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Essential and Practical Bioindication Methods and Systems for the Water Quality Assessment

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Abstract

We are presented the most applicative systems of the water quality and the aquatic ecosystem state bioindication. The systems included most effective indication of the organisms' substrate and nutrition type preferences, water salinity, alkalinity, organic pollution and trophic state. Each of system is divided into the indicator groups with its detail description and our abbreviation. The correlations between major indicative variables are also given. At the end of the bioindication systems and calculated indices description is given an example of full set of indication systems application on the spatial dynamic of the Kiev Reservoir phytoplankton after the Chernobyl 1986 catastrophe.

Keywords: Bioindication; Water Quality; Aquatic ecosystem; Self-purification; Indices

Introduction

Previously we are discussing the main systems of the water quality classification [1] that based on the Ecosystem model of [2]. The major point of this approach is the amplitude of the water variables that covered of all possible parameters for surface and technical waters, as well as the amplitude of variables in which the aquatic ecosystem can survive. Considering that water quality assessment is rather expensive, elaboration of express-methods of its assessment is an urgent problem. Therefore, the bioindication methods were involved for the water quality assessment. This approach is based on the hierarchic organization of the biotic community, which is described by the model of trophic pyramid [1]. The distribution of the groups of organisms or species over the intervals of the environmental factors is also of considerable importance. The aim of present study is to describe the major most used essential and practical bioindication methods and systems for the water quality assessment as a part of the surface water quality monitoring.

Aquatic Ecosystem State Assessment

Pollution in the freshwater aquatic objects is complicated system. As was mention earlier [1: Figure 1] was present our system of matter transformation in the aquatic ecosystem. The methods and indices that can be used for assessment of pollution impact on the natural water bodies are based on the ecological point of view to the water and biota relationships. The production of proteins is involved level of primary producers by photosynthetic process, that assume that algae can be used as bioindicators of pollution impact. Yes, of course, the first trophic level of aquatic ecosystem defined all processes and contributions on the upper levels of trophic pyramid. That gives us base to assume that basic photosynthetic organisms such as algae and cyanobacteria can be used as bioindicators if it possible to describe its environmental amplitude of grows. The attention for this environmental variables definition for each species was implemented and developed in many systems and countries because it using can decrease the monitoring expenses [3,4].

Bioindication Methods

Algae are mainly autotrophic organisms that represent first trophic level in ecosystem pyramid [1]. Thus, they are involved in the process of organic matter production using the compounds of nitrogen and phosphorus. The content of nutrients influences not only algae abundance, but also their species composition. Thus, algae numbers and their species composition are taken into account in using the bioindication method. They reflect all natural and anthropogenic processes occurring in water bodies. In addition, a bioindication using algae community is inexpensive express-method as compared to chemical analysis.

At present, several systems of bioindication of the quality of surface waters are used. In this case, organisms of the lowest trophic level are widely used for the purpose of bioindication

[5-7]. For the most part bioindication is used in assessing water quality; however, sometimes this method is used in assessing the influence of heavy metals, aquatic genotoxins, and toxicity, and in determining hydrological conditions, habitats, and specific contamination [8]. The bioindication method is used in assessing the intensity of self-purification from pesticides and copper. Paleontological indication is performed in studies of temperature conditions and chemical composition of the water. The biosanitary state of water bodies, their trophic level [9], and even general assessment of the state of aquatic ecosystems are also assessed in terms of indicator organisms.

In many of the above-mentioned publications, bioindication methods are used in assessing the influence of individual environmental factors [3]. However, it is possible to determine the general state of ecosystems and prospects of their development. In addition, it is possible to predict the response of aquatic communities to changes in climatic conditions. A necessity of elaboration of the unified system of bioindication and assessment of the ecological state of water bodies based on comprehensive approach is widely discussed in literature. In this case, the main attention is paid to the study of the biota and regularities of its functioning overall. Unfortunately, new indices are put forward only for certain regions [10] or only for diatoms [11]. The promotion of new indices, which make it possible to assess the influence of climatic changes on the aquatic biota, is also an urgent problem that comes from the habitat latitude and as a result from the non-diatom species enrichments of aquatic communities [1].

Table 1: Major Bioindicator groups and number of indicators taxa (mainly algae) that we are revealed for the freshwater ecosystems.

