PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

ESPECIFICAÇÕES BIOINDICATIVAS, ECOLÓGICAS E ANALÍTICAS DE FLUXOS MENORES SOB A INFLUÊNCIA DE OBJETOS ARTIFICIAIS PERIGOSOS

BIOINDICATIVE, ECOLOGICAL AND ANALYTICAL SPECIFICATIONS OF MINOR STREAMS UNDER THE INFLUENCE OF HAZARDOUS MAN-MADE OBJECTS

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RESUMO

Os corpos hídricos são os meios mais vulneráveis em termos de impacto causado pelo homem e a coleta de informações de monitoramento sobre o estado da biota e o regime hidroquímico é obrigatória de acordo com as recomendações da Convenção-Quadro da Água. O artigo trata dos arranjos necessários para o monitoramento e análise integrados de bancos de dados analíticos hidrobiológicos e ambientais para fins de prognóstico e remediação em pontos de observação da água afetados por objetos tecnogênicos quimicamente perigosos produzidos pelo homem (armas químicas). O objetivo deste artigo foi apresentar dados de monitoramento hidrobiológico e hidroquímico de rios na área de objetos perigosos fabricados pelo homem (armas químicas), conforme recomendado pela Convenção-Quadro da Água, para uma descrição comparativa das reações da biota aquática européia aos efeitos do estresse. Foi validado o uso de índices hidrobiológicos e de diversidade biológica para registrar o impacto antropogênico na água. Os recursos dos dados analíticos ambientais para análise adicional da dinâmica das especificações de monitoramento foram identificados. Os parâmetros de escala do monitoramento hidrobiológico com o cálculo da diversidade α, índice de Shannon e índice de saprobidade devem ser baseados em um exame completo da vegetação e flora aquáticas e semi-aquáticas. A análise do impacto antropogênico de um objeto artificial quimicamente perigoso na região de Bryansk (Federação Russa) em ecossistemas aquáticos por um longo período de tempo usando o método de bioindicação (que consiste na avaliação da diversidade de espécies, cálculo do índice de Shannon e índice de saprobidade da água) revelou que o componente tecnogênico do impacto dos pontos de referência nos cursos de água é mínimo.

Palavras-chave: *Monitoramento ambiental integrado, Armas químicas perigosas, Avaliação de impacto, Ions biogênicos, Indicadores hidrobiológicos*.

ABSTRACT

Water bodies are the most vulnerable mean in terms of human-made impact, and the collection of monitoring information on the state of biota and the hydrochemical regime is mandatory per the recommendations of the Water Framework Convention. The paper deals with the necessary arrangements for integrated monitoring and analysis of hydrobiological and environmental analytical databases for prognostic and remediation purposes at water observation points affected by human-made chemically hazardous technogenic object (chemical weapons). The purpose of this paper was to present data of hydrobiological and hydrochemical monitoring of rivers in the area of hazardous human-made objects (chemical weapons) as recommended by the Water Framework Convention for a comparative description of the reactions of European aquatic biota to stress effects. The use of hydrobiological indices and indices of biological diversity to record the anthropogenic impact on water has been validated. The features of environmental analytical data for additional analysis of monitoring specifications dynamics have been identified. The scale parameters of hydrobiological monitoring with the calculation of α-diversity, Shannon index, saprobity index should be based on a complete examination of aquatic and semi-aquatic vegetation and flora. The analysis of the anthropogenic impact of a chemically hazardous human-made object in the Bryansk region (Russian Federation) on aquatic ecosystems over a long period of time using bioindication method (which consists in the assessment of species diversity, calculation of the Shannon index and water saprobity index) revealed that the technogenic component of the impact of reference points on watercourses is minimal.

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Keywords: *Integrated environmental monitoring, Hazardous chemical weapons, Impact assessment, Biogenic ions, Hydrobiological indicators*.

1. INTRODUCTION:

The safety of the population in the operation of hazardous technogenic facilities in the Russian Federation and worldwide is a priority task, the solution of which depends on the planning and implementation of integrated environmental monitoring studies, including those conducted at water bodies (Anischenko, 2013; Ashikhmina, 2002, p. 442). A chemically hazardous technogenic object (chemical weapons storage and disposal facility) was in operation for a long time on the territory of the Bryansk region, which is the old-developed region of the Russian Federation.

Water bodies are the most vulnerable objects in terms of human-made impact. Thus, the collection of monitoring information on the state of biota and the hydrochemical regime is mandatory following the recommendations of the Water Framework Convention and is relevant in European countries (Alrumman *et al*., 2016; European Parliament and Council of the European Union, 2000; Ruiz Jimenez *et al*., 2011).

When analyzing databases on the current and prospective state of any water bodies, it is necessary to take into account additional environmental factors determining the state of aquatic and semi-aquatic communities, and first of all, the ions of biogenic elements. The presence of ions of biogenic elements, quickly migrating in water, accelerates the development of plant biomass, and also proves to be a limiting and toxic condition for their development (Adesuyi *et al*., 2015; Mursaleen *et al*., 2018).

