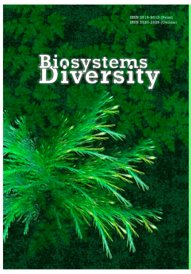

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Influence of flow velocity, river size, a dam, and an urbanized area on biodiversity of lowland rivers

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Biodiversity of aquatic organisms is formed under the influence of not only natural, but also anthropogenic factors. In this work, the influence of the flow velocity, river size, flow regulation and urbanization on various groups of aquatic organisms was studied in several lowland rivers. The study was conducted in 2013 on six tributaries of the Upper Sukhona River. Five sampling sites were in different parts of the Vologda River and five sites on small rivers, Losta, Lukhta, Komya, Chernyj Shingar, and Belyj Shingar (one site per river). Phytoplankton, zooplankton and zoobenthos were sampled six times, from April to October, and macrophytes were studied in August. In total, 469 species of aquatic organisms were found in the tributaries of the Upper Sukhona River, belonging to the following phyla: Cyanophyta (5 species), Chrysophyta (8), Bacillariophyta (62), Xanthophyta (1), Cryptophyta (10), Dinophyta (4), Euglenophyta (12), Chlorophyta (17), Streptophyta (1), Bryophyta (2), Marchantiophyta (3), Equisetophyta (1), Magnoliophyta (63), Rotifera (22), Cnidaria (1), Platyhelmintes (1), Annelida (29), Mollusca (33), Arthropoda (194). The maximum number of species was found in the Vologda River, the largest of all the tributaries. The number of zoobenthos species was similar at different sites in the Vologda River and in the small rivers. The number of species of other groups of aquatic organisms in the small rivers was lower than those registered in the Vologda River. The greatest number of macrophyte and zoobenthos species was recorded in the Upper Vologda River and Belyj Shingar River, where the flow is strong all the year round. The greatest number of phyto- and zooplankton species was found at the extra-city sites where current is almost absent. In the dam backwater, species richness was higher than that registered downstream of the dam. At the same time, the species richness of macrophytes and zoobenthos in the dam backwater was lower. The smallest number of species was found in the Vologda River, downstream of the city of Vologda. Decreases in the species richness and Shannon's biodiversity index were witnessed in the Vologda River city site and in the small rivers, as they get closer to the city. Cluster analyses performed for the studied groups of aquatic organisms showed dissimilar results; however, the studied sites on the Vologda River having the highest anthropogenic load formed a cluster. Aquatic organisms of the Upper Sukhona tributaries experience both natural (flow velocity and size of the watercourse) and anthropogenic factors (proximity to the city and flow regulation).

Keywords: macrophytes; phytoplankton; zooplankton; zoobenthos; anthropogenic load; species richness

Introduction

The biological diversity of rivers is a well established indicator of their ecological status. With environmental degradation, the greatest decrease in species diversity is observed in freshwaters rather than in terrestrial ecosystems (Sala et al., 2000). The species richness in rivers varies under the influence of both natural and anthropogenic factors. Natural factors include changes in the hydrological characteristics of the flow in different parts of the river and extreme natural events (Alimov et al., 2013). It is believed that biodiversity also depends on the size of the watercourse (Alimov et al., 2013; Vorste et al., 2017). Anthropogenic load leads to changes in the habitat conditions of aquatic organisms and, as a consequence, the loss of the most sensitive species. There are four groups of factors threatening the biodiversity of rivers, namely: water management, pollution, drainage basin disturbance and biotic factors (Vörösmarty et al., 2010). According to another approach, there are five categories of threats to freshwater biodiversity: over-exploitation, pollution, water level fluctuations, habitat disturbance, and invasions (Dudgeon et al., 2006).

Alteration of the hydrological regime of a watercourse with a dam causes changes in habitat conditions. Consequently, various communities of aquatic organisms are formed upstream and downstream of the dam. It is believed that the species richness of plankton is significantly higher in the reservoirs than in the downstream areas (Alhassan et al., 2015; Fan et al., 2015). Upstream of the dam, the accumulation of pollutants by sediments can lead to a decrease in the diversity of the bottom dwelling aquatic organisms, compared with the downstream areas. However, the species richness in the backwater areas may either be lower and higher, depending on the specific habitat conditions (Mbaka & Mwaniki, 2015). The channels in the banks affect the species richness and diversity of zoobenthos negatively due to the habitat disturbance (Horsak et al., 2009).

There are different types of pollution, including heat pollution, eutrophication, toxification. In natural ecosystems, pollution is usually complex. With increasing pollution, species diversity decreases due to the elimination of the most sensitive organisms (Barinova et al., 2008; Lock et al., 2011; Karpova & Klepets, 2014; Wright et al., 2017). Disturbance of drainage basins includes various types of agriculture as well as areas impermeable to runoff, including urban areas. Thus, negative impacts of agriculture on aquatic species diversity was reported by Carvalho et al. (2011), Opiso et al. (2014), and Kim et al. (2016); the influence of urban areas was characterized by Beixin et al. (2012), Lakew & Moog (2015). Urban areas exert multiple pressures on river ecosystems, undermining their biodiversity (Rusanov & Khromov, 2016; Grizzetti et al., 2017; Kuzmanovic et al., 2017). Human population density can cause a negative impact on biodiversity (Luck, 2007). Thus, it seems highly relevant to assess the influence of natural and anthropogenic factors on the biodiversity of river ecosystems as an indicator of the ecological status of both a water body and its basin.

The purpose of this study was to determine the species diversity of several groups of aquatic organisms, namely, higher aquatic plants, phytoplankton, zooplankton, and zoobenthos, in lowland rivers, with an emphasis on the changes in species diversity caused by disturbance of the hydrological regime and the complex impact of urban areas.

