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Qualitative Composition and Ecological Characteristics of Epiphytic Algal Assemblages in Bosnia and Herzegovina

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Abstract

The main characteristic of epiphytes is that they are attached algae or microorganisms on the surface of plants that are submerged in water or are present on the surface of the water habitat. In aquatic ecosystems, it has been shown that these forms of cohabitation have a great influence on the surrounding environment since epiphytic algae systems increase the complexity of the habitat and provide larger surface areas for colonization of invertebrates and other smaller organisms. To assess the diversity of epiphytic cyanobacteria and algae, stoneworts (*Chara virgata*), moss (*Fontinalis antipyretica*) and several aquatic macrophytes (*Calitriche palustris, Ceratophylum demersum, Nuphar lutea, Nymphaea alba, Potamogeton natans* and *Ranunculus aquatilis*) were studied. In the qualitative and quantitative composition of epiphytic cyanobacteria of algae identified from different macroalgae and aquatic macrophytes sampled at selected localities in Bosnia and Herzegovina, a total of 46 taxa were found. Identified taxa belong to the following classes: *Bacillariophyceae* (31 species or 68,89%), *Zygnematophyceae* (5 species or 11,11%), *Chlorophyceae* (2 species or 4,44%), *Cyanophyceae* (2 species or 4,44%), *Trebouxiophyceae* (2 species or 4,44%), *Xanthophyceae* (1 species or 2,22%), *Dinophyceae* (1 species or 2,22%) i *Euglenophyceae*(1 species or 2,22%). Based on

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the conducted research it can be concluded that the macroalgae and aquatic macrophyte can serve as a good substrate for colonization with different groups of algae, especially diatoms. In the future, it is necessary to continue this type of research and establish a database of epiphytic algae and use it as a good bioindicator in the monitoring of freshwater ecosystems.

Key words: *Epiphytic algae, Aquatic macrophyte, Biomonitoring, Freshwater ecosystems.*

1. Introduction

Epiphytic diatoms are an important group of organisms that live on the surface of aquatic plants, algae, and other substrates in freshwater and marine environments (Leliaert et al., 2009; Gao (2006), Lebednik & Armitage (2019), Peralta-Morales et al., (2021), Zhang et al. 2020, Marinho-Soriano & Branco (2005).

Freshwater environments benefit greatly from the presence of epiphytic algae. The ecological roles of epipelic algae including the biostabilization of sediments, control of benthic-pelagic nutrient cycle, and primary production. The most significant carbon source for benthic invertebrates including *Asellus aquaticus*, *Gammarus pulex*, and *Potamopyrgus antipodarum* was epiphytic algae growing on *Potamogeton perfoliatus*.

So far, there hasn't been a more in-depth assessment of freshwater biodiversity of epiphytic diatoms and their role in determining water quality on the many lakes and freshwater habitats Bosnia and Herzegovina has to offer. Over the last decade, we have witnessed a staggering decline in our water supply's quality. An increased anthropomorphic effect on our lakes due to potentially toxic waste is evident. In addition to that, the loss of quality and complexity of biodiversity can be attributed to the large floods which have been happening over the last decade in Bosnia and Herzegovina.

The focus of this research was to evaluate the biodiversity, ecosystems, and relative frequency of epiphytic algae on few different macrophytes (*Ranunculus aquatilis, Sium erectum, Callitricha palustris, Fontinalis antipyretica, Nuphar lutea, Ceratophylum demersum, Nymphea alba*), as well as their relationship with different ecological factors. Our findings imply that epiphyte facilitation by these algal hosts is vital not only for preserving species biodiversity throughout the year, but also for supplying food resources for biota.

2. Material and methods

Algological material was collected from nine micro-localities during summer seasons (2021) and transported to the Laboratory for the study of the Systematics of algae and fungi, Department of Biology, Faculty of Science, University of Sarajevo (Bosnia and Herzegovina). Epiphyte samples were collected from selected macroalgae and aquatic macrophytes. The collected material was fixed with a 4% formalin. Laboratory processing of diatoms was carried out applying methods used by Hustedt (1930). Light microscope observation was conducted using Best Scope 2020 microscope. Species composition and the quantitative relationship of diatoms were estimated from the permanent slides under 1000x magnification. At least 400 valves in each slide were counted for all samples. The identification of diatoms was supported by the following references: Lange-Bertalot & Metzeltin (1996); Cantonati et al. (2017). The nomenclature of identified algae was adjusted according to the following Guiry & Guiry (2023). Omnidia software version 6.0.8, was used for ecological data (Lecointe et al. 1993).