When the facilities make the environmental impact for storage and disposal of chemical weapons, the phosphate ion is recognized as the marker ion for any habitat. Therefore, the detection of an excess amount of this ion in the environment indicates the need for additional monitoring of security systems at the enterprise. Exceeding the maximum permissible concentrations of phosphate ions can be diagnosed in waters based on biomass growth and by increased biodiversity, for example, of pleistophytic communities. A close relationship has been established between such biological indicators as α-diversity, Shannon index, saprobity index with the concentration of ammonium cation and nitrate ions; dominant biomass and saprobity index are associated with the concentration of phosphate ions (Barinova *et al*., 2016; Chappuis *et al*., 2014; Glibert, 2014; Mikulyuk *et al*., 2011).

In the process of a long-term assessment of any hazardous human-made objects in terms of habitat components, experience in landscapes of the Non-Black Earth Area of the Russian Federation will be in demand, as it is aimed not only at identifying the state of natural ecosystems, but also at revealing the processes of their degradation, providing control of long-term effects (accumulation and transformation in environmental components) of toxic substances and products of their destruction. Bioindicative indicators of aquatic macrophyte communities of small watercourses under the anthropogenic pressure will complement large-scale global hydrobiological studies (Barinova, 2017a; Ostroumov, 2010; Saloua *et al*., 2017).

The purpose of this paper was to present data of hydrobiological and hydrochemical monitoring of rivers in the area of hazardous man-made objects as recommended by the Water Framework Convention for a comparative description of the reactions of European aquatic biota to stress effects.

2. MATERIALS AND METHODS:

Large-scale monitoring of the environment with an integrated focus and analysis of the results was carried out on the premises of this facility at 121 reference points from 2005 to 2016 (Anischenko, 2013; Rybalsky *et al*., 2007, p. 1144). After the completion of the production cycle, the database of surveys, including those at 5 water reference points, is in demand to optimize observations, assessment, forecast, as well as to arrange remediation measures that are actively deployed on the territory of a chemically hazardous object. The studies of watercourses in the area of a dangerous technogenic object in the Russian Federation were carried out in 2011-2016.

A map of the location of observation points and the location of rivers in the Pochep district of the Bryansk region is shown in Figure 1.

Ecological, production and indication works were carried out based on route survey, on floristic and production analysis of aquatic and semi-aquatic river plants in rivers, as well as on describing the flora of aquatic and semi-aquatic plants; the species was determined taking into account generally accepted determinants (Karpov and Savostin, 2003, p. 243; Pechenyuk, 2004, p. 129). The nomenclature of species of vascular plants is indicated by the work of S.K. Cherepanov (1995, p. 992).

The aquatic vegetation was surveyed at the reference points of the chemical weapons disposal facility (object 1204) Russian Federation, this vegetation being subject to a powerful anthropogenic impact. The results obtained during the monitoring were to be used for the rehabilitation of water bodies and watercourses.

In the course of the study of aquatic biota, such methods were employed as route, geobotanical methods (according to the recommendations of J. Brown-Blanquet International School (Braun-Blanquet, 1964, p. 865), hydrobiological methods (product definition, calculation of biodiversity indices), statistical methods, the descriptions of which are shown below. To determine the abundance of aquatic plants and the overgrowing of objects, methods of ecological profiling were used on the transects located along-shore and across the entire size of the water body (Karpov and Savostin, 2003; Ramensky, 1909).

The distribution schemes of plant communities were compiled on the basis of maps of the survey area, according to V.G. Papchenkov (Papchenkov, 2003). When geobotanical descriptions are made on the ground, the boundaries of water cenoses were distinguished according to their physiognomic and ecological principles. The sizes of test plots for cenoses descriptions are from 1 to 4 m^2 or within the natural boundaries of communities (Mirkin, 1997). The obtained characteristics of aquatic macrophyte communities were compared to the data of researchers conducted in Europe and Asia (Barinova, 2017b; Chappuis *et al*., 2012, 2011; Parsons *et al*., 2011). The names of syntaxons correspond to the code of phytosociological nomenclature, made under the approach of J. Braun-Blanquet (Braun-Blanquet, 1964; Weber *et al*., 2000).

To measure the biomass on trial plots, from 2 to 4 angle sites of 0.25 m^2 each were laid, the net primary output of hydrophytes was calculated taking into account hydrobiological methods (Mirkin, 1997; Papchenkov, 2003). Floristic diversity is estimated as the number of species on the site of a standard size, as well as the average number of species in the syntaxon coenoflora (Karpov and Savostin, 2003; Shitikov *et al*., 2003). The uniformity of species is determined using Simpson and Shannon indices, which were calculated according to standard formulae, with the definition of some statistical characteristics (Lakin, 1990, p. 352; Magarran, 1992, p. 184; Shannon and Weaver, 1998, p. 117; Shitikov *et al*., 2003, p. 463). The basic ions of biogenic elements were determined by generally accepted standards and were compared with sanitary and hygienic standards (Ministry of Health of the Russian Federation, 2003).

Stationary observation sites are selected following the state environmental monitoring sampling system since information is needed on the background ecological conditions (of air, water, soil). Stationary sites are located according to the following principle: the boundary of the zone of protective measures, ½ of the radius of the zone of protective measures.

The description of plant communities based on the reference points of a chemically dangerous human-made object is presented below.