Material and Methods

The study area is located in the southern taiga, in the south of the central part of the Vologda Region, northwest Russia (Fig. 1). All rivers studied are the tributaries of the Upper Sukhona River. The drainage basins of these rivers are located within three landscapes with different morphological features; in the south-west, the largely paludified Prisukhonskaya lowland is adjoined by the terraced Vologda-Gryazovets upland, and in the south-east, by the dome-shaped Avniga upland (Vorobyov, 2007). The flat terrain of the Prisukhonskaya lowland and backwaters of the Sukhona River support the hydrological characteristics of the rivers located in the area; during the baseflow period, the almost complete absence of current causes intensive sedimentation. The Vologda-Gryazovets upland is characterized by a long history of development and a high degree of urbanization. In the territory of the Prisukhonskaya lowland, economic activity is low on account of the significant degree of paludification.

Field studies were conducted on six water bodies: five small rivers located at different distances from the city, and one medium river, the Vologda River. In the Vologda river, sampling was carried out at five sites, namely: in the upper part (1a, Fig. 1, Table 1), in the reservoir (1b), one in the reservoir downstream of the dam, upstream of the city of Vologda (1c), within the city (1d), and downstream of the city (1e). Only in the Upper Vologda River (1a), is the current observed during the whole vegetation period. Sampling site 1b is located in the backwater of a dam and is characterized by the greatest depths. Sampling sites 1c, 1d, 1e are located downstream of the dam and have hydrological conditions similar to each other. The Vologda River passing through the city receives industrial discharges and rainwater sewage. In four studied small rivers, the Lukhta, Komya, Chernyj Shingar, Belyj Shingar, sampling sites were located in lower courses, the Losta River had a sampling site in the middle course. In these rivers, except the Belyj Shingar River, the flow velocity is very low, almost absent; only the Belyj Shingar River due to passing through the steep slope of the Avniga Upland has a pronounced flow throughout the growing season. The drainage basins of the small rivers are characterized by varying degrees of disturbance (Ivicheva & Filonenko, 2017): with the proximity to the city, the share of forests decreases and the share of open territories increases. The least affected by human activity is the drainage basin of the Chernyj Shingar River (it is located in the heavily paludified Prisukhonskaya lowland), the most affected is the drainage basin of the Lower Vologda River (within and downstream of the city).

Hydrochemical analysis was performed in the Accredited Testing Laboratory of the Federal State Institution of the State Agrochemical Service Center "Vologodskiy" (accreditation certificate No РОСС RU.0001.21ПЧ08). The territory genesis determines the high content of iron, copper and zinc in the river water. The waters in the studied rivers belong to the hydrocarbonate class, calcium group, with high TDS levels. Hydrocarbonates predominate in the anionic complex, which is a characteristic feature of water in the entire Vologda Region (Vorobyov, 2007).

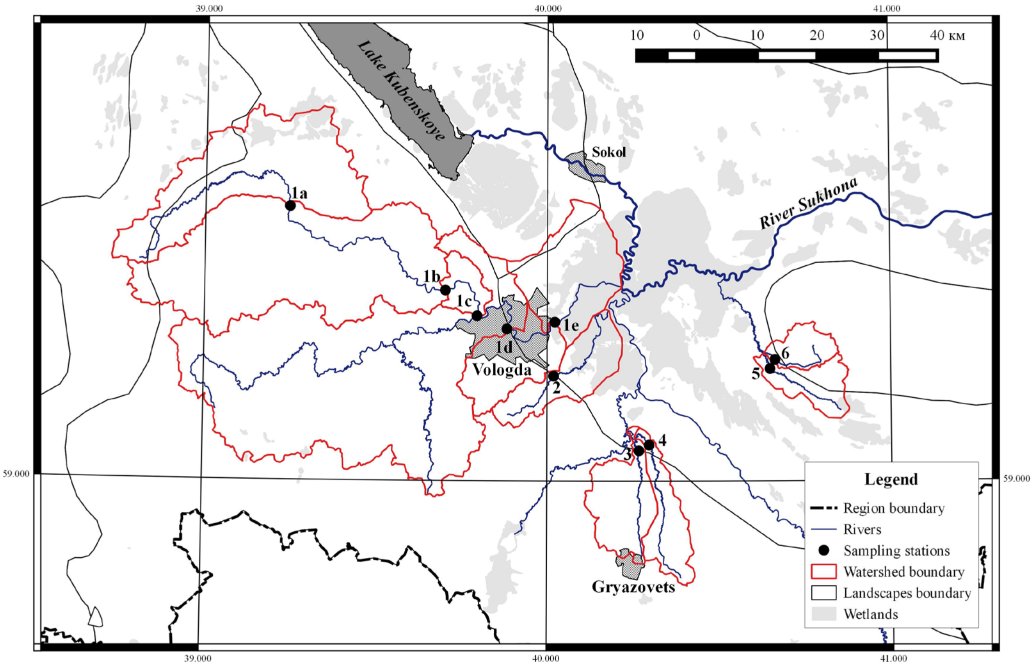

Fig. 1. Sampling sites on the tributaries of the Upper Sukhona River: rivers and sampling sites are listed in Table 1.

