DIAGNOSTICS OF THE WATER QUALITY OF THE KUIBYSHEV RESERVOIR LITTORALS WITH VARIOUS ANTHROPOGENIC LOAD: HYDROBIOLOGICAL AND MULTIFRACTAL ANALYSIS

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SUMMARY

We analyzed indicated structural indexes of zooplankton communities of the Kuibyshev reservoir intertidal zones. Species diversity of zooplankton was evaluated using a multifractal analysis. We found that total population size and biomass of zooplankton, population size and biomass of *Copepoda* and *Cladocera* species, index of species diversity in biomass, number of alpha animals, multifractal spectrum of species diversity of zooplankton were the characteristics that reflect adequately environmental changes. Quantitative indexes of rotifers, index of species diversity in population size, saprogenic index and $Q_{B/T}$ index are not reliable criteria in the assessment of water's quality.

KEYWORDS:
zooplankton, multifractal analysis, water quality.

INTRODUCTION

The problem of expert judgements in the ascertainment of water quality might be resolved during the investigation of alterations in chemistry and populations of water organisms. However, analysis of interaction between chemical components of water and biological indicative data is not always adequate. Surprisingly, aquatic organisms live and propagate in waters that were marked as very dirty according to aqueous methods [1]. The most probable reasons for that are single-step characteristics of the hydrochemical and hydrobiological regime of a stream. This approach does not take into account effects of combined action of chemicals (environmental synergism and antagonism) as well as interactions between aquatic organisms that may increase of toxic-resistance of some populations of aquatic organisms [2]. A surveying system for estimation of changes in biotic components caused by anthropogenic and structural factors is a key element in the environmental monitoring. In this connection, it is important to emphasize some features that are most powerful tests for assessment of organization peculiarities of aquatic communities in general and zooplankton, specifically. For example, a whole list of structural, functional and integral criterions was presented in the work by Andronnikova [3]. These criteria were used for the assessment of trophism in lake ecosystems.

There is an analogous reaction of the zooplankton communities on the increase of organic and biogenic load in small rivers. Namely, there is an increase in number of rotifers while a decrease in the quantity of crustaceans is observed. In addition, there is a prevalence of species that are indicators for organic contamination. In small rivers, maximal species diversity is observed during the spring period [4, 5]. It was found that the following parameters are the most informative to assess the complex technogenic contamination: the balance between species of *Rotatoria*, *Cladocera* and *Copepoda*; correlation between biomass of rotifers and crustaceans [6-8]. Index of the zooplankton species biodiversity, prevalence of crustaceans, poor species structure as well as species specific complexes that are resistant to acidification is the most frequent feature of the acidification influence on the water ecosystem [9].

Reservoir littorals are characterized by a high degree of biodiversity and by intensive processes of bioproduction and biodestruction. At the same time, these regions are significantly influenced by anthropogenic load. Initial changes at the ecosystem level might be registered there.

In this work, we aimed to analyze structural features of zooplankton in the macrophyte-filled littoral zone. For this purpose, we used a broad spectrum of standard hydrobiological characteristics as well as multifractal analysis of biotic environment. We used a methodological approach suggested by Iudin et al. [10] and assessed species distribution by using both animal numbers and biomass.

MATERIALS AND METHODS

Two soundings of the Kuibyshev reservoir (Republic of Tatarstan, Russia) that differed by anthropogenic load were studied during 2002 and 2003. The first reach (Borisov's channel) was near Pobedilovo and represented a small channel (falling into Kuibyshev reservoir) with tabular muck bottom and bank vegetation (osiery). In July (both 2002 and 2003) the projective plant coverage reached 100% (50% of reed mace and 50% of free-swimming plants – multiwheeler, duckweed). At the end of August (both 2002 and 2003) plant distribution was as follows: 90% of reed mace and 10% of free-swimming plants.

