Article

Database of Ecological Indicators of Freshwater Algae and Cyanobacteria

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ABSTRACT: Accumulation of ecological data on species of algae and cyanobacteria represents 9531 taxa-indicators from 18 taxonomic phyla. The most represented among the indicators is the taxonomic group of diatoms. The indicators are grouped into twelve ecological groups, which can be indicators of nine environmental parameters. The environmental characteristics for each of the indicator systems and the relationship between some of them are given. Individual abbreviations of ecological indicator groups that have been established as a result of long-term use are given. References are given to examples of the application of analysis of specific water bodies using bioindication methods, and prospects for use in monitoring and assessing water quality are shown. A specific example of using the database is given. The table of indicator taxa contains cumulative ecological data and is easy to use. This table is a living tool that can be supplemented and transformed when new information about indicator species comes.

Keywords: Algae; Ecological preferences; Bioindicators; Database

1. Introduction

The maintenance of water quality at a high level is of considerable importance. For the most part, the water comes from natural sources, including rivers, lakes, and reservoirs. The quality of their water should not only be assessed but also predicted. Under natural conditions, water quality depends on the river basin and the ecosystem of the water body. Considering that water quality assessment is rather expensive, the elaboration of express methods of its assessment is an urgent problem. Over the years, there has been a need to use biological parameters of algae and cyanobacteria species found in aquatic ecosystem communities to assess water quality, biomonitoring, river and stream health, organic and toxic pollution of natural and waste waters, and to assess the trophic status of water bodies [1–6].

Methods based on the ecological properties of aquatic organisms are used not only to assess biotic responses to environmental changes but also for monitoring purposes [7]. The use of surface water organisms as bioindicators has a long history [8]. The types and uses in environmental quality assessment are defined in general terms [9]. Previously, we summarized the known and most widely used bioindication methods and systems for the water quality assessment [10], which can be useful for assessing the distribution and conservation of aquatic organism diversity and enriching the ecological characteristics of species used in the most well-known databases [11,12]. Different groups of aquatic organisms can be used as bioindicators. The database for aquatic plants and invertebrates was collected and published [13,14]. Since the group of aquatic photosynthetic organisms is the richest, most diverse, and widely used in monitoring, there is a need to summarize the available data on the indicator properties of species in a single database [15]. We have been working on accumulating ecological data on algae and cyanobacteria species in a database for several years. By now, the data has been partially published in monographs [16,17] and many articles showing the possibilities of using the ecological base for flora [18] or diversity conservation [19].

The bioindication is based on the hierarchical organization of the biotic community, which is described by the model of the trophic pyramid [20]. However, in natural ecosystem relationships, distinguishing between the levels is more complicated [21]. The distribution of the groups of organisms or species over the intervals of environmental factors is also of considerable importance.

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Pollution of freshwater aquatic systems is a complicated problem, and therefore, relevant assessment methods to determine the ecosystem's structure must be chosen carefully. The methods and indices that can be used to assess pollution impact on natural water bodies are based on the ecological character of the water and biota relationships within the ecosystem. Aquatic ecosystems of fresh and brackish water bodies are well represented on the Earth's surface.

The relationships between algal biodiversity and environmental conditions are determined by the adaptation level of the species and the community as a whole. Bioindication is based on the principle of congruence between community composition in nature and the complexity of environmental factors. However, defining the role of each environmental variable as well as predicting the community's response to environmental change is still problematic. Furthermore, summarizing the accumulated information on environmental factors and biota to classify the variables and assess the impact of pollution is quite challenging. Especially problematic up to now is collecting and summarizing the ecological properties of algae species due to the fragmented and often scanty information on the ecology of species.

The history of collecting ecological information about algae and cyanobacteria species started in 1996 [22], when the database included about 500 species and was related to the organic pollution indication only. Few books and many papers were published to develop the bioindicators database, but the new stage of enrichment and improvement of the indicators list was started in 2001.

We set out to collect ecological information about species of algae and cyanobacteria inhabited continental waterbodies organisms from solid books, papers, and electronic sources. We aimed to summarize known information about the ecological preferences of species of algae and cyanobacteria, for the purpose of using it for water quality bioindication.

2. Materials and Methods

2.1. Principle Approach

The bioindication method, which involves analyzing the response of biota to changes in environmental conditions, is highly significant for assessing the impact of pollution on aquatic ecosystems. It should be noted that the bio-indication method reflects the real changes under natural conditions, in contrast to standard bioassays that are conducted under controlled laboratory conditions. Therefore, the major methods used for the assessment of pollution impact can be divided into two different groups: (1) methods of bioindication based on species that were found in the studied natural habitats and (2) methods of bio-testing that were based on the organism's response to the environmental conditions to which it is exposed during laboratory experiment. Thus, the database includes information on indicator species according to group 1 that live in a natural, non-laboratory environment, *i.e.*, their occurrence and abundance are based on the characteristics of the environment in which they are found in natural systems, namely, hydrochemical data of the habitat.