Table 1
Characteristics of the sampling sites

Site Index	River, sampling site	Coordinates	D, km	W, m	d, м	V, m/s	Bottom substrate	pH	TDS, mg/l
	Vologda								
1a	– upstream	59°24'18" N, 39°14'54" E	101.2	13	0.3–1.0	0.4	coarse sand, gravel, boulders	7.1	558
1b	– reservoir	59°16'47" N, 39°42'21" E	57.8	42	0.5–5.0	0.01	silted sand	7.3	726
1c	– downstream of the dam	59°14'25" N, 39°47'56" E	46.0	36	0.5–3.5	0.01	silted sand	7.6	686
1d	– city of Vologda	59°13'28" N, 39°53'23" E	32.4	70	0.5–4.0	0.01	sand, detrital matter	7.2	681
1e	– downstream of the city	59°13'59" N, 40°01'28" E	16.3	90	0.5–3.0	0.01	silt, detrital matter	7.1	588
2	Losta	59°09'20" N, 40°01'25" E	23.4	3–4	0.5–1.2	0.01	silt, detrital matter	6.9	490
3	Lukhta	59°01'56" N, 40°15'51" E	10.0	3–5	0.2–1.0	0.01	sand, detrital matter	6.9	683
4	Komya	59°02'49" N, 40°18'28" E	7.8	4–5	0.3–1.0	0.01	sand, detrital matter	6.9	586
5	Chernyj Shingar	59°10'13" N, 40°38'47" E	3.8	3–5	1.0–1.5	0.01	silt, detrital matter	7.0	507
6	Belyj Shingar	59°10'42" N, 40°39'53" E	3.2	2.5–3.5	0.2–0.6	0.4	sand	7.0	522

Note: D – distance to the mouth of the river, W – river width, d – depth, V – flow velocity during the baseflow period, TDS – total dissolved solids.

Sampling of plankton and zoobenthos was carried out in 2013, six times during the entire vegetation period: in April (only small rivers), beginning and end of May, June (only the Vologda River), July, August, October. In total, 32 samples of phytoplankton, 42 samples of zooplankton, and 292 samples of zoobenthos were collected. Study of higher aquatic plants was carried out in August, including floristic and geobotanical descriptions of sample plots and collection of herbarium samples (ca. 70 sheets), which were analyzed and forwarded to the IBIW collection. Sampling and processing of samples was carried out according to the standard methods (Lobunicheva et al., 2013).

The species names are given according to the latest nomenclature reports (Ignatov et al., 2006; Konstantinova et al., 2009; de Jong, 2013; Plantae in GBIF, 2017; Guiry & Guiry, 2018). In Table 2, flowering plants are arranged according to classification of APG IV (The Angiosperm, 2016); the algae divisions are arranged according to the classification proposed by Vasser (1989), genus and species names are given based on the reports by Komárek & Fott (1983), Komárek & Anagnostidis (2005), and Komárek (2013).

The abundance of species was estimated on a three-point scale. For zooplankton and zoobenthos, 1 – sporadic species (up to 5% of the total number), 2 – common species (from 5 to 35% of the total number), 3 – dominant species (more than 35% of the total number). For macrophytes, 1 point was assigned to rare and sporadic species; 2 points – species found in different phytocoenoses, but whose projective cover does not exceed 20–25%; 3 points – species forms communities or patches or acts as a co-dominant. For phytoplankton, by the number of cells in the sample, 1 point – less than 2.5%, 2 points – 2.5–9.9%, 3 points – 10.0% and more.

Cluster analysis was carried out using the Bray-Curtis Index based on average monthly (during the studied season) biomass for phytoplankton and average monthly species numbers for zooplankton and zoobenthos. Graphic processing of data was carried out using a PAST v. 3.17 software.

Results

In the studied tributaries of the Sukhona River, 469 species of aquatic organisms were recorded, including Cyanophyta – 5, Chrysophyta – 8, Bacillariophyta – 62, Xanthophyta – 1, Cryptophyta – 10, Dinophyta – 4, Euglenophyta – 12, Chlorophyta – 17, Streptophyta – 1, Bryophyta – 2, Marchantiophyta – 3, Equisetophyta – 1, Magnoliophyta – 63, Rotifera – 22, Cnidaria – 1, Platyhelmintes – 1, Annelida – 29, Mollusca – 33, Arthropoda – 194 (Table 2, 3).