At point 110, the Costa River, there are communities of *Lemno-Spirodeletum polyrhizae* W. Koch 1954 em. Müll. Et Görs. 1960. Communities are spread in the form of small spots along the backwaters of the river from the depth of 0.2 to 0.7 m. The soil is slightly silty. The total projective cover is 50%.

The coenoses of the association *Lemnetum trisulcae* Kelh. Ex Knapp et Stoffers 1962 with the Far East *Lemna trisulca* are found in the impounded river stretches having a depth of up to 0.7 m. They endure only a weak current and are formed when the illumination is at least 50% of the total. The projective cover is up to 80%. The area of distribution is up to 3-5 m^2.

Communities of association *Lemno-Hydrocharitetum morsus-ranae* Oberd. 1957, are confined to shallow areas, and described along the banks of the backwaters (mainly up to a depth of 0.6 m), on the stream openings. The total projective cover is from 65%.

The association *Potamogetonetum natantis* Soó 1927, is distributed on silty substrates at a depth of 0.8-1.3 m. *Potamogeton natans* forms the basis of phytocenoses with a projective coating of 75%. Communities are located at a distance of 3-5 meters from the water rim and often have an elongated oval shape. Association *Polygonetum natantis* Soó 1927, these associations are confined to habitats with sandy soils. The distribution depths of phytocenoses are up to 0.95 m. Communities do not form extensive vegetation, they are encountered in separate «inclusions» along the bank. They are formed when the illumination is from 50 to 100%. The total projective cover of plants is low: from 30 to 65%.

Semi-aquatic communities are mainly formed by the following association communities. The communities of association *Typhetum latifoliae* Nowiński 1930 are common in the riverside strip under study, they are composed of high-grass helophyte - broad-leaved cattail. Plants form small spots, grow to a depth of 0.5 m with silt soils. The total projective cover is up to 90%. The communities of association *Phragmitetum australis* Savnič 1926, are formed along the river banks, and often form a solid «wall» of plants. Semi-aquatic communities grow on medium silty soils, the total projective cover of species is 98%.

Communities of the association *Sagittario sagittifoliae-Sparganietum emersi* Tüxen 1953, are two-tiered, and are composed only of gelophytic species growing on heavily silty soils under conditions of significant lighting of up to 90-100%.

Communities of the association *Rorippo-Phalaridetum arundinaceae* Kopecký 1961, are two-tiered with a total projective cover of up to 100%. They are formed on silty soils, and on the coast – on heavy clay loam.

At point 142 - the Semchanka River there are communities of the association *Lemno-Spirodeletum polyrhizae* W. Koch 1954 em. Müll. Et Görs. 1960, which are distributed throughout the profile of the study area to a depth of 0.4 m with slightly silty soil. The total projective cover is 40%. The communities of Ass. *Elodeetum canadensis* Egller 1933, are distributed in small spots in shallow waters at shallow depths of up to 0.35 m, on silty soils.

Phytocenoses of ass. *Lemno-Sagittarietum natantis* Taran et Tyurin 2005, LW: *Sagittaria sagittifolia*, *Lemna minor*, were registered in areas with sandy-silt soil, and with illumination from 60 to 90%. The total projective cover is from 30 to 65%.

The semi-aquatic communities dominating in the coastal strip are listed below: *Rorippo-Phalaridetum arundinaceae* Kopecký 1961, *Phragmitetum australis* Savnič 1926, *Butometum umbellati* Philippi 1973 which are formed in the shallow waters of the explored river habitats; they are single-tier, monodominant communities, sometimes with a small mixture of floating manna grass. The total projective cover is up to 65%.

Communities of Ass. *Oenantho aquaticae-Rorippetum amphibiae* Lohmeyer 1950, are widely distributed in riverside shallow waters to a depth of 0.3 m in well-lit habitats with silty soils.

In conditions of point 78 - in the Horn River - communities of associations *Lemno-Spirodeletum polyrhizae* W. Koch 1954 em. Müll. Et Görs. 1960, *Lemno-Hydrocharitetum morsus-ranae* Oberd. 1957, *Potamogetonetum natantis* Soó 1927 are formed.

Communities of Ass. *Ceratophylletum demersi* (Soó 1928) Eggler 1933, are registered in the shallow places of the river backwater. Water depths are insignificant - mostly up to 0.5 m. The soil has substantial silt deposit. Association communities occupy the entire water column to the very bottom.

The association *Potamogetonetum lucentis* Huek 1931, the total projective cover of plants in the community is from 60 to 95%. These communities are described in the river to a depth of 1.5 m. The soil in the reservoir is the most diverse: from sandy to heavily silty. Communities evolve when illuminated from 60 to 100%.

The semi-aquatic communities are few in terms of the composition of the cenoses participating in the establishment of vegetation: ass. *Typhetum latifoliae* Nowiński 1930, *Oenantho aquaticae-Rorippetum amphibiae* Lohmeyer 1950, *Sagittario sagittifoliae-Sparganietum emersi* Tüxen 1953.

Association *Equisetetum fluviatilis* Nowiński 1930, is formed on silty soils, in the backwaters of the river to a depth of 0.3 m with a single-tier structure. The total projective cover is small - 45%.