3. Results

3.1. Qualitative - quantitative composition of identified epiphytic algae

In qualitative-quantitative composition of epiphytic cyanobacteria and algae identified from different aquatic macrophytes sampled in selected localities in Bosnia and Herzegovina 45 taxon were stated in total. Identified taxa belong to classes: *Bacillariophyceae* (31 species or 68,89%), *Zygnematophyceae* (5 species or 11,11%), *Chlorophyceae* (2 species or 4,44%), *Cyanophyceae* (2 species or 4,44%), *Trebouxiophyceae* (2 species or 4,44%), *Xanthophyceae* (1 species or 2,22%), *Dinophyceae* (1 species or 2,22%) i *Euglenophyceae* (1 species or 2,22%).

Diversity of cyanobacteria and algae, distribution and type of substrate is presented tabularly and graphically (Table 1.).

Table 1. Diversity of cyanobactria and algae

Phylum	Classis	N	%
CYANOPHYTA	*Cyanophyceae*	2	4,44
HETEROKONTOPHYTA	*Xanthophyceae*	1	2,22
	Bacillariophyceae	31	68,89
DINOPHYTA	*Dinophyceae*	1	2,22
EUGLENOPHYTA	*Euglenophyceae*	1	2,22
CHLOROPHYTA	*Chlorophyceae*	2	4,44
	Zygnematophyceae	5	11,11
	Trebouxiophyceae	2	4,44
	Total:	45	100,00

Dominant taxa noted in the researched samples are: *Cocconeis placentula, Gomphonema truncatum, Cymbella aspera, Epithemia turgida, Gyrosigma sp., Achnanthidium minutissimum, Brebissonia lanceolata, Chlorella vulgaris, Cocconeis pediculus, Cocconeis lineata, Ellerbeckia arenaria, Encyonema minutum , Epithemia adnata, Eunotia bilunaris, Gomphonema acuminatum, Hantzschia amphioxys, Melosira varians, Mougeotia sp., Navicula radiosa, Navicula sp., Scenedesmus quadricauda* i *Ulnaria ulna*. The largest number of taxa was stated on macroalgae *Chara* virgata (18 species), while the smallest number of species was stated on moss *Fontinalis antipyretica* (1 species) and *Berula erecta* (1 species).

Qualitative-quantitative composition of epiphytic cyanobacteria and algae is presented tabularly and graphically (Table 2., Figure 2.). Overview of dominant species is presented in plate (Figure 1.).

Figure 1. Overview of dominant species of cyanobacteria and algae – 1. *Scenedesmus quadricauda*, 2. *Spirogyra* sp., 3. *Tribonema vulgare*, 4. *Craticula cuspidata*, 5. *Oscillatoria* sp., 6. *Euglena viridis.*

Table 2. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified from different microlocalities