Between Tatar Saraly and Atabaevo, there was a second reach that represented a reservoir bay with small islands. This region falls into the Saraly part of the Volga-Kama National Park. Samples were taken from the coastal water of the islands. The littoral region of the second reach was covered with osiery and reed mace. In July (both 2002 and 2003) projective plant coverage of the region was represented by reed mace (about 60%) as well as duckweed and multiwheeler (about 30-40%). Accessibility and exposure to air (airiness) and wave wash were characteristic features of the region.

Water samples (volume of 2 L) were taken every two weeks using the Molchanov's bathometer (digging depths of 0.50-0.70 m, 0.7-1.0 m and 1.0-1.20 m). Temperature, pH as well as values of oxidation-reduction potential and content of dissolved oxygen were determined using a small-sized dissolved oxygen analyzer (Mark-201, VZOR LLC). Chemical analysis of other water components was performed according to standard procedures [11, 12]. In general, we analyzed 123 samples (63 samples were taken from the first reach, 60 samples from the second one). Various physicochemical parameters were used for the assessment of the water' quality (pH, chemical consumption of oxygen, biological consumption of oxygen, contents of oxygen, nitric oxide, nitrous oxide, oxygenous phosphate and total phosphorus) according to complex environmental health manual [13, 14].

An Apshtein net (24 cm in diameter; aperture size of 90-100 µm) was used for water filtration (10-50 L depending on the water depth in the region) and collection of zooplankton samples. For quantitative analysis, zooplanktonic organisms were fixed with 4% formaldehyde solution according to standard recommendations [15]. For qualitative analysis, the invertebrates were used alive. Zooplankton samples were analyzed using a BIOLAR microscope, and specific differences were detected according to Kutikova [16]. Using an eyepiece micrometer, we measured the specimen size of the water organisms. Zooplankton community was assessed by qualitative content, number of species (Q), population size (N), biomass (B) as well as by the taxonomic group ratio (*Rotatoria – Cladocera - Copepoda*). Population biomass was calculated using population size (n_i/N) and individual mass (b_i/B). An individual mass was assessed using power functions connecting organism's mass and length [17]. Predominant complexes were revealed according to function of rank distribution [18]. Prevalence of the single species was assessed according to Lebedeva et al. [19]. Index of the species diversity was calculated using population size criterion (H_N) [20] and biomass (H_B) [21]. $Q_{B/T}$ index was calculated as ratio *Brachionus* genus versus *Trichocerca* genus. The saprogenic index was calculated for the evaluation of the water quality [22].

We collected 100 samples (52 from the first reach and 48 from the second one) were analyzed quantitatively while 43 samples were assessed qualitatively (23 from the first reach and 20 from the second one). Paired Student test (*t*-test) was used for statistical analysis.

Multifractal analysis according to established procedures [23, 24] was applied for assessment of the zooplankton species diversity and distribution by number and biomass. For each zooplanktonic community, data on number and biomass were summed using a special program that took into consideration local features of environment [25] and the corresponding multifractal spectra were presented.

RESULTS AND DISCUSSION

Hydrochemical peculiarities of the Kuibyshev littorals

The chemical composition of the investigated intertidal regions differed significantly. The first reach was characterized by an increased mineralization (470 mg/L) while the second reach did not (248 mg/L) according to the Aleksin's classification [11]. The middle content of sulfates, calcium and magnesium ions were 3-folder and 2-folder, respectively, in the first reach (Table 1). The middle contents of the mineral and total phosphorus were similar in the regions under study while contents of nitrate and ammonium nitrogen differed significantly (Table 1). In both regions, nitrate nitrogen was dominant (herewith in the first region its content was 40% higher). The first region was also marked by the higher content of ammonium nitrogen, non-oxygenated (about 30% of bichromate oxidability) and oxygenated (about 20% of biological consumption of oxygen during the 5 days) organic compounds (Table 1). The revealed chemical contamination of the first region was connected with the influence of entry of polluted effluents. Sulfates, chlorides and heavy metals were the most frequent pollutants [26]. Oxygen concentrations were higher in the first region (Fig 1A, B). We did not find any significant correlations between oxygen content and content of organic compounds. Most likely the production-destruction features of the region were the reason for the phenomenon.