Table 2
Phytodiversity of the Upper Sukhona River tributaries

Taxon	Rivers and sites									
	1a	1b	1c	1d	1e	2	3	4	5	6
Macrophytes										
Streptophyta										
Chara vulgaris L.	–	1	1	–	–	–	–	–	–	–
Chlorophyta										
Cladofora glomerata (L.) Kütz.	2	2	2	2	2	–	–	2	–	–
Bryophyta										
Leptodictium riparium (Hedw.) Warnst.	1	–	–	–	–	–	–	–	–	–
Fontinalis antipyretica Hedw.	2	–	–	–	–	–	–	–	–	–
Marchantiophyta										
Marchantia polymorpha polymorpha L.	1	–	–	–	–	–	–	–	–	1
Pellia neesiana (Gottsche) Limpr.	1	–	–	–	–	–	–	–	–	–
Riccia cavernosa Hoffm.	–	–	1	–	–	–	–	–	–	–
Equisetophyta										
Equisetum fluviatile L.	–	2	–	–	–	2	3	3	2	–
Magnoliophyta										
Nuphar lutea (L.) Smith	3	3	3	3	–	–	–	3	3	3
Lemna minor L.	1	1	1	–	–	3	1	2	1	1
Lemna trisulca L.	2	–	–	–	–	–	–	–	2	–
Spirodela polyrhiza (L.) Schleid.	–	–	–	–	–	2	–	2	2	2
Alisma plantago-aquatica L.	1	1	1	–	–	–	–	–	–	–
Sagittaria sagittifolia L.	–	–	1	2	1	1	1	–	1	–
Butomus umbellatus L.	1	–	2	3	–	–	–	–	–	–
Elodea canadensis Michx.	–	2	–	–	–	–	–	2	2	–
Potamogeton crispus L.	–	–	2	–	–	–	–	–	–	–
Potamogeton gramineus L. s. l.	2	–	–	–	–	–	–	–	–	–
Potamogeton lucens L.	–	3	–	–	–	–	–	–	–	–
Potamogeton pectinatus L.	–	–	3	–	–	–	–	–	–	–
Potamogeton perfoliatus L.	–	2	2	–	–	–	–	3	–	–
Potamogeton × sparganifolius Laest. ex Fries	3	–	–	–	–	–	–	–	–	–
Sparganium emersum Rehm.	–	–	2	–	–	2	2	–	–	2
Typha latifolia L. s.l.	–	–	2	–	–	2	–	–	–	–
Juncus articulatus L.	–	–	1	–	–	–	–	–	–	–
Juncus bufonius L. s. l.	–	–	1	–	–	–	–	–	–	–
Carex acuta L.	3	3	3	1	1	3	3	3	3	–
Eleocharis acicularis (L.) Roem. et Schult.	–	2	2	–	–	–	–	–	–	–
Eleocharis palustris (L.) Roem. et Schult.	–	1	–	1	1	–	–	–	–	–
Schoenoplectus lacustris (L.) Palla	3	3	3	–	–	–	3	–	–	–
Agrostis stolonifera L.	3	3	3	–	–	–	–	–	–	–
Glyceria fluitans (L.) R. Br.	–	–	1	–	–	–	–	–	–	–
Glyceria maxima (Hartm.) Holmb.	–	–	2	2	–	–	–	–	–	–
Phalaroides arundinacea (L.) Rausch.	3	3	2	–	–	3	3	–	3	–
Phragmites australis (Cav.) Trin. ex Steud.	3	–	–	–	–	–	–	–	–	–
Batrachium kauffmannii (Clerc) V. Krecz.	3	–	2	–	–	–	–	–	–	2
Caltha palustris L.	1	–	–	–	–	–	–	–	1	–
Ranunculus repens L.	1	1	–	–	–	–	–	–	–	1
Ranunculus reptans L.	–	–	–	–	1	–	–	–	–	–
Ranunculus sceleratus L.	–	–	1	–	1	–	–	–	–	–
Myriophyllum spicatum L.	3	2	–	–	–	–	–	–	–	–
Potentilla anserina L.	–	–	–	–	1	–	–	–	–	–
Echinocystis lobata (Michx.) Torr. et A. Gray	–	–	–	–	–	–	1	–	–	–
Epilobium hirsutum L.	–	–	–	–	–	1	–	–	–	–
Epilobium montanum L.	–	–	–	–	–	–	–	–	–	1
Cardamine dentata Schult.	–	1	–	–	–	–	–	–	–	–
Rorippa amphibia (L.) Bess.	–	–	3	3	–	–	–	–	–	–
Rorippa palustris (L.) Bess.	–	1	1	–	1	–	1	–	–	1
Persicaria amphibia (L.) S. F. Gray	2	3	–	–	–	–	–	–	–	–
Persicaria lapathifolia (L.) S. F. Gray	–	–	1	–	1	–	–	–	–	–
Polygonum aviculare L.	–	–	–	–	1	–	–	–	–	–
Rumex aquaticus L.	–	1	–	–	–	–	–	–	–	–
Chenopodium rubrum L.	–	–	1	–	–	–	–	–	–	–
Lysimachia vulgaris L.	1	–	1	–	–	–	–	–	–	1
Naumburgia thyrsiflora (L.) Reichb.	2	–	–	–	–	–	–	–	–	–
Galium palustre L.	1	1	–	–	–	–	–	–	1	–
Solanum dulcamara L.	–	–	–	–	–	1	–	–	–	–
Plantago uliginosa F.W. Schmidt	–	–	1	–	1	–	–	–	–	–
Limosella aquatica L.	–	–	–	–	1	–	–	–	–	–
Veronica anagallis-aquatica L.	–	1	–	–	–	–	–	–	–	1
Veronica beccabunga L.	1	–	–	–	–	–	–	–	–	–
Veronica longifolia L.	1	–	–	–	–	–	–	–	–	–
Mentha arvensis L.	1	–	–	1	–	–	–	–	–	–
Scutellaria galericulata L.	1	1	–	–	–	–	–	–	–	–
Stachys palustris L.	1	–	–	1	–	–	–	–	–	–
Bidens cernua L.	–	–	1	–	1	–	–	–	–	–
Bidens tripartita L.	–	–	1	–	1	–	–	–	–	–
Tussilago farfara L.	1	–	–	–	–	–	–	–	–	–
Valeriana officinalis L. s.l.	–	–	–	–	–	–	–	–	–	1
Oenanthe aquatica (L.) Poir.	1	–	–	–	–	–	–	–	–	–
Sium latifolium L.	2	1	–	–	–	–	1	1	–	–
Phytoplankton										
Cyanophyta										
Anabaena sp.	–	–	–	–	–	–	–	3	–	–
Pseudanabaena limnetica (Lemmermann) Komárek	–	–	–	3	–	–	–	–	–	–
Jaaginema sp.	–	–	–	–	–	–	–	–	2	–
Geitlerinema acutissimum (Kufferath) Anagnostidis*	–	–	–	–	–	–	–	–	3	–
*Phormidium tergestinum*Kütz. ex Anagnostidis et Komárek	–	–	–	–	–	–	–	–	3	–
Chrysophyta										
Kephyrion rubri-claustri Conrad	–	1	–	–	–	–	–	–	–	–
Dinobryon bavaricum var. *medium* (Lemmermann) Krieger	1	–	–	–	–	–	–	–	–	–
Dinobryon divergens Jmhof	1	–	–	–	–	–	–	–	–	–
Dinobryon sociale Ehrenb.	1	–	2	–	–	–	–	–	–	–
Dinobryon sociale var. *stipitatum* (Stein) Lemmermann	1	–	–	–	–	–	–	–	–	–
Mallomonas sp. 1	–	1	–	–	–	–	–	–	–	–
Mallomonas sp. 2	–	1	–	–	–	–	–	–	–	–