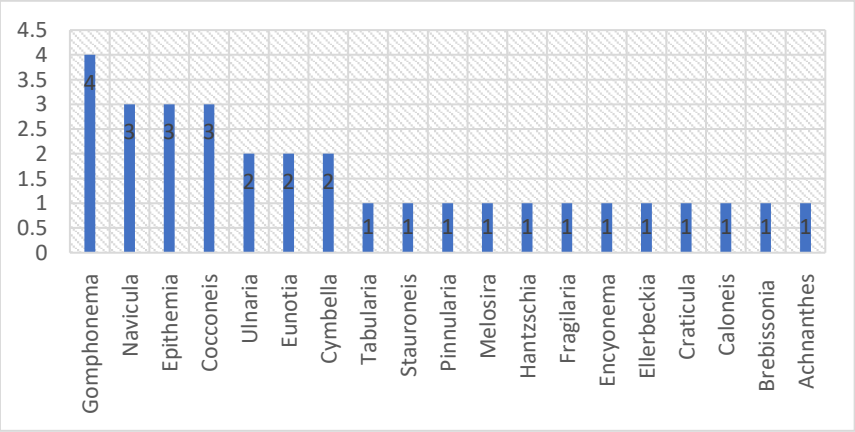
	Chara virgata	*Fontinalis antipyretica*	*Berula erceta*	*Calitriche palustris*	*Ceratophylum demersum*	*Numphar lutea*	*Nymphea alba*	*Potamogeton natans*	*Ranunculus aquatilis*	
Taxon list	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**F**
CYANOPHYTA	.	.	.	.	.	.	.	.	.	.
Cyanophyceae		.	.	.	.	.	.	.	.	.
Oscillatoria princeps	.	.	.	+	.	.	.	.	.	1
Phormidium sp.	.	.	.	.	.	+	.	.	.	1
HETEROKONTOPHYTA	.	.	.	.	.	.	.	.	.	.
Xanthophyceae	.	.	.	.	.	.	.	.	.	.
Tribonema vulgare	.	.	.	.	.	.	.	+	.	1
Bacillariophyceae	.	.	.	.	.	.	.	.	.	.
Achnanthes minutissima	.	.	.	+	.	+	.	.	.	2
Brebissonia lanceolata	+	.	.	.	.	.	.	.	.	1
Caloneis silicula	.	.	.	.	.	.	+	.	.	1
Cocconeis placentula	+	.	+	.	.	.	.	.	+	3
Cocconeis pediculus	+	.	.	.	.	.	.	.	.	1
Cocconeis lineata	+	.	.	.	.	.	.	.	.	1
Craticula cuspidata	.	.	.	.	.	.	.	.	+	1
Cymbella aspera	+	.	.	.	+	.	.	.	+	3
Cymbella lanceolata	.	.	.	.	+	.	.	.	.	1
Ellerbeckia arenaria	.	.	.	+	.	.	.	.	.	1
Encyonema minutum	+	.	.	.	.	+	.	.	.	2
Epithemia adnata	+	.	.	.	+	.	.	.	.	2
Epithemia turgida	+	.	.	.	+	.	.	.	.	2
Epithemia sorex	+	.	.	.	.	.	.	.	.	1
Eunotia bilunaris	.	.	.	.	+	.	.	.	.	1
Eunotia minor	.	.	.	.	+	.	.	.	.	1
Fragilaria capucina	.	.	.	.	.	.	+	.	.	1
Gomphonema acuminatum	.	.	.	.	.	.	.	.	+	1
Gomphonema dichotomum	.	.	.	+	.	.	.	.	.	1
Gomphonema truncatum	+	.	.	.	.	.	+	.	+	3
Gomphonema minutum	+	.	.	.	.	.	.	.	.	1
Hantzschia amphyoxus	.	.	.	.	.	.	.	.	+	1
Melosira varians	.	.	.	.	.	.	.	.	+	1
Navicula radiosa	.	+	.	.	.	.	.	.	.	1
Navicula sp.	.	.	.	+	+	.	.	.	.	2
Navicula viridula	.	.	.	.	.	.	.	.	+	1
Pinnularia major	.	.	.	.	+	.	.	.	.	1
Stauroneis anceps	.	.	.	.	.	.	.	+	.	1
Tabularia affinis	.	.	.	.	.	.	.	.	+	1
Ulnaria delicatissima	+	.	.	.	.	.	.	.	.	1
Ulnaria ulna	.	.	.	.	.	.	.	.	+	1

DINOPHYTA	.	.	.	.	.	.	.	.	.	.
Dinophyceae	.	.	.	.	.	.	.	.	.	.
Peridinium sp.	.	.	.	.	+	.	.	.	.	1
EUGLENOPHYTA	.	.	.	.	.	.	.	.	.	.
Euglenophyceae	.	.	.	.	.	.	.	.	.	.
Euglena viridis	.	.	.	.	.	.	.	.	+	1
CHLOROPHYTA	.	.	.	.	.	.	.	.	.	.
Chlorophyceae	.	.	.	.	.	.	.	.	.	.
Coelastrum astroideum	.	.	.	.	.	.	+	.	.	1
Scenedesmus quadricauda	+	.	.	.	.	.	+	.	.	2
Trebouxiophyceae	.	.	.	.	.	.	.	.	.	.
Chlorella vulgaris	.	.	.	.	.	.	.	+	+	2
Oocystis naegelii	+	.	.	.	.	.	.	.	.	1
Zygnematophyceae	.	.	.	.	.	.	.	.	.	
Cosmarium sp.	+	.	.	.	.	.	.	.	.	1
Mougeotia sp.	.	.	.	.	+	.	.	+	.	2
Pleurotaenium trabecula	.	.	.	.	+	.	.	.	.	1
Spirogyra crassa	+	.	.	.	.	.	.	.	.	1
Spirogyra weberi	+	.	.	.	.	.	.	.	.	1
Stuarastrum gracile	+	.	.	.	.	.	.	.	.	1
UKUPNO	**18**	**1**	**1**	**5**	**11**	**3**	**5**	**4**	**12**	

3.2. Diversity of epiphytic diatoms

A total of 31 taxa belong to class *Bacillariophyceae*. Genera with the highest number of species were *Epithemia* (4), *Gomphonema* (4), *Navicula* (3), *Cocconeis* (2 taxa), *Cymbella* (2 taxa), *Eunotia* (2) and *Ulnaria* (2 taxa). All identified taxa belonging to the pennate diatoms.