Unfortunately, most new taxa described in recent years based on molecular sequences cannot be included in the database, as their descriptions are based on cells grown in laboratory cultures. Therefore, the chemical characteristics of culture media such as F2 or BG11 cannot be used as environmental or habitat parameters. Moreover, ecological confines and distribution (if any) for molecularly described taxa are often not provided.

To assess the impact of pollution on natural aquatic ecosystems, our study presents descriptions and results of approaches used to determine water quality or evaluate ecosystem health through bioindication. For these purposes, we have collected the relevant ecological data for each of the aquatic species in our database.

2.2. Collecting Methods and Presentation

Data on ecological preferences of algal species were taken from 112 monographs, electronic resources, published papers, and our own research. The collected information about each of the species was inserted into an Excel table. Then the ecological data were disassembled according to categories of bioindication. The ecological characteristics of algal species were used for the water quality assessment according to the following major environmental variables: pH, salinity, temperature, streaming and oxygenation, trophic state, nutrition preference, and saprobity in two parallel systems. The work was done on the Microsoft Access Program because the summarising material was so large. Information was compiled from recent references for freshwater algae ecology published from 1951 to the present.

The ecological preferences of each taxon were described in many different sources, from which we took all available information and then summarized it for each indicator group for each taxon for which such information is available [23–117]. In the data integration process, we used all sources found in different languages, regardless of quality and year of publication, with the priority being the reliability and completeness of the information. In addition to the 112 sources, the list also includes additional information on individual taxon and old indicator lists, which have now been updated in the main 112 publications [118–166]. If the information contained in various references did not match, we selected data from the most reliable source. First, the most recent information was chosen; second in importance was the information from field observations, third was information from taxonomic summaries, and fourth was the information from references on fossil communities. The main database in the Supplement Table S1 is organized for easy navigation in an Excel table with key fields in the form of a unique row number in column 1. The information in the Supplement Table S1 on ecological preferences includes not only algae and cyanobacteria, but also other groups of organisms that live in water or in areas adjacent to it. Each group of indicators can be separately assessed according to its significance for bioindication. Each species can be an indicator in several bioindication systems.

3. Main Systems of Bioindication in Aquatic Habitats

3.1. pH-Classification System According to F. Hustedt

The method relies on the observation that the occurrences of diatom species in aquatic environments reflect, among other things, the pH of their environment [80,81]. F. Hustedt [167,168] was perhaps the first researcher to recognize such relationships. He presented a pH classification scheme that recognized five diatom-pH sensitivity categories (Table 1), ranging from alkalibiontes (surviving at a pH = 8 and higher) to acidobiontes (surviving in acid waters, with a pH = 5 and less). Algae and cyanobacteria database after the last addition of the references contains information about 3018 pH-sensitive species.

Table 1. pH-sensitive species groups according to F. Hustedt with our abbreviation.

pH-Species Groups	Our pH-Groups Abbreviation	Distribution
Acidobiontic	acb	Optimum distribution at pH below 5.5 (occurs only in acidic habitats)
Acidophilic	acf	Widest distribution at pH less than 7
Indifferent	ind	Distribution around pH 7
Alkaliphilic	alf	Widest distribution at pH greater than 7
Alkalibiontic	alb	Occur only in at pH greater than 7

3.2. Salinity Classification System According to F. Hustedt

Evidence of the relationship of algal diversity to salinity comes from studies of algal assemblages collected over steep salinity gradients in salt-polluted continental waters, estuaries, inland seas, and saline lakes. The indicators of salinity, primarily the diatom algae, were analyzed with respect to the classification system proposed by Kolbe [169], developed by Hustedt [170], and presently widely used in bioindication [171]. The system divides the indicator species into four groups (Table 2).

Table 2. Classification of water salinity and groups of salinity algae indicators into four groups according to F. Hustedt.

Groups of Salinity Indicators	Classification of Salinity	NaCl g L^{-1}
Polyhalobes	Salts water	40–300
Euhalobes	Marine water	30–40
Mesohalobes	Brackish	5–20
Oligohalobes	Freshwater	0–5

The Hustedt's description of indicator groups preferences is given below: Polyhalobes, living in hypersaline waters from 40‰ to 300‰. Euhalobes inhabiting marine waters of 20–40‰. Mesohalobes of brackish shelf seas and estuaries, as well as of inland basins with salinity ranging from 5‰ to 20‰. Oligohalobes of fresh water or slightly saline habitats from 0 to 5‰, which, in turn, is divided into four groups (Table 3): (1) Halophiles, essentially freshwater, but enhanced by a slightly elevated concentration of NaCl, (2) Indifferents, typically freshwater, occurring, but never abundant, in slightly brackish waters, (3) Halophobes, strictly freshwater, perishing even at a slight increase of NaCl concentration. An algal database contains information on 3314 species indicative of chloride concentrations.

