PLANTS, MOSSES, CHAROPHYTES, PROTOZOAN, AND BACTERIA WATER QUALITY INDICATORS FOR ASSESSMENT OF ORGANIC POLLUTION AND TROPHIC STATUS OF CONTINENTAL WATER BODIES

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ABSTRACT

This paper presents data compilation for indicator species of organic pollution and trophic state of continental waters. Information was collected from research papers, monographs, electronic resources, and our research. Altogether 316 species of higher plants, plants, mosses, charophytes, protozoan, and bacteria from 11 taxonomical phyla are represented with ecological preferences for saprobity indicators with saprobity index (S) and indicators of trophic state. This comprehensive data can be used for the purpose of aquatic ecosystem assessment and monitoring of water quality based on bioindication methods.

ZUSAMMENFASSUNG: Pflanzen, Moose, Charophyten, Protozoen und Bakterien als Indikatoren für die Beurteilung organischer Verschmutzung und trophischen Zustand kontinentaler Gewässer.

Dieses Papier präsentiert eine Datenzusammenstellung für Indikatorarten der organischen Verschmutzung und des trophischen Zustands kontinentaler Gewässer. Informationen wurden aus Forschungsarbeiten, Monographien, elektronischen Ressourcen und unserer eigenen Forschung gesammelt. Insgesamt sind 316 Arten höherer Pflanzen, Moose, Charophyten, Protozoen und Bakterien aus 11 taxonomischen Phyla mit ökologischen Präferenzen für Saprobitätsindikatoren mit Saprobitätsindex (S) und Indikatoren für den trophischen Zustand vertreten. Diese umfassenden Daten können für die Bewertung aquatischer Ökosysteme und die Überwachung der Wasserqualität auf der Grundlage von Bioindikationsmethoden verwendet werden.

REZUMAT: Plante, mușchi, carofite, protozoare şi bacterii, indicatori ai calității apei pentru evaluarea poluării organice și a stării trofice a corpurilor de apă continentale.

Această lucrare prezintă o compilare a datelor pentru speciile indicatoare de poluare organică și a stării trofice a apelor continentale. Informațiile au fost colectate din lucrări de cercetare, monografii, resurse electronice și propriile noastre cercetări. În total, 316 specii de plante superioare, mușchi, carofite, protozoare și bacterii din 11 phylumuri taxonomice sunt reprezentate cu preferințele ecologice pentru indicatorii de saprobitate cu indicele de saprobitate (S) și indicatorii stării trofice. Aceste date pot fi utilizate în scopul evaluării ecosistemului acvatic și al monitorizării calității apei pe baza metodelor de bioindicaţie.

INTRODUCTION

The biological variables, proposed by the European Union Water Framework Directive (European Parliament, 2000) as quality elements for the classification of the ecological status of waters included composition and abundance not only of algae and cyanobacteria but also other aquatic flora (i.e., macroalgae and angiosperms) (Ponti et al., 2009). Macrophytes, the large group of aquatic plants including Charophytes macroalgae, bryophytes, and vascular plants, are essential groups for assessing the water quality of surface waters. Because they can become very abundant, often showing the dominance of those species that are usually related to trophic states of water bodies (Pešić et al., 2020). The bioindication method, based on analyzing the response of biota to changes in environmental conditions, is of great significance in estimating the effect of pollution on aquatic ecosystems (Schindler, 1987; Kent, 2000; Fennessy et al., 2001; Mack, 2001; USEPA 2003; Reiss and Brown, 2005). Saprobity index S can be calculated for the macrophytes community and then incorporated into the water quality assessment system, especially for organic pollution (Savitskaya, 2017; Zueva and Bobrov, 2018). Assessment of anthropogenic impact by macrophytes is used for the lakes and wetlands (Poikane et al., 2018). And it is also a developed system with combined assessment methods for the diatoms, invertebrates, and other aquatic inhabitants (Friedrich et al., 1996; Hering et al., 2006).

Our work in collecting the environmental preferences of aquatic species has a long history. First of all, we paid attention to the ecological characteristics of algae and cyanobacteria, collecting information from solid published works of reliable authors and combining information into a database. The work continued for more than 30 years, and data were compiled for 11 groups of indicators in various indicator systems. Currently, part of this array of data on the ecological preferences of algae and cyanobacteria includes 9,450 species (Barinova and Fakhima, 2017). It was published in two books, the indicator tables are in English and are available via electronic link in references (Barinova et al., 2006, 2019). In this work, we have set the task to collect indicative data on other organisms inhabiting the aquatic environment. The material turned out to be so large that we considered it logical to divide into two parts, each of which combined into different publications. Currently, both these parts are ready for publication. The ecological preferences of aquatic invertebrates will be presented in the next volume of Transylvanian Review of Systematical and Ecological Research (24.1, 2022). Here, we present descriptions and results that combine reference data on indicator species from different phyla of aquatic plants, mosses, and other organisms that are not algae, cyanobacteria, and invertebrates. It can serve as an indicator of water quality to assess the impact of pollution on aquatic ecosystems.

We aimed to compile the list of aquatic species inhabitants in continental water bodies from plants, mosses, some protozoan, and bacteria with each species preferences for different level of water organic pollution and trophic state.

MATERIAL AND METHODS

The data collected on ecological preferences of aquatic species of plants, mosses, protozoan, and bacteria were taken from the available nine monographs, published papers, and electronic resources (Nevo and Wasser, 2000 [1]; Schneider and Melzer, 2003 [9]; Marvan et al., 2005 [2]; Haury et al., 2006 [8]; Porter, 2008 [4]; Jäger, 2010 [7]; Nagengast and Kuczyńska-Kippen, 2015 [5]; Becker et al., 2016 [3]; and Trbojević et al., 2020 [6]). The number in square brackets corresponds to the reference number in the environmental preferences table. Each species information was collected and inserted into the table, the data is classified according to categories of bioindication (Barinova, 2017a). The ecological

characteristics of species are grouped according to the following significant variables: trophic state and water saprobity with self-purification zones according to Sládeček (1973), and species-specific Index saprobity S.