The most common species were: *Achnanthes minutissima, Cocconeis placentula, Cymbella aspera, Encyonema minutum, Epithemia adnata, Epithemia turgida, Gomphonema truncatum* and *Navicula* sp. (Graph 2).



Graph 2. Diversity of epiphytic diatoms on selected substrates

3.2. Biological characteristics of aquatic macrophytes and overview of diversity of epiphytic algae

In order to analyze epiphytes cyanobacteria and algae, representatives were selected: macroalgae (*Chara* virgata), moss (*Fontinalis antipyretica*) and aquatic macrophytes (*Calitriche palustris, Ceratophylum demersum, Nuphar lutea, Nymphaea alba, Potamogeton natans* and *Ranunculus aquatilis*).

3.3.Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Chara virgata (Charophyceae)

Chara virgata is a green algae in the family *Characeae*. They are multicellular and superficially resemble land plants because of stem-like and leaf-like structures. They are found in freshwater, particularly in limestone areas throughout the northern temperate zone, where they grow submerged, attached to the muddy bottom. They prefer less oxygenated and hard water. They are covered with calcium carbonate deposits and are commonly known as stoneworts. Cyanobacteria have been found growing as epiphytes on the surfaces of *Chara*, where they may be involved in fixing nitrogen, which is important to plant nutrition.

Epiphytic algae that inhabit macroalgae *C. virgata* belong to the class *Bacillariophyceae* (13 species or 72,22%), while with a lower degree of biodiversity were algae from classes: *Zygnematophyceae* (3 species or 16,66%), *Trebouxiophyceae* (1 species or 5,55%) and *Chlorophyceae* (1 species or 5,55%).

The following epiphytic algae were identified: *Cocconeis pediculus* Ehrenberg, *Cocconeis placentula* Ehrenberg, *Cocconeis lineata* Ehrenberg, *Cosmarium sp., Cymbella aspera* (Ehrenberg) Cleve, *Brebissonia lanceolata* (C.Agardh) R.K.Mahoney & Reimer, *Encyonema minutum* (Hilse) D.G.Mann, *Epithemia adnata* (Kützing) Brébisson, *Epithemia sorex* Kützing, *Epithemia turgida* (Ehrenberg) Kützing, *Gomphonema minutum* (C.Agardh) C.Agardh, *Gomphonema truncatum* Ehrenberg, *Oocystis naegelii* A.Braun*, Scenedesmus quadricauda* (Turpin) Brébisson in Brébisson & Godey, *Spirogyra crassa* (Kützing) Kützing, *Spirogyra weberi* Kützing, *Staurastrum gracile* Ralfs ex Ralfs and *Ulnaria delicatissima* (W.Smith) Aboal & P.C.Silva*.*

3.4. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Fontinalis antipyretica (Bryophyta)

Fontinalis antipyretica, greater water-moss or common water moss, is a species of submerged aquatic moss belonging to the subclass Bryidae. It is found in both still and flowing freshwater in Europe, Asia, Greenland and Africa. *F. antipyretica* has

branched, trailing stems that are triangular in cross-section and may get as long as 60 cm. The leaves are quite stiff and are arranged in three overlapping rows. Each leaf is lance-shaped or egg-shaped, with a keel and a sharp point, some 4 to 9 mm (0.16 to 0.35 in) long. There are no flowers but minute spores are sometimes produced in smooth sporangia (capsules) between 2 and 2.6 mm long. It grows attached to submerged rocks in fast-flowing water. It also occurs attached to the substrate in lakes and as floating masses in still water, and may be cast up on beaches at the waterside. It thrives in shaded environments and prefers acid water, a pH of around 8.4 being the maximum tolerated. *F. antipyretica* grows in large clumps and mats and provides refuge for fish eggs and fry. Numerous invertebrates shelter among the fronds; Chironomid larvae hide in the bases of the leaves and mayfly, caddisfly and stonefly larvae cling to the fronds, and in fast-flowing water black fly larvae are often present. Diatoms and other microscopic algae grow epiphytically on the fronds. Epiphytic algae which inhabit water moss *F. antipyretica* belong to class Bacillariophyceae (1 species or 100%). Only one type of silicate algae was identified, namely: *Navicula radiosa* Kützing.

