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The Hydrochemical and Hydrobiological Analysis of the Condition of the Kuibyshev Reservoir Littorals (Republic of Tatarstan, Russia)

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Abstract

This paper reports the results of an annual hydrochemical and hydrobiological survey carried out in the littorals of the Kuibyshev reservoir (Republic of Tatarstan, Russia). 26 hydrochemical and 16 hydrobiological assessment parameters were taken into consideration during the evaluation of the composition of the sampled water. In general, 100 samples were analyzed quantitatively while 43 samples were assessed qualitatively (23 from the first region and 20 from the second one). It was found that some indexes reflected adequately environmental changes while others not. Therefore, we concentrated on here what markers may be considered as the most appropriate during analysis of the water quality.

Keywords: *Kuibyshev reservoir, multifractal analysis, pollution, plankton.*

INTRODUCTION

Waters near large industrial cities are characterized by high pollutant charge, especially where an intensive shipping takes place. Therefore, biomonitoring of the areas is quite important. The problem of expert judgements in the ascertainment of water quality might be resolved during the investigation of alterations in chemistry and populations of aquatic organisms. However, analysis of the 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 untenable according to aqueous method (Matkovskii and Aleksijuk 2000). The most probable reasons for that is the single-step characteristics of the hydrochemical and hydrobiological regime of the stream. This approach does not take into account the effects of the combined action of chemicals (environmental synergism and antagonism) as well as interactions between aquatic organisms that may increase because of the toxicoresistance of some populations of aquatic organisms (Vymazal 1987, Ratushnyak 2002). A surveying system for estimation of changes in biotic components caused by anthropogenic and structural factors is a key element in environmental monitoring. In this connection, it is important to emphasize some features that are the most powerful tests for the assessment of organization peculiarities of aquatic communities in general and zooplankton, specifically. For example, a whole list of structural, functional and integral criterions were presented in the work by Andronnikova (Andronikova 1996). These criteria were used for assessment of trophism in lake ecosystems.

In small rivers, there is the analogous reaction of the zooplankton communities on the increase of organic and biogenic load. Namely, there is an increase in the 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 (Krylov 1996, 2003). It was found that the following parameters are the most informative during the complex technogenic contamination: the balance between species of *Rotatoria, Cladocera* and *Copepoda*; correlation between biomass of rotifers and crustaceans as well as some others (Vandysh 1998, 2000, 2004). The index of the zooplanktonic species biodiversity, prevalence of crustaceans, poor species structure as well as specific species complexes that are resistant to acidification is the most frequent feature of the acidification influence on the water ecosystem (Moiseenko 2005).

Investigation of reservoir littoral is of great interest. These zones are characterized by a high degree of biodiversity and by intensive processes of bioproduction and biodestruction. Also, these regions are significantly aptituded to anthropogenic influence. Initial changes at the ecosystem level might be registered there.

In this work, our aim was the analysis of the structural features of the zooplankton community residing in the macrophyte-filled littoral. For this purpose, we used a broad spectrum of standard hydrobiological characteristics as well as a multifractal analysis of the biotic environment. We expanded the practical policies suggested by some authors (Iudin et al. 2003) and species distribution was assessed using both animal numbers and biomass.

MATERIALS AND METHODS

During 2002-2003, we studied two soundings of the Kuibyshev reservoir (Republic of Tatarstan, Russia) that differed by anthropogenic load (Fig. 1). The first sampling region (Borisov's channel) was near Pobedilovo, it is inhabited locally and represented an oxbow of an unknown river (flowing into the Kuibyshev reservoir) with a tabular muck bottom and bank vegetation (osiery). In July, projective plant coverage reached 100% (50% of reed mace and 50% of free-swimming plants -multiwheeler, duckweed). At the end of August, plant distribution was as follow: 90% of reed mace and 10% of free-swimming plants.

The second sampling region was between the Tatar Saraly and Atabaevo inhabited localities and 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 region was covered with osiery and reed mace. In July, 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 airiness and wave wash was a characteristic feature 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 "Mark-201" device. Chemical analysis of other water components was performed according to standard procedures (Aleksin 1970, Lurie 1973). In general, we analyzed 123 samples (63 samples were taken from the first sampling region while 60 samples -from the second one). Various physicochemical parameters were used for the assessment of the water' quality (pH, chemical oxygen demand, biological oxygen demand, contents of oxygen, nitric oxide, nitrous oxide, oxygenous phosphate and total phosphorus) according to a complex environmental health manual (Oksijuk 1993, Anonymous 2003).