The ecological preferences of each taxon are usually described in different sources, from which we took all the available information and then summarized it for each indicator. In the data integration process, we provided the indicator values mentioned in the reference, and if there were several data, then the highest of them. For example, if there were different values of the species-specific index of saprobity, then we gave the highest. On the other hand, if different values of the trophic category are indicated for the same species, then the highest was tacked; for example, from the mesotrophic and eutrophic, the eutrophic was chosen.

Integrated data about saprobity is defined in a scale of water quality with the relationship between saprobity index S and water quality category (Romanenko et al., 1990; Barinova, 2017a) (Tab. 1).

Table 1: Relationship between Water Quality Class, Rank, Index of Saprobity S, and self-purification zones.

Water Quality Class	Self-purification zone	Rank	EU Color code	Index Saprobity S	Saprobity zone
1	1	1	Blue	0-0.5	xenosaprobity
2	2a	2	Green	0.5-1.0	β-oligo-saprobity
2	2b	3	Green	1.1-1.5	α-oligo-saprobity
3	3a	4	Yellow	1.6-2.0	β'-meso-saprobity
3	3b	5	Yellow	2.1-2.5	β''-meso-saprobity
4	4a	6	Orange	2.6-3.0	α'-alpha-meso-saprobity
4	4b	7	Orange	3.1-3.5	α''-alpha-meso-saprobity
5	5a	8	Red	3.6-4.0	β-polysaprobity
5	5b	9	Red	> 4.0	α-polysaprobity
6	6	9	Black	> 4.0	transsaprobity

Index S community tolerance to the organic matter enrichments can be calculated on the base of collected data about species-specific index S. With the following equation, where S is the index of saprobity for the community; s_i is the species-specific saprobity index; a_i is the species frequency values (Eq. 1):

$$S = \sum_{i=1}^{n}(s_i.a_i) \Big/ \sum_{i=1}^{n}(a_i)$$

Equation 1

Trophic state preferences data is compared to the bioindicators category of this parameter (Barinova, 2017a) in the system started by Herman Van Dam in 1994 (Van Dam et al., 1994).

Species-indicators names are adopted to the modern taxonomic system with the help of available online sources (Cavalier-Smith, 1998, 2006; GBIF; WoRMS; Guiry and Guiry, 2021).

RESULTS AND DISCUSSION

As a result of collecting and integrating data about ecological preferences of aquatic plants, mosses, protozoans, and bacteria analyzed data from nine sources of references for 316 species (Tabs. 2-8) were analyzed. In all tables the same abbreviations were used: saprobity groups: x – xenosaprob, x–o – xeno–oligosaprob, o–x – oligo–xenosaprob, x–b – xeno–betamesosaprob, o – oligosaprob, o–b – oligo–beta–msosaprob, b–o – beta–oligosaprob, o–a – oligo–alpha–mesosaprob, b – beta–mesosaprob, b–a – beta–alpha–mesosaprob, a–o – alpha-oligosaprob, a – alpha-mesosaprob, i – i-eusaprob. Trophic state groups: ot – oligotraphentic; om – oligo–mesotraphentic; m – mesotraphentic; me – meso–eutraphentic; e – eutraphentic; o–e – oligo–eutraphentic; he – hypereutraphentic. "–" property is unknown. Their reference number is in square brackets and is the same in the reference list.

Table 2: Index saprobity S, saprobic zone groups, and group of trophic states for species of aquatic Bigyra with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Bigyra				
1.	*Bicosoeca dinobryoidea* Lemmermann 1914	2.00	b	–	[2]
2.	*Bicosoeca kepneri* Reynolds 1927	1.60	b-o	–	[2]
3.	*Bicosoeca lacustris* James-Clark, 1867	2.00	b	–	[2]
4.	*Bicosoeca mitra* Fott, 1946	2.00	b	–	[2]
5.	*Bicosoeca oculata* Zacharias, 1894	2.00	b	–	[2]
6.	*Bicosoeca ovata* Lemmermann, 1914	2.00	b	–	[2]
7.	*Bicosoeca pascheri* Conrad	2.50	b-a	–	[2]
8.	*Bicosoeca petiolata* (Stein F.) Pringsheim E. G. 1946	2.50	b-a	–	[2]
9.	*Bicosoeca socialis* Kent W. S. 1871	2.00	b	–	[2]
10.	*Bicosoeca campanulata* Bourrelly 1953	2.70	a-o	–	[2]
11.	*Bicosoeca conica* Lemmermann, 1914	2.00	b	–	[2]
12.	*Bicosoeca crystalline* Skuja 1956	2.70	a-o	–	[2]
13.	*Bicosoeca cylindrical* (Lackey) Bourrelly, 1951	1.60	b-o	–	[2]
14.	*Bicosoeca irregularis* (Pascher 1942) Bourrelly 1951	2.50	b-a	–	[2]
15.	*Bicosoeca planctonica* Kisselev 1931	1.80	o-a	–	[2]
16.	*Bicosoeca ruttneri* Wawrik	2.00	b	–	[2]
17.	*Bicosoeca synoica* Skuja, 1956	2.00	b	–	[2]
18.	*Poteriodendron petiolatum* Stein F., 1878	2.50	b-a	–	[2]
19.	*Pseudobodo minimus* Ruinen, 1938	3.00	a	–	[2]