3.5. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Berula erecta (Cormophyta)

Berula erecta, known as lesser water-parsnip or cutleaf waterparsnip or narrow-leaved water-parsnip, is a member of the carrot family. Growing to around 1 m tall, it is found in or by water. It is widespread across a significant part of Europe, Asia, Australia, and North America. *B. erecta* has a hollow stem. Underwater leaves consist of compounds with thread-like lobes; leaves above the surface of the water are flatter and broader. The plant produces many small white flowers in a compound umbel. *B. erecta* occurs on poorly drained neutral and acidic soils of the lowlands and upland fringe. It typically resides in shallow aquatic environments containing moderate nutrient levels. During the winter, its stem and body become completely submerged underwater. *B. erecta* has been shown to survive and grow better after living in stressful conditions with either limiting or excess nutrients or mechanical stress. *B. erecta* has toothed leaves from one and a half to two inches across, each containing around twenty white flowers.

Epiphytic algae which inhabit the aquatic macrophyte *B. erecta* belong to the class *Bacillariophyceae* (1 species or 100%).

On the surface of aquatic macrophyte only one type of silicate algae was identified, namely: *Cocconeis placentula* Ehrenberg.

3.6. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Calitriche palustris (Cormophyta)

Calitriche palustris - Water starwort, also known as vernal water starwort or common waterwort, belongs to *Callitrichaceae*, the water starwort family. The majority of the leaves float in small clusters atop the water's surface, with the entire plant growing up to a foot in height, roots relatively firmly planted in the soil. It's native to North America, Europe, and the majority of Asia, typically growing in and around the slow-moving, shallow waters of creeks, small lakes, and vernal ponds where it helps provide valuable habitat to frogs, turtles, and other reptiles and amphibians that depend upon vernal pools for survival.

Epiphytic algae that inhabit aquatic macrophyte *C. palustris* belong to classes: *Bacillariophyceae* (4 species or 80%) and *Euglenophyceae* (1 species or 20%).

The following epiphytic algae were identified: *Achnanthes minutissima* Kutzing, *Ellerbeckia arenaria* (D. Moore ex Ralfs) Dorofeyuk & Kulikovskiy, *Gomphonema dichotomum* Kutzing , *Navicula* sp. and *Oscillatoria princeps* Vaucher ex Gomont.

3.7. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Ceratophylum demersum (Cormophyta)

Ceratophyllum demersum, commonly known as hornwort, rigid hornwort, coontail, or coon's tail, is a species of Ceratophyllum. It is a submerged, free-floating aquatic plant, with a cosmopolitan distribution, native to all continents except Antarctica. It is a harmful introduced weed in New Zealand. It is also a popular aquarium plant. An aquatic plant, *C. demersum* has stems that reach lengths of 1–3 m, with numerous side shoots making a single specimen appear as a large, bushy mass. The leaves are produced in whorls of six to twelve, each leaf 8–40 mm long, simple, or forked into two to eight thread-like segments edged with spiny teeth; they are stiff and brittle. It is monoecious, with separate male and female flowers produced on the same plant. The flowers are small, 2 mm long, with eight or more greenish-brown petals; they are produced in the leaf axils. The fruit is a small nut 4–5 mm long, usually with three spines, two basal and one apical, 1–12 mm long. *C. demersum* has allelopathic qualities as it excretes substances that inhibit the growth of phytoplankton and cyanobacteria (blue-green algae). Its dense growth can outcompete native underwater vegetation, leading to loss of biodiversity.

Epiphytic algae that inhabit aquatic macrophyte *C. demersum* belong to class *Bacillariophyceae* (11 species or 100%).

The following epiphytic algae were identified: *Cymbella aspera* (Ehrenberg) Cleve, *Epithemia adnata* (Kützing) Brébisson, *Epithemia turgida* (Ehrenberg) Kützing, *Eunotia bilunaris* (Ehrenberg) Schaarschmidt, *Eunotia minor* (Kützing) Grunow, *Mougeotia* sp., *Cymbella lanceolata* C.Agardh, *Navicula* sp., *Peridinium* sp., *Pinnularia major* (Kützing) Rabenhorst and *Pleurotaenium trabecula* Nägeli.