An integral grade estimation of the two investigated regions according to median rank index is presented in Table 2.

The obtained data suggest that the first investigated region differed from the second one. Namely, the first region referred to α-mesosaprogenic zone with polluted water (class 4) while the second region referred to β- mesosaprogenic zone with satisfactory quality (class 3). According to maximal indexes, the both regions referred to β-polysaprogenic zone with piggish water (class 5).

TABLE 1 - Hydrochemical parameters of the investigated regions of the Kuibyshev reservoir littorals.

Parameter	Region № 1			Region № 2		
	Mean + SD	Minimal value	Maximal value	Mean + SD	Minimal value	Maximal value
O_2, mgO/L	10.7±0.9	2.2	19.6	7.6±0.8	0.4	16.3
ORP, mV	148.5±10.2	57.0	223.0	130.4±21.4	201.0	313.0
pH	7.3±0.1	6.0	8.7	7.2±0.1	6.4	9.1
Total mineralization, mg/L	468.2±15.9	307.6	854.0	248.6±6.2	171.0	414.9
Ca^{2+}, mg/L	84.7±3.9	40.0	178.0	44.1±1.4	20.8	96.0
Mg^{2+}, mg/L	20.1±1.7	1.8	40.9	9.3±0.7	1.2	29.2
HCO_3^-, mg/L	170.6±3.8	122.0	263.6	136.8±3.5	110.0	276.1
SO_4^{2-}, mg/L	165.4±8.3	21.0	377.0	54.3±2.6	15.8	99.9
Cl^-, mg/L	39.9±1.2	24.8	59.6	22.7±0.9	15.6	46.8
BO, mgO/L	33.9±2.6	14.3	92.8	24.0±2.3	3.1	78.0
PO, mgO/L	12.2±0.9	1.7	28.8	11.5±0.5	6.7	20.4
BCO_2/5 days, mgO/L	5.9±0.6	0.9	11.5	4.8±0.8	0.5	18.6
Total phosphorus, mg/L	0.28±0.03	0.07	0.59	0.29±0.04	0.05	0.74
PO_4^{3-}, mg/L	0.09±0.01	0.003	0.46	0.10±0.02	0.001	0.80
NO_3^-, mg/L	1.88±0.22	0.10	7.86	1.15±0.11	0.11	3.60
NO_2^-, mg/L	0.09±0.02	0.003	0.69	0.07±0.02	0.001	1.25
NH_4^+, mg/L	0.67±0.10	0.02	5.34	0.49±0.04	0.02	1.48
Cd, µg/L	1.15±0.27	0.01	7.50	1.0±0.2	0.1	4.6
Pb, µg/L	11.6±2.1	0.1	48.0	9.3±1.6	0.2	31.5
Cu, µg/L	6.4±0.7	0.5	29.5	5.8±0.5	0.5	16.1
Co, µg/L	7.9±0.6	0.7	14.3	6.3±0.5	0.9	14.2
Ni, µg/L	12.5±0.9	1.0	19.7	10.8±0.8	0.5	19.9
Zn, µg/L	17.8±1.7	1.1	42.6	17.9±2.5	0.9	67.1
Cr, µg/L	4.9±0.7	1.5	9.5	3.4±0.5	1.7	8.1
Mn, µg/L	89.4±29.3	3.5	1198.0	114.6±35.7	6.0	1176.0
Fe, µg/L	239.0±47.4	1.0	1344.0	209.5±42.7	22.5	1555.0

Abbreviation: SD=standard deviation; BO=bichromate oxidability; PO=permanganate oxidability; ORP=oxidation-reduction potential; BCO_2/5 days=biological consumption of oxygen during the 5 days.