Table 3: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Katablepharidophyta and Chlorobi with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Katablepharidophyta				
1.	*Katablepharis hyalurus* Skuja	3.00	a	–	[2]
2.	*Katablepharis notonectoides* Skuja	3.00	a	–	[2]
3.	*Katablepharis ovalis* Skuja	3.00	a	–	[2]
4.	*Katablepharis phoenikoston* Skuja	3.00	a	–-	[2]
	Chlorobi				
1.	*Ancalochloris perfilievii* Gorlenko and Lebedeva 1971	5.80	m	–	[2]
2.	*Chlorobacter symbioticum* Lauterborn, 1915	4.50	i	–	[2]
3.	*Chlorobacter vantieghemii* Pringsheim	4.50	i	–	[2]
4.	*Chlorobium limicola* Nadson, 1906	6.00	m	–	[2]
5.	*Chlorobium limicola* f. *thiosulfatophilum* (Larsen, 1952) Pfennig and Truper, 1971	6.00	m	–	[2]
6.	*Chlorobium chlorochromatii* Vogl et al., 2006	6.00	m	–	[2]
7.	*Chlorobium phaeobacteroides* Pfennig, 1968	6.00	m	–	[2]
8.	*Chlorobium phaeovibrioides* Pfennig 1968	6.00	m	–	[2]
9.	*Chlorobium vibrioforme* Pelsh, 1936	6.00	m	–	[2]
10.	*Chlorochromatium glebulum* Skuja, 1956	4.50	i	–	[2]
11.	*Chloroflexus aurantiacus* var. *mesophilus* Pivovarova et Gorlenko, 1976	5.80	m	–	[2]
12.	*Chloroflexus aurantiacus* Pierson and Castenholz, 1974	0.00	x	–	[2]
13.	*Chloronema giganteum* Dubinina and Gorlenko, 1975	5.70	m	–	[2]
14.	*Chloronema spiroideum* Dubinina and Gorlenko, 1975	5.90	m	–	[2]
15.	*Chloronostoc abbreviatum* Pascher, 1925	5.30	m	–	[2]
16.	*Chloroplana vacuolata* Dubinina et Kuznetsov, 1976	5.50	m	–	[2]
17.	*Microchloris nadsonii* Pringsheim 1953	5.50	m	–	[2]

Table 4: Index saprobity S, saprobic zone groups, and group of trophic states for species of aquatic Chloroflexi with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Chloroflexi				
1.	*Bacterium chlorophyllophorum* Winberg et Sivko 1952	6.00	m	–	[2]
2.	*Clathrochloris hypolimnica* Skuja, 1956	4.50	i	–	[2]
3.	*Clathrochloris* Witt et al., 1989	5.90	m	–	[2]
4.	*Cylindrogloea bacterifera* Perfiliev, 1914	6.00	m	–	[2]
5.	*Cylindrogloea solitaria* Skuja 1964	5.50	m	–	[2]
6.	*Pelodictyon aggregatum* Perfil'ev, 1914	4.50	i	–	[2]
7.	*Pelodictyon clathratiforme* (Szafer, 1911) Lauterborn, 1913	5.90	m	–	[2]
8.	*Pelodictyon luteolum* (Schmidle, 1901) Pfennig et Truper, 1971	4.50	i	–	[2]
9.	*Pelodictyon parallelum* (Szafer, 1910) Perfiliev, 1914	4.50	i	–	[2]
10.	*Pelodictyon phaeum* Gorlenko, 1972	5.80	m	–	[2]
11.	*Pelogloea bacillifera* Lauterborn, 1915	5.50	m	–	[2]
12.	*Pelogloea chlorine* Lauterborn, 1913	4.50	i	–	[2]
13.	*Pelosphaera rotans* Lauterborn, 1915	5.50	m	–	[2]
14.	*Prosthecochloris phaeoasteroides* Puchkova et Gorlenko, 1976	5.80	m	–	[2]
15.	*Sorochloris aggregate* Pascher 1925	5.10	m	–	[2]

Table 5a: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Proteobacteria and Ascomycota species with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Proteobacteria				
1.	*Allochromatium warmingii* (Cohn, 1875) Imhoff et al., 1998	5.40	m	–	[2]
2.	*Amoebobacter bacillosus* Winogradsky, 1888	5.70	m	–	[2]
3.	*Amoebobacter granula* Winogradsky, 1888	5.90	m	–	[2]
4.	*Amoebobacter pendens* (Molisch 1906), Pfennig and Trüper, 1971	5.70	m	–	[2]
5.	*Amoebobacter roseus* Winogradsky, 1888	5.00	m	–	[2]
6.	*Blastochloris viridis* (Drews and Giesbrecht 1966)	4.20	i	–	[2]
7.	*Chromatiopsis cinerea* Skuja, 1948	4.80	i	–	[2]
8.	*Chromatiopsis maior* Skuja	4.30	i	–	[2]
9.	*Chromatium buderi* Trüper and Jannasch, 1968	5.40	m	–	[2]
10.	*Chromatium fallax* (Warm.) Kolkw.	5.50	m	–	[2]
11.	*Chromatium gliscens* (Ehrenb.) Kolkw.	5.70	m	–	[2]
12.	*Chromatium gracile* Strzeszewski, 1913	6.00	m	–	[2]
13.	*Chromatium linsbaueri* Gicklhorn, 1921	5.90	m	–	[2]
14.	*Chromatium minus* Winogradsky, 1888	6.00	m	–	[2]
15.	*Chromatium minutissimum* Winogradsky, 1888	5.60	m	–	[2]
16.	*Chromatium molischii* (Bersa, 1926) van Niel, 1948	5.60	m	–	[2]
17.	*Chromatium okenii* (Ehrenberg, 1838) Perty, 1852	5.40	m	–	[2]
18.	*Chromatium vanda* Osnitzkaya and Chudina, 1978	5.80	m	–	[2]
19.	*Chromatium vinosum* (Ehrenberg, 1838) Winogradsky, 1888	5.60	m	–	[2]
20.	*Chromatium violacens* Perty, 1852	5.60	m	–	[2]
21.	*Chromatium warmingii* (Cohn, 1875) Migula, 1900	5.40	m	–	[2]
22.	*Ectothiorhodospira shaposhnikovii* Cherni et al. 1969	5.70	m	–	[2]
23.	*Lamprocystis gelatinosa* (Winogradsky 1888) Migula 1900	5.90	m	–	[2]
24.	*Lamprocystis rosea* (Kütz.) Drouet F.E., Daily W.A.	5.60	m	–	[2]
25.	*Lamprocystis roseopersicina* (Kutzing, 1849) Schroeter, 1886	5.00	m	–	[2]
26.	*Lamprocystis rubra* (Miyoshi) Migula	5.90	m	–	[2]
27.	*Lamprocystis symbiotica* Ponomarev	5.90	m	–	[2]
28.	*Lamprocystis violacea* (Miyoshi) Migula	5.90	m	–	[2]