Table 3. Groups of salinity indicators with our abbreviation.

Salinity Groups	Our Salinity Groups Abbreviation	Habitat Relation to Salinity
Polyhalobes	ph	Inhabit water with salinity greater than normal marine habitats
Euhalobes	eu	Living in seawater
Mesohalobes	mh	Living in estuarine systems and river mouths
Oligohalobes as a whole	oh	Inhabit freshwater with low salinity
1. Halophiles	hl	(1). Typically inhabit in fresh water, but low increase of salinity stimulation increases their biomass
2. Indifferents	i	(2). Typically inhabit fresh water and usually have large biomass. However, they are able to inhabit low-salinity water, but never in large amounts of biomass
3. Halophobes	hb	(3). Inhabit fresh water only. Salinity decreases their numbers

Because the salinity system includes a wide range of concentrations typical to natural waters, it can be measured by different equipment, but indicators reflect the chloride content only. Mainly, electrical conductivity and dissolved solids content (TDS) are measured in studies of water bodies. Thus, it is essential to compare these data with the concentration of chloride (Table 4).

Table 4. Water salinity and electrical conductivity classification comparison.

Electrical Conductivity [172]		‰, Cl, g L^{-1} [169]	TDS, mg L^{-1} [172]	Salinity Class [169]	Salinity Range, ‰ [169]	Salinity, mg L^{-1}, (Approx.) [172]
Salinity Class	mSm cm^{-1}					
I	<0.3	<0.1	<150	4	0–5	<50
II	0.3–1.0	0.1–0.6	150–600			50–250
III	1.0–3.0	0.6–2.0	600–2000			250–1000
IV	3.0–10.0	2–8	2000–8000	3	5–20	1000–4000
V	10.0–30.0	8–20	8000–20,000			4000–10,000
VI	>30.0	20–80	20,000–80,000	2	20–40	10,000–40,000
VII		>80	>80,000	1	40–300	

3.3. The Saprobic System

The saprobic approach was the first river assessment system to be developed, already at the beginning of the 20th Century by Kolkwitz and Marsson (1902) [173], and later on expanded by V. Sládeček [174]. The determination of saprobic value is based on sampling and identifying species of fauna and flora, followed by a comparison with the known saprobic characteristics of each species. Sládeček's description [174] has been adapted for classes of water quality, the Saprobic Index S, and the self-purification zone in water ecosystems (Table 5).

The objective is to classify water quality based on the pollution tolerance of the indicator species present. Every species has a specific dependency on organic substances and, thus, on the dissolved oxygen content: this tolerance is expressed as a saprobic indicator value [175]. These zones (Table 5) are characterized by indicator species, certain chemical conditions, and the general nature of the bottom of the water body and of the water itself. All five zones are characterized by indicator species that live almost exclusively in the aforementioned zones. We found 5080 indicator taxa for organic pollution tolerance.

Table 5. The connection between classes of water quality (EU color codes), index saprobity S and self-purification zone in water ecosystems (according to [174]).

Class of Water Quality	Self-Purification Zone	Index Saprobity S	Water Quality
I	Xenosaprobic	0–0.5	Very good
II	Oligosaprobic	0.5–1.5	Good
III	β-mesosaprobic	1.5–2.5	Fair
IV	α-mesosaprobic	2.5–3.5	Fairly poor
V	Polysaprobic zone	3.5–4.0	Poor
VI	None	>4.0	Very poor

Therefore, a comparison of the species list from a particular sampling station with the list of indicator species for the five zones enables surface waters to be classified into quality categories described below according to [176]:

Class I—*Xenosaprobic zone* (no organic pollution).

Class II—*Oligosaprobic zone* (no organic pollution or very slight organic pollution): Oxygen saturation is common. Mineralization results in the formation of inorganic or stable organic residues (e.g., humid substances). These waters are clear and blue with high amounts of dissolved oxygen. Most organisms are sensitive to changes in the amount of dissolved oxygen and pH values.

Class III—*β-mesosaprobic zone* (moderate organic pollution): Aerobic conditions sustained by photosynthetic aeration. The water is usually transparent or slightly turbid, odor-free, and generally not colored.

Class IV—*α-mesosaprobic zone* (severe organic pollution): The water is usually dark gray and smells rotten or unpleasant due to H_2S.