Ecological group of indicators	No. of indicator taxa
Habitat (substrate) preferences	6308
Temperature	413
Rheophility (water moving) and oxygenation	1953
Water pH	2898
pH range	480
Halobity (Salinity)	2615
Organic pollution according Watanabe	764
Self-purification zone	5644
Index saprobity S	5678
Trophic state	2440
Nutrition type (autotrophy-heterotrophy)	491
H_2S (sulfides)	13
Total no. of indicator taxa	8475

The analysis of the species composition of algal communities is the main stage of bioindication. Previously the system of bioindication was based on the presence or absence of the species under certain environmental conditions. With time, the list of indicator species increased. The system included new species, which later were classified in terms of the main characteristics of the environment. More recently, species abundance (in scale scores or in percent) was also taken into account [12]. We collected information about species preferences in aquatic habitats and compiled large ecological database that included 8,475 taxa (Table 1) that can help to implement the main bioindication systems in the water quality and ecosystem state assessment.

Main Systems of Bioindication in Aquatic Habitats

pH-classification system according to F. Hustedt [13]

Table 2: pH-sensitive species groups according to F. Hustedt [13] .

pH-species groups	Our pH-groups abbreviation	Distribution
Acidobiontic	acb	Optimum distribution at pH below 5.5 (occur 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

Friedrich Hustedt performed the bioindication of water acidity in 1938 in Germany [13]. In the past decades, one of the methods that have been frequently applied to the study of pH changes in lakes employs the composition of diatom assemblages preserved in lake sediment [14]. In water bodies where sediments are absent or often disturbed, e.g. fast flowing rivers or shallow pools, pH-decreases have been observed by comparison of diatom assemblage in old and recent periphyton and plankton samples [15]. The method relies on the observation that the occurrences of diatom species in aquatic environments reflect, among other things, the pH of their environment [16]. F. Hustedt [13] was perhaps the first researcher to recognize such relationships. He presented a pH classification scheme that recognized five diatom-pH sensitivity categories (Table 2), ranging from alkalibiontes (surviving at a pH = 8 and higher) to acidobiontes (surviving in acid waters, with a pH = 5 and less). Algal and cyanobacteria database whom described by Barinova et al. [5] and after later referenced literature contain information about 2,898 species, compiled from six divisions, most of them belonging to diatom (82%) components by euglenoids, green, blue-greens, Rhodophyta, Charophyta, and Chrysophyta.

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Salinity classification system according to F. Hustedt [17]

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 in respect to the classification system proposed by Kolbe [18], developed by Hustedt [17], and presently widely used in bioindication [19]. The system divides the indicator species into four groups (Table 3).

Table 3: Classification of water salinity and groups of salinity algae indicators by four groups according [19].

Groups of salinity indicators	Classification of salinity	NaCl gL^{-1}
Polyhalobes	Salts water	40 - 300
Euhalobes	Marine water	30 – 40
Mesohalobes	Brackish	5 – 20
Oligohalobes	Freshwater	0 - 5

Table 4: Groups of salinity indicators [17] with our abbreviation.

Salinity groups	Our Salinity groups abbreviation	Habitatrelationtosalinity
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	stimulation increases their biomass
2. Indifferents	i	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	Inhabit fresh water only. Salinity decreases their numbers

The Hustedt's description of indicator groups preferences are given below: Polyhalobes, living in hyper saline waters from 40‰ to 300‰. Euhalobes in habiting 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 4).

a. Halophiles, essentially freshwater, but enhanced by a slightly elevated concentration of NaCl.

b. In differents, typically freshwater, occurring, but never abundant, in slightly brackish waters.

c. Halophobes, strictly freshwater, perishing even at a slight increase of NaCl concentration. Algal database contains information on 2,615 species indicative of chloride concentrations [20].

Because the salinity system includes a wide range of concentrations typical to natural waters, it can be measured by different equipment but indicators are 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 5).

Table 5: Water salinity and electrical conductivity classification comparison [18, 20].