Taxon	Rivers and sites									
	1a	1b	1c	1d	1e	2	3	4	5	6
Mallomonas sp. 3	–	1	1	–	–	–	–	–	–	–
Bacillariophyta										
Stephanodiscus sp. 1	–	–	1	–	–	–	–	–	–	–
Stephanodiscus sp. 2	–	3	2	–	–	–	–	–	–	–
Cyclotella kuetzingiana Thwaites	–	–	–	1	–	–	–	–	–	–
Cyclotella stelligera Cleve et Grunow	–	1	–	–	–	–	–	–	–	–
Melosira varians Agardh	–	–	–	–	–	3	–	–	–	3
Aulacoseira ambigua (Grunow) Simonsen	–	3	3	–	–	–	–	–	–	–
Aulacoseira distans (Ehrenb.) Simonsen	–	2	–	–	–	–	–	–	–	–
Aulacoseira granulata (Ehrenb.) Simonsen	–	2	–	–	–	–	–	–	–	–
Aulacoseira italica (Kütz.) Simonsen	–	–	3	2	–	–	–	–	–	–
Aulacoseira sp.	–	2	–	–	–	–	–	–	–	–
Fragilaria bicapitata A. Mayer	–	–	–	–	–	1	–	–	–	–
Fragilaria capucina Desmazières	–	–	–	–	1	1	–	–	–	1
Fragilaria capucina var. *lanceolata* Grunow	2	1	2	–	–	–	–	–	1	–
Fragilaria intermedia Grunow	2	–	2	–	–	–	–	–	–	–
Synedra rumpens Kütz.	–	1	–	–	–	–	–	–	–	–
Synedra tenera W. Smith	2	2	1	1	2	–	–	–	–	–
Synedra ulna (Nitzsch) Ehrenb.	3	1	–	3	3	3	–	–	–	2
Asterionella formosa Hassall	–	2	–	–	–	–	–	–	–	–
Diatoma vulgaris Bory	–	–	–	–	–	–	–	–	1	2
Meridion circulare (Greville) C.A. Agardh	1	–	–	–	2	–	–	–	2	1
Meridion circulare var. *constrictum* (Ralfs) Van Heurck	–	–	–	–	–	–	–	–	1	–
Navicula cryptocephala Kütz.	–	–	–	–	–	3	3	3	–	3
Navicula cuspidata var. *ambigua* (Ehrenb.) Grunow	–	–	–	–	–	–	–	3	2	–
Navicula dicephala (Ehrenb.) W. Smith	2	–	–	–	–	–	–	–	–	–
Navicula gracilis Ehrenb.	–	–	–	–	–	–	–	–	1	3
Navicula hungarica var. *capitata* Cleve	–	1	–	–	–	–	–	–	–	–
Navicula radiosa Kütz.	–	–	–	–	–	–	–	–	–	1
Navicula rhynchocephala Kütz.	–	–	–	1	–	–	–	–	–	–
Navicula sp. 1	1	1	1	–	–	–	–	–	–	–
Navicula sp. 2	2	–	–	–	–	–	–	–	–	–
Navicula sp. 3	1	–	–	–	–	–	–	–	–	–
Navicula menisculus Schumann	–	2	–	–	–	–	–	–	–	–
Stauroneis anceps Ehrenb.	–	–	–	–	–	–	3	–	–	–
Gyrosigma attenuatum (Kütz.) Rabenhorst	–	–	–	–	–	–	–	1	2	1
Gyrosigma sp.	3	–	–	–	–	–	–	–	–	–
Pinnularia gibba f. *subundulata* A. Mayer	–	–	–	–	–	–	–	–	1	–
Pinnularia gibba var. *mesogongyla* (Ehrenb.) Hustedt	–	–	–	–	–	–	–	–	2	–
Pinnularia viridis (Nitzsch) Ehrenb.	–	–	–	–	–	–	3	–	–	1
Cocconeis placentula Ehrenb. var. *placentula*	3	–	–	–	–	–	–	–	–	–
Cocconeis placentula var. *lineata* (Ehrenb.) Van Heurck	–	–	–	–	–	1	–	–	2	–
Cocconeis sp.	–	1	–	–	–	–	–	–	–	–
Eunotia bilunaris (Ehrenb.) Mills var. *bilunaris*	–	–	–	–	–	–	–	–	1	1
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot	–	1	–	–	–	–	–	–	–	–
Amphora ovalis Kütz.	–	–	–	–	–	–	–	–	–	1
Amphora sp.	–	1	–	–	–	–	–	–	–	–
Gomphonema angustatum (Kütz.) Rabenhorst	2	–	–	–	–	1	–	–	1	3
Gomphonema augur Ehrenb.	2	–	–	–	–	–	–	–	–	–
Gomphonema parvulum (Kütz.) Grunow	–	–	–	1	–	–	–	–	3	–
Gomphonema sp.	–	1	–	–	–	–	–	–	–	–
Entomoneis ornata (Bailey) Reimer	–	–	–	–	–	–	–	–	–	2
Epithemia sorex Kütz.	3	–	–	–	–	–	–	–	–	–
Nitzschia acicularis W. Smith	–	–	–	–	–	–	1	–	1	–
Nitzschia intermedia Hantzsch	–	1	–	–	–	–	–	–	–	–
Nitzschia palea (Kütz.) W. Smith	1	–	–	–	–	–	–	–	–	–
Nitzschia sp.	–	2	–	–	–	1	–	–	–	–