Class V—*Polysaprobic zone* (extremely severe organic pollution): Rapid degradation processes and predominantly anaerobic conditions. Hydrogen sulfide (H_2S), ammonia (NH_3), and carbon dioxide (CO_2) are produced as end products of degradation. Polysaprobic waters are usually cloudy gray with a smell of decay and are highly turbid due to an enormous mass of bacteria and colloids. Such waters are characterized by the absence of common autotrophic organisms and the dominance of bacteria, particularly thio-bacteria that are well adapted to the presence of H_2S. Various blue-green algae are also typical of polysaprobic communities.

3.4. The Indices of Saprobity (S) Calculation

Index of saprobity S represents the tolerance of the entire community to dissolved organic matter. Its value is related to the Water Quality Class and self-purification zones [177] and can be calculated based on all revealed species (as index S) or for diatom species only (as EPI and other). The sum of saprobic values for the entire indicator species determined at the sampling point can be calculated by the sum of all frequency values (algal abundance, [178]) for the indicator species, which produces the Saprobic Index (S). Index S community tolerance to the organic matter enrichments can be calculated from the following formula (where S is the index of saprobity for the algal community; s_i is the species-specific saprobity level; a_i is the frequency values (Equation (1)):

$$S = \sum_{i=1}^{n} (s_i h_i) \,/\, \sum_{i=1}^{n} (h_i) \quad (1)$$

An alternative method [151] defines three groups of indicators: saproxenes of clean water, eurysaprobes of medium quality water, and polysaprobes of polluted water. According to Watanabe’s scale, our database contains a list of 730 species that are indicators of organic pollution.

It is essential to compare the degree of organic contamination, water salinity, and trophic level of the studied water body with the classes of water quality (Table 6).

Table 6. Compliance of saprobity levels, halobity, and trophy with water quality classes for Dell Uomo [179].

Class of Water Quality	Saprobity Level	Halobity Level	Trophic Level
0	Xenosaprobity	Halophobe	Hypotrophy
I	Oligosaprobity	Oligohalobe-indifferents	Oligotrophy
II	beta-mesosaprobity	Oligohalobe-indifferents	Mesotrophy
III	alpha-mesosaprobity	Oligohalobe-halophiles	Eutrophy
IV	polysaprobity	Halophiles-mesohalobes	Hypertrophy

3.5. Other Indicator Systems

The indicator classification systems outlined above include only the main groups, the abbreviations of which are mainly made by us and in addition to Porter [89]. However, there are groups that do not fall under the above, for which the abbreviations are made by us with the number of indicators for each group that represented in our database. Below Table 7 is given not only the presence and name of the indicator groups, but also their arrangement, which corresponds to the gradient of the parameter for which each of the systems is developed. The arrangement of groups in descending or ascending order of the parameter is important to observe when conducting bioindicator analysis of communities. The arrangement of groups can show not only the predominant indicator groups, but also highlight their dynamics along the environmental indicator.

Table 7. Indicator groups with abbreviation.

Abbreviations	Description
Aquatic habitat (substrate) preferences (7395 indicator taxa)	
B	Benthic in a broad sense, associated with the substrate
S	Soil, terrestrial moistened substrates
pb	Phycobiont (lichens)
P-B	Plankton-benthic
P	Planktonic
Ep	Epiphyte, Epibiont
R	Fossil, bottom sediments
Temperature preferences (852 indicator taxa)	
warm	Taxa that have its known optimum in the temperature intervals of °C: 20–35, 18–27, 18–38, 20–40, 20–38, 20–37. Thermophilic or warm water inhabitant
cool	Cryophilic
temp	Taxa that have its known optimum in the temperature intervals of °C: 10–35, 15, 15–37, 15–35, 20–30, 10–40, 10–35, 17–27, 15–30, 20–27, 18–27, 16–30, 16–29, 16–27, 15–32, 15–31, 15–30, 10–40, 10–30, 0–28, 0–30. Moderate temperature, temperate temperature, and/or temperature indifferent
eterm	Eurythermic
Rheophility (2055 indicator taxa)	
st	Standing water
str	Streaming water
st-str	Standing-streaming, and / or indifferent
aer	Aerophil
reoph	Rheophil
eoxibt	Euryoxybiont
Organic pollution Indicators Groups according to Watanabe (diatoms only) (730 indicator taxa)	
sx	Saproxen
sp	Saprophil
es	Eurysaprob
Self-purification zones according to Pantle-Buck in the modification of Sládeček with individual indices of each group of saprobionts (5080 indicator taxa)	
Class of Water Quality I	
x	0.0, xenosaprobiont
x-o	0.4, xeno-oligosaprobiont
Class of Water Quality II	
o-x	0.6, oligo-xenosaprobiont
x-b	0.8, xeno-beta-mesosaprobiont
o	1.0, oligosaprobiont
o-b	1.4, oligo-beta-mesosaprobiont
Class of Water Quality III	
x-a	1.55, xeno-alpha-mesosaprobiont
b-o	1.6, beta-oligosaprobiont
o-a	1.8, oligo-alpha-mesosaprobiont
b	2.0, beta-mesosaprobiont
b-a	2.4, beta-alpha-mesosaprobiont
Class of Water Quality IV	
a-o	2.6, alpha-oligosaprobiont
a	3.0, alpha-mesosaprobiont
b-p	3.0, beta-polysaprobiont
a-p	3.5, alpha-polysarobiont
Class of Water Quality V	
a-b	3.6, alpha-beta-mesosaprobiont
p	4.0, polysaprobiont
p-a	poly-alpha-saprobiont
Halobity (salinity preferences) (3314 indicator taxa)	
ph	Polyhalob
mh	Mesohalob
oh	Oligohalob
i	Oligohalob-indifferent
hl	Oligohalob-halophil
hb	Oligohalob-halophob