3.8. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Nuphar lutea (Cormophyta)

Nuphar lutea, the yellow water-lily, brandy-bottle, or spatterdock, is an aquatic plant of the family *Nymphaeaceae*, native to northern temperate and some subtropical regions of Europe, northwest Africa, western Asia, North America, and Cuba. This interesting species found on both sides of the Atlantic Ocean was used as a food source and in medicinal practices from prehistoric times with potential research and medical applications going forward.

Epiphytic algae that inhabit aquatic macrophyte *N. lutea* belong to classes *Bacillariophyceae* (2 species or 66,66%) and *Cyanophyceae* (1 species or 33,33%).

The following epiphytic algae were identified: *Achnanthidium minutissimum* (Kützing) Czarnecki, *Encyonema minutum* (Hilse) D.G.Mann and *Phormidium* sp.

3.9. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Nymphaea alba (Cormophyta)

Nymphaea alba, the white water lily, European white water lily or white nenuphar, is an aquatic flowering plant in the family *Nymphaeaceae*. It is native to North Africa, temperate Asia, Europe and tropical Asia (Jammu and Kashmir). It grows in water that is 30–150 cm (12–59 in) deep and likes large ponds and lakes. The leaves can be up to 30 cm (12 in) in diameter and take up a spread of 150 cm (59 in) per plant. The flowers are white and they have many small stamens inside.

Epiphytic algae that inhabit aquatic macroalgae *N. lutea* belong to classes *Bacillariophyceae* (3 species or 60,00%) and *Chlorophyceae* (2 species or 40,00%).

The following epiphytic algae were identified: *Caloneis silicula* (Ehrenberg) Cleve, *Coelastrum astroideum* De Notaris, *Fragilaria capucina* Desmazières, *Gomphonema truncatum* Ehrenberg and *Scenedesmus quadricauda* (Turpin) Brébisson in Brébisson & Godey.

3.10. Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Potamogeton natans (Cormophyta)

Potamogeton natans, commonly known as broad-leaved pondweed, floating pondweed, or floating-leaf pondweed, is an aquatic species in the genus *Potamogeton* native to quiet or slow-flowing freshwater habitats throughout the Holarctic Kingdom. It produces both floating and submerged leaves on the same plant. The floating leaves are ovate to oblong-ovate and almost always cordate at the base. They are dark green, leathery, opaque, with translucent longitudinal veins. They are 5 to 10 cm long, pointed at the tips, and rounded at the base. The stipules are 4 to 17 cm long. The submerged grass-like structures are called phyllodes, and are actually modified leaf stalks. The stems are cylindrical, without many branches, and grow from 1 to 2 meters. The main difference between this species and other pondweeds is a discolored flexible joint just below the top of the long leaf stalk. The flower spikes are dense, and cylindrical. They are 5 to 10 cm long, pointed at the tip and rounded at the base. It flowers from May to September. The fruits are 4 to 5 mm long and obovate.

Epiphytic algae that inhabit aquatic macrophyte *N*. *lutea* belong to classes *Bacillariophyceae* (1 species or 25,00%), *Xanthophyceae* (1 species or 25,00%) i *Zygnematophyceae* (2 species or 50,00%).

The following epiphytic algae were identified: *Chlorella vulgaris* Beijerinck, *Mougeotia* sp., *Stauroneis anceps* Ehrenberg and *Tribonema vulgare* Pascher.

3.11.Qualitative-quantitative composition of epiphytic cyanobacteria and algae identified on Ranunculus aquatilis (Cormophyta)

Ranunculus aquatilis, the common water-crowfoot or white water-crowfoot, is a plant species of the genus Ranunculus, native throughout most of Europe and western North America, and also northwest Africa. This is an aquatic plant, growing in mats on the surface of water. It has branching thread-like underwater leaves and toothed floater leaves. In fast flowing water the floaters may not grow. The flowers are white petaled with yellow center and are held a centimeter or two above the water. The floater leaves are used as props for the flowers and grow at the same time.

Epiphytic algae that inhabit aquatic macrophyte *R*. *aquatilis* belong to classes *Bacillariophyceae* (10 species or 83,33%), *Euglenophyceae* (1 species or 8,33%) and *Trebouxiophyceae* (1 species or 8,33%).