Electrical conductivity [20]		‰, g L^{-1} [18]	TDS, mg L^{-1} [20]	Salinity Class [18]	Salinity range, ‰ [18]	Salinity, mg L^{-1}, (approx.) [20]
Salinity Class	mSm cm^{-2}					
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	600-2,000			250-1.000
IV	3.0-10.0	2-8	2.000-8.000	3	5-20	1,000-4.000
V	10.0-30.0	8-20	8.000-20.000			4.000-10.000
VI	>30.0	20-80	20.000-80.000	2	20-40	10.000-40.000
VII		>80	> 80.000	1	40-300	

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 [21] (1902), and later on expanded by [2]. A determination of the saprobic value is based on the sampling and the identification of species of fauna and flora and a comparison with the saprobic characteristics for each species. Sladecek's description [2] has been adapted for classes of water quality, the Saprobic Index S and self-purification zone in water ecosystems (Table 6). The objective is to provide a water quality classification based on the pollution tolerance of the indicator species present. Every species has a specific dependency of organic substances and, thus, of the dissolved oxygen content: this tolerance is expressed as a saprobic indicator value [22]. These zones (Table 6) 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 of the five zones are characterized by indicator species that live almost exclusively in the aforementioned zones. We found 5,678 indicator taxa for organic pollution tolerance (Table 1).

Table 6: The connection between classes of water quality (EU color codes), index saprobity S, and self-purification zone in water ecosystems according to [2].

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	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 [23]:

i. ***Xenosaprobic zone* (no organic pollution).**

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). More sensitive species such as aquatic mosses, planaria, and insect larvae can be found. These waters are clear and blue with high amount of dissolved oxygen. Also, the number of bacteria is very less. Most organisms are sensitive to changes in the amount of dissolved oxygen and pH values.

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. The surface waters are characterized with rich submerged vegetation, abundant macro zoobenthos (in particular the Mollusca, Insecta, Hirudinae, and Entomostraca), and robust fishes (Cyprinidae).

iv. ***α-mesosaprobic zone* (severe organic pollution):** Amino acids and their degradation products, mainly fatty acids, are present. Free oxygen causes a decline in reduction processes. The water is usually dark gray and smells rotten or unpleasant due to H_2S or the residues of protein and carbohydrate fermentation. This zone is characterized by "sewage fungus", a mixture of organisms dominated by the bacterium *Sphaerotilusnatans*. The mass of organisms, which form long strands, is detached from the bottom of sediment by the gas generated during respiration and decomposition processes, and then drift in the water column as cloudy gray masses. Frequently, these masses form a mat over the entire surface of the stream's bed. Sewage fungus is particularly common in waters containing wastes rich in carbohydrates, such as sewage and effluents from sugar and wood processing factories.

v. ***Polysaprobic zone* (extremely severe organic pollution):** Rapid degradation processes and predominantly anaerobic conditions. Protein degradation products, peptones and peptides, are present. 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. In many cases, the bottom of the watercourse is silty (black sludge) and the undersides of stones are colored black by a coating of iron sulfide (FeS). Such waters are characterized by the absence of common autotrophic organisms and a dominance of bacteria, particularly thio-bacteria that are well adapted to the presence of H_2S. Various blue-green algae, rhizopods, zooflagellates, and ciliated protozoa are also typical of polysaprobic communities. A few invertebrates that can live in the polysaprobic zone often have a special blood pigment, haemoglobin, (e.g., *Tubifex, Chironomus thummi*) or organs for the intake of atmospheric air (e.g., *Eristalis*). Fishes scarcely survive in this zone.

The indices of saprobity (S) calculation

Index of saprobity S is represented the tolerance of entire community to dissolved organic matter. Its value is related with the Water Quality Class and self-purification zones [1] and can be calculated on the base of 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, [12]) for the indicator species 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 algal community; s_i is the species-specific saprobity level; a_i is the frequency values $S = \sum_{i=1}^{n}(s_i.a_i) \Big/ \sum_{i=1}^{n}(a_i)$ (Equation . 1):

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Environment Pollution Index (EPI)

A diatom-based index for eutrophication and/or pollution (EPI) has been established [10] for biological assessment of water quality. This index shows significant correlation with the chemical and physical properties of the water (BOD_5, nutrients, conductivity, chlorides, phosphates, etc.). As in Sládeček [2,24] the method defines the saprobic tolerances of indicator species and their abundance in the algal communities, added by the individual species coefficient. The Environmental Pollution Index (EPI) is calculated as follows (Eq. 2):

$EPI = \Sigma a_j r_j i_j / \Sigma a_j r_j$, (Eq. 2)

Where aj is the abundance of each species, i_j is the index of EPI of each species and r_j is the reliability R, according to the diatom-based list (Dell'Uomo, 1996). The following criteria were used when assigning an index value to the diatom-based list (Table 7).

