N, 18°0'7.54" E, (Klas 1936*); as *T. brodensis*
- *Ad trabes inudetes in Sava fluvi prope Brod, Jugoslavia, Hedvigia, Bot. 75, p. 273–284 (1936) (ZA)

Class Porphyridiophyceae M.Shameel, 2001
Order Porphyridiales Kylin, 1937
Family Porphyridiaceae Kylin, 1937
Genus *Porphyridium* Nägeli, 1849, nom. cons.

17. *Porphyridium cruentum* (S.F.Gray) Nägeli 1849: 71
(Fig. 37)

- urban streams in Zagreb City, 45°47'39.97" N, 15°56'10.55" E, (Vouk 1953)
- Glogovec Stream near Koprivnica City, 46°10'41.57" N, 16°50'51.79" E, (Vouk 1953)

Class Stylonematophyceae
Order Stylonematales H.S.Yoon, K.M.Müller, Sheath, F.D.Ott & D.Bhattacharya, 2006
Family Stylonemataceae K.M.Drew, 1956
Genus *Chroodactylon* Hansgirg, 1885

18. *Chroodactylon ornatum* (C.Agardh) Basson 1979: 67, pl. IX [9]: fig. 52
(Figs. 30, 37)

- Vir Stream near Pitomača City, on stream substrate, 45°57'02.1" N, 17°16'45.1" E, May 2018, leg. N. Hanžek & I. Stanković, det. N. Koletić (Koletić *et al.* 2019c)

Discussion

Publications and collections of freshwater macroalgae in Croatia have been somewhat rare throughout history. The only related publications at the end of the 20th century were papers on the algal flora of the karst rivers in Croatia (Matoničkin & Pavletić 1959–1967, Viličić 1980) and the overview of freshwater rhodophytes of Yugoslavia (Vouk 1953), which when combined catalogued 12 rhodophyte species.

This detailed study including new field surveys, and analysis of available literature and herbarium material revealed 18 rhodophytes in Croatia to date. The number is certainly greater as we have omitted representatives of the genus *Batrachospermum* Roth (1797) collected during the field trips. The genus *Batrachospermum* is the most specious and diverse within the order Batrachospermales and divided in two sub-genera (*Batrachospermum* and *Acarposporophytum* O.Necchi (1987: 446)) (Necchi Jr. *et al.* 2019), the former containing eight sections (Kumano 2002): *Aristata* (Skuja 1933), *Batrachospermum*, *Contorta* (Skuja Emended (Vis and Entwisle 2000)), *Gonimopropagulum* (Sheath and Whittick 1995), *Setacea* (De Toni 1897), *Turfosa* (Sirodot Emmend, Necchi 1990) *Virescentia* (Sirodot 1873) and *Hybrida* which has been subsumed into section *Contorta*. All phylogenetic studies of the freshwater red algal order Batrachospermales have demonstrated the genus *Batrachospermum* to be paraphyletic (Vis *et al.* 1998; Entwisle *et al.* 2009). Namely, identification of the *Batrachospermum* species via morphological features can sometimes be uncertain and molecular analysis is required to conclusively identify *Batrachospermum* species in the rhodophyte flora. Results of these analyses are planned to be published as an update to this catalogue.

The number of rhodophyte species for some European countries remains uncertain, as new records are being collected and published regularly, but mostly in local journals, whose visibility is sometimes limited (Koletić *et al.*

2018b). Kwadrans & Eloranta (2010) published a paper about the diversity of freshwater rhodophytes in Europe, providing a total number of approximately 60 species; however more than one-third are listed with only one to a few localities. In comparison with the number of rhodophycean species in the countries of Central and Southeast Europe, such as Austria with 22 (Rott *et al.* 1997), Bosnia & Herzegovina with 15 (Anonymous 2007) Hungary with 9 (Kiss & Pelyhe 2004) and Serbia with 10 (Cvijan *et al.* 2003), the Croatian list with 18 species (without *Batrachospermum*) fits within the expected number of species.