euhl	Euryhaline
Groups of the water pH indicators and acidification (3018 indicator taxa)	
acb	Acidobiont
acf	Acidophilus
ind	pH Indifferent and/or neutrophil (neu)
alf	Alkaliphil
alb	Alkalibiont
Groups of Autotrophy-Heterotrophy—nitrogen uptake metabolism (973 indicator taxa)	
ats	nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen
ate	nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen
hne	facultatively nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen
hce	obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen
Groups of Trophic state—trophic state (3022 indicator taxa)	
ot	oligotraphentic
om	oligo-mesotraphentic
m	mesotraphentic
me	meso-eutraphentic
e	eutraphentic
o-e	oligo- to eutraphentic (hypereutraphentic)
he	hypereutraphentic

4. Results

The largest taxonomic representations are listed below. Integrated information on the species' ecological preferences is presented in our database (Table 8) and includes 18 positions. Taxa names are given as in the algaebase.org [12], but accessed in 2023 because the list of taxa is large. Thus, to date, we have managed to collect indicator information for 9531 taxa of algae and cyanobacteria. Diatoms are extremely rich, but four of the five dominant higher taxa in the table also have significant (above standard deviation) numbers of indicators (Figure 1a). These five higher taxa represent 8683 indicator species and 91.1% of the total list (Supplement Table S1).

Table 8. Taxonomical presentation of ecological information in database.

No.	Taxa	No of Indicators
1	Bacillariophyta	3809
2	Charophyta	1472
3	Euglenozoa	1206
4	Chlorophyta	1203
5	Cyanobacteria	993
6	Ochrophyta (Chrysophyceae)	489
7	Miozoa	142
8	Ochrophyta (Xanthophyceae)	70
9	Rhodophyta	56
10	Cryptophyta	41
11	Ochrophyta (Eustigmatophyceae)	19
12	Ochrophyta (Raphidophyceae)	9
13	Haptophyta	7
14	Ochrophyta (Synurophyceae)	7
15	Glaucophyta	6
16	Eubacteria	1
17	Ochrophyta (Phaeophyceae)	1
18	Ochrophyta incertae sedis	1
	Total:	9531

Table 9 presents the results of the number of indicator species for 12 positions. It is evident that the number of algae and cyanobacteria indicators for specific positions differs significantly. The number of indicators of the organisms' relationship to the habitat in connection with the substrate prevails. At the same time, there is very little data on temperature indicators and sulfide concentrations. This is because each researcher records the habitat in which the species they describe exists or was found—for example, in plankton or associated with the substrate—while notes on the presence of sulfides in the environment are extremely rare.

Table 9. Major bioindicator groups and number of indicators taxa of algae and cyanobacteria in the freshwater ecosystems (Supplement Table S1).

No.	Ecological Group of Indicators	No. of Indicator Taxa
1	Habitat (substrate) preferences	7395
2	Temperature	852
3	Rheophility (water moving) and oxygenation	2055
4	Water pH	3018
5	pH range	1270
6	Halobity (Salinity)	3314
7	Organic pollution according Watanabe	730
8	Self-purification zone	5080
9	Index saprobity S	5057
10	Trophic state	3022
11	Nutrition type (autotrophy-heterotrophy)	973
12	H_2S (sulfides)	12
	Total no. of indicator taxa	9531

Figures 1–3 show the distributions of the number of indicator species by groups for each indicator system. The calculated standard deviation lines indicate the predominant groups among the known indicator taxa. Thus, in many habitat indicators, benthic species predominate, although the number of planktonic species is also quite high (Figure 1b).