3. RESULTS AND DISCUSSION:

The survey of macrophytes, as well as semi-aquatic plants in the biomonitoring system, is a recommended direction for collecting data for the monitoring base, since these objects are highly informative, they are distributed as background ones in aquatic habitats, and have high accumulative capacities (Barinova, 2017a, 2017b; Bolpagni *et al*., 2012; Bornette and Puijalon, 2011).

Monitoring indicators of the status of water macrophytes and saprobity indices, which form the basis of hydrobiological monitoring in any water objects, are presented for aquatic and semi-aquatic communities during the period of active observations and active production cycle at the chemical weapons disposal facility.

Hydrobiological indices are determined as indicators of biological diversity in reference points (Table 1, Table 2).

The analysis of the reference points obtained as a result of water biomonitoring using the bioindication method indicates a favorable state of the environment, corresponding to its background state.

The species diversity of macrophytes and semi-aquatic vegetation is high, the Shannon index is significant. The species composition is represented by typically river species of 6 ecological groups. The human-made impact on the watercourse is minimal. The studies of saprobity showed the absence of oxygen starvation, significant overgrowth of the river; the water is clear. The quality of water and the condition of the water body, assessed according to the biomass and dominants productivity, is favorable and characteristic of natural hydrocenoses. The research results did not reveal the impact of a man-made object on the water flow of reference points.

Saprobity indices are shown in Table 3.

The studies of saprobity showed the absence of oxygen starvation, significant overgrowth of the river; the water is clear. The quality of water and the condition of the water body, assessed according to the biomass and dominants productivity, is favorable and characteristic of natural hydrocenoses. The research results did not reveal the impact of a human-made object on the water flow of reference points.

The saprobity indices calculated when conducting monitoring studies in other years using aquatic macrophytes are shown in Table 4.

The studies of saprobity showed the absence of oxygen starvation, significant overgrowth of the river; the water is clear. The quality of water and the condition of the water body, assessed according to the biomass and dominants productivity, is favorable and characteristic of natural hydrocenoses. The research results did not reveal the impact of a man-made object on the water flow of reference points.

To add the data to the database and have their reliable processing, the biomonitoring indicators in the reference points of a chemically hazardous human-made object were supplemented with ecoanalytic signs of water, obtained following the provisions of the GOST R (Russian National Standard) system.

The dependence of the biological indicators of macrophyte communities on the hydrochemical parameters of water (C (NH_4^+), C(NO_3^-), C (PO_4^{3-}), mg/l) is represented by the following parameters (Table 5).

The results of statistical analysis of the Shannon index dependence on the content of ammonium ions, which was calculated for macrophyte communities, revealed a significant interrelation of the two values. Still, the most substantial is the effect of the increased concentration of ammonium-containing compounds on the increase in α-diversity (Figure 2). The dominants biomass does not correlate with the concentration of the ions under consideration.

A linear dependence between the content of nitrate ions and the calculated Shannon index has not been revealed. However, an increase in the concentration of nitrate ions causes a regular increase in α-diversity (Figure 3) and indicators of saprobity index (the equations are given in Table 6)

A high correlation dependence was revealed between the phosphate content in the points under study and the dominant biomass; the dependence of the calculated saprobity index on the concentration of phosphorus-containing compounds is also high (Figure 4).

Thus, a close relationship between biological indicators: α-diversity, Shannon index, saprobity index was revealed for the concentration of ammonium cation and nitrate ions, the dominant biomass, and saprobity index are related to the concentration of phosphate ions.

The bioindication method, widely used for the diagnostic assessment of aquatic ecosystems, showed the possibility of its use in terms of the recommendations of the Water Framework Directive of the European Union for small European watercourses. In the monitoring area of a chemical hazardous technogenic object of the Russian Federation, semi-aquatic and aquatic vegetation is represented by two classes of 4 orders, 5 unions and 12 associations, which is determined by the latitudinal gradient and Central European conditions for the development of communities. The number of vegetation species that constitute the community remained unchanged for all years of research (from 63 to 74 species), typically river macrophytes dominate, the change of ecological groups is not registered, the indicators of α-diversity indicate a considerable diversity of community species. Indicators of the Shannon index for communities testify to the background state of the waters, the absence of the stressful influence of a man-made object, and are similar to the results obtained by other authors (Bornette and Puijalon, 2011; Chappuis *et al*., 2011; Moore *et al*., 2012). Geobotanical and ecological characteristics of aquatic macrophyte communities, which were taken into account for hydrobiomonitoring works of semi-aquatic communities are similar to data obtained in the course of European studies.

A slight change in plant production (biomass) was recorded within the statistical significance of differences due to the dynamics of climatic factors affecting the plants production. The Overgrowing of backwaters of small rivers is small, as the flow factor determines the development of a particular biomass of macrophytes and semi-aquatic plants. Consequently, it is recommended to employ ecological and biological indicators and their change for small rivers under the stressful impact of man-made objects during long-term monitoring work: changes in the spatial and species composition of communities, species diversity and ecological groups of species indicate the direct and indirect effects on river waters (Mikulyuk *et al*., 2011; Steffen *et al*., 2014).

According to the index of ecological quality of water bodies, recommended by the Water Framework Convention, the biological elements of the rivers of the Non-Black Earth Region of the Russian Federation show a “good” state of the waters.