Table 7: Relationship between EPI index and different environment variables [10].

Saprobic degree	Tropic degree	Water quality	EPI
xenosaprobic	hypotrophic	Level 0	0
oligosaprobic	oligotrophic	Level 1	1
β-mesosaprobic	mesotrophic	Level 2	2
α-mesosaprobic	eutrophic	Level 3	3
polysaprobic	hypertrophic	Level 4	4

Table present:

a. Relationship to different nutrient levels (Trophic degree).

b. Relationship to organic pollution according to [2] that recognized five different saprobic levels of limnosaprobity.

The resulting EPI is a whole or decimal number between 0 and 4, whose progression is correlated with decreasing water quality. The water quality of the station examined can be estimated with the aid of the following relationship (Table 8).

Table 8: The correlation between EPI and water quality according to [10].

EPI range	Water quality
0.0 – 0.5	Natural, unpolluted water
0.5 – 1.0	Excellent water quality
1.0 – 1.5	Good water quality
1.5 – 2.0	Fairly good water quality
2.0 – 2.5	Slightly polluted water
2.5 – 3.0	Rather polluted water
3.0 – 3.5	Strongly polluted water
3.5 – 4.0	Heavily polluted water

An alternative method [11] defines three groups of indicators: saproxenes of clean water, eurysaprobes of medium quality water, and polysaprobes of polluted water. We have 764 species in our database list that are indicators of organic pollution according to Watanabe's scale. 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 9).

Table 9: Compliance of saprobity levels, halobity, and trophy with water quality classes for Dell'Uomo [10].

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

Detail characteristics and our abbreviation of the major indicator groups including that not under above mentioned systems and in addition to [25]

Aquatic habitat (substrate) preferences (6,308 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 (413 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.

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Rheophility (1,953 indicator taxa):

St – Standing water;

Str – Streaming water;

St-str – Standing-streaming, and / or indifferent;

Aer – Aerophil;

Reoph – Rheophil;

Eoxibt – Euryoxibiont;

Organic pollution Indicators Groups according Watanabe [11] (diatoms only) (764 indicator taxa):

sx – Saproxen;

sp – Saprophil;

es – Eurysaprob

Self-purification zones according to Pantle-Buck in the modification of Sládeček [2] with individual indices of each group of saprobionts (5,644 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) according to [17] (2,615 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 according to [13] (2,898 indicator taxa):

ind – pH Indifferent and / or neutrophil;

alf – Alkaliphil;

alb – Alkalibiont;

acf – Acidophil.

Groups of Autotrophy-Heterotrophy– nitrogen uptake metabolism according to [9] (2,491 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 Trophy– trophic state according to [9] (2,440 indicator taxa):

ot – oligotraphentic;

om – oligo-mesotraphentic;

m – mesotraphentic;

me – meso-eutraphentic;

e – eutraphentic;

o-e – oligo- to eutraphentic (hypereutraphentic);

he – hypereutraphentic.

An example of the application of a complex bioindication of a water body on the basis of the above mentioned bioindication systems.

Over the past several years, we have applied a comprehensive assessment of the state of diversity of aquatic organisms and

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water quality by the example of various types of water bodies from standing such as lakes and reservoirs to flowing ones such as coarse slowly flowing rivers and fast flowing tributaries. This gave us an opportunity to characterize not only the state of the ecosystem of the water body, but also to trace the spatial and temporal dynamics of its bioindication characteristics. Bioindication analysis was used for assessment diverse aquatic habitats [5,6,26]. As an example of the application of a complex bioindication to the Kiev Reservoir ecosystem assessment on the base of its phytoplankton species richness and abundance we can demonstrate the possibilities of proposed method.

The main recommendation for conducting a bioindication analysis is the location on the histogram of the indicator groups of each variable in order to strengthen this variable. So, the groups of substrate preferences indicators on (Figure 1) are placed in order to strengthen of substrate connection from right to left. The same order was used for the bioindication histograms on (Figures 2-5). So, Figure 1 show that species richness of the Kiev Reservoir phytoplankton [27] is decreased from 1970 to 2011 as a whole with the same distribution over the Taxonomic Division as shown on STDEV lines. The polynomial trend lines have similar upper points. Distribution of species richness over studied periods also demonstrated low fluctuation of the phytoplankton diversity. The same tendency can be seen in the substrate preferences with slightly increasing of benthic and planktonic species. Species richness decreasing mean that anthropogenic impact to the Kiev Reservoir ecosystem was decreased after the Chernobyl 1986 catastrophe, and current velocity also slightly increase.