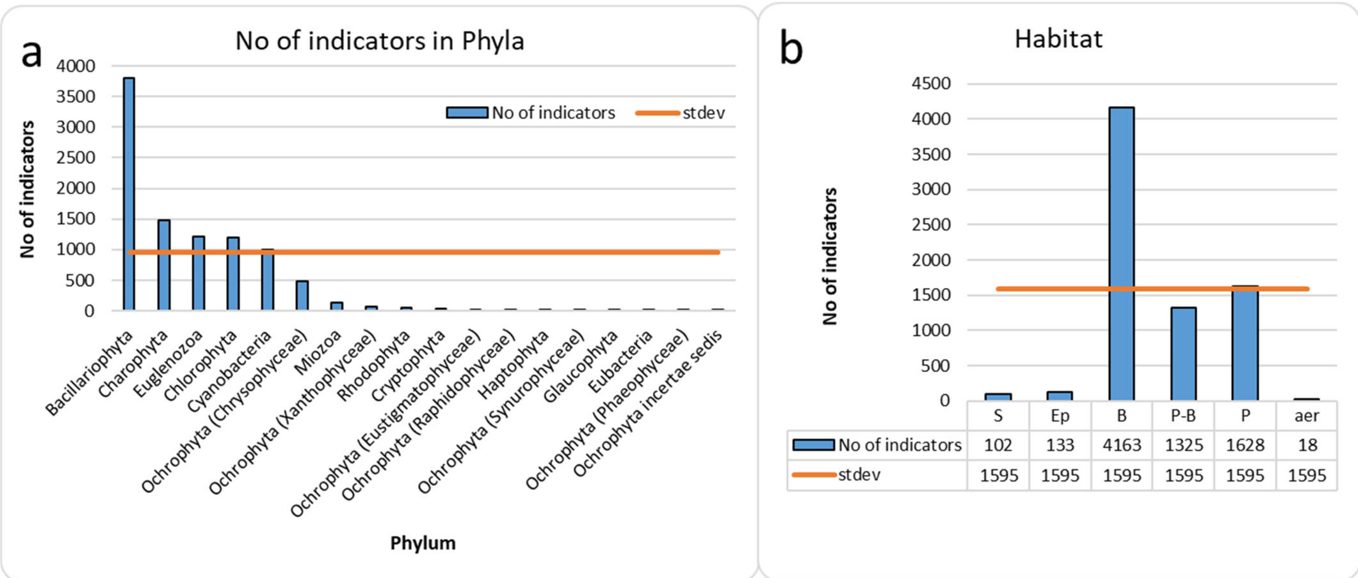

Figure 1. Distribution of number indicator taxa in taxonomic phyla (**a**) and in groups of habitat preference indicator (**b**). Orange line is the line of standard deviation for each distribution. Groups in (**b**) distribution are in order of the variable decreasing.

Among the indicator groups of water pH, acidophiles predominated (Figure 2a), but the indicator groups of neutral and slightly alkaline waters were also well represented. The richest group of indifferents was among the water salinity indicators (Figure 2b). The groups of indicators of standing and slowly flowing waters were the most represented among the indicators of oxygen saturation and mobility of the aquatic environment (Figure 2c). Among the few water temperature indicators, the temperate group was more prevalent, although warm-water species were also represented (Figure 2d).

The indicators of organic pollution according to Watanabe among diatoms, showed a predominance in the groups of moderately polluted and pure water groups (Figure 3a). The indicators of organic pollution with known species-specific saprobity indices were most abundant among the groups of 2 and 3 water quality classes (Figure 3b). In relation to the type of nutrition, autotrophic indicators of both groups prevailed, while mixotrophs were noticeably fewer (Figure 3c). Among the known indicators of the trophic state of a water body, the distribution by groups was uneven. In general, eutrophic indicators predominated, but a significant number of species groups also preferred mesotrophic and oligotrophic waters (Figure 3d).