The ecological state of waters at the reference points of a dangerous man-made object is also determined by hydrochemical indicators, primarily biogenic ions, oxygen availability, saprobity, which indirectly determines the oxygen regime; as well as by hydrophysical indicators: water consumption, continuity of the water flow and others (Ali *et al*., 2014; Guggenmos *et al*., 2011).

Long-term observations of the river water saprobity have shown the absence of oxygen starvation, the preservation of significant water flow. A change in the saprobity index from 2.1 to 2.7 (beta-mesosaprobic zone) corresponds to the European indicators and is typical of natural cenoses (Bolpagni *et al*., 2012; Bornette and Puijalon, 2011; Chappuis *et al*., 2012, 2011; Ramavandi and Farjadfard, 2014). Thus, hydrobiological and hydrochemical parameters are interrelated, and aquatic biota directly determines the chemical parameters of the watercourses understudy, which has been proven by many studies (Guggenmos *et al*., 2011).

Technologically determined methods for controlling discharges into water bodies of the area under study have proven high efficiency: the concentrations of biogenic ions in flowing waters correspond to the most stringent indicators of the Russian rationing. The significant connection between the concentration of ammonium-containing compounds, nitrate ions and the increase in the α-diversity of vegetation is understandable since aquatic species most successfully absorb nitrogen compounds in this form (Ali *et al*., 2014).

Phosphate ions that serve as markers for dangerous technogenic objects for the disposal of chemical compounds are the limiting indicators for the development of all aquatic biota according to the empirical rule of J. Liebig. The presence of phosphates in river waters determines the growth of biomass (production) and determines the estimated index of saprobity of monitoring objects (Ali *et al*., 2014; Guggenmos *et al*., 2011). According to the recommendations of the Water Framework Convention, in determining the environmental quality of water bodies, it is mandatory to take into account hydromorphological parameters, including bottom sediments, determined by phosphoric compounds. Measuring and controlling water ions of biogenic elements are significant for hydrochemical studies (Barinova, 2017a, 2017b; Bolpagni *et al*., 2012; Ostroumov, 2010). When the excess concentration of biogenic ions in water is revealed, it is possible to recommend the use of macrophyte biomass for ion sorption and phytoremediation of water bodies (Naghipour *et al*., 2016; Ramavandi and Farjadfard, 2014; Ruiz Jimenez *et al*., 2011).

4. CONCLUSIONS:

The analysis of the anthropogenic impact on aquatic ecosystems of a chemically hazardous man-made object in the Bryansk region (Russian Federation) using the method of bioindication (which consists in the assessment of species diversity, calculation of the Shannon index and water saprobity index) revealed that the technogenic component of the impact on watercourses is minimal, the state of water bodies corresponds to natural hydrocenoses, the water is clean.

In the monitoring area of a chemical hazardous technogenic object of the Russian Federation, semi-aquatic and aquatic vegetation is represented by two classes of 4 orders, 5 unions and 12 associations, which is determined by the latitudinal gradient and Central European conditions for the development of communities. Indicators of the Shannon index for communities testify to the background state of the waters, the absence of the stressful influence of a man-made object. It is recommended to employ ecological and biological indicators and their change for small rivers under stressful impact of man-made objects during long-term monitoring work: changes in the spatial and species composition of communities, species diversity and ecological groups of species indicate the direct and indirect effects on river waters. Long-term observations of the river water saprobity have shown the absence of oxygen starvation, the preservation of significant water flow. A change in the saprobity index from 2.1 to 2.7 (beta-mesosaprobic zone) corresponds to the European indicators and is typical of natural cenoses.

Thus, the proposed indicators for the organization of hydrobiological monitoring of hazardous man-made objects and their effect on water stand is most preferable. When analyzing the databases on the current and prospective state of any water bodies, it is necessary to take into account additional environmental factors determining the state of aquatic and semi-aquatic communities: first of all, ions of biogenic elements. The presence of these easily migrating ions in water accelerates the development of plant biomass, and also turns out to be a limiting and toxic condition for their development.

When facilities cause the environmental impact for the storage and disposal of chemical weapons, the phosphate ion is recognized as the marker ion in any habitat. Therefore, the detection of an excess amount of this ion in the environment indicates the need for additional monitoring of security systems in the enterprise. Exceeding the maximum permissible concentrations of phosphate ions can be diagnosed in the waters both by biomass growth and by increasing biodiversity, for example, of pleistophytic communities.

5. COMPLIANCE WITH ETHICAL STANDARDS:

This article does not contain any studies involving human participants or animals performed by any of the authors.

6. FUNDING:

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7. CONFLICT OF INTEREST:

The authors report no conflict of interest.

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Table 1. *The main indicators of water macrophytes in test sites of reference points*

Points	**Data**	**Prior data (2011)**	**Data (2013)**	**Data (2015)**	**Conclusions**
78	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	74 / 1.28	74 /1.28	74 / 1.28	The species composition of macrophytes and semi-aquatic species has not changed.
	Dominants biomass (kg/m^2 of dry matter)	2.3	2.3	2.9	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.023 per year	0.023 per year	0.031 per year	The production has increased.
	The degree of weediness of the area under study % / class	9 % / 1st class	9 % / 1st class	11 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.
142	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	65 / 1.04	65 /1.04	65 /1.04	The species composition of macrophytes and semi-aquatic species has not changed.
	Dominants biomass (kg/m^2 of dry matter)	2.8	2.9	3.5	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.036 per year	0.032 per year	0.039 per year	The production has increased.
	The degree of weediness of the area under study % / class	9.8 % / 1st class	10.2 % / 1st class	11 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.
110	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	63 / 1.06	63 /1.06	63 /1.06	The species composition of macrophytes and semi-aquatic species has not changed.
	Dominants biomass (kg/m^2 of dry matter)	2.1	2.25	3.5	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.019 per year	0.019 per year	0.024 per year	The production has increased.
	The degree of weediness of the area under study % / class	8.3 % / 1st class	8 % / 1st class	11 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.