Table 5b: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Proteobacteria and Ascomycota species with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Proteobacteria				
29.	*Magnetospirillum fulvum* (van Niel 1944) Hördt et al. 2020	6.00	m	–	[2]
30.	*Magnetospirillum molischianum* (Giesberger 1947) Hördt et al. 2020	6.00	m	–	[2]
31.	*Pararhodospirillum photometricum* (Molisch 1907) Lakshmi et al. 2014	6.00	m	–	[2]
32.	*Pelochromatium roseoviride* (Gorlenko and Kuznetsov, 1971)	5.80	m	–	[2]
33.	*Pelochromatium roseum* Lauterborn, 1913	5.70	m	–	[2]
34.	*Rhodobacter capsulatus* (Molisch 1907) Imhoff et al. 1984	4.80	i	–	[2]
35.	*Rhodoblastus acidophilus* (Pfennig 1969) Imhoff 2001	4.70	i	–	[2]
36.	*Rhodocyclus purpureus* Pfennig 1978	6.00	m	–	[2]
37.	*Rhodomicrobium vannielii* Duchow and Douglas 1949	5.80	m	–	[2]
38.	*Rhodopedia tetras* Skuja	5.10	m	–	[2]
39.	*Rhodopseudomonas gelatinosa* (Molisch 1907) van Niel 1944	5.60	m	–	[2]
40.	*Rhodopseudomonas globiformis* Pfennig 1974	5.80	m	–	[2]
41.	*Rhodopseudomonas issatchenkoi* Osnick.	5.90	m	–	[2]
42.	*Rhodopseudomonas palustris* (Molisch 1907) van Niel 1944 emend. Venkata Ramana et al. 2012	5.60	m	–	[2]
43.	*Rhodopseudomonas sphaeroides* van Niel 1944	4.80	i	–	[2]
44.	*Rhodopseudomonas sulfoviridis* Keppen and Gorlenko 1975	6.00	m	–	[2]
45.	*Rhodopseudomonas sulphidophila* Hans. et Veldk.	5.80	m	–	[2]
46.	*Rhodopseudomonas vannielii* Scard.	5.70	m	–	[2]
47.	*Rhodospirillum rubrum* (Esmarch, 1887) Molisch, 1907	5.50	i	–	[2]
48.	*Rhodospirillum tenue* Pfennig 1969	5.80	m	–	[2]
49.	*Thiocapsa pfennigii* Eimhjellen 1970	5.90	m	–	[2]
50.	*Thiocapsa roseopersicina* Winogradsky 1888	5.90	m	–	[2]
51.	*Thiocystis gelatinosa* (Winogradsky 1888) Pfennig and Truper 1971	5.40	m	–	[2]
52.	*Thiocystis rufa* Winogradsky 1888	5.90	m	–	[2]
53.	*Thiocystis violacea* Winogradsky 1888	5.90	m	–	[2]

Table 5c: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Proteobacteria and Ascomycota species with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Proteobacteria				
54.	*Thiodictyon bacillosum* (Winogradsky 1888) Pfennig and Truper 1971	5.70	m	–	[2]
55.	*Thiodictyon elegans* Winogradsky 1888	5.90	m	–	[2]
56.	*Thiopedia rosea* Winogradsky, 1888	4.80	i	–	[2]
57.	*Thiopolycoccus ruber* Winogradsky 1888	5.90	m	–	[2]
58.	*Thiosarcina rosea* (Schroeter) Winogradsky	5.90	m	–	[2]
59.	*Thiospirillum jenense* (Ehrenberg 1838) Migula 1900	4.80	i	–	[2]
60.	*Thiospirillum rosenbergii* (Warming) Migula 1972	5.90	m	–	[2]
61.	*Thiospirillum rufum* (Perty) Migula 1900	5.70	m	–	[2]
62.	*Thiospirillum sanguineum* (Ehrenberg) Winogradsky 1888	5.90	m	–	[2]
	Ascomycota				
1.	*Hyalobotrys hypolimnicus* Skuja 1964	4.50	i	–	[2]