Zooplankton samples were taken in parallel to water sampling and 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). For quantitative analysis, zooplankton organisms were fixed with a 4% formaldehyde solution according to (Anonymous 1982). For qualitative analysis, these invertebrates were used alive. Zooplankton samples were analyzed using a BIOLAR microscope, and specific differences were detected according to (Kutikova 1998). Using an eyepiece micrometer, we detected the dimensions of the water organisms. The 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 (ni/N) and individual mass (bi/B). An individual mass was assessed using power functions connecting the organism's mass and length (Balushkina and Vinberg 1979). Predominant complexes were revealed according to the function of rank distribution (Feodorov 1977). Prevalence of the single species was assessed according to (Lebedeva 1999). An index of the species diversity was calculated using population size criterion (HN) (Shannon, 1948) and biomass (HB) (Gilyarov, 1970). The QB/T index was calculated as ratio Brachionus genus versus Trichocerca genus. The saprobic index was calculated for evaluation of the water quality (Sladecek 1973).

In general, 100 samples (52 from the first region and 48 from the second one) were analyzed quantitatively while 43 samples were assessed qualitatively (23 from the first region and 20 from the second one).

Paired Student test (t-test) were used for statistical analysis.

Assessment of the zooplankton species diversity and distribution by number and biomass was made using a multifractal analysis according to established procedures (Bacry et al. 2001, Frontier 1987). For each zooplanktonic community, data on number and biomass were summed using a special program (Borisovich and Borisovich 2000) and the corresponding multifractal spectra were presented.

In multifractal analysis, ordinate of point, shows species diversity while abscissa of point characterizes quantity of some species. Spectrum width reflects species distribution in some zooplankton communities. An extreme variant for the species distribution is an equal quantity of each species within the zooplankton community. At that, the entire spectrum is concentrated at one point whose ordinate corresponds to the monofractal dimension of the zooplankton community.

RESULTS AND DISCUSSION

This complex ecosystem approach was applied because insight was gained in the strong interaction between all abiotic conditions and the biotic response of the aquatic community. For the development of ecological assessment methods as a tool to check on the status as well as the potentials of the aquatic ecosystem, an adequate and detailed description of a reference situation is necessary. Therefore, we present here both the hydrochemical and hydrobyological analyses of the regions under study. However, as it will be stated below, sometimes even hydrobiological analysis cannot reflect adequately the real condition of the water quality. For this reason, a multifractal analysis was applied as a more promising tool in the assessment of water quality.

Hydrochemical features of the Kuibyshev littorals were studied. The investigated intertidal regions differed significantly by chemical content. The first region was characterized by an increased mineralization (470 mg/L) while the second region did not (248 mg/L) according to the Aleksin's classification (Aleksin, 1970). Water samples from the both regions referred to the calcium group of the bicarbonate class. The middle content of sulfates, calcium and magnesium ions were 3-folder and 2-folder, respectively, in the first region (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 (in the first region its content was 40% higher). The first region was also marked by the higher content of ammonium nitrogen while differences in the nitrite nitrogen content were not significant between the regions. Non-oxygenated (about 30% of bichromate oxidability) and oxygenated (about 20% BOD_5, biological oxygen demand for 5 days) organic compounds (Table 1) were found in the first region. It is important to mention here that BOD_5 does not depend on the oxygen content in the water. This parameter really reflects only content of oxygen that is needed for oxygenation of the free oxidable substances. The revealed chemical contamination of the first region was connected with the influence of polluted effluents. Sulfates, chlorides and heavy metals were the most frequent pollutants (Stepanova 1999). Oxygen concentrations were higher in the first region (Fig. 2A, B). We did not find any significant correlations between oxygen content and content of organic compounds. In this connection, it would be interesting to compare our results with literature data. Namely, it is known that rotifers are predominant zooplankters in the highly polluted waters (Hanazato and Yasuno 1990, Havens and Hanazato 1993). However, we did not find the same dependences: instead, the number of rotifers was less than the crustacean zooplankters (Table 3). Most likely that production-destruction feature of the region was the reason for the phenomenon observed.

