

UPDATING KNOWLEDGE ON THE DISTRIBUTION OF RED ALGAE (RHODOPHYTA) IN SERBIA (SOUTHEAST EUROPE)

Rakonjac B. Aleksandra*, Simić B. Snežana

University of Kragujevac, Faculty of Science, Department of Biology and Ecology,
Radoja Domanovića 12, 34000 Kragujevac, Serbia

*Corresponding author; E-mail: aleksandra.mitrovic@pmf.kg.ac.rs

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ABSTRACT. Freshwater red algae (Rhodophyta) were surveyed in Serbia by examining 411 localities of 196 springs, streams and rivers during 2017-2022. A total of 80 new records of algae were made: species of the genera with *Batrachospermum*-like morphology (18), *Hildenbrandia rivularis* (30), *Lemanea* sp. (1), *L. fluviatilis* (2), *Paralemanea annulata* (15), *P. catenata* (11) and *P. torulosa* (3).

Keywords: red algae, *Batrachospermum*, *Hildenbrandia*, *Lemanea*, *Paralemanea*.

Red algae (Rhodophyta) are predominantly marine, with less than 3% occurring in freshwater environments. Freshwater members are distributed worldwide, but in scattered locations. These algae are mostly macroalgae and are well-represented in lotic environments (NECCHI, 2016; NECCHI and VIS, 2021; VIS and NECCHI, 2021a, 2021b). Freshwater red algae inhabit springs, streams, rivers, and lakes, principally being encountered in soft, clean, pure waters on a rocky substrate and variable current velocity (CESCHIN *et al.*, 2013; NECCHI, 2016). Due to their long and complex life cycle and high sensitivity to environmental impacts, the distribution and abundance of freshwater red algae are environmentally dependent (ELORANTA and KWANDRANS, 2004; NECCHI, 2016; NECCHI and VIS, 2021; VIS and NECCHI, 2021a, 2021b).

The first data about red algae in Serbia date back to the end of the 19th century when MAGNUS (1889) reported the occurrence of *Thorea hispida* (Thore) Desvaux (= *T. ramosissima* Bory) in the Danube River. From that period till now, 19 freshwater red algal taxa have been documented to occur in approximately 125 localities in Serbian aquatic ecosystems: *Audouinella chalybea* (Roth) Bory (as *Chantransia chalybea* (Roth) Fries), *A. pygmaea* (Kützing) Weber Bosse (as *Ch. pygmaea* Kützing), *Bangia atropurpurea* (Roth) C.Agardh, *Batrachospermum* sp., *B. cayennense* Montagne ex Kützing, *B. confusum* (Bory) Hassal, *B. ectocarpum* Sirodot, *B. gelatinosum* (Linnaeus) De Candole, *B. turfosum* Bory, *B. virgatodecaisneanum* Sirodot, *Hildenbrandia rivularis* (Liebmann) J.Agardh, *Lemanea* sp., *Lemanea fluviatilis* (Linnaeus) C.Agardh, *L. fucina* Bory, *L. rigida* (Sirodot) De Toni, *Paralemanea annulata* (Kützing) M.L.Vis & R.G.Sheath, *P. catenata* (Kützing) M.L.Vis & Sheath, *P. torulosa* (Roth) Sheath & A.R.Sherwood, and *T. hispida* (SIMIĆ and KRIZMANIĆ, 2018; MITROVIĆ and SIMIĆ, 2021; MITROVIĆ *et al.*, 2021; SABOVLJEVIĆ *et al.*, 2022; TOMOVIĆ *et al.*, 2022). The most frequently reported are the species of genera *Audouinella* and *Batrachospermum*, while *H. rivularis* is the most rarely reported freshwater red alga in Serbia (SIMIĆ and KRIZMANIĆ, 2018).

According to the Rulebook on the Declaration and Protection of Strictly Protected and Protected Wild Species of Plants, Animals, Fungi and Mushrooms – Appendix 1, ten species belonging to the genera *Bangia*, *Batrachospermum*, *Hildenbrandia*, *Paralemanea*, and *Thorea* are strictly protected in Serbia (ANONYMUS, 2010–2016). Although these algae are rare and protected in Serbia, and many of their habitats are located within the protected areas, their representatives and habitats are still under-protected or unprotected, and under the influence of various negative anthropogenic impacts (SIMIĆ *et al.*, 2010; MITROVIĆ and SIMIĆ, 2021; MITROVIĆ *et al.*, 2021).