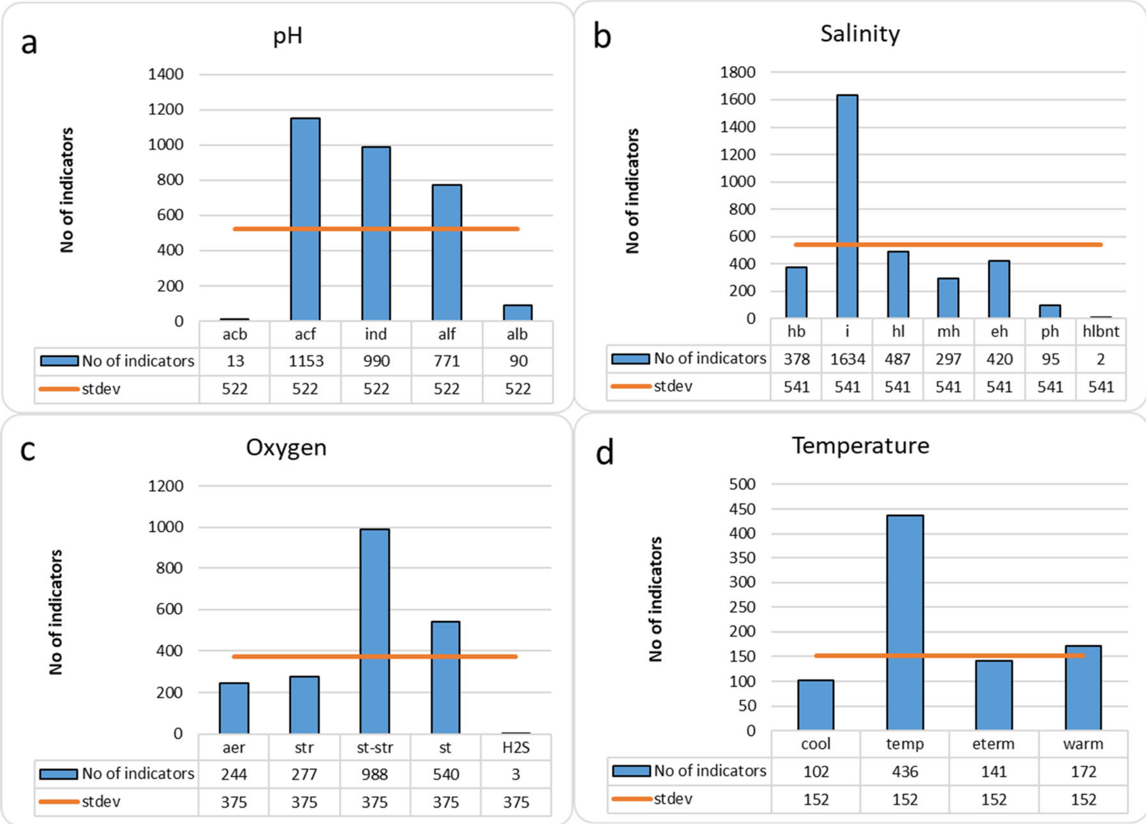

Figure 2. Distribution of the number of indicator taxa in groups according to the water pH system (**a**), salinity (**b**), water movement and oxygen saturation (**c**) and water temperature preferences (**d**). Orange line is the line of standard deviation for each distribution. Groups in each distribution are in order of the variable increasing.