Although there is a lot of various methods for biological water quality assessment that have been developed (Pittwell 1976, De Pauw and Vanhooren 1983) since that period when Cohn in 1853 (Cohn 1853) observed that organisms that occur in polluted water are different from organisms that occur in clean water, we used the saprobic index developed by Pantle and Buck and modified by Sladecek (Sladecek 1973). Results of the analysis are 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-mesosaprobic zone with polluted water (class 4) while the second region referred to ß-mesosaprobic zone with satisfactory quality (class 3). According to maximal indexes, both the regions referred to a ß-polysaprobic zone with highly polluted water (class 5).

The structural organization of the zooplankton communities in the Kuibyshev littorals under study was also assessed. We found that zooplankton features of the first region differed frivolously from the ones of the second region (Table 3). In general, the total number of species and index of species diversity in population size are reduced in polluted water while the saprobic index and QB/T index are increased (Andronikova 1996). 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, proportion of rotifers in the second region was slightly more that in the first region. This finding can be explained by fact that soundings of the second region are amenable to winds and waves. This can favor an additional superinducement of rotifers from the open places of the Kuibyshev reservoir.

Thus, only a few criteria might be taken into consideration during the assessment of the water quality.

Data from Table 3 suggest 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 *Cladocera* and species diversity index in biomass. Differences in *Cladocera* biomass between the two investigated regions was 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-fold (in biomass of *Copepoda*).

Therefore, an increase in quantitative indexes was revealed in the polluted zooplankton coenosis. Moreover, differences were obtained concerning the structure-forming complex of the zooplankton species (Table 4). It is clear from Table 3 that *Bosmina longirostris* was a dominant species (in number) in the first region while four species were dominant in the second region. In biomass, the first region was characterized by the 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 connected with distortion of biological equilibrium due to anthropogenic contamination. It is also important to note that the presence of

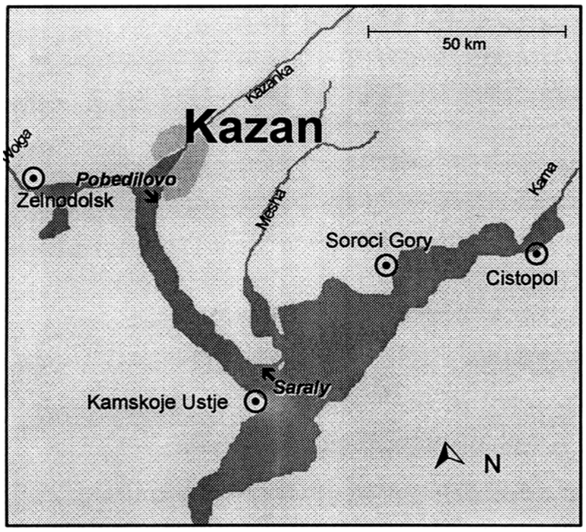

Figure 1. The scheme of the investigated regions. Locations of the sampling sites are indicated by cursors.

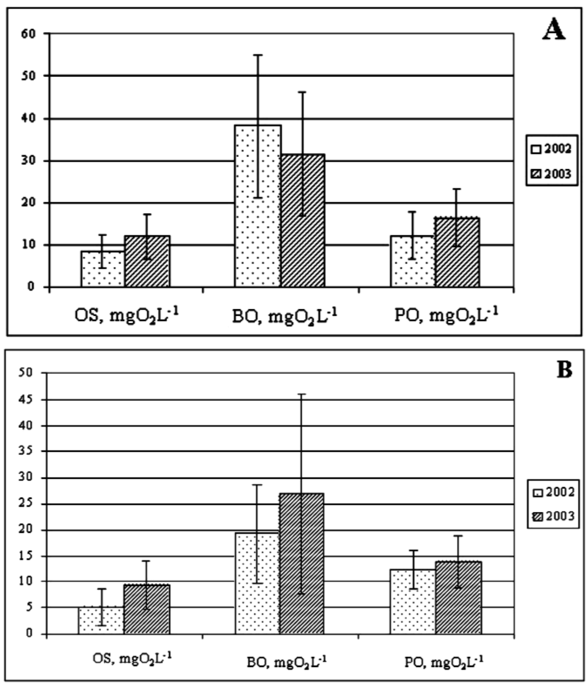

Figure 2. Dynamics of the dissolved oxygen and organic compounds in the water of the Kuibyshev reservoir littorals (A-region 1; B-region 2). Abbreviation: OS= oxygen solubility; BO= bichromate oxidability; PO= permanganate oxidability

oligosaprobic and ß-saprobic species in the waters confirms once again that the saprobic index cannot be considered as a possibility to check water quality appropriately.