Table 6a: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Bryophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Bryophyta				
1.	*Amblystegium fluviatile* (Hedw.) Schimp	2.50	b-a	–	[2]
2.	*Amblystegium riparium* (Hedw.) Schimp	1.80	o-a	–	[2]
3.	*Amblystegium tenax* (Hedw.) C.E.O. Jensen	0.50	x-o	–	[2]
4.	*Calliergon cuspidatum* (Hedw.) Kindb.	1.20	o	–	[2]
5.	*Calliergonella cuspidata* (Hedw.) Loeske	1.20	o	–	[2]
6.	*Chiloscyphus polyanthus* (L.) Corda	0.50	x-o	–	[2]
7.	*Chiloscyphus rivularis* (Schrad.) Loeske	1.40	o-b	–	[2]
8.	*Cinclidotus aquaticus* (Hedwig) Bruch and Schimper	1.10	o	–	[2]
9.	*Cinclidotus fontinaloides* (Hedw.) P. Beauv.	1.10	o	–	[2]
10.	*Cinclidotus nigricans* (Brid.) Wijk and Margad.	1.80	o-a	–	[2]
11.	*Cinclidotus riparius* (Host ex Bridel) Arnott	1.80	o-a	–	[2]
12.	*Cirriphyllum crassinervium* (Tayl.) Loeske and Fleisch.	1.20	o	–	[2]
13.	*Cratoneuron commutatum* (Brid.) G. Roth	0.10	x	–	[2]
14.	*Drepanocladus aduncus* (Hedw.) Warnst.	1.40	o-b	–	[2]
15.	*Eurhynchium crassinervium* (Taylor in Mackay) Schimper	1.20	o	–	[2]
16.	*Fissidens arnoldii* Ruthe	1.90	o-a	–	[2]
17.	*Fissidens crassipes* Wilson ex Bruch and Schimp.	1.80	o-a	–	[2]
18.	*Fontinalis antipyretica* Hedw.	1.30	o	–	[2]
19.	*Grimmia alpicola* (Thériot) H. Crum	1.70	b-o	–	[2]
20.	*Hygroamblystegium fluviatile* (Hedw.) Loeske	2.50	b-a	–	[2]
21.	*Hygroamblystegium irriguum* (Hook. and Wilson) Loeske	0.50	x-o	–	[2]
22.	*Hygroamblystegium tenax* (Hedw.) Jenn.	0.50	x-o	–	[2]
23.	*Hygrohypnum alpinum* (Lindb.) Loeske	0.20	x	–	[2]
24.	*Hygrohypnum luridum* (Schleicher ex Bridel) C. E. O. Jensen	0.50	x-o	–	[2]
25.	*Hygrohypnum ochraceum* (Turn. ex Wils.) Loeske	0.50	x-o	–	[2]
26.	*Hygrohypnum palustre* Loeske	0.50	x-o	–	[2]
27.	*Jungermannia atrovirens* Dumort.	0.90	x-b	–	[2]
28.	*Jungermannia cordifolia* Hook.	1.50	o-b	–	[2]

Table 6b: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Bryophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state gr.	References
29.	*Jungermannia exsertifolia cordifolia* (Dum.) Vana	1.50	o-b	–	[2]
30.	*Jungermannia lanceolata* (K. Muell.) Buch	0.90	x-b	–	[2]
31.	*Leptodictyum riparium* (Hedw.) Warnst.	1.80	o-a	–	[2]
32.	*Leskea polycarpa* Ehrh. ex Hedwig	2.60	a-o	–	[2]
33.	*Marchantia polymorpa* L.	1.00	o	–	[2]
34.	*Marsupella aquatica* (Lindb.) Schiffn.	0.50	x-o	–	[2]
35.	*Marsupella emarginata* (Ehrh.) Dum.	0.70	o-x	–	[2]
36.	*Marsupella emarginata aquatica* (Lindenb.)	0.50	x-o	–	[2]
37.	*Marsupella sphacelata* (Lindenb.) Dumort.	0.50	x-o	–	[2]
38.	*Palustriella commutata* (Hedw.) Ochyra	0.10	x	–	[2]
39.	*Pellia endiviifolia* (Dicks.) Dumort.	1.00	o	–	[2]
40.	*Pellia fabbroniana* Raddi	1.00	o	–	[2]
41.	*Phaeoceros carolinianus* (Michx.) Prosk.	0.80	x-b	–	[2]
42.	*Phaeoceros laevis* (L.) Prosck.	0.80	x-b	–	[2]
43.	*Philonotis fontana* (Hedw.) Brid.	0.30	x	–	[2]
44.	*Platyhypnidium riparioides* (Hedw.) Dixon	1.00	o	–	[2]
45.	*Platyhypnidium rusciforme* (Neck.) Fleischn.	1.00	o	–	[2]
46.	*Rhynchostegium riparioides* (Hedw.) Cardot	1.00	o	–	[2]
47.	*Riccia fluitans* L.	1.30	o	–	[2]
48.	*Riccia glauca* L.	1.30	o	–	[2]
49.	*Ricciocarpus natans* (L.) Corda	1.40	o-b	–	[2]
50.	*Scapania undulata* (L.) Dumort.	0.80	x-b	–	[2]
51.	*Schistidium agassizii* Sull. et Lesq.	1.70	b-o	–	[2]
52.	*Schistidium alpicola* (Hedw.) Limpr.	1.70	b-o	–	[2]
53.	*Solenostoma crenulatum* (Sm.) Mitt.	0.60	o-x	–	[2]
54.	*Sphagnum* sp.	1.70	b-o	–	[2]
55.	*Syntrichia latifolia* (Hartm.) Hueben.	1.70	b-o	–	[2]
56.	*Thamnobryum alopecurum* (Hedw.) Nieuwland ex Gangulee	0.20	x	–	[2]
57.	*Thuidium tamariscifolium* (Hedw.) Lindb.	0.80	x-b	–	[2]
58.	*Thuidium tamariscinum* (Hedw.) Schimp.	0.80	x-b	–	[2]
59.	*Trichocolea tomentella* (Ehrb.) Dumort.	0.70	o-x	–	[2]