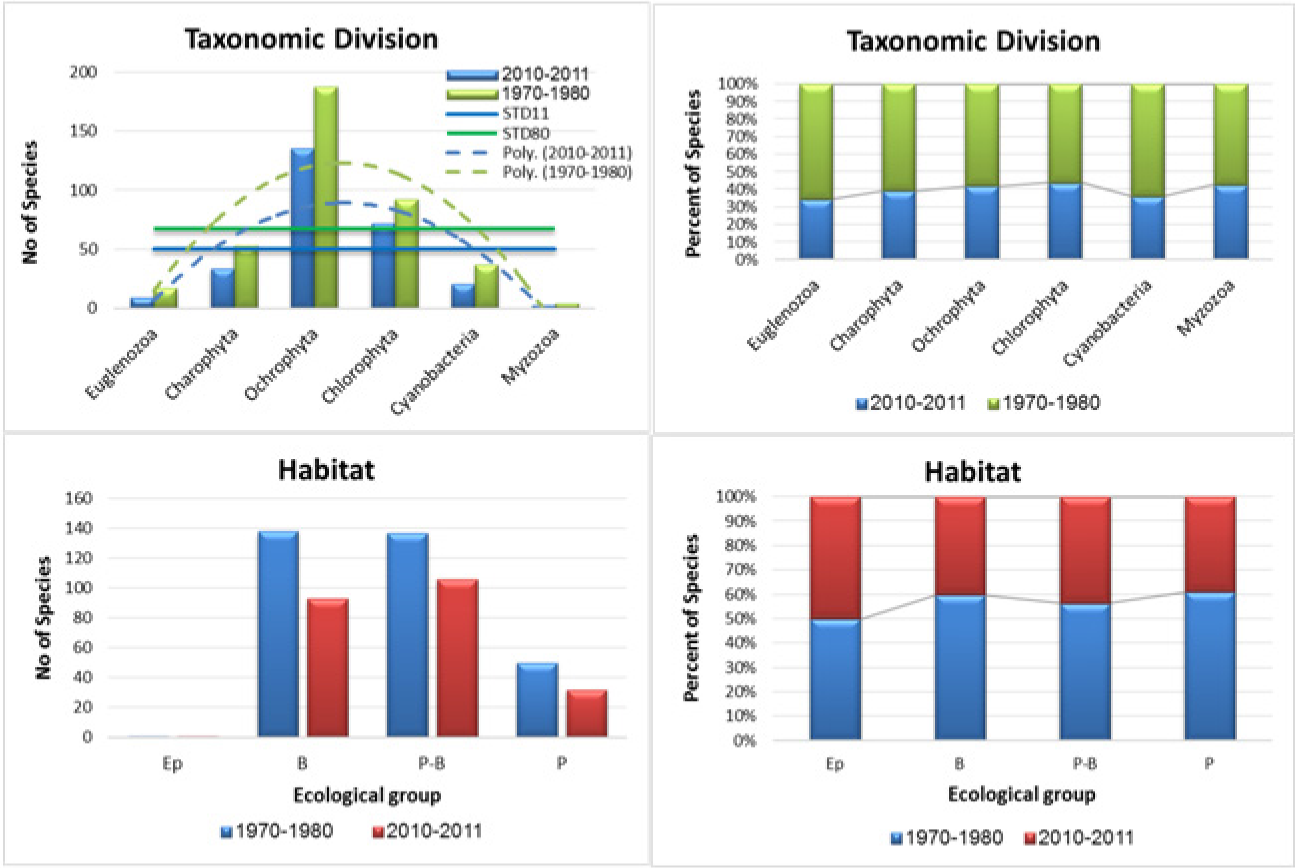

Figure 1: Bioindication of the Kiev Reservoir ecosystem dynamic in 1970-1980 and 2010-2011 for species richness in Taxonomic Division, and substrate preferences.

Bioindication results on (Figure 2) demonstrated decreasing indicator species in groups of temperature and diatom saprobity. Can be seen that col-water and eurythermic species in time after catastrophe are decrease with diatom indicators of organic pollution slightly increasing. That reflects the temperature impact to the water of the reservoir after 1986 catastrophe, mainly to the groundwater.