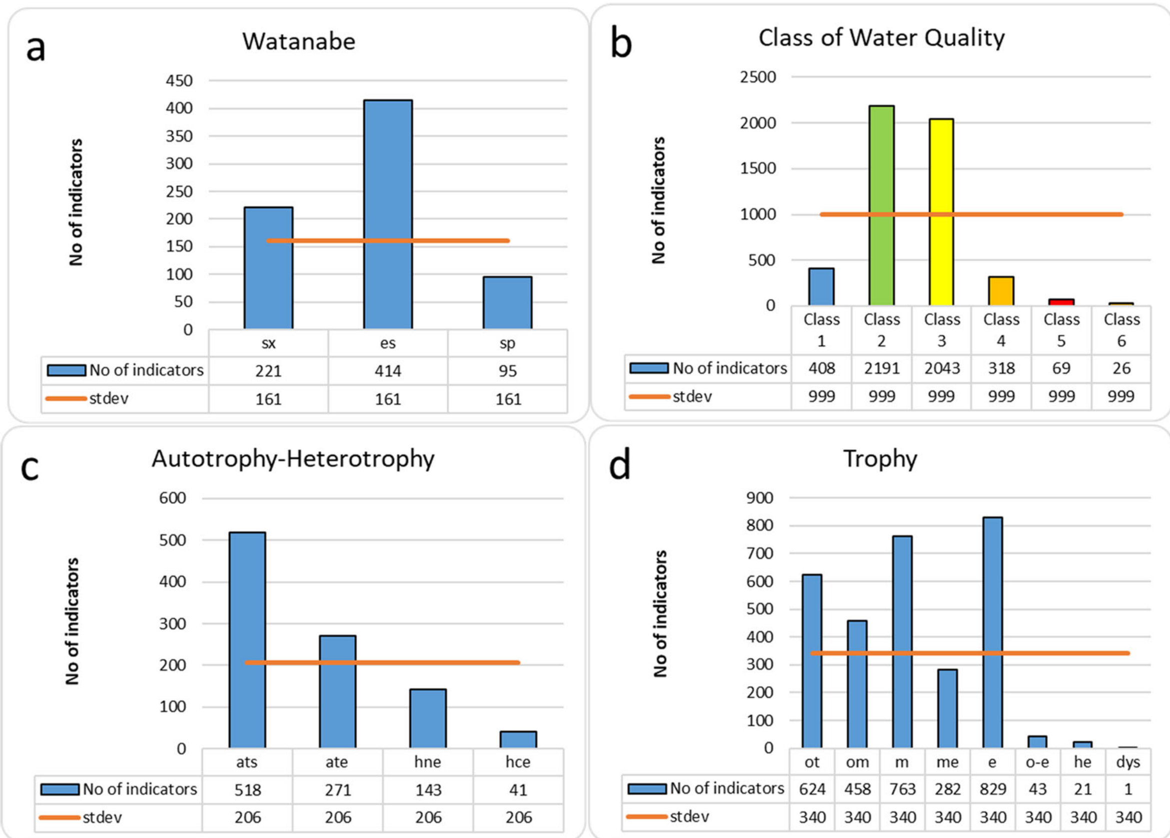

Figure 3. Distribution of the number of indicator taxa in groups according to the system of Watanabe (**a**), Class of Water Quality according index S of organic pollution (**b**), autotrophy-heterotrophy (**c**) and trophic state (**d**). Orange line is the line of standard deviation for each distribution. Groups in each distribution are in order of the variable increasing.

Although the indicator groups for each indicated parameter in Figures 2 and 3 are in order of a gradient of change of the indicated parameter, these distributions cannot be assessed as characteristic of any entire water body. Rather, they reflect scientific interest in studying a particular type of water body or in the response of algal and cyanobacterial species to specific environmental parameters, such as pH or salinity. Thus, it is possible to analyze either a particular water body in relation to all nine indicated environmental parameters, having a list of taxa for this water body, or to study the response of a particular community to individual environmental parameters, also having a list of species of this community.

5. Discussion

Since the article is more of a review than a specific study, it would be logical to discuss how to most conveniently use the database of ecological preferences of algae and cyanobacteria species, attached to the Supplement Table S1. In any case, before using the list of taxes of a specific water body, the synonyms are verified using the algaebase.org [12].

First, in each cell for each indicated environmental parameter, preference groups are given—one or more. The first group in the cell is the priority. For example, *Chlorella vulgaris* Beyerinck, a species that is found as plankton-benthic inhabitant, also was recognized in soil and as a phycobiont. The main group for assessing the aquatic environment is the first—a planktonic-benthic inhabitant. However, other, accompanying groups do not exclude its presence in soil communities or as a symbiont of lichens. These auxiliary groups can be used when describing the niche of specific taxa.

The easiest way to use the data from the Supplement Table S1 in practical terms is shown in detail in Supplement file S1. In the Excel table, the first column contains a unique number for each taxon. In the list of a specific community (or flora), insert the indicator taxon number from the Supplement Table S1 into an empty column in Excel. Then, in Access, connect both tables by the number of the first column and select the ecological parameters for the list of species in the analyzed community. Further use depends on the purposes of analyzing a specific community or flora. As a result, you can obtain a set of parameters characterizing the environment where this community lives and identify dominant or accompanying groups, calculate indices, and draw conclusions in accordance with the direction of analysis. The use of indicators based on algae and cyanobacteria has been used for more than twenty years [16–19,27,29,103,180–186]. It allows one to characterize the optimal and critical environmental parameters for a specific water body, as well as to track changes in community composition along gradients of certain environmental parameters, such as salinity or the altitude above sea level of the studied site. Mapping the results of the identified distribution of indicators and indices also allows one to draw broader conclusions about the preferences of the analyzed community in the conditions of a trend of environmental changes, including pollution or climatic parameters.

6. Conclusions

Thus, as a result of the accumulation of ecological data on species of algae and cyanobacteria over the last twenty years, it was possible to identify 9531 taxa-indicators from 18 taxonomic phyla. The indicators are grouped into twelve ecological groups, which can be indicators of nine environmental parameters. The most represented among the indicators is the taxonomic group of diatoms. The environmental characteristics for each of the indicator systems and the relationship between some of them are given. Individual abbreviations of ecological indicator groups that have been established as a result of long-term use are given. References are given to examples of the application of analysis of specific water bodies using bioindication methods, and prospects for use in monitoring and assessing water quality are shown. The attached table of 9531 indicator taxa contains cumulative ecological data and is easy to use.

This Supplement Table S1 is a living tool that can be supplemented and transformed, taking into account new information about indicator species.

Supplementary Materials

The following supporting information can be found at: https://www.sciepublish.com/article/pii/536, Supplement: Table S1 of indicator taxa of algae and cyanobacteria with ecological data of species preferences, Supplement file S1 with example of bioindicator analysis on the natural data.

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Author Contributions

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Not applicable.

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The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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