Nitzschia vermicularis (Kütz.) Hantzsch	–	–	–	–	–	–	–	–	1	–
Hantzschia amphioxys var. *constricta* Pantocsek	–	–	–	1	–	–	–	–	–	–
Surirella angustata Kütz.	–	–	–	–	3	–	–	–	–	–
Surirella ovata var. *pinnata* (W. Smith) Hustedt	–	–	–	–	2	–	–	–	–	–
Surirella tenera Gregory	–	–	–	–	–	–	–	–	–	2
Cymatopleura elliptica (Bréb.) W. Smith	–	–	–	–	–	–	–	–	–	3
Cymatopleura solea (Bréb.) W. Smith	–	–	–	–	–	–	–	–	–	1
Xanthophyta										
Characiopsis spinifer var. *robusta* Ettl*	–	–	–	–	–	–	–	1	–	–
Cryptophyta										
Chroomonas acuta Utermöhl	2	3	3	1	3	–	–	–	–	–
Chroomonas caudata Geitler	–	–	–	3	–	–	–	–	–	–
Chroomonas sp.	2	–	–	–	–	–	–	–	–	–
Cryptomonas curvata Ehrenb.	2	3	3	3	–	–	–	3	–	–
Cryptomonas erosa Ehrenb.	–	2	2	–	3	–	–	–	–	–
Cryptomonas gracilis Skuja	2	1	–	–	–	–	–	–	–	–
Cryptomonas marssonii Skuja	3	3	–	1	–	–	3	3	3	–
Cryptomonas obovata Skuja	1	–	–	3	–	–	–	–	2	–
Cryptomonas ovata Ehrenb.	–	2	2	–	1	–	–	–	–	–
Cryptomonas reflexa (Marsson) Skuja	1	3	3	3	–	–	–	–	3	–
Dinophyta										
Gymnodinium sp. 1	–	1	–	–	–	–	–	–	–	–
Gymnodinium sp. 2	–	3	–	–	3	–	–	–	–	–
Gymnodinium uberrimum (Allman) Kofoid et Swezy	–	3	–	–	–	–	–	–	–	–
Glenodinium quadridens (Stein) Schiller	–	1	–	1	–	–	–	–	–	–
Euglenophyta										
Trachelomonas planctonica Swirenko f. *planctonica*	–	1	–	–	–	–	3	–	–	–
Trachelomonas volvocina var. *punctata* Playfair	–	–	–	–	–	–	–	1	–	–
Euglena acus var. *acus* Ehrenb.	–	1	–	–	–	–	1	–	–	–
Euglena tripteris (Dujardin) Klebs	–	–	–	–	–	–	–	–	1	–
Euglena variabilis Klebs	–	3	–	–	–	–	–	2	–	–
Euglena viridis Ehrenb. f. *viridis*	1	2	–	–	–	–	–	3	–	–
Lepocinclis ovum (Ehrenb.) Lemmermann var. *ovum*	–	–	–	–	–	–	3	–	–	–
Lepocinclis ovum var. *palatina* Lemmermann	–	–	–	–	–	–	–	–	2	–
Phacus caudatus Hübner var. *caudatus*	1	–	–	–	–	–	–	–	–	–
Phacus nordstedtii Lemmermann	–	1	–	–	–	–	–	–	–	–
Phacus pleuronectes (Ehrenb.) Dujardin var. *pleuronectes*	–	–	–	–	–	–	1	1	–	1
Phacus sp.	–	–	–	–	–	–	–	–	1	–
Chlorophyta										
Pediastrum tetras (Ehrenb.) Ralfs	–	–	–	–	3	–	–	2	–	–
Monoraphidium arcuatum (Korschikov) Hindák	–	–	–	–	–	–	–	1	–	–
Monoraphidium contortum (Thuret) Komárková- Legnerová	1	2	–	–	–	–	–	–	–	–
Monoraphidium griffithii (Berkeley) Komárková-Legnerová	–	1	–	–	–	–	–	–	–	–
Crucigenia tetrapedia (Kirchner) W. et G. S. West	2	–	–	–	–	–	–	–	–	–
Crucigeniella truncata (G. M. Smith) Komárek*	–	2	–	–	–	–	–	–	–	–
Scenedesmus aldavei Hegewald et Schnepf*	–	2	–	3	–	–	–	–	–	–
Scenedesmus dimorphus (Turpin) Kütz.*	–	–	–	3	–	–	–	3	–	–
Scenedesmus gutwinskii var. *heterospina* Bodrogközy	–	–	–	–	–	–	–	3	–	–
Scenedesmus intermedius var. *bicaudatus* Hortobágyi	–	2	–	–	–	–	–	–	–	–
Scenedesmus quadricauda (Turpin) Bréb.	2	–	–	2	–	–	–	–	–	–
Westellopsis linearis (G. M. Smith) Jao*	3	–	–	–	–	–	–	–	–	–
Mougeotia sp.	–	3	–	–	–	–	–	–	–	–
Closterium aciculare T. West var. *aciculare*	–	–	1	–	–	–	–	–	–	–
Closterium peracerosum var. *elegans* G. West	–	–	–	–	–	–	–	–	–	3
Closterium tumidulum Gay	–	–	–	–	–	–	–	–	3	–
Total number of plant species	65	71	48	28	25	18	19	24	36	31