Table 7a: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Magnoliophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Magnoliophyta				
1.	*Acorus calamus* L.	1.50	o-b	he	[2], [5]
2.	*Anacharis canadensis* (Michx.) Planch.	2.10	b	–	[2]
3.	*Baldingera arundinacea* (L.) Dumort.	2.10	b	–	[2]
4.	*Batrachium aquatile* (L.) Dumort	2.20	b	–	[2]
5.	*Batrachium carinatum* Schur	2.60	a-o	–	[2]
6.	*Batrachium circinati* (Sibth.) Fr.	–	–	me	[5]
7.	*Batrachium fluitans* (Lam.) Wimm.	1.70	b-o	–	[2]
8.	*Berula angustifolia* (L.) Koch	1.20	o	–	[2]
9.	*Berula erecta* (Huds.) Coville	1.20	o	o-m	[2], [8]
10.	*Bidens tripartita* Linn.	2.20	b	–	[2]
11.	*Butomus umbellatus* L.	1.90	o-a	–	[2]
12.	*Callitriche cophocarpa* Sendtn.	0.80	x-b	–	[2]
13.	*Callitriche hamulata* Kütz.	–	-	e	[8]
14.	*Callitriche hermaphroditica* L.	1.00	o	–	[2]
15.	*Callitriche obtusangulata* Le Gall	1.00	o	e	[2], [8]
16.	*Callitriche polymorpha* Lönnr.	0.80	x-b	–	[2]
17.	*Callitriche platycarpa* Kütz.	–	-	m	[8]
18.	*Carex acuta* L.	0.70	o-x	–	[2]
19.	*Carex gracilis* Curt.	0.70	o-x	–	[2]
20.	*Ceratophyllum demersum* L.	2.20	b	e	[2], [5], [8]
21.	*Cicuta virosa* L.	1.80	o-a	–	[2]
22.	*Coleogeton pectinatus* (L.) D. H. Les and Haynes	2.70	a-o	–	[2]
23.	*Eichhornia crassipes* (C. Mart.) Solms	1.90	o-a	–	[2]
24.	*Elatine hydropiper* L.	1.50	o-b	–	[2]
25.	*Eleocharis palustris* L.	1.10	o	–	[2]
26.	*Elodea Canadensis* Rich.	2.10	b	me	[2], [8]
27.	*Glyceria fluitans* (L.) R. Br.	1.50	o-b	e	[2], [5]
28.	*Glyceria maxima* (Hartm.) Holmb.	2.30	b	–	[2]
29.	*Groenlandia densa* (L.) Fourr.	–	–	me	[8]

Table 7b: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Magnoliophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Magnoliophyta				
30.	*Hippuris vulgaris* L.	2.20	b	–	[2]
31.	*Hottonia palustris* L.	1.70	b-o	–	[2]
32.	*Hydrocharis morsus-ranae* L.	2.10	b	–	[2]
33.	*Iris pseudocorus* L.	1.30	o	–	[2]
34.	*Juncus conglomeratus* L.	1.30	o	–	[2]
35.	*Lemna gibba* L.	2.40	b-a	–	[2]
36.	*Lemna minor* L.	2.20	b	–	[2]
37.	*Lemna polyrrhiza* L.	2.10	b	–	[2]
38.	*Lemna triscula* L.	1.90	o-a	–	[2]
39.	*Limnanthemum nymphoides* (L.) Hoffmanns. et Link	1.80	o-a	–	[2]
40.	*Limnanthemum peltatum* Griseb.	1.80	o-a	–	[2]
41.	*Limosella aquatica* L.	1.60	b-o	–	[2]
42.	*Malaxis paludosa* (L.) Swartz	1.90	o-a	–	[2]
43.	*Myriophyllum alterniflorum* D. C.	0.90	x-b	e	[2], [8]
44.	*Myriophyllum spicatum* L.	2.30	b	me	[2], [5]
45.	*Myriophyllum verticillatum* L.	1.80	o-a	e	[2], [5]
46.	*Najas marina* L.	1.90	o-a	e	[2], [5]
47.	*Nasturtium officinale* W. T.Aiton	–	–	e	[9]
48.	*Nuphar lutea* (L.) Smith	1.80	o-a	–	[2]
49.	*Nymphaea alba* L.	1.90	o-a	–	[2]
50.	*Nymphoides peltata* (S.G. Gmel.) O. Kuntze	1.80	o-a	–	[2]
51.	*Oenanthe aquatica* (L.) Poiret	1.50	o-b	–	[2]
52.	*Oenanthe fluviatilis* (Bab.) Coleman.	–	–	e	[8]
53.	*Oenanthe phellandrium* Lam.	1.50	o-b	–	[2]
54.	*Persicaria amphibian* (L.) Delarbre	2.10	b	–	[2]
55.	*Phalaris arundinacea* L.	2.10	b	–	[2]
56.	*Phalaroides arundinacea* (L.) Rauschert	2.10	b	–	[2]
57.	*Phellandrium aquaticum* L.	1.50	o-b	–	[2]
58.	*Phragmites australis* (Cav.) Steud.	2.30	b	me	[2], [5]