During field surveys conducted in 2017–2022, a total of 411 localities in 196 riverine ecosystems were studied. A total of 80 samples of freshwater red algae were collected from 71 localities. 55% of these localities are located within the boundaries of different protected areas (Tab. 1). After detailed morphological and reproductive analysis under the light microscope Motic BA310, the collected samples were identified according to NECCHI and VIS (2021) and VIS and NECCHI (2021a, b). However, some freshwater genera cannot be easily distinguished based on morphology, especially in the case of the absence of reproductive organs in the sampling period. This is extremely expressed in the genus *Batrachospermum* sensu stricto, for which the usage of molecular analyses in combination with morphological analyses is required for reliable identification (VIS and NECCHI, 2021b). Regarding the *Batrachospermum* sensu stricto, only five species are currently recognized to belong to this genus, while other species have been placed in several new genera that came out from the genus *Batrachospermum* (VIS and NECCHI, 2021b).

In our field surveys, species of genera with *Batrachospermum*-like morphology (such as *Batrachospermum*, *Kumanoa*, *Paludicola*, *Sheathia*, *Visia* and *Volatus*) were collected at 18 new localities belonging to 16 riverine ecosystems. *Hildenbrandia rivularis*, one of the most rarely reported red alga in Serbia, has been found at 30 new localities (28 ecosystems), while *Lemanea* sp. was found at one and *L. fluviatilis* at two new localities. *Paralemanea annulata* was found at 15 new localities (11 ecosystems), *P. catenata* at 11 localities (7 ecosystems), and *P. torulosa* has been recorded at three new localities (Fig. 1, Tab. 1).

Concerning the genus *Batrachospermum*, from the six currently recognized species in Serbia, only *B. gelatinosum* stayed in the *Batrachospermum* genus, while the other five species are currently placed in the genera *Kumanoa*, *Sheathia*, *Paludicola*, and *Visia*. As we analyzed only morphological and reproductive features in our research, reliable identification of genera with *Batrachospermum*-like morphology was not possible, but our further molecular analyses that are in progress will try to resolve *Batrachospermum* and morphologically similar genera species diversity in Serbia.

Data presented in this paper indicates that *H. rivularis* is not as rare as thought, it is more probably overlooked. The species has been found in springs, where appeared together with the species of the genera with *Batrachospermum*-like morphology, but it was also found in upper, middle, and downstream parts of riverine ecosystems, non-rarely together with *Paralemanea* genus. In cave springs of the Degurić Stream and the Panjica River, it was found covering almost the entire bottom. In this paper, we also report the first occurrence of the species of the genera with *Batrachospermum*-like morphology growing together with *P. torulosa* at the Jelovičko Spring and with *P. catenata* at the Drina River.

According to already published data and data presented in this study, freshwater red algae have been found at in a total of 205 localities in Serbia: *Audouinella chalybea* (23 localities), *A. pygmaea* (9 localities), *Bangia atropurpurea* (10 localities), species of the genera with *Batrachospermum*-like morphology (48 localities), *Hildenbrandia rivularis* (33 localities), *Lemanea* sp. (3 localities), *L. fluviatilis* (18 localities), *L. fucina* (1 locality), *L. rigida* (3 localities), *Paralemanea annulata* (31 localities), *P. catenata* (14 localities), *P. torulosa* (7 localities), *Thorea hispida* (5 localities) (SIMIĆ and KRIZMANIĆ, 2018; MITROVIĆ and SIMIĆ, 2021; MITROVIĆ *et al.*, 2021; SABOVLJEVIĆ *et al.*, 2022; TOMOVIĆ *et al.*, 2022).

Table 1. New freshwater red algae localities in Serbia (2017–2022).