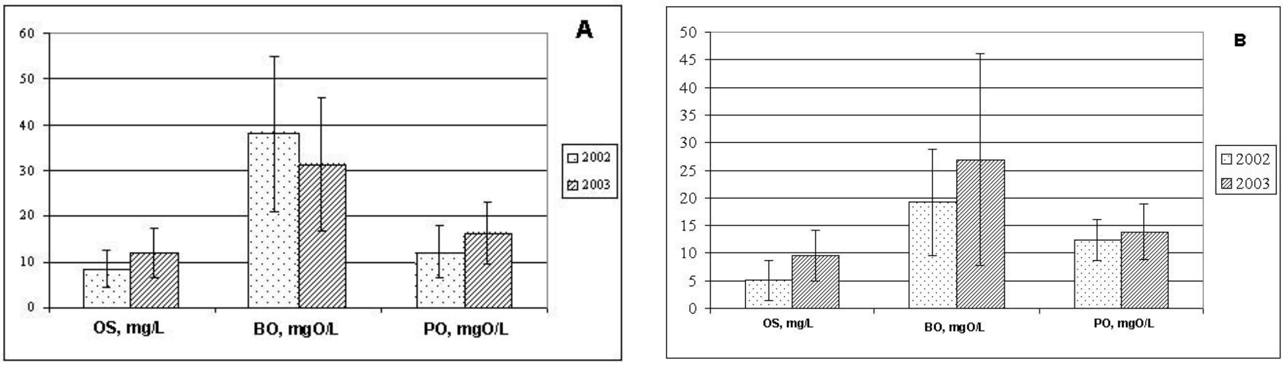

FIGURE 1 - Dynamics of the dissolved oxygen and organic compounds in the water of the Kuibyshev reservoir littorals (A-region 1; B-region 2). OS=oxygen solubility; BO=bichromate oxidability; PO=permanganate oxidability.

TABLE 2 – Classification of waters of the investigated Kuibyshev reservoir regions

Re-gion№	Index values	Mean rank value	Water quality rank	Saprogenic zone	Water quality class
№ 1	Minimal	2.1	2a – very pure	β – oligosaprogenic	2 - pure
	Dominant	5.8	4a – moderately polluted	α – mesosaprogenic	4 – polluted
	Maximal	8.2	5a – very dirty	β – polysaprogenic	5 - dirty
№ 2	Minimal	3.0	2b – fully pure	α – oligosaprogenic	2 - pure
	Dominant	5.3	3b - slightly polluted	β - mesosaprogenic	3 – satisfactorily pure
	Maximal	8.3	5a – very dirty	β – polysaprogenic	5 - dirty

Structural organization of zooplankton communities in the Kuibyshev littorals

We found that the zooplankton features of the first region differed slightly from the ones of the second region (Table 3). In general, total number of species and index of species diversity in population size are reduced in polluted water while the saprogenic index and $Q_{B/T}$ index are increased [3]. The above characteristics are most frequently used in the assessment of the water quality. A total number of species, number and biomass of rotifers also did not differ significantly between the two investigated regions. Despite the predominance of rotifers (45-51% of the total number of species), their number (12-33%) and biomass (3-10%) cannot be taken into account during the assessment of anthropogenic pollution. However, the proportion of rotifers in the second region was slightly higher than that in the first region. This finding can be explained by the fact that soundings of the second region are amenable to wind and waves. This may provoke an additional superinducement of rotifers from the open places of the Kuibyshev reservoir.

Table 3 suggests that there were significant differences between the first and second regions concerning the species number of *Cladocera* and *Copepoda*, total number and biomass, number and biomass of *Copepoda* biomass of *Cladocera* and species diversity index in biomass. Differences in *Cladocera* biomass between the two investigated regions were not significant. In the first region, the indicated zooplankton values were increased 3.2-fold (in total number), 4.3-fold (in biomass), 4.5-fold (in number of *Cladocera*), 3.7-fold (in number of *Copepoda*), 3.5-fold (in biomass of *Cladocera*) and 4.5-fol (in biomass of *Copepoda*).