Bioindication of available oxygen show slightly decreasing of well-oxygenated water indicators in the time after Chernobyl. In the same time, indicators of water salinity are slightly increased with even one polyhalobic species finding whereas as a whole reflects the fresh waters (Figure 3). Indicators of water pH reflect as completely low alkaline water but in time after 1986 the numbers of alkaliphiles and even alkalibiontes are significantly increased (Figure 4). Nutrition type indicators demonstrated the autotrophes prevailing but in time after Chernobyl was increased the number of facultative heterotrophes. This situation can be if the groundwater is enriched the reservoir water with some concentration of the elements suppressed the photosynthetic process of the producers.

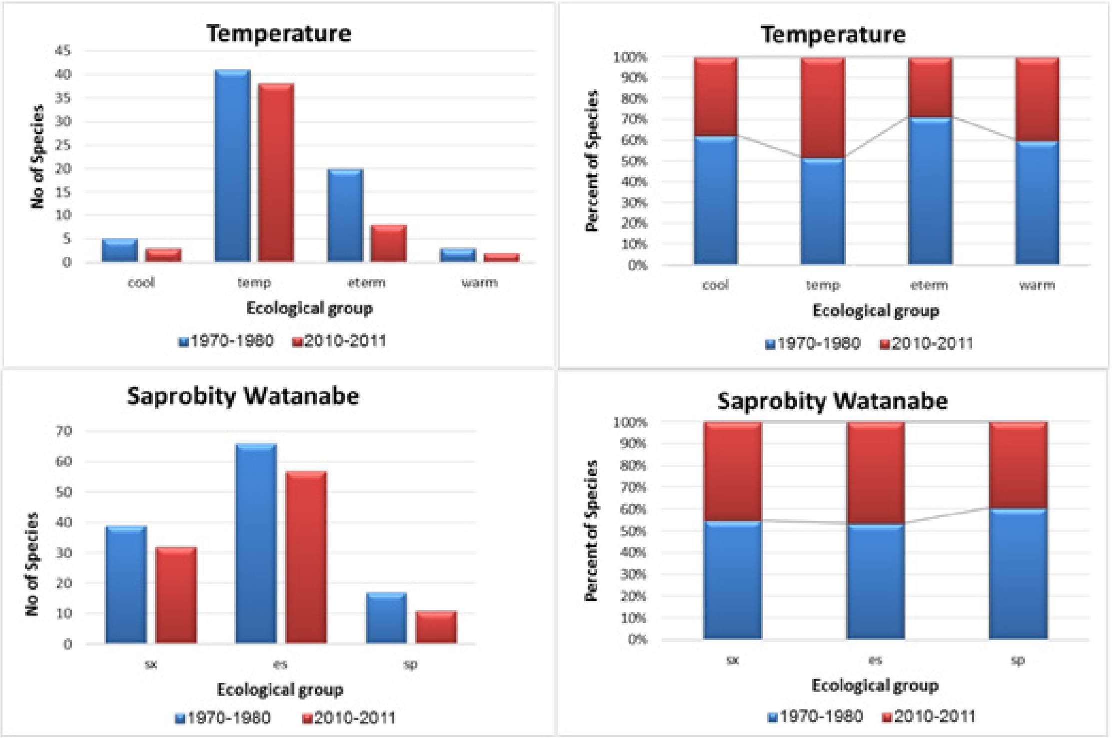

Figure 2: Bioindication of the Kiev Reservoir ecosystem dynamic in 1970-1980 and 2010-2011 for water temperature and organic pollution based on Diatoms.