Table 2. *The main indicators of water macrophytes in test sites of reference points*

Points	Data	Data (2012)	Data (2015)	Data (2016)	Conclusions
78	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	74 /1.28	74 /1.28	73 /1.28	The species composition of macrophytes and semi-aquatic species has decreased (insignificantly).
	Dominants biomass (kg/m^2 of dry matter)	2.3	2.9	2.7	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.023 per year	0.031 per year	0.027 per year	The production has increased.
	The degree of weediness of the area under study % / class	9 % / 1st class	11 % / 1st class	9,0 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.
142	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	65 /1.04	65 /1.04	65 /1.04	The species composition of macrophytes and semi-aquatic species has not changed.
	Dominants biomass (kg/m^2 of dry matter)	2.9	3.5	3.9	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.032 per year	0.039 per year	0.032 per year	The production has decreased.
	The degree of weediness of the area under study % / class	10.2 % / 1st class	11 % / 1st class	10.2 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.
110	Number of species of macrophytes and semi-aquatic plants (α-diversity) / species diversity index	63 /1.06	63 /1.06	63 /1.06	The species composition of semi-aquatic species has not changed.
	Dominants biomass (kg/m^2 of dry matter)	2.25	3.5	3.5	The biomass of three dominants has increased. The biomass is considerable, which testifies to background conditions of aquatic environments.
	Primary production of dominants (tons)	0.019 per year	0.024 per year	0.024 per year	The production has not changed.
	The degree of weediness of the area under study %/class	8 % / 1st class	11 % / 1st class	11 % / 1st class	The weediness of the riverside sections is insignificant, indicating a good flow of water.

Table 3. *The state of waters on test sites of reference points according to the saprobity index using macrophytes*

Points	Data (2011)	Data (2013)	Data (2015)	Conclusions
78	2.3 beta-mesosaprobic zone	2.5 beta-mesosaprobic zone	2.4 beta-mesosaprobic zone	Saprobity has not changed, the saprobity index indicates the medium decomposition of organic matter, and the background state of water.
142	2.7 beta-mesosaprobic zone	2.7 beta-mesosaprobic zone	2.5 beta-mesosaprobic zone	Saprobity has decreased, the saprobity index indicates the medium decomposition of organic matter and the background state of water.
110	2.1 beta-mesosaprobic zone	1.9 beta-mesosaprobic zone	2.2 beta-mesosaprobic zone	Saprobity has increased, the saprobity index indicates the medium decomposition of organic matter and the background state of water.

Table 4. *The state of waters on test sites of reference points according to the saprobity index using macrophytes*

Points	Data (2012)	Data (2015)	Data (2016)	Conclusions
78	2.5 beta-mesosaprobic zone	2.4 beta-mesosaprobic zone	2.4 beta-mesosaprobic zone	Saprobity has not changed, the saprobity index indicates the medium decomposition of organic matter, and the background state of water.
142	2.7 beta-mesosaprobic zone	2.5 beta-mesosaprobic zone	2.7 beta-mesosaprobic zone	Saprobity has slightly increased, the saprobity index indicates the medium decomposition of organic matter and the background state of water.
110	1.9 beta-mesosaprobic zone	2.2 beta-mesosaprobic zone	2.0 beta-mesosaprobic zone	Saprobity has decreased, the saprobity index indicates the medium decomposition of organic matter and the background state of water.

Table 5. *Dependence of biological indicators of macrophyte communities on hydrochemical water parameters (C NH_4^+) in reference observation points of a chemically dangerous man-made object*

Reference points (r.p.) / indicators	C NH_4^+	Shannon index	α-diversity	Dominants biomass (kg/m^2 of dry matter)	Saprobity index
r.p. 78	0.46	1.28	74	2.45	2.43
r.p. 110	0.33	1.06	63	2.52	2.02
r.p.142	0.41	1.04	65	3.03	2.65
Correlation index (r)		**0.7444***	**0.8849**	0.02167565	**0.7369**
Correlation and regression equation		y=1.5116x+ 0.522	y=79.07x+ 35.705	-	y=3.593x+0.9295
Reliable approximation (R^2)		**0.5541**	**0.783**	-	**0.543**

Table 6. *Dependence of biological indicators of macrophyte communities on hydrochemical water parameters (C (NO_3^-)) in reference observation points of a chemically dangerous man-made object*