Note: rivers and sampling sites are listed in Table 1; asterisk (*) marks new species reported for the territory of the Vologda Region; numbers denote the abundance of species: 1 – sporadic, 2 – common, 3 – dominant.

Macrophytes. The flora of macrophytes (which traditionally include vascular plants, mosses, liverworts and macroscopic algae) in the studied rivers was represented by 71 species (Table 2), 64 of which were vascular plants (Equisetophyta – 1, Magnoliophyta – 63), 5 mosses (Marchantiophyta – 3, Bryophyta – 2), 2 macroalgae (Streptophyta – 1, Chlorophyta – 1). The species belong to 36 families. By the number of species, the foremost families were Potamogetonaceae (6), Poaceae and

Ranunculaceae (5 each), Cyperaceae, Polygonaceae, and Scrophulariaceae (4 each), Asteraceae, Brassicaceae, Lamiaceae, and Lemnaceae (3 each). These top 10 families account for 56.3% of the entire river flora (40 species). The foremost genus was *Potamogeton* (6 species). Another 9 genera have 2 species each (*Bidens*, *Eleocharis*, *Epilobium*, *Glyceria*, *Juncus*, *Persicaria*, *Rorippa*) or 3 species (*Ranunculus*, *Veronica*). The core of the aquatic flora represented 54.9% or 39 species: 18 species of hydrophytes (Lemnaceae, Potamogetonaceae, *Batrachium*, *Elodea*, *Nuphar*, *Myriophyllum*, *Chara*), 10 species of helophytes (*Alisma*, *Butomus*, *Equisetum*, *Sagittaria*, *Schoenoplectus*, *Phragmites*, *Typha*, *Sparganium*), 11 species of hygrohelophytes (*Eleocharis*, *Glyceria*, *Rorippa*, *Veronica*). The shoreline-aquatic plant complex was not rich (partly because only those plants that inhabit the narrow shoreline area were included in the list). It has 32 species, 25 of which are – hygrophytes, 3 – hygromesophytes, 4 – mesophytes.

The composition of macrophytes, in general, was typical for water bodies in this part of the Vologda Region (Lobunicheva et al., 2013; Philippov & Bobrov, 2016). Interesting findings includes some relatively rare macrophytes: *Potamogeton* × *sparganifolius* (Upper Vologda River), *P. crispus* (near the dam), *Riccia cavernosa* (sandbanks near the dam), and *Chara vulgaris* (in the reservoir and near the dam). The last two findings were published in separate papers earlier (Sofronova et al., 2015; Vishnyakov & Philippov, 2018). As for the adventive plants, *Elodea canadensis* and *Echinocystis lobata* were found.

The size of the flora in the studied rivers varied greatly: from 9–12 species in small rivers – the Losta, Lukhta, Komya, Chernyj Shingar, Belyj Shingar, to 65 species in the Vologda River. The richness of the flora in the Vologda River can be explained not only by greater number of studied sites, but also by the more diverse conditions, which include both naturally preserved areas (upper course) and anthropogenically transformed (reservoir, dam, city). As the degree of anthropogenic impact on the river and its drainage basin increases, the number of macrophyte species decreases (from 33 in the upper course to 10 in the center of the city of Vologda). Downstream of the city, the species richness is also small (14 species), with most of the species found in the shoreline-aquatic ecotone area.

Cluster analysis (Fig. 2a) showed that all studied sites can be divided into two groups. The first group includes the most urbanized sites of the Vologda River, center of the city and downstream of the city. All other sites made up the second group. All the small rivers united in one subgroup, and the Vologda River – into another; the Belyj Shingar River site was the most specific.

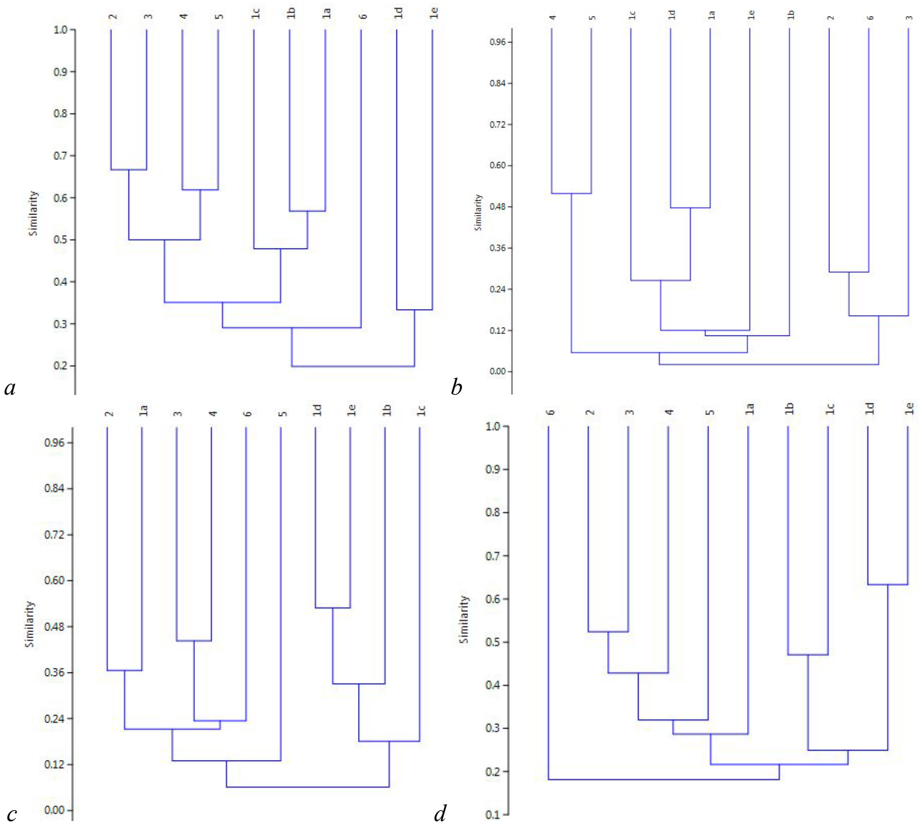

Fig. 2. Similarity of macrophyte flora (*a*), algae flora (*b*), zooplankton fauna (*c*) and zoobenthos fauna (*d*) based on the Bray-Curtis Index: rivers and sampling sites are listed in Table 1