Taxa	Numerical symbol of the locality	Ecosystem ^{level of protected area}	Date of the first find	Geographical coordinates	Altitude (m a.s.l.)
<i>Species of the genera with <i>Batrachospermum</i>-like morphology</i>	1	Banjski Stream ⁴	11/11/2020	43.892028° N, 20.187917° E	355
	2	Drina River	07/24/2020	44.137652° N, 19.481928° E	186
	3	Gračanica River	09/06/2019	43.302361° N, 19.668806° E	478
	4	Channel near the Mileševka River	07/06/2019	43.365667° N, 19.724889° E	586
	5	Panjica River	11/11/2020	43.650583° N, 20.03449° E	643
	6	Veliki Rzav River	09/09/2021	43.562139° N, 19.971444° E	829
	7	Đerekarska River ³	10/14/2019	43.021236° N, 20.170276° E	1188
	8	Đerekarska River ³	06/26/2020	43.07662° N, 20.08061° E	1152
	9	Raška River	11/01/2020	43.115717° N, 20.371043° E	751
	10	Samokovska River ¹	09/13/2021	43.357372° N, 20.74241° E	997
	11	Mirovštica River ³	10/22/2019	43.795713° N, 21.903359° E	399
	12	Mirovštica River ³	10/22/2019	43.812586° N, 21.886045° E	317
	13	Crni Timok River	05/12/2019	43.825814° N, 21.747898° E	375
	14	Svrljiški Timok River	07/14/2020	43.378954° N, 22.264379° E	643
	15	Lisinska River ⁵	10/09/2019	44.104494° N, 21.641001° E	404
	16	Jelovičko Spring ²	08/20/2019	43.183384° N, 22.833397° E	791
	17	Mečkino kladenče Stream ³	08/08/2020	42.986028° N, 22.635306° E	496
	18	Krupačko Spring ⁵	05/28/2019	43.104806° N, 22.690475° E	373
<i>Hildenbrandia rivularis</i>	1	Banjski Stream ⁴	11/11/2020	43.892028° N, 20.187917° E	355
	19	Zapadna Morava River	09/13/2019	43.866392° N, 20.464924° E	158
	20	Kamenica River	05/23/2022	43.933466° N, 20.224159° E	482
	21	Godina River	07/24/2020	43.954605° N, 19.42612° E	281
	22	Đetinja River	09/24/2020	43.852661° N, 19.824176° E	536
	23	Bresnička River	08/07/2019	43.583139° N, 20.551797° E	428
	24	Brusnička River ⁶	08/07/2019	43.416889° N, 20.370306° E	787
	25	Brvenica River ²	08/07/2019	43.428139° N, 20.456306° E	1032
	26	Gradačka River ²	08/07/2019	43.367286° N, 20.537722° E	509
	27	Izobra River ⁶	08/07/2019	43.422893° N, 20.416815° E	1003
	28	Nošnica River	08/08/2019	43.533988° N, 20.225981° E	531
	29	Trnavska River	08/07/2019	43.287194° N, 20.575528° E	528
	30	Ibar River	07/14/2020	43.694081° N, 20.596717° E	249
	31	Gobeljska River ¹	06/18/2019	43.362528° N, 20.821056° E	1020
	32	Unnamed brook at the Kopaonik Mountain ¹	06/14/2022	43.320775° N, 20.799892° E	1102
	5	Panjica River	11/11/2020	43.650583° N, 20.03449° E	643
	33	Boračka River ⁵	05/17/2019	43.965028° N, 20.562167° E	332
	34	Unnamed brook at the Avala Mountain ⁴	04/28/2020	44.694639° N, 20.523861° E	502
	35	Voljevica River	09/24/2020	43.9932° N, 21.071483° E	447
	36	Voljevica River	09/24/2020	43.965113° N, 21.101674° E	235
	37	Degurić Stream ⁴	06/13/2019	44.237789° N, 19.884096° E	233
	38	Popovo Spring ⁴	06/13/2019	44.234564° N, 19.863327° E	257
	39	Beli Timok River	07/15/2020	43.881667° N, 22.297611° E	130
	40	Beli Timok River	07/15/2020	43.684528° N, 22.276694° E	198
	41	Hot spring in the Krivi Vir village	07/14/2020	43.823833° N, 21.746861° E	365
	42	Bigar Stream ²	10/29/2020	43.344889° N, 22.439361° E	498
	43	Rakitska River ²	08/20/2019	43.343217° N, 22.677865° E	734
	44	Rosomačka River ²	08/17/2019	43.153181° N, 22.856651° E	775
	45	Temštica River	08/20/2019	43.26319° N, 22.550054° E	395
	46	Nišava River ²	07/20/2020	43.311987° N, 22.052008° E	242