Reference points (r.p.) / indicators	**C NO_3^-**	**Shannon index**	**α-diversity**	**Dominants biomass (kg/m^2 of dry matter)**	**Saprobity index**
r.p. 78	3.9	1.28	74	2.45	2.43
r. p. 110	1.93	1.06	63	2.52	2.02
r.p.142	3.4	1.04	65	3.03	2.65
Correlation index (r)		0.64043199	**0.8086***	0.16543099	**0.8266**
Correlation and regression equation		y=0.0833x + 0.8704	y=4.6267x + 53.099	-	y=0.2581x + 1.5726
Reliable approximation (R^2)		0.4102	**0.6538**	-	**0.6832**

Table 7. *Dependence of biological indicators of macrophyte communities on hydrochemical water parameters (PO_4^{3-}) in reference observation points of a chemically dangerous man-made object*

Reference points (r.p.) / indicators	**PO_4^{3-}**	**Shannon index**	**α-diversity**	**Dominants biomass (kg/m^2 of dry matter)**	**Saprobity index**
r.p. 78	0.33	1.28	74	2.45	2.43
r. p. 110	0.25	1.06	63	2.52	2.02
r.p.142	0.8	1.04	65	3.03	2.65
Correlation index (r)		**-0.4473***	**-0.2154**	**0.9699**	**0.8467**
Correlation and regression equation		-	-	y=1.0334x + 2.1913	y=0.2581x + 1.5726
Reliable approximation (R^2)		**-**	**-**	**0.9408**	**0.6832**

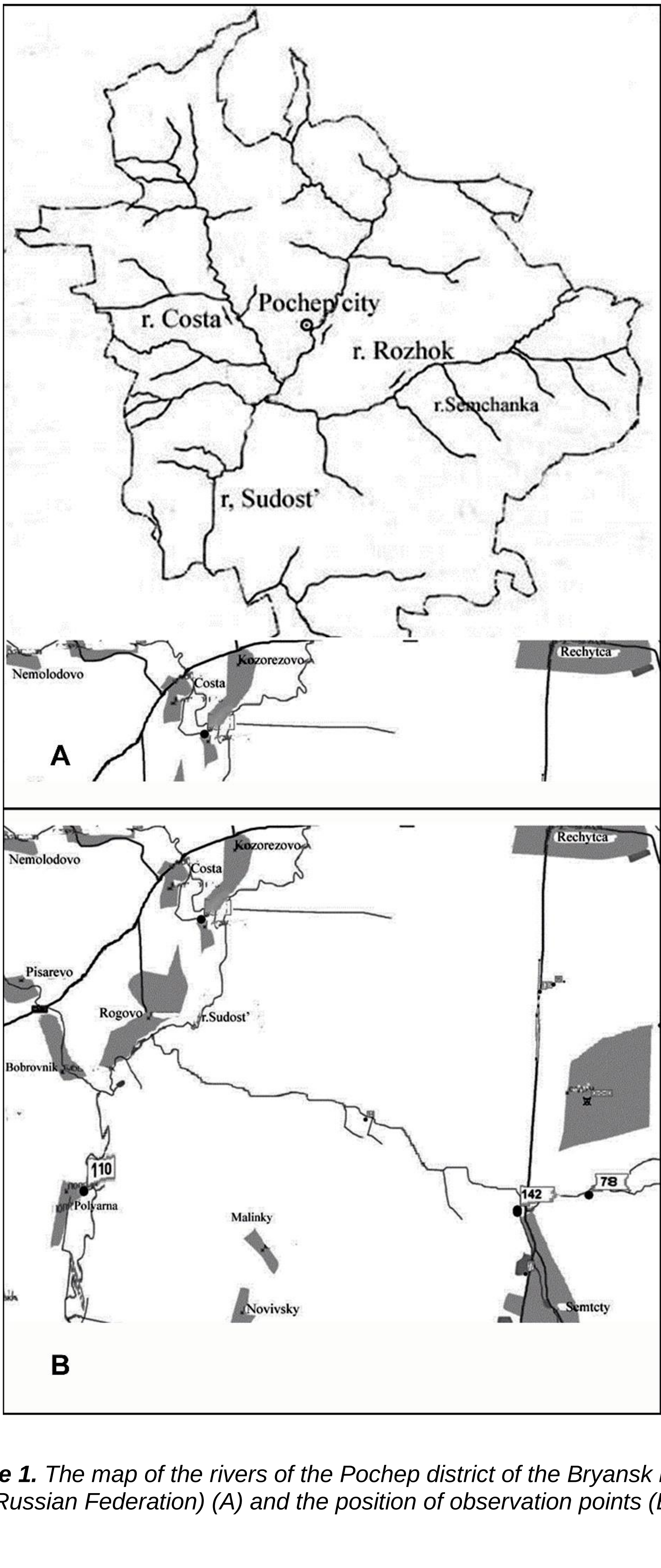

Figure 1. *The map of the rivers of the Pochep district of the Bryansk region (Russian Federation) (A) and the position of observation points (B)*