In our study, the number of rhodophyte records per location is rather low, but this is expected taking into account that the contribution of freshwater rhodophytes to the algal flora is generally low, usually constituting only 0.1–1.7% of the total number of species (Sheath & Hambrook 1990). On the other hand, despite the fact that only 6.1% out of ca. 550 suitable locations explored during 2009–2019 included rhodophytes, this accounts for 48% of all freshwater rhodophytes records for Croatia. This percentage is higher than the 1950s and 1960s, when 38% of all records were published (Fig. 35).

Certain populations recorded on the Krka River confirmed historical records, such as *Bangia atropurpurea* (Mertens ex Roth) C.Agardh (1824: 76) (Vouk 1953, Matoničkin & Pavletić 1962), *Lemanea fluviatilis* (Linnaeus) C.Agardh (1811: 25) (Hansgirg 1890, Golubić 1957) and *L. fucina* Bory (1808b: 185, pl. 21: fig. 3) (Golubić 1957, Matoničkin & Pavletić 1961) recorded in 2018 and collected on specific tufa waterfalls. Similarly, *L. mamillosa* Kützing (1845: 261) was recorded in the Dobra River in 2016, six decades after the first record from Croatia, from the same river (Vouk 1953). Interestingly, rhodophyte taxa were not recorded recently on any surveyed location in the Plitvice Lakes National Park, despite numerous studies throughout recent years and sampling during different seasons. We consider this result rather alarming, as historical data from mid-20th century provided reports of *Bangia atropurpurea* and *Batrachospermum* sp. present on specific tufa barriers and waterfalls (Marčenko 1958, Matoničkin & Pavletić 1961, 1967a, 1967b). Given that Plitvice Lakes are protected as a National Park and are defined as an area of world natural heritage (UNESCO 2019), we found the potential loss of rhodophytes concerning.

While revising the literature data, we omitted *Chantransia pygmaea* Kützing (1843: 285) (= *Audouinella pygmaea* (Kützing) Weber Bosse (1921: 191)) listed by Vouk (1953). Namely, *Chantransia* were recognized as sporophyte stages of freshwater florideophycean rhodophytes belonging to Batrachospermales or Thoreaales (Van den Hoek *et al.* 1995, Necchi Jr. *et al.* 1993a, 1993b, Necchi Jr. & Zucchi 1997). The ZA collection holds only four historical herbarium sheets of freshwater rhodophytes collected in Croatia. One is a type specimen of *Thorea brodensis* Klas (1936: 283, pl. V [5]: fig. 1; pl. VI [6]: figs 3, 4) (Fig. 31), a species never again found in Croatia and eventually demonstrated by Sheath *et al.* (1993) to be *T. violacea*. It is important to note that Johnston *et al.* (2018) recognized *T. violacea* only from its type locality in the Indian Ocean and state that further investigation is needed to clarify the taxonomic status of *T. brodensis*. Other historical specimens found in the collection are *Lemanea fucina* Bory (1808b: 185, pl. 21: fig. 3) (Fig. 32) from 1916, *Thorea ramosissima* Bory (1808a: 128) (= *T. hispida*) from 1918 (Fig. 33) and *Bangia atropurpurea* from 1937 (Vouk 1953) (Fig. 34).

As a result of our field surveys, new specimens are continuously being added to the collection, such as *Composopogon caeruleus* (Balbis ex C.Agardh) Montagne (1846: 154) from the Neretva River Valley, *Chroodactylon ornatum* (C.Agardh) Basson (1979: 67, pl. IX [9]: fig. 52) from the Vir Stream, *Sirodotia suecica* Kylin (1912: 38, figs 3, 16 a-f) from the Cetina River, *Paralemanea torulosa* (Roth) Sheath & A.R.Sherwood (2002: 137) from the Kupa River and *Polysiphonia subtilissima* Montagne (1840: 199) from the Zrmanja River and the Neretva River Valley (Koletić *et al.* 2019b, 2019c), recorded for the first time in Croatia in our study. Despite the numerous locations surveyed during our research, some species are still known only from the historical literature, such as *Porphyridium cruentum* (S.F.Gray) Nägeli (1849: 71) (Vouk 1953). Further surveys are necessary to locate this species in Croatian freshwaters. Furthermore, efforts to combine molecular and morphological methods are required for accurate species identification in future studies to complement the species list of the genus *Batrachospermum* and all other freshwater rhodophytes from Croatia.

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