Table 1. continue

Taxa	Numerical symbol of the locality	Ecosystem ¹ level of protected area	Date of the first find	Geographical coordinates	Altitude (m a.s.l.)
<i>Lemanea fluviantilis</i>	47	Rupska River	08/12/2019	42.914881° N, 22.154971° E	622
	48	Dobrodolska River	06/06/2021	43.21037° N, 22.61183° E	582
<i>Lemanea</i> sp.	49	Stream in the Nature Reserve "Arbinje" ³	06/05/2021	43.316467° N, 22.795937° E	1333
<i>Paralelmanea annulata</i>	50	Ibar River	09/21/2019	42.933194° N, 20.421528° E	758
	30	Ibar River	07/14/2020	43.694081° N, 20.596717° E	249
	51	Resava River	06/07/2018	44.100398° N, 21.464933° E	208
	40	Beli Timok River	07/15/2020	43.684528° N, 22.276694° E	198
	52	Javorska River ²	08/21/2019	43.339671° N, 22.682063° E	732
	43	Rakitska River ²	08/20/2019	43.343217° N, 22.677865° E	734
	44	Rosomačka River ²	08/17/2019	43.153181° N, 22.856651° E	775
	53	Toplodolska River ²	08/21/2019	43.335427° N, 22.668165° E	701
	54	Temštica River	08/20/2019	43.296894° N, 22.610648° E	620
	55	Temštica River ²	08/20/2019	43.297273° N, 22.607376° E	504
	45	Temštica River ²	08/20/2019	43.26319° N, 22.550054° E	395
	56	Nišava River	06/22/2019	43.321793° N, 21.93905° E	198
	57	Jerma River ³	08/19/2019	42.979272° N, 22.638412° E	660
	58	Jerma River ³	08/08/2020	42.920497° N, 22.641796° E	606
	59	Ripivoda Waterfall ²	06/02/2020	43.024028° N, 21.492944° E	937
<i>Paralelmanea catenata</i>	60	Drina River	07/24/2020	43.959678° N, 19.420374° E	248
	2	Drina River	07/24/2020	44.137652° N, 19.481928° E	186
	61	Lim River	07/20/2020	43.226908° N, 19.724417° E	498
	62	Lim River	07/20/2020	43.575049° N, 19.530462° E	397
	63	Mlava River	08/07/2019	44.274898° N, 21.524715° E	172
	64	Crni Timok River	07/13/2020	43.904222° N, 22.210278° E	143
	65	Dojkinačka River ²	08/18/2019	43.200773° N, 22.806955° E	808
	66	Dojkinačka River ²	08/18/2019	43.177803° N, 22.827353° E	751
	67	Jelašnica River ²	08/20/2019	42.632542° N, 22.116223° E	433
	68	Vučjanka River ⁵	06/13/2019	42.856334° N, 21.914234° E	273
69	Vučjanka River	05/26/2019	42.862779° N, 21.911174° E	194	
<i>Paralelmanea torulosa</i>	70	Jelovička River ²	08/20/2019	43.182825° N, 22.831657° E	749
	16	Jelovičko Spring ²	08/20/2019	43.183384° N, 22.833397° E	791
	71	Gradiška River ⁴	05/28/2019	42.613992° N, 22.221978° E	898

Protected area levels: ¹National Park, ²Nature Park, ³Nature Reserve, ⁴Landscape of Outstanding Qualities, ⁵Nature Monument, ⁶Biosphere Reserve.

Despite the numerous ecosystems and localities surveyed in our research and quite updated knowledge on the diversity and distribution of red algae in Serbia, some species are still known only from a few localities, such as *L. fucina*, *L. rigida*, *T. hispida* and *P. torulosa*. Therefore, we emphasize the importance of further surveys with the aim to find new locations or new species of freshwater red algae in Serbia. Furthermore, a combination of morphological and molecular methods is required for reliable species identification and resolving the question about the list of species of the genera with *Batrachospermum*-like morphology in Serbia.

