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The influence of the community of water macrophytes on regulation of water quality and biodiversity of the Kuibyshev reservoir littorals (Republic of Tatarstan, Russia)

A.A. Ratushnyak[1], N.Sh. Ahmetsyanova[1], A.T. Gorshkova[1], M.G. Andreeva[1], O.V. Morozova[1], K.I. Abramova[1], M.V. Trushin[2,3]

[1] Institute for Ecology of Natural Systems, Tatarstan Academy of Sciences, Kazan, Russia
[2] Kazan State University, Department of Genetics, Kazan, Russia
[3] Kazan Institute of Biochemistry and Biophysics, Lobachevskiy st. 2/31, P.O. BOX 30, Kazan 420111, Russia
Correspondence to: MV Trushin **e-mail**: mtrushin@mail.ru

Abstract

Natural waterplant communities may help prevent the introduction of pollutants. We explore the role of macrophytes in ameliorating the waters of the Kuibyshev reservoir littoral zones through investigating plant and zooplankton communities. We suggest that water vegetation can play a sanative role to improve water quality according to hydrobotanical, zooplanktonic and benthic data.

Keywords: Macrophyte, water autopurification, biohydrocommunity, zooplankton.

Introduction

Numerous investigations have shown that natural biohydrocommunities may be of great help in preventing the introduction of pollutants into waters (Banuelos *et al*. 1997; Amaya-Chávez *et al.* 2006). Macrophytes, the prime components of broad shallow waters, may play a key role in the processes (Singhal & Mahto 2004; Wang & Qin 2006; Maine *et al.* 2007). The deactivating properties of plants may be also used for reducing existing water pollution owing to their ability to absorp pollutants when in contact with them (Rahman *et al.* 2007). However, quantitative characteristics of the sanative role of macrophytes have not yet been investigated. We explore here the role of macrophytes in the repair of naturally pure water of the Kuibyshev reservoir littorals by investigating its plant and zooplankton communities.

Materials & Methods

The following zones of the Kuibyshev reservoir were investigated:

1. A part of Sviyazhsk Bay between hamlets Britvino and Isakovo. This zone separates the narrow part of the bay (that accepts the polluted waters of the rivers Sviyaga and Arya) from the main water masses. Geobotanical and hydrological characteristics of the zone are as follows: weed area 2.8 km^2, cover 80%, dominant species *Typha angustifolia* Linnaeus, weed density 50-70 m^{-2}, plant height 2.0-2.5 m, number of leaves per plant 8-10, leaf width 0.8-1.2 cm, phytomass 4 kg m^{-2}, water depth 0.5-1.5 m.
2. Mesha Reach. This zone includes two flowing channels overgrown with water plants: (a) Tashkirmen station, located between the Mansurov islands, influenced by the Kuibyshev reservoir backup, characterised by weed area 2.2 km^2, cover 75-80%, dominant species *Typha angustifolia* Linnaeus (80-90% among 11 other species), weed density 50-65 m^{-2}, plant height 1.8-2.5 m, water depth 0.5-1.5 m, speed of flow 0.2-0.5 m min^{-1}; (b) Narmonka station, where weed area 1.8 km^2, cover 70-80%, dominant species *Typha angustifolia* Linnaeus (80-90% among 18 other species), weed density 50-60 m^{-2}, water depth 0.5-1.5 m, speed of flow 0.1-0.3 m min^{-1}.

2-l water samples were taken every two weeks using Molchanov's bathometer. Temperature, pH, oxidation-reduction potential and dissolved oxygen were determined using a miniature dissolved oxygen analyzer (Mark-201, VZOR LLC). Chemical analysis of other water components followed standard procedures. Various physicochemical parameters were used for the assessment of water quality.

Zooplankton samples were taken in parallel to water sampling. An Apshtein net (24 cm diameter; aperture size 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 and identified using a bipolar microscope. The zooplankton community was assessed by population size (N) and biomass (B), as well as by taxonomic group. We analyzed a total of 1500 samples. Paired t-tests were used for statistical analysis; $p<0.05$ was considered to indicate significance; data are presented as mean ± SD. In the tables, dashes indicate missing data.

Results

Because of the natural biofiltration properties of the vegetation, we observed water autopurification during the period of active vegetative growth. In littorals of Sviyazhsk bay between hamlets Britvino and Isakovo we observed reduction of the following pollutants: hard-to-oxidise organic waste 61%, petrochemicals 92%, ammoniate ions 54%, nitrates 30%, nitrites 24%, phosphates 25%, sulphates 46%, total mineralization 24%, saprophilic microorganisms 97%, petroleum-oxidising bacteria 89%, and coliform bacteria 92%. Figures for the littoral zones of Mesha reach (Narmonka and and Tashkirmen stations) are similar (Table 1).