The following epiphytic algae were identified: *Chlorella vulgaris* Beijerinck, *Cocconeis placentula* Ehrenberg, *Craticula cuspidata* (Kutzing) D.G.Mann, *Cymbella aspera* (Ehrenberg) Cleve, *Euglena viridis* (O.F.Müller) Ehrenberg, *Gomphonema acuminatum* Ehrenberg, *Gomphonema truncatum* Ehrenberg, *Hantzschia amphyoxus* (Ehrenberg) Grunow in Cleve & Grunow, *Melosira varians* C.Agardh, *Navicula viridula* (Kützing) Ehrenberg, *Tabularia affinis* (Kützing) Snoeijs and *Ulnaria ulna* (Nitzsch) Compère.

4. Disscussion

There haven't been many studies of epiphytic algae in Bosnia and Herzegovina. The works of Hafner & Jasprica (2013) and Hafner et al. (2013) contain information on the variety of this incredibly fascinating group of species. The aforementioned research focuses on analyzing various habitat types, particularly mountain lakes and wetland environments. In the mentioned study, the scientists looked at the variety of epiphytic algae on vascular plants (*Nymphaea alb*a) and stoneworts (*Chara sp*.). They discovered 37 distinct taxa on stenworts, including: *Achnanthidium affine, Amphora lybica, Cocconeis pediculus, Cyclotella meneghiniana, Cymbella turgida, Denticula sp., Diatoma elongatum var. minor, Ellerbeckia arenaria, Encyonema prostratum, Eucocconeis flexella, Eunotia praerupta, Gomphonema augur, Gomphonema olivaceum var. calcareum, Gomphonema sp., Grunowia sinuata, Gyrosigma sp. 1, Gyrosigma sp. 2, Gyrosigma sp. 3, Hantzschia amphyoxys, Mastogloia lacustris, Melosira varians, Navicula exigua, Navicula radiosa, Navicula tripunctata, Neidium affine var. amphyrinchus, Nitzschia sigmoidea, Nitzschia sp. 1., Nitzschia vermicularis, Pinnularia borealis, Pinnularia rabenhorstii, Pinnularia viridis, Rhopalodia gibba var. parallela, Stauroneis smithii, Staurosirella leptostauron, Surirella spiralis, Ulnaria danica* and *Ulnaria oxyrhynchus.* On the leaves of the aquatic macrophyte *Nymphea alba,* a total of 21 taxa have been identified, including: *Amphora ovalis, Brebissonia lanceolata, Cocconeis plancetula, Cocconeis plancetula var. lineata, Cyclotella comta, Cymatopleura solea, Denticula tenuis, Encyonema silesiacum, Epithemia turgida, Eunotia arcus, Eunotia bilunaris, Eunotia tenella, Gomphonema intricatum, Gomphonema longiceps, Gomphonema truncatum, Gyrosigma acuminatum, Rhopalodia gibba, Stauroneis phoenicenteron, Staurosira construens, Ulnaria capitata* and *Ulnaria ulna.*

Comparison of our findings with information from the literature or studies conducted in Bosnia and Herzegovina are shown in Table 3.

Table 3. Comparative overview of diversity of epiphytic algae distributed on different substrates and localities

Locality	Reference	Coordinate N	Coordinate E	Altitude	Macroalgae species	Macrophyte species	Number of taxa
Hutovo blato*	*	43°02’23.71”	17°44’22.76”	432	0	*Nymphaea alba*	21
Orlovačko jezero (Maglić)	**	43°22’39”	18°32’57”	1443	*Chara virgata*	0	18
Trebižat*	*	43°09’21.8”	17°36’21.2”	47	*Chara sp. (Charophyceae)*	0	12
Stojčevac	**	43°48'36"	18°17'20"	500	*0*	*Ranunculus aquatilis*	12
Čvrsnica*	*	43°38’09.8”	17°32’26.3”	1290	*Chara sp. (Charophyceae)*	0	11
Zemaljski muzej Bosne i Hercegovine	**	43°51'16.21"	18°24'9.50"	600?	0	*Ceratophylum demersum*	11
Bjelašnica (Lake Kalajli)*	*	43°43’27.4”	18°07’32.3”	1650	*Chara sp. (Charophyceae)*	0	9
Mostarsko Blato*	*	43°21’13.9”	17°43’58.6”	230	*Chara sp. (Charophyceae)*	0	5
Stojčevac	**	43°48'36"	18°17'20"	500	*0*	*Callitriche palustris*	5
Zemaljski muzej Bosne i Hercegovine	**	43°51'16.21"	18°24'9.50"	600?	0	*Nymphea alba*	5
Vranica	**	43°57.400’	17°42.993'	1660	0	*Potamogeton / Callitriche*	4
Boračko jezero	**	43°33’09”	18°01’52”	397	0	*Nuphar lutea*	3
Stojčevac	**	43°48'36"	18°17'20"	500	0	*Sium erectum*	1
Stojčevac	**	43°48'36"	18°17'20"	500	0	*Fontinalis antipyretica*	1

*Literature
** Current research

There are a total of 45 taxa listed in the qualitative-quantitative composition of epiphytic cyanobacteria and algae isolated from various water macrophytes in chosen locations in Bosnia and Herzegovina.