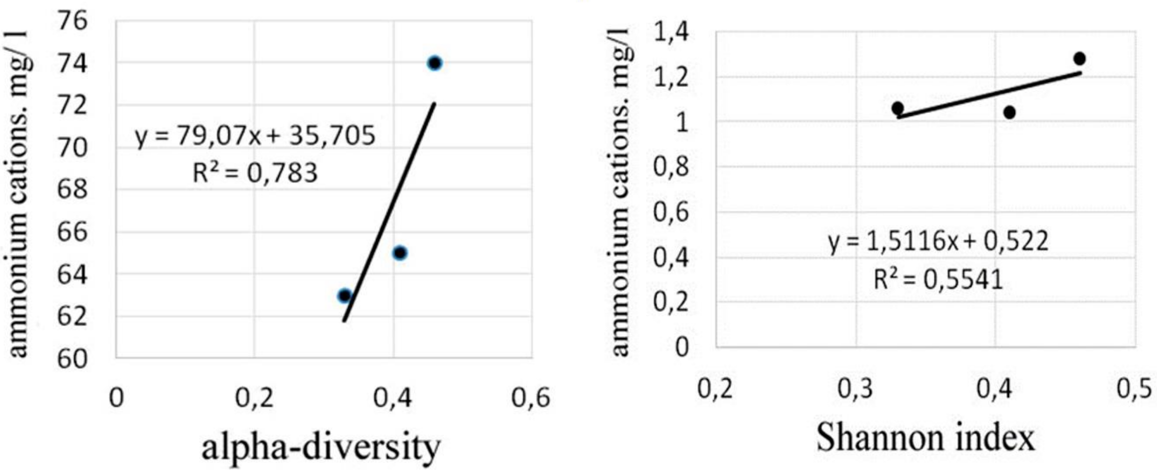

Figure 2. *Dependence of biological indicators of macrophyte communities on the concentration of ammonium ions (NH_4^+)*

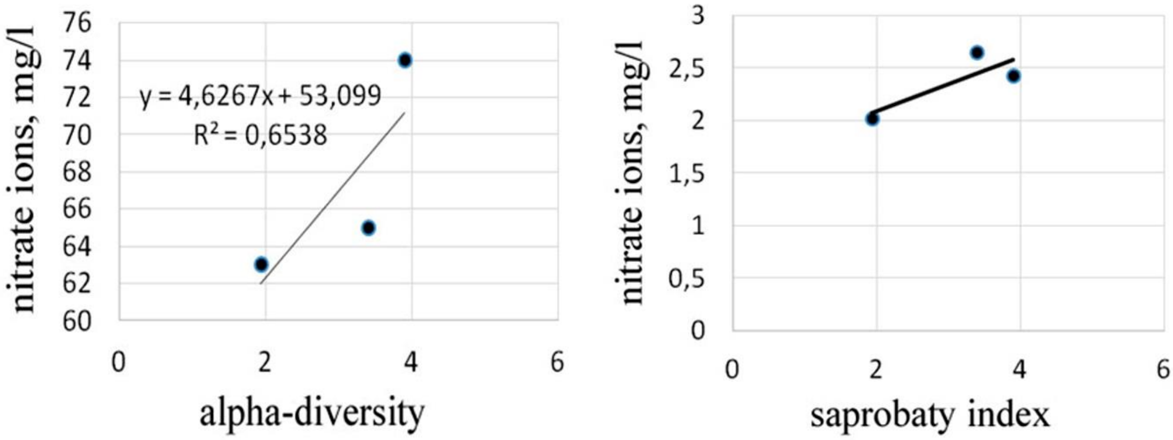

Figure 3. *Dependence of biological indicators of macrophyte communities on nitrate ions (NO_3^-) concentration*

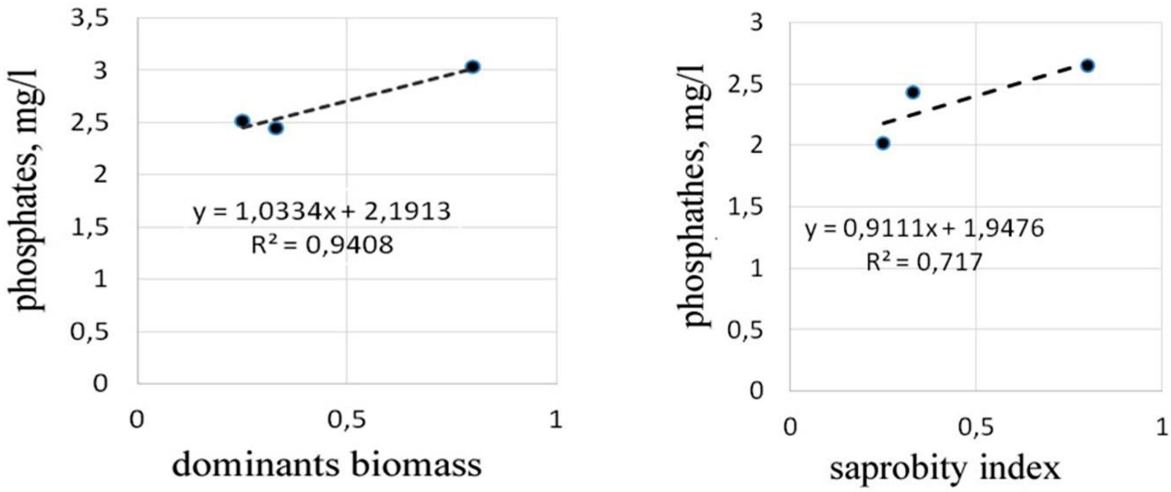

Figure 4. *Dependence of biological indicators of macrophyte communities on phosphate ions (PO_4^{3-}) concentration*