Table 1: Hydrochemical changes after contact with macrophytes (negative values indicate reduction% of markers, positive values indicate increase%; all mean values ± SD). BCO2/5 days = biological O2 consumption over 5 d; CCO = chemical consumption of oxygen. ND = no data.

Parameter	Narmonka	Tashkirmen
CCO	-21.7 ± 1.7	-52.5 ± 2.6
BCO_2 per 5 d	-28.9 ± 2.1	-47.9 ± 3.0
NO_3^-	-31.7 ± 2.8	-36.0 ± 3.1
NO_2^-	-72.8 ± 4.3	-54.3 ± 3.4
NH_4^-	-30.8 ± 1.9	-26.3 ± 2.1
PO_4^{3-}	-3.6 ± 0.2	-53.3 ± 3.1
SO_4^{2-}	-27.2 ± 2.5	-32.2 ± 2.4
Cl^-	-5.9 ± 0.5	-18.9 ± 1.5
HCO_3^-	-8.4 ± 0.7	-16.4 ± 1.5
Ca_2^+	-12.9 ± 1.0	-21.2 ± 1.4
Fe_{total}	-31.6 ± 1.9	-56.2 ± 4.8
Total mineralization	-14.2 ± 1.0	ND
Suspended matter	-62.2 ± 4.5	-54.9 ± 3.9
O_2	103.2 ± 7.3	102.5 ± 8.8

During the late autumn (third decade of October), autopurification processes decreased (Table 2). Concentrations of microflora decreased (saprophiles by 75%, coliform bacteria by 88%) but some contaminants increased (e.g. petroleum-oxidising bacteria by 43%). The overall effect was still purification. The increase of some compounds during autumn suggests that these substances are remediated via phytoextraction mechanisms that are inactive in autumn and winter (Table 2).

Table 2. Seasonal dynamics of the hydrochemical regime (values and abbreviations, see Table 1). SDs omitted, but all had CVs of 5-15%.

Parameter	March	April	May	June	July	Aug	Sept	Oct
Calcium	-7.9	0	-9.1	-8.2	-5.7	-20.3	4.0	6.8
Total mineralization	-1.2	-1.3	-7.7	-8.3	-24.2	-8.5	-2.4	-11.3
Suspended matters	-19.2	-8.5	ND	-7.5	-58.0	-14.8	ND	ND
CCO	3.6	20.6	-22.1	-32	-61.4	-25.6	-4.6	13.4
BCO2/5 days	1.4	10.5	-8.8	-28	-23.1	-14.3	-12.6	ND
Nitrates	11.4	2.5	-30.0	-11.2	-18.9	-24.7	-12.5	6.5
Ammonium nitrogen	14.2	14.4	-31.8	-23	-54.4	-65.2	-3.4	10.4
Nitrites	14.2	42.8	13.9	-19.3	-9.5	-24.1	-33.8	-2.5
Phosphates	2.9	2.5	-30	-11.2	-18.9	-24.9	-12.2	10.8
petrochemicals	ND	ND	ND	-91.9	ND	ND	ND	-82.9
Sulphates	0	-10.8	-13.0	-8.2	-46.5	-9.9	-14.5	10.1
Chlorides	0	40.3	-29.6	-32.3	-26.5	-37.0	-42.3	-9.2
Bicarbonates	0	0	0	-13.3	-50.5	-7.7	-17.2	-6.0

The water macrophyte community on the shores of Kuibyshev reservoir resulted not only in the improvement of water quality, but also in an increase in the biodiversity of the areas studied. The number and biomass of zooplankton species were 5.1 and 7.8 times higher respectively among the macrophytes than in open-water zones (Table 3).

Table 3. The average density (m^{-2}) and biomass ($g\ m^{-2}$) of various ecological groups of plants and invertebrates from open littoral areas of the Mesha reach of the Kuibyshev reservoir.