Therefore, an increase in quantitative indexes was revealed in the polluted zooplankton coens. Moreover, differences were obtained concerning the structure-forming complex of the zooplankton species (Table 4). It is clear from the Table 2 that *Bosmina longirostris* was a dominant species (in number) in the first region while four species (*Bosmina longirostris, Euchlanis dilatata Ehrenberg, Diaphanosoma brachyurum Lievin, Alona costata Sars*) were dominant in the second region. In biomass, the first region was characterized by presence of six species (2 co-dominant and 4 sub-dominant) while the second region was marked by uniform distribution of eight species. Predominance of some zooplankton species might be

TABLE 3 – Some zooplankton parameters of the investigated regions of the Kuibyshev reservoir littorals (mean±standard deviation).

Parameter	Region		Probability	*t*-value
	№1	№2		
Total Q	10.3 ± 0.7	8.9 ± 0.8	0.1863	1.33
Q of *Rotatoria*	3.3 ± 0.4	4.5 ± 0.5	0.0928	1.71
Q of *Cladocera*	4.0 ± 0.4	2.7 ±0.4	0.0217 *	2.36
Q of *Copepoda*	3.0 ± 0.4	1.7 ± 0.2	0.0028 *	3.13
Total *N*, x1000/m^3	247.9 ± 73.7	78.4 ± 17.2	0.0378 *	2.13
N of *Rotatoria*, x1000/m^3	29.7 ± 9.1	25.7 ± 5.8	0.7189	0.36
N of *Cladocera*, x1000/m^3	135.6 ± 68.9	30.0 ± 9.2	0.1558	1.43
N of *Copepoda*, x1000/m^3	82.6 ± 18.6	22.7 ± 6.6	0.0053 *	2.90
Total *B*, g/m^3	1.76 ± 0.48	0.35 ± 0.09	0.0081 *	2.75
B of *Rotatoria*, g/m^3	0.05 ± 0.02	0.04 ± 0.01	0.4972	0.68
B of *Cladocera*, g/m^3	0.75 ± 0.22	0.16 ± 0.06	0.0201 *	2.39
B of *Copepoda*, g/m^3	0.96 ± 0.32	0.16 ± 0.06	0.0215 *	2.36
H_B, bit/copy	2.39 ± 0.11	1.94 ± 0.13	0.0097 *	2.67
H_N, bit/copy	2.45 ± 0.10	2.32 ± 0.14	0.5580	0.58
S	1.58 ± 0.02	1.65 ± 0.06	0.2891	1.07
$Q_{B/T}$ index	1.3	1.3	-	1.33

Abbreviation: *Q*=number of species; *N*=total number; *B*=total biomass; *S*=saprogenic index; H_B=species diversity index calculated by biomass; H_N= species diversity index calculated by number. Statistically significant values (p<0.05) are indicated by asterisk (*). Values of the paired Student *t*-test are presented.

TABLE 4 - Dominating zooplankton species of the Kuibyshev reservoir littorals

Region №1	Region №2
Ranked by number	
Bosmina longirostris O.F. Muller (0.60)	*Bosmina longirostris* (0.25) *Euchlanis dilatata Ehrenberg* (0.15) *Diaphanosoma brachyurum Lievin* (0.06) *Alona costata Sars* (0.06)
Ranked by biomass	
Bosmina longirostris (0.18) *Acanthocyclops vernalis Fischer* (0.17) *Simocephalus vetulus O.F. Muller* (0.09) *Alona quadrangularis O.F. Muller* (0.08) *Macrocyclops albidus Jurine* (0.07) *Mesocyclops leucarti Claus* (0.07)	*Bosmina longirostris* (0.10) *Acanthocyclops vernalis* (0.09) *Eurytemora affinis Poppe* (0.09) *Mesocyclops leuckarti* (0.09) *Acroperus harpae Baird* (0.09) *Scapholeberis mucronata O.F. Muller* (0.06) *Simocephalus vetulus* (0.06) *Eucyclops serrulatus Fischer* (0.06)

Note: species rank by number and biomass is indicated in the brackets

connected with the distortion of the biological equilibrium due to anthropogenic contamination. To characterize completely the structure of zooplankton coens, it is necessary to consider the whole spectrum of structural indexes.