Table 7c: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Magnoliophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Magnoliophyta				
59.	*Phragmites communis* Trin.	2.30	b	–	[2]
60.	*Polygonum amphibium* L.	2.10	b	–	[2]
61.	*Polygonum amphibium* f. *natans* Moench	–	–	he	[5]
62.	*Potamogeton alpinus* Balbis	1.10	o	e	[2], [8]
63.	*Potamogeton berchtoldii* Fieber	1.90	o-a	–	[2]
64.	*Potamogeton coloratus* Hornem.	–	–	ot	[8]
65.	*Potamogeton crispus* L.	2.60	a-o	he	[2], [5]
66.	*Potamogeton gramineus* L.	1.50	o-b	–	[2]
67.	*Potamogeton lucens* L.	2.00	b	he	[2], [5], [8]
68.	*Potamogeton natans* L.	1.50	o-b	he	[2], [5]
69.	*Potamogeton nodosus* Poir.	–	–	he	[8]
70.	*Potamogeton pectinatus* L.	1.70	b	he	[2], [5], [8]
71.	*Potamogeton perfoliatus* L.	2.30	b	–	[2]
72.	*Potamogeton polygonifolius* A.Benn.	–	–	ot	[8]
73.	*Potamogeton pusillus* L.	1.90	o-a	he	[2], [5]
74.	*Ranunculus aquatilis* L.	2.20	b	–	[2]
75.	*Ranunculus fluitans* Lamk.	1.70	b-o	e	[2], [8]
76.	*Ranunculus hederaceus* L.	2.60	a-o	–	[2]
77.	*Ranunculus peltatus* Schrank	–	–	o-m	[8]
78.	*Sagittaria sagittifolia* L.	1.80	o-a	–	[2]
79.	*Schoenoplectus lacustris* (L.) Palla	2.20	b	he	[2], [5]
80.	*Scirpus lacustris* L.	2.20	b	–	[2]
81.	*Sium erectum* Hudson	1.20	o	–	[2]
82.	*Sium latifolium* L.	2.10	b	–	[2]
83.	*Sparganium erectum* L.	1.70	b-o	he	[2], [5]
84.	*Sparganium ramosum* Hudson	1.70	b-o	–	[2]
85.	*Spirodela polyrrhiza* (L.) Schleid.	2.10	b	–	[2]
86.	*Trapa natans* L.	2.00	b	–	[2]
87.	*Typha angustifolia* L.	1.10	o	me	[2], [5]

Table 7d: Index saprobity S, saprobic zone groups, and a group of trophic states for species of aquatic Magnoliophyta species with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Magnoliophyta				
88.	*Typha latifolia* L.	1.90	o-a	he	[2], [5]
89.	*Utricularia australis* R. Brown	2.00	b	–	[2]
90.	*Utricularia vulgaris* L.	2.10	b	–	[2]
91.	*Veronica anagallis-aquatica* L.	2.20	b	–	[2]
92.	*Veronica beccabunga* L.	1.00	o	–	[2]
93.	*Wolffia arrhiza* (L.) Wimmer	2.10	b	–	[2]
94.	*Zannichellia palustris* L. 1753	2.70	a-o	e	[2], [5], [8]

Table 8: Index saprobity S, saprobic zone groups, and group of trophic states for species of aquatic Polypodiophyta and Pteridophyta with numbered source data.

No.	**Species**	Index S	Saprobity group	Trophic state group	References
	Polypodiophyta				
1.	*Equisetum fluviatile* L.	1.10	o	–	[2]
2.	*Equisetum limosum* L.	1.10	o	–	[2]
3.	*Equisetum palustre* L.	1.00	o	–	[2]
4.	*Isoetes lacustirs* L.	0.30	x	–	[2]
5.	*Marsilea quadrifoliata* L.	1.00	o	–	[2]
6.	*Salvinia natans* (L.) All.	1.50	o-b	–	[2]
	Pteridophyta				
1.	*Azolla filiculoides* Lam.	1.00	o	–	[2]

Table 9a: Index saprobity S, saprobic zone groups, and group of trophic state for species of aquatic Charophyta with numbered of source data.

No	**Species**	Index S	Saprobity group	Trophic state group	References
	Charophyta				
1.	*Chara aculeolata* Kützing 1832	–	–	om	[3]
2.	*Chara aspera* Willdenow 1809	1.20	o	om	[2], [3]
3.	*Chara baltica* (Hartman) Bruzelius 1824	–	–	o-e	[3]
4.	*Chara baueri* A.Braun 1847	–	–	e	[6]
5.	*Chara braunii* C.C.Gmelin 1826	1.20	o	o-e	[2], [3]
6.	*Chara canescens* Loiseleur 1810	–	–	o-e	[3]
7.	*Chara connivens* Salzmann ex Braun A. 1835	–	–	om	[1], [3]
8.	*Chara contraria* Braun A. ex Kützing 1845	1.10	o	o-e	[2], [3]
9.	*Chara contraria* var. *excels* (Allen T. F.) Raam, 2010	–	–	m	[4]
10.	*Chara denudata* A.Braun, 1843	–	–	m	[1], [3], [7]
11.	*Chara filiformis* Hertzsch 1855	–	–	om	[3]
12.	*Chara globularis* Thuiller 1799	1.20	o	me	[2], [3], [5]
13.	*Chara hispida* Linnaeus 1753	0.90	x-b	he	[2], [3], [5]
14.	*Chara horrida* Wahlstedt 1862	–	–	me	[3]
15.	*Chara papillosa* Kützing 1834	–	–	om	[3]
16.	*Chara strigosa* A.Braun 1847	–	–	om	[3]
17.	*Chara subspinosa* Ruprecht 1846	–	–	om	[3]
18.	*Chara tenuispina* A.Braun 1835	1.10	–	om	[2], [3]
19.	*Chara tomentosa* Linnaeus 1753	1.20	–	o-e	[2], [3], [5]
20.	*Chara virgata* Kützing 1834	–	–	o-e	[3]
21.	*Chara vulgaris* Linnaeus 1753	1.10	–	o-e	[1], [2], [3]
22.	*Lamprothamnium papulosum* (Wallroth) J. Groves 1916	–	m	–	[3]
23.	*Lychnothamnus barbatus* (Meyen) Leonhardi 1863	–	–	ot	[3]
24.	*Nitella capillaries* (Krocker) J.Groves and Bullock-Webster 1920	1.50	o-b	om	[2], [3]
25.	*Nitella confervacea* (Brébisson) Braun A. ex Leonhardi 1863	0.80	x-b	om	[2], [3]
26.	*Nitella flexilis* (Linnaeus) Agardh C. 1824	1.30	o	om	[2], [3]
27.	*Nitella gracilis* (Smith J. E.) Agardh C. 1824	1.10	o	om	[2], [3]
28.	*Nitella hyalina* (De Candolle) Agardh C.	–	–	me	[3]

Table 9b: Index saprobity S, saprobic zone groups, and group of trophic state for species of aquatic Charophyta with numbered of source data.