To characterize completely the structure of zooplankton coenosis, it is necessary to consider the

Table 1. Hydrochemical parameters of the investigated regions of the Kuibyshev reservoir littorals.

Parameter	Region No:1 Mean + SD	Region № 2 Mean + SD	Δ*
O_2, mg O_2L^{-1}	10.7±0.9	7.6±0.8	3.1 (28.9%)
ORP, mV	148.5±10.2	130.4±21.4	18.1 (12.2%)
PH	7.3±0.1	7.2±0.1	0.1 (1.4%)
Total mineralization, mgL^{-1}	468.2±15.9	248.6±6.2	219.6 (46.9%)
Ca^{2+}, mgL^{-1}	84.7±3.9	44.1±1.4	40.6 (47.9%)
Mg^{2+}, mgL^{-1}	20.1±1.7	9.3±0.7	10.8 (53.7%)
HCO_3^-, mgL^{-1}	170.6±3.8	136.8±3.5	33.8 (19.8%)
SO_4^{2-}, mgL^{-1}	165.4±8.3	54.3±2.6	111.1 (67.2%)
Cl^-, mgL^{-1}	39.9±1.2	22.7±0.9	17.2 (43.1%)
BO, mgO_2L^{-1}	33.9±2.6	24.0±2.3	9.9 (29.2%)
PO, mgO_2L^{-1}	12.2±0.9	11.5±0.5	0.7 (5.7%)
BOD_5, mgO_2L^{-1}	5.9±0.6	4.8±0.8	1.1 (18.6%)
Total phosphorus, mgL^{-1}	0.28±0.03	0.29±0.04	0.01 (3.4%)
PO_4^{3-}, mgL^{-1}	0.09±0.01	0.10±0.02	0.01 (10%)
NO_3^-, N mgL^{-1}	1.88±0.22	1.15±0.11	0.73 (38.8%)
NO_2^-, N mgL^{-1}	0.09±0.02	0.07±0.02	0.02 (22.3%)
NH_4^+, N mgL^{-1}	0.67±0.10	0.49±0.04	0.18 (26.9%)
Cd, μgL^{-1}	1.15±0.27	1.0±0.2	0.15 (13.0%)
Pb, μgL^{-1}	11.6±2.1	9.3±1.6	2.3 (19.8%)
Cu, μgL^{-1}	6.4±0.7	5.8±0.5	0.6 (9.4%)
Co, μgL^{-1}	7.9±0.6	6.3±0.5	1.6 (20.3)
Ni, μgL^{-1}	12.5±0.9	10.8±0.8	1.7 (13.6)
Zn, μgL^{-1}	17.8±1.7	17.9±2.5	0.1 (0.6)
Cr, μgL^{-1}	4.9±0.7	3.4±0.5	1.5 (30.6%)
Mn, μgL^{-1}	89.4±29.3	114.6±35.7	25.2 (22.0%)
Fe, μgL^{-1}	239.0±47.4	209.5±42.7	29.5 (12.3)

Abbreviations: SD=standard deviation; BO=bichromate oxidability; PO=permanganate oxidability; ORP=oxidation-reduction potential; BOD_5=biological oxygen demand for 5 days. Note: Δ*=difference of mean values between region 1 and region 2 (in absolute values and in %); those values are scored where parameters of Region 1 are less that in Region 2.

Table 2. Water quality of the two Kuibyshev reservoir regions according to ecological and sanitary classification.

RegionNo	Index values	Average value	Degree of pollution	Saprobity class	Water quality class
No 1	Minimal	2.1	2a –very clear water	β –oligosaprobic	2 –clear water
	Dominant	5.8	4a –moderately polluted	α –mesosaprobic	4 –polluted
	Maximal	8.2	5a –very critically polluted	β –polysaprobic	5 –critically polluted
No 2	Minimal	3.0	2b –nearly clear water	α –oligosaprobic	2 –clear water
	Dominant	5.3	3b –very slightly polluted	B –mesosaprobic	3 –slightly polluted
	Maximal	8.3	5a –very excessively polluted	β –polysaprobic	5 –excessively polluted

whole spectrum of structural indexes. Therefore, we used a multifractal analysis. Using a multifractal analysis, we assessed the species diversity of zooplankton of the two littoral regions. We found that the multifractal spectra (calculated by number) of the first and second regions were different (Fig. 3).