The *Nymphea alba* species had the highest number of taxa found on its leaves, whereas *Sium erectum* and *Fontinalis antipyretica* had the lowest number of taxa found throughout all analyzed localities, including algae and aquatic macrophytes.

On the surfaces of *Chara*, cyanobacteria have been observed developing as epiphytes, suggesting that they may be involved in fixing nitrogen, a crucial component of plant nutrition. Green algae belonging to the *Characeae* family include

Chara virgata. They grow submerged and connected to the muddy bottom in freshwater, especially in limestone regions of the northern temperate zone.

Greater water-moss, sometimes known as common water moss, is a type of submerged aquatic moss that belongs to the family *Bryidae*. Fish eggs and fry are protected by the huge clusters and mats of *F. antipyretica*. Several insects find refuge amid the fronds. On the fronds, diatoms and other tiny algae develop epiphytically.

The carrot family includes *Berula erecta*, sometimes referred to as smaller water-parsnip, cutleaf water-parsnip, or narrow-leaved water-parsnip. Its stem and body fully submerge underwater throughout the winter. It has been demonstrated that *B. erecta* thrives in stressful environments that include either a lack of or an abundance of nutrients or mechanical stress.

The aquatic plants from family, *Callitrichaceae*, includes *Calitriche palustris*, often known as vernal water starwort or common waterwort. The majority of the leaves are floating in small groups on the water's surface, and the total plant can reach a height of up to a foot, with roots that are largely securely embedded in the ground.

A species of *Ceratophyllum* is *Ceratophyllum demersum*, often called hornwort, rigid hornwort, coontail, or coon's tail. With the exception of Antarctica, it is a native to all continents and is a submerged, free-floating aquatic plant with a global distribution. Because of the chemicals that *C. demersum* excretes that prevent cyanobacteria and phytoplankton from growing, it exhibits allelopathic properties (blue-green algae). Because of its intense growth, it may displace natural submerged plants, reducing biodiversity.

The intriguing yellow water lily, *Nuphar lutea*, has been utilized as a food source and in traditional medicine since prehistoric times.

The most effective portions of the white water lily, *Nymphaea alba*, utilized in traditional herbal medicine, are the petals and other floral parts.

The plant *Potamogeton natans*, also referred to as floating pondweed, produces both submerged and floating leaves.

Epiphytic biofilms play an important role in freshwater ecosystems. They are one of the main primary producers in shallow freshwater ecosystems and are comprised of an autotrophic community made up of diatoms, green algae, and cyanobacteria, and a heterotrophic community consisting of bacteria, protozoa, fungi, and other microorganisms. Macrophytes are the host domain for epiphytic biofilm, providing substrate and influencing epiphytic biofilm via structural characteristics. Strong competitive, mutualistic, and commensalistic relationships between epiphytic

biofilm and macrophytes have resulted from interactions for resources (e.g., light and nutrients) and trophic and allelopathic dynamics (Gao, 2006).

Epiphytic biofilms play multiple roles in aquatic ecosystems and are important for maintaining ecosystem structure, specifically community composition and diversity, as well as functions such as primary production and respiration, trophic interactions, nutrient uptake and cycling, decomposition, pollutant removal, and microbial gene pool preservation (Lebednik & Armitage, 2019).

5. Conclusions

Epiphytic algae are a group of algae found attached and living on submerged aquatic vegetation, which includes freshwater angiosperms and macroalgae. These organisms are considered as a primary source of food for small fish and several invertebrates in the littoral zone. They also serve as good indicators of water quality and environmental conditions in an aquatic ecosystem. They play a major role in the ecological balance between various groups of living organisms (macrophytes) and their environment. Macrophytes may provide epiphytes with dual benefits of substrate and a nutrient source. For future studies, it might be interesting to investigate the effect of the structural complexity of aquatic macrophytes on epiphytic algal, macroinvertebrates, and their interspecific relationships.

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Author contribution

All authors in this article have contributed equally to the preparation and writing of this article.

Conflict of Interest Statement

The authors declare that there aro no conflicts of interest regarding the publication ot this work.