No	**Species**	Index S	Saprobity group	Trophic state gr.	References
	Charophyta				
29.	*Nitella mucronata* (Braun A.) Miquel 1840	1.30	o	me	[1], [2], [3]
30.	*Nitella opaca* Agardh C. 1824	1.30	o	om	[2], [3]
31.	*Nitella syncarpa* (Thuillier) Chevallier 1827	1.30	o	om	[2], [3]
32.	*Nitella tenuissima* (Desvaux) Kützing 1843	0.80	x-b	o-e	[2], [3]
33.	*Nitella translucens* (Persoon) Agardh C. 1824	-	-	om	[3]
34.	*Nitellopsis obtuse* (Desvaux) Groves J. 1919	-	-	m	[3], [5]
35.	*Tolypella intricata* Leonhardi 1863	0.80	x-b	o-e	[2], [3]
36.	*Tolypella prolifera* Leonhardi 1863	1.10	-	me	[2], [3]
37.	*Tolypella glomerata* (Desvaux) Leonhardi 1863	-	-	om	[3]
38.	*Tolypella nidifica* (Müller O. F.) Braun A. 1857	-	-	om	[3]

The most prosperous indicator group was Magnoliophyta with 94 species, then followed Bryophyta with 59 indicators of trophic state and organic pollution, and Proteobacteria with 62 species (Tab. 10). These groups included more than 2/3 of the total indicators represented in tables 2-8. Because higher plants and mosses are widely studied and represented in water bodies, they, with about half of the species list (153 species-indicators), may be enough for bioindicational assessment of organic pollution and trophic state of water.

Table 10: Distribution of species-indicators of saprobity and trophic state over phyla of aquatic inhabitants.

No.	Phylum	No. of species
1.	Ascomycota	1
2.	Bigyra	19
3.	Bryophyta	59
4.	Charophyta	38
5.	Chlorobi	17
6.	Chloroflexi	15
7.	Katablepharidophyta	4
8.	Magnoliophyta	94
9.	Polypodiophyta	6
10.	Proteobacteria	62
11.	Pteridophyta	1
Total		316

As an example of the bioindicational assessment of some waterbodies, state, and level of organic pollution, two histograms were constructed on the base of tables 2-8. Figure 1 shows the distribution of species number in ecological groups placed on the x axes to increase organic pollution or trophic state. The Class of Water Quality histogram reveal two indicator groups divided into clusters of clear water and organically polluted water. In the clear-water group, the indicators of class 3 are the richest and followed class 2, this group combined species of macrophytes and mosses. Between the groups of polluted waters, class 6 prevailed, including bacteria and flagellated protozoan with the ability of heterotrophic nutrition.

The distribution of trophic state indicators also reveal two groups: prevailing oligo-mesotraphentic species of macrophytes and mosses, and the second one that included high-trophicity indicators of hypertrophic conditions, which mainly contain flagellates and bacteria. Therefore, collected data about organic pollution indicators with species-specific index S can improve the assessment results because Index S is related to about of hundred chemical and biological variables of aquatic ecosystems (Romanenko et al., 1990; Barinova, 2017b).

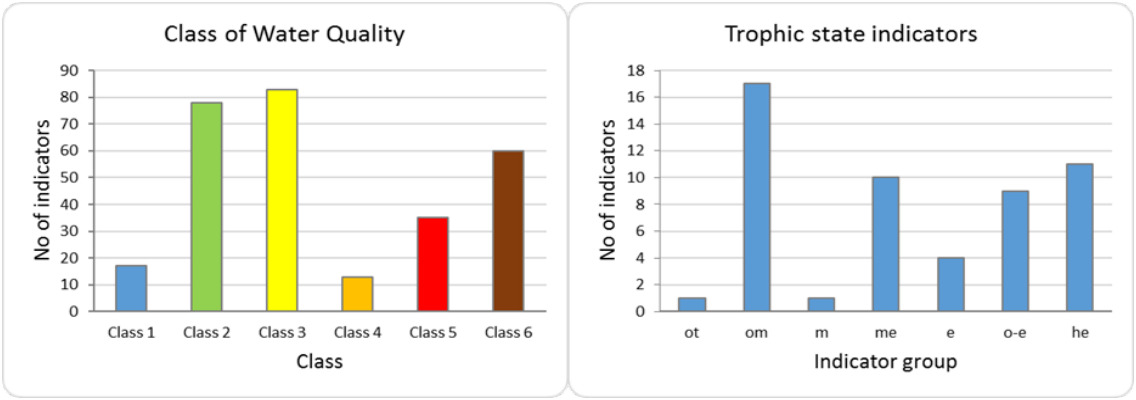

Figure 1: Distribution of species-indicators of organic pollution over Water Quality Classes and groups of trophic state conditions. Ecological groups are located on the x-axis following the increase of the indicated parameter. Class of water quality is as in EU colors.

CONCLUSIONS

To be able to determine the water quality by organic pollution and assess the aquatic ecosystem trophic state, we have collected the relevant ecological data from nine main references published as books, papers, or electronic resources for each of the aquatic species of macrophytes and some other aquatic inhabitants that are non-algae or cyanobacteria and non-invertebrates. Therefore, the list of indicators includes 316 species belonging to 11 phyla of aquatic macrophytes, mosses, charophytes, protozoan, and bacteria. In comparison, macrophytes and mosses prevail and demonstrate preferences of low to middle organically polluted waters. Classes 2 and 3 and oligo- to the mesotrophic environment, the indicator-species in protozoan and bacteria preferred organically polluted waters classes of 5-6 and high trophic conditions. Data collected of organic pollution indicators with species-specific index S can improve water quality and trophic state assessment to monitor organic pollution in diverse continental water bodies.

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