The bell curve for the second region is more high and tight. This finding suggests a more uniform distribution and high species diversity in comparison with the first region. The curve points for the second region show more remote location from abscissa axis and origin of coordinates. This fact confirms that there was more than one dominating species (the similar data is presented in Table 4). Conversely, the bell curve for the first region is more displaced to 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 the multifractal spectra calculated by biomass (Fig. 4). However, dominance by biomass was absent in the second region while the same criterion was less than dominance calculated by number. In other words, zooplankton species distribution by biomass is more uniform than by number. So, multifractal analysis of the zooplankton species structure revealed that more diverse and balanced zooplankton communities reside in the second region with less anthropogenic pollution.

Thus, 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*; and index of species diversity calculated by biomass; number of alpha animals according to function of the rank distribution;

Table 3. Structural parameters of zooplankton communities of the investigated regions of the Kuibyshev reservoir littorals (mean±standard deviation).

Parameter	Region No 1	Region No 2	Probability	*t*–value
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=saprobic index; HB=species diversity index calculated by biomass; HN= 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. The dominant zooplankton species of the Kuibyshev reservoir littorals (species rank by number and biomass is indicated in the brackets).

Region No 1	Region No 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 (0.10)
Bosmina longirostris (0.18)	*Acanthocyclops vernalis* (0.09)
Acanthocyclops vernalis Fischer (0.17)	*Eurytemora affinis* Poppe (0.09)
Simocephalus vetulus O.F. Muller (0.09)	*Mesocyclops leuckarti* (0.09)
Alona quadrangularis O.F. Muller (0.08)	*Acroperus harpae* Baird (0.09)
Macrocyclops albidus Jurinc (0.07)	*Scapholeberis mucronata* O.F. Muller (0.06)
Mesocyclops leuckarti Claus (0.07)	*Simocephalus vetulus* (0.06)
	Eucyclops serrulatus Fischer (0.06)

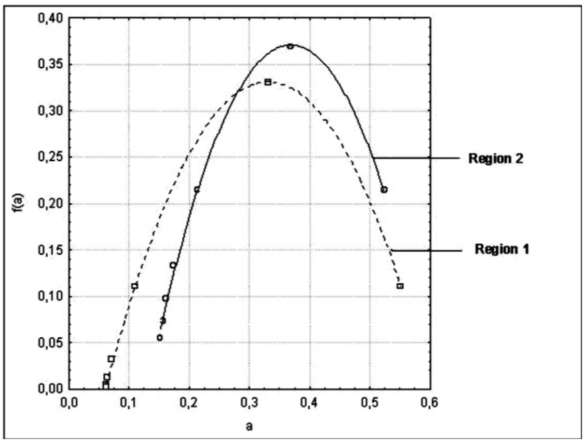

Figure 3. Multifractal spectra (calculated by number) for species structure of zooplankton communities of the Kuibyshev reservoir littorals.

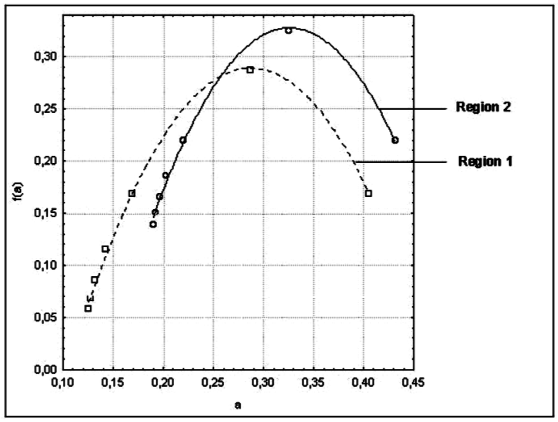

Figure 4. Multifractal spectra (calculated by biomass) for species structure of zooplankton communities of the Kuibyshev reservoir littorals

multifractal spectra of zooplankton species distribution. In anthropogenically polluted biotopes, tendencies for the increase in the *Cladocera* and *Copepoda* content, their total number and biomass as well as augment of dominance degree of a single species (in comparison with pure regions) was revealed. Quantitative indexes of rotifers, index of species diversity calculated by number, saprobic index and QB/T index are not reliable values for the assessment of the water quality by the zooplankton community.

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