Groups of macrophyte	Samples	Average for the season	
		Density	Biomass
Group 1 (*Potomogeton* spp)	23	4477.8 ± 915.7	28.7 ± 6.0
Potamogeton pusillus L.	12	6389.3 ± 1503.4	38.3 ± 10.6
P. pectinalis L.	4	3984.0 ± 938.2	27.9 ± 9.1
P. perfoliatus L.	7	1483.0 ± 431.6	14.7 ± 5.1
Group 2 (*Eleocharis-Sagittaria*)	89	1534.6 ± 189.9	15.7 ± 2.2
Eleocharis palustris (L.) Brown	54	1629.0 ± 288.9	18.1 ± 3.4
Sagittaria sagittifolia L.	35	1388.8 ± 188.5	12.1 ± 1.8
Group 3 (*Typha-Glyceria*)	108	1075.5 ± 97.1	14.6 ± 1.4
Typha angustifolia L.	53	949.4 ± 107.2	15.8 ± 2.2
Glyceria maxima (Hrtm) Holmberg	55	1196.2 ± 159.5	13.5 ± 1.6
Total (for areas with plants)	220	1616.9 ± 146.7	16.4 ± 1.3
Total (for areas without plants)	175	317.4 ± 23.7	2.1 ± 0.2

The most favorable conditions for development of water invertebrates are formed in areas with immersed plants that have soft stems and pronounced dissection of leaves (Group 1 of Table 3). The main invertebrates of the immersed plants are: larvae of *Glyptotendipes glaucus* (Meigen, 1818), *Endochironomus albipennis* (Meigen, 1830), *Cricotopus* (*Isocladius*) gr. *silvestris* (Fabricius, 1794), amphipods (*Dikerogammarus hemobaphes* (Eichwald, 1841)) as well as pupae of *Numphula*. Higher densities and biomass were measured for invertebrates associated with *Potamogeton pusillus* Linnaeus. Seasonal variation in the macrofauna on Group 1 plants was mediated by plant properties, from the beginning of July when invertebrate numbers were relatively low, through flowering to autumn when, because of the accumulation of detritus, significant densities of benthic animals were observed and a general increase in invertebrate densities.

Invertebrate densities on surface plants (*Eleocharis palustris*, *Sagittaria sagittifolia*) were lower than in Group 1 (Group 2 of Table 3), with large numbers of larvae of *G. glaucus*, *Glyptotendipes gripekoveni* (Kieffer, 1913), *Glyptotendipes imbecillis* (Walker, 1856), the phytophilic molluscs *Anisus stelmachoiteus* (Bourg, 1860), *Anisus draparnaldi* (Sheppard, 1823) and *Physa fontinalis* (Linnaeus, 1758), mayflies *Caenis horaria* (Linnaeus, 1758) and *Caenus robusta* (Eaton, 1884), and the bug *Sigara falleni* (Fieber, 1848). Seasonal dynamics peaked in August, connected with active development of the plants *Lemna trisulca* Linnaeus and *Spirodela polyrhiza* (Linnaeus) Schleiden.

Table 4. Seasonal dynamics of density (m^{-2}) and biomass ($g\ m^{-2}$) of invertebrates in water plants and open littoral of Mesha reach of the Kuibyshev reservoir.

Groups of macrophyte	May	June	July	Aug	Sept	Oct
Number						
Group 1	-	-	1982.2 ± 332.4	-	7540.3 ± 1915.7	-
Group 2	652.0 ± 173.5	1460.3 ± 280.1	1308.0 ± 382.3	2384.0 ± 741.7	1830.4 ± 272.4	684.4 ± 204.8
Group 3	781.5 ± 177.6	975.1 ± 131.3	1691.6 ± 157.4	1866.9 ± 384.2	505.4 ± 85.5	541.2 ± 81.8
Average value	755.7 ± 138.4	1173.0 ± 152.7	1578.1 ± 189.3	2148.1 ± 410.7	3088.3 ± 696.8	1593.9 ± 90.9
Open littoral	440.5 ± 58.4	204.0 ± 35.0	600.8 ± 82.9	313.3 ± 35.8	145.6 ± 15.5	193.4 ± 36.1
Biomass						
Group 1	-	-	9.2 ± 3.3	-	40.4 ± 8.1	-
Group 2	2.7 ± 0.4	12.2 ± 3.0	11.6 ± 3.3	24.4 ± 9.0	17.4 ± 1.9	17.3 ± 8.7
Group 3	15.1 ± 4.2	17.6 ± 3.9	19.6 ± 2.7	17.5 ± 4.1	8.5 ± 1.5	8.8 ± 1.3
Average value	12.4 ± 3.2	14.9 ± 2.6	13.2 ± 1.7	20.9 ± 4.9	21.2 ± 3.1	11.9 ± 3.3
Open littoral	1.4 ± 0.2	1.4 ± 0.5	2.7 ± 0.5	2.6 ± 0.5	1.6 ± 0.3	3.5 ± 0.8

The lowest densities occurred in the rooted Group 3 plants (*Typha angustifolia*, *Glyceria maxima* (Hartman)), dominated by *G. glaucus*, *G. gripekoveni*, *E. albipennis*, *Endochironomus impar* (Walker, 1856) and the molluscs *Bithynia tentaculata* Linnaeus, 1758, *Planorbis planorbis* Linnaeus, 1758, *A. stelmachoiteus* and *Dreissena polymorpha* (Pallas, 1771). The molluscs and other organisms colonised the plants during the period of active growth and flowering, decreasing again in autumn.