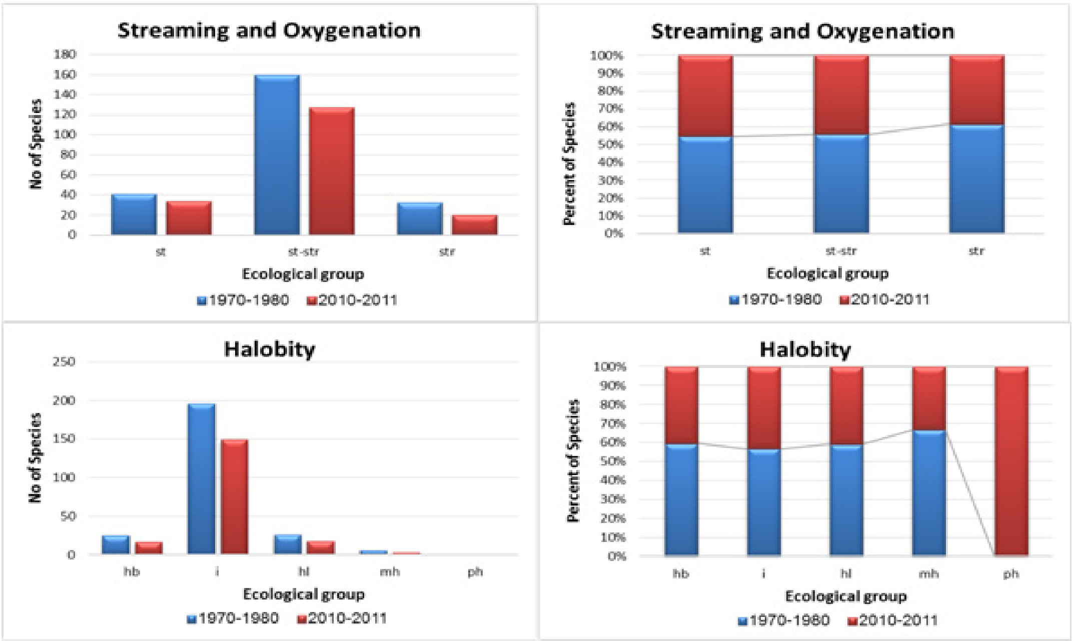

Figure 3: Bioindication of the Kiev Reservoir ecosystem dynamic in 1970-1980 and 2010-2011 for water oxygen enrichment and salinity.

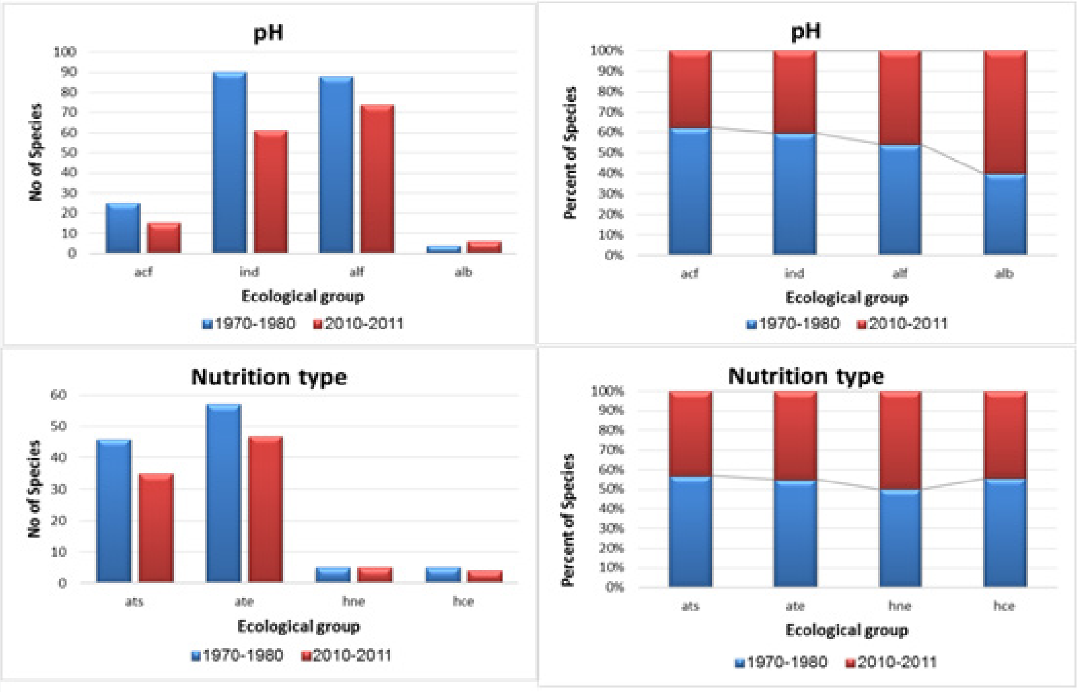

Figure 4: Bioindication of the Kiev Reservoir ecosystem dynamic in 1970-1980 and 2010-2011 for water pH and algal species nutrition type.