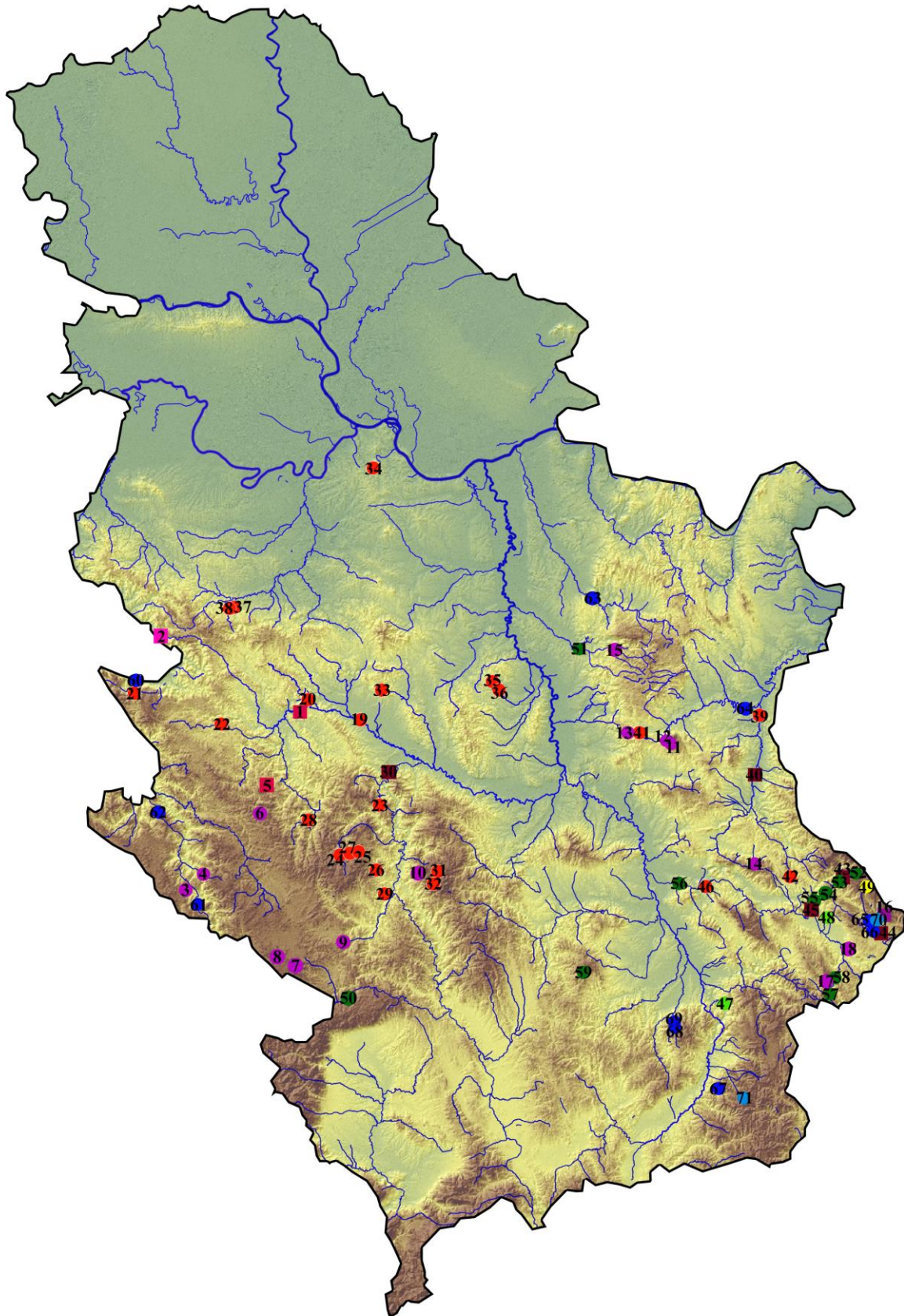


Figure 1. Geographical distribution of new Rhodophyta localities in Serbia (2017–2022):
 ● genera with *Batrachospermum*-like morphology, ● *Hildenbrandia rivularis*, ● *Lemanea* sp., ● *L. fluviatilis*, ● *Paralemanea annulata*, ● *P. catenata*, ● *P. torulosa*, ■ genus with *Batrachospermum*-like morphology and *H. rivularis*, ■ genus with *Batrachospermum*-like morphology and *P. catenata*, ■ genus with *Batrachospermum*-like morphology and *P. torulosa*, ■ *H. rivularis* and *P. annulata*.
 Numerical symbols are explained in Tab. 1.

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