Multifractal analysis

To assess species diversity of zooplankton of the two littoral regions, we used multifractal analysis. We found that multifractal spectra (calculated by number) of the first and second regions were different (Fig 2).

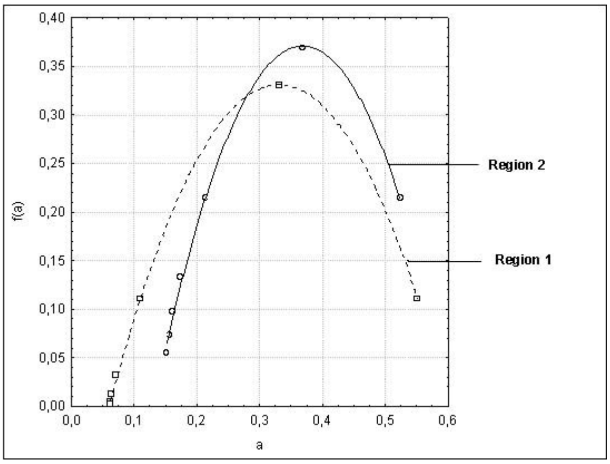

FIGURE 2 - Multifractal spectra (calculated by number) for species structure of zooplankton communities of the Kuibyshev reservoir littorals.

The peak in the bell curve of the second region is higher and incomprehensive. This finding suggests a more uniform distribution and high species diversity in comparison with the first region. Curve points for the second region show a more remote location on the abscissa axis and origin of coordinates. This fact confirms that there was more than one dominating species (similar data are presented in Table 4). Conversely, the bell curve for the first region is more displaced from axis of ordinates. Points of the left part of the curve tend to zero. This fact confirms that there is an increased dominance degree of zooplankton in the first region.

Analogous results were observed in multifractal spectra calculated by biomass (Fig 3). However, a dominance by biomass was absent in the second region while the same criterion was less than the dominance calculated by number. In other words, zooplankton species distribution by biomass is more uniform than by number.

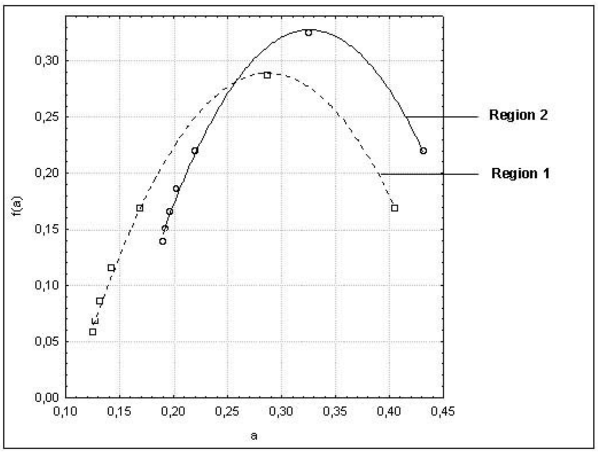

FIGURE 3 - Multifractal spectra (calculated by biomass) for species structure of zooplankton communities of of the Kuibyshev reservoir littorals.

Thus, multifractal analysis of zooplankton species structure revealed that more diverse and balanced zooplankton communities reside in the second region with less anthropogenic pollution.

CONCLUSION

The most informative structural indexes of zooplankton that may adequately reflect environmental changes are given below:

- total number and biomass of zooplankton;
- number and biomass of *Copepoda* and *Cladocera*;
- index of species diversity calculated by biomass;

- number of alpha animals according to function of the rank distribution;
- multifractal spectra of zooplankton species distribution.

In anthropogenically polluted biotopes, tendencies to increase of *Cladocera* and *Copepoda* content, their total number and biomass as well as augment of dominance degree of single species (in comparison with pure regions) were revealed.

Quantitative indexes of rotifers, index of species diversity calculated by number, saprogenic index and $Q_{B/T}$ index are not reliable values for assessment of water's quality by zooplankton community.

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