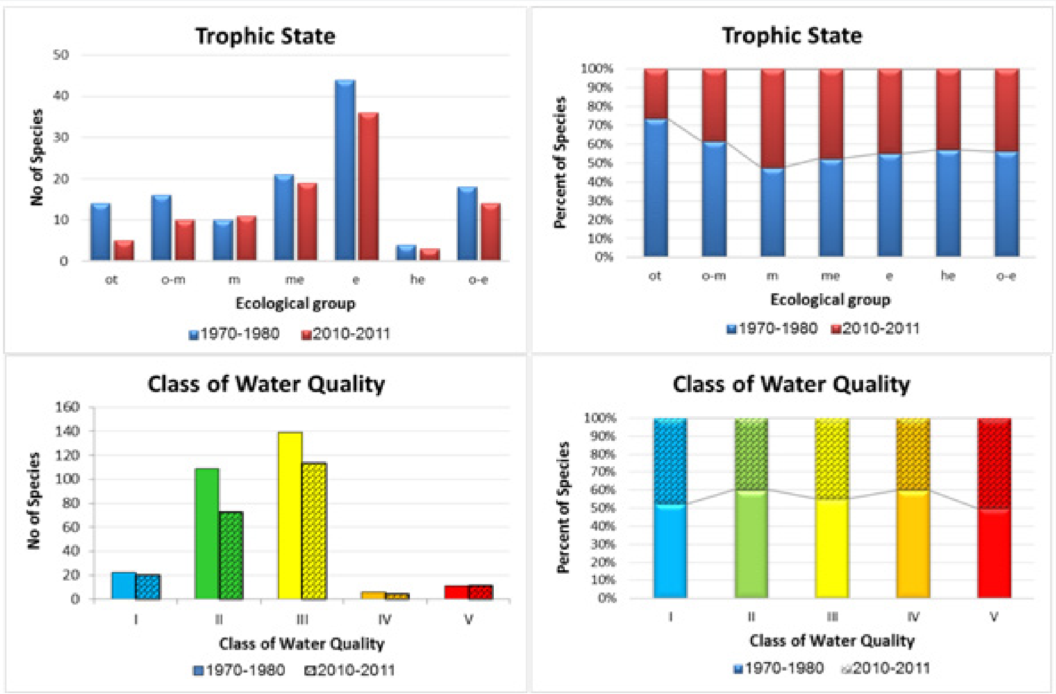

Figure 5: Bioindication of the Kiev Reservoir ecosystem dynamic in 1970-1980 and 2010-2011 for water trophic state and the Water Quality Class according the EU color codes.

Analysis of trophic state indicators in the phytoplankton of the reservoir show (Figure 5) that all ecological groups of trophy are presented in community of the reservoir phytoplankton. Time-scale fluctuation of this type indicators are demonstrated dramatically decreasing of oligotrophic-species number that show increasing of trophic level of the Kiev Reservoir ecosystem after the Chernobyl catastrophe. Bioindication of the water quality show prevailing of indicators of Class II and III but increasing in

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time the Class V indicators as the reservoir ecosystem response to the increasing pollution after 1986 catastrophe. Therefore, bioindication analysis show not only ecosystem variable state in the reservoir ecosystem such as freshwater, low alkaline with medium organic and oxygen enrichments of its water but also temporal dynamic of major variables after the Chernobyl catastrophe to the decreasing of species richness, increasing of water pH, temperature, salinity, organic enrichments, and trophic state. This result is reflect increasing the role of alkaline groundwater with higher temperature that stimulate the organic enrichments of the reservoir water despite the closure of the river basin territory up to the Kiev Reservoir for anthropogenic activity and settlements after 1986 Chernobyl catastrophe.

Conclusion

This example show the sensitivity and simplicity of the bioindication methods application in the aquatic ecosystem analysis for the ecosystem state assessment as well as for the temporal dynamics of the major indicative variables of studied aquatic object. We are given here an example of bioindication of lentic water body, but the same analysis can be doing for the river ecosystem as an analysis of spatial dynamic of indicative variables from upper reaches to the river mouth [28]. More of them, the bioindication systems that were described above can be related with the major classification systems of the aquatic ecosystem variables and water quality of the surface water [1]. Thus, bioindication systems reflect the main water indicators based on the organisms found in the communities living in the water body. On the other hand, it is possible to assume what type of organisms can survived in waters of a certain quality, reflected in the classification of the main parameters of aquatic ecosystems from an ecological point of view.

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