Table 5. The influence of macrophytes on the density (x 1000 m^{-3}, numerator) and biomass (mg m^{-3}, denominator) of some zooplankton species of Mesha Reach of the Kuibyshev reservoir in the period of actively growing vegetation.

Species	Before macrophytes	After macrophytes
Rotatoria		
Cephalodella fluviatilis Lawad	-	$\frac{64.0 \pm 16,0}{12.8 \pm 3.4}$
Keratella longispina Kell.	-	$\frac{1 \pm 0.17}{0.3 \pm 0.066}$
Keratella quadrata Müller	-	$\frac{50.0 \pm 10.0}{25.0 \pm 6.0}$
Mytilina mucronata Müller	$\frac{1.0 \pm 0.21}{0.2 \pm 0.038}$	$\frac{170.0 \pm 30.6}{85.0 \pm 19.6}$
Cladocera		
Bosmina coregoni Baird	-	$\frac{3.0 \pm 0.57}{75.0 \pm 18.75}$
Bythotrephes longimanus Leydig	-	$\frac{1.0 \pm 0.22}{500.0 \pm 135.0}$
Chidorus sphaericus O.F. Müller	$\frac{14.0 \pm 2.52}{140.0 \pm 30.8}$	$\frac{60.0 \pm 12.6}{600.0 \pm 144.0}$
Daphnia cuculata Sars	$\frac{124.0 \pm 26.04}{4464.0 \pm 758.9}$	$\frac{240.0 \pm 55.2}{5200.0 \pm 832.0}$
Daphnia longispina O.F. Müller	-	$\frac{4.0 \pm 0.76}{120.0 \pm 27.6}$
Copepoda		
Acanlocyclops vernalis Fisher	$\frac{1.0 \pm 0.25}{63.0 \pm 16.38}$	$\frac{32.0 \pm 7.7}{2176.0 \pm 478.7}$
Cyclops strenus Fisher	$\frac{3.0 \pm 0.69}{108.0 \pm 20.52}$	$\frac{25.0 \pm 6.5}{1500.0 \pm 405.0}$
Euritemora velox Lill	-	$\frac{27.0 \pm 5.4}{2214.0 \pm 487.1}$
Heterocope appendiculata Sars	-	$\frac{30.0 \pm 6.9}{2100.0 \pm 441.0}$
Termocyclops dubowskii Lande	-	$\frac{1.0 \pm 0.19}{46.0 \pm 10.12}$
Mesocyclops leucarti Claus	-	$\frac{1.0 \pm 0.26}{40.0 \pm 10.12}$
Copepodit	$\frac{1.0 \pm 0.23}{20.0 \pm 4.02}$	$\frac{14.0 \pm 3.92}{280.0 \pm 61.6}$
Nauplii	$\frac{11.0 \pm 2.53}{24.2 \pm 4.6}$	$\frac{26.0 \pm 5.2}{52.0 \pm 11.5}$
Total:	$\frac{154.0 \pm 32.47}{4819.4 \pm 835.44}$	$\frac{775.0 \pm 162.17}{15078.1 \pm 3091.8}$

Table 6. The influence of macrophytes on density (x1000 m^{-3}, numerator) and biomass (mg m^{-3}, denominator) of some zooplankton species of Mesha Reach of the Kuibyshev reservoir in the late-autumn period (the end of vegetation).

Species	Before macrophytes	After macrophytes
Rotatoria		
Keratella guadrata Muller	$\frac{0.8 \pm 0.17}{0.16 \pm 0.03}$	$\frac{2.4 \pm 0.6}{0.48 \pm 0.12}$
Brachionus calyciflorus Pallas	$\frac{0.8 \pm 0.19}{0.78 \pm 0.17}$	$\frac{0.4 \pm 0.08}{0.84 \pm 0.18}$
Brachionus angularis bideus Plate	$\frac{0.4 \pm 0.07}{0.84 \pm 0.20}$	-
Cladocera		
Bosmina longirostris O.F.Muller	$\frac{0.8 \pm 0.18}{8.8 \pm 2.29}$	-
Daphnia cuculata Sars	-	$\frac{0.8 \pm 0.21}{20.8 \pm 5.4}$
Copepoda		
Cyclops strenus Fischer	$\frac{0.8 \pm 0.21}{40.0 \pm 10.4}$	$\frac{0.2 \pm 0.04}{12.0 \pm 3.5}$
Total:	$\frac{3.6 \pm 0.8}{50.98 \pm 12.99}$	$\frac{3.8 \pm 0.93}{34.12 \pm 9.2}$

Table 7. The influence of macrophytes on density (x1000 m^{-3}, numerator) and biomass (mg m^{-3}, denominator) of some zooplankton species in the channel flow of Mesha Reach of the Kuibyshev reservoir in the late-autumn period (the end of vegetation).

Species	Channel values
Rotatoria	
Keratella guadrata Muller	$\frac{2.40 \pm 0.53}{0.48 \pm 0.12}$
Asplanchna priodonta Gosse	$\frac{1.20 \pm 0.23}{3.60 \pm 0.90}$
Brachionus calyciflorus Pallas	$\frac{0.80 \pm 0.17}{0.92 \pm 0.21}$
Mytilina mucronata Muller	$\frac{1.00 \pm 0.23}{0.20 \pm 0.05}$
Cladocera	
Bosmina longirostris O.F.Muller	$\frac{0.40 \pm 0.11}{0.20 \pm 0.90}$
Daphnia cuculata Sars	$\frac{6.00 \pm 1.38}{276.00 \pm 55.20}$
Moina restirostris Leydig	$\frac{4.00 \pm 1.04}{104.00 \pm 21.84}$
Copepoda	
Cyclops strenus Fischer	$\frac{2.00 \pm 0.50}{120.00 \pm 28.50}$
Acanthocyclops vernalis Fisher	$\frac{6.00 \pm 1.68}{240.00 \pm 50.40}$
Total:	$\frac{23.80 \pm 5.87}{749.00 \pm 158.12}$

Rotatoria, Copepoda and Cladocera (Table 5) were used to study the influence of macrophyte plants on changes in water quality. Because of the natural biofiltering of water by macrophytes, the density and biomass of these zooplankton repeatedly increased when sampling the flowing water before and after the area with macrophytes. Species diversity was mainly represented by Cladocera. During the late autumn, zooplankton densities reduced and there was now little difference in density or biomass before and after the area with water plants (Table 6). It is interesting to note that diversity at that time is greater in the channel flow of Mesha Reach than in areas with moribund water plants (Table 7).

Discussion

The complex investigation of the littoral zones of Sviyazhsk Bay and Mesha Reach of the Kuibyshev reservoir points to the important role of water plants in forming the quality of the water and its biodiversity. The following factors were influential: species-specific features of plant associations and hydrobionts, plant type, the density and coverage of plants, the flow regime, speed of water current and seasonal features. Saprophagous organisms served as indicators for the improvement of water quality. In the water before reaching the water plants, there were no oligo-saprophagous zooplankton, i.e. species absent from pure water. After the water plants, the content of zooplankton and macrophytofauna was enriched. Large types of Rotatoria and cladocerans appeared in the zooplankton. These organisms can be detoxicators as well as a valuable food resource for fish breeding.

Hydrobiological analysis of indicators showed improvement of the water quality after contact with water plants. For example, the saprobity index was 3.85 before contact with plants, and it reduced to 2.6 after contact with plants. At the same time, species diversity increased from 0.5 to 3.5.

In overgrown areas the phytophilous macrofauna constitute organisms that are indicators for oligo-β-mesosaprobic zones: *G. glaucus, G. gripekoveni, G. imbecellis, E. albipennis, E. impar, D. haemobaphes, D. polymorpha, P. planorbis, A. stelmachoiteus, B. tentaculata*. In the open littoral zones, indicators for α-mesosaprobic and polysaprobic zones (Tubificidae and *Chironomus*) were dominant. Improvement of zooplankton biodiversity was also detected. We consider that the observed phenomenon may be connected for two reasons. First, direct detoxication of water might favor the increase of zooplankton owing to the reduction of harmful components. Second, water pollutants transformed by plant enzymes into more benign components may be used for plankton feeding. This fact can be connected with the different phytodegradation capability of plants (see Banuelos *et al*. 1997).

Littoral zones overgrown with water plants are zones of restoration of the basic gene pool of hydrobionts. Transitory water flows do not have their own production potential: the accumulation of hydrobionts there is due to mechanical washover from zones of restoration (water macrophyte communities) (Gorshkova *et al.* 1996). Thus during the growth season, the sanative role of biohydrocommunities may result in improvement of water quality, according to hydrobotanical, zooplanktonic and benthic data.

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