Phytoplankton. In the studied rivers, phytoplankton was represented by 118 species, varieties and forms of algae from 8 divisions, 11 classes, 30 families, 49 genera were registered (Table 2). Bacillariophyta had the greatest species richness – 62 species (52.5% of the total amount). Chlorophyta and Euglenophyta had 16 and 12 species (13.6 and 10.2%), respectively. Less represented were Cryptophyta – 10 species (8.5%), Chrysophyta – 8 species (6.8%), Cyanophyta – 5 species (4.2%), Dinophyta – 4 species (3.4%), Xanthophyta – 1 species (0.8%). Families and genera represented by a single species (or intraspecific taxon) were dominant – 40.0% of all families and 61.2% of all genera. Most of the species found belong to the families Naviculaceae (17 species), Euglenaceae (12), Cryptomonadaceae (10), Fragilariaceae (8), Scenedesmaceae (8), Nitzschiaceae (6), Aulacosiraceae (5), Dinobryaceae (5), Surirellaceae (5), Gomphonemataceae (4). The most species- rich genera are *Navicula* (11 species), *Cryptomonas* (7), *Aulacoseira* (5), *Nitzschia* (5), *Scenedesmus* (5), *Dinobryon* (4), *Euglena* (4), *Fragilaria* (4), *Gomphonema* (4), *Phacus* (4). In Cryptophyta and Euglenophyta, on average, 5.0 and 3.0 species per genus, respectively, were registered. Phytoplankton in the Vologda River, upstream of the city, were characterized by genus index 3.2. In the small rivers, genus indices were smaller and varied from 1.5 in the Lukhta River to 2.5 in the Chernyj Shingar River. Genus indices in the Lukhta, Losta (2.0) and Belyj Shingar Rivers (1.9) indicate less favourable environmental conditions that impede the existence of closely related species in the same community. For the first time in the Vologda Region, *Geitlerinema acutissimum*, *Characiopsis spinifer* var. *robusta*, *Crucigeniella truncata*, *Scenedesmus aldavei*, *S. dimorphus* and *Westellopsis linearis* were registered. In the phytoplankton of the rivers, among species with known geographical distribution, cosmopolitan species were dominant (90.1%), Holarctic species made up 1.2%, arcto-alpine – 1.2%, boreal – 7.4%. In the Vologda River, true plankton algae species were mostly found; in the small rivers, from site 2 to site 6, the share of facultative planktonic and randomly planktonic (benthic) species increased. The largest number of benthic algae species was registered in the Belyj Shingar River, where the flow velocity is higher.

The phytoplankton community of the Vologda River is distinguished by the largest number of species (81 species). The richest area was the reservoir site (46 species), the number of species decreased downriver (to 11 – downstream the city). In the upper course of the Vologda River and in the reservoir, phytoplankton is formed by algae from a greater number of large taxa, with predominance of diatoms, cryptophytes and green algae. At the sites below the dam, the role of the diatom complex increases. The Shannon Index calculated using abundance of phytoplankton has the maximum values in the reservoir (Table 4). Other sites in the Vologda River do not differ significantly by the Shannon Index values; the upper sites of the Vologda River had slightly lower Shannon Index values in spring.

In the small rivers, 54 species were recorded. The smallest number of species was registered in the Losta River (8) and Lukhta River (9), the greatest number in the Chernyj Shingar River (25). The Shannon Index calculated using abundance was relatively high throughout the growing season in the Belyj Shingar River, and relatively small in the Komya River (Table 3).

Table 3
Diversity of aquatic invertebrates of the Upper Sukhona River tributaries

Taxon	1a	1b	1c	1d	1e	2	3	4	5	6
Zooplankton										
Rotifera										
Philodina sp.	–	1	–	–	–	–	–	–	–	–
Conochilus unicornis Rousselet	–	2	3	2	2	–	–	–	–	–
Filinia longiseta (Ehrenb.)	1	2	1	3	2	–	–	–	–	2
Testudinella emarginula (Stenroos)	–	2	–	–	–	–	–	–	–	–
Pompholyx sulcata Hudson	–	3	–	–	–	–	–	–	–	–
Synchaeta pectinata Ehrenb.	–	2	3	3	3	–	–	–	–	–
Polyarthra sp.	2	2	3	2	2	1	–	–	–	–
Gastropus hyptopus (Ehrenb.)	–	–	2	–	–	–	–	–	–	–
Trichocerca capucina (Wierzejski et Zacharias)	–	2	–	–	–	–	–	–	–	–
Cephalodella sp.	–	–	–	–	–	–	1	–	–	–
Asplanchna priodonta Gosse	–	3	2	3	3	–	–	–	–	–
Mytilina ventralis (Ehrenb.)	–	–	–	–	–	1	–	–	–	–
Trichotria truncata (Whitelegge)	–	–	–	1	–	–	–	–	–	–
Brachionus calyciflorus Pallas	–	3	2	3	3	–	–	–	–	–
Brachionus quadridentatus Herman	–	2	–	1	–	–	–	–	–	–
Brachionus variabilis Hempel	–	–	–	1	–	–	–	–	–	–
Keratella cochlearis (Gosse)	3	2	2	2	3	2	–	1	–	3
Keratella quadrata (O. F. Müller)	2	2	2	3	2	–	3	3	2	3
Kellicottia longispina (Kellicott)	–	–	1	–	–	1	–	3	–	1
Euchlanis meneta Myers	–	2	2	1	–	2	–	1	–	–
Euchlanis oropha Gosse	2	–	–	–	–	–	–	–	–	–
Lecane luna (O. F. Müller)	–	–	3	1	–	–	–	–	–	1
Arthropoda										
Cladocera										
Ceriodaphnia quadrangula (O. F. Müller)	–	–	–	1	–	1	2	3	–	–
Ceriodaphnia reticulata (Jurine)	–	2	–	–	–	–	–	–	–	–
Ceriodaphnia setosa Matile	–	–	–	–	1	–	–	–	–	–
Daphnia cucullata Sars	–	1	–	1	–	–	–	–	–	–
Daphnia galeata Sars	2	–	–	–	–	–	–	–	–	–
Daphnia hyalina Leydig	1	–	–	–	–	–	–	–	–	–
Daphnia longispina O. F. Müller	–	–	–	1	–	–	–	1	–	2
Daphnia sp.	–	–	–	–	–	–	1	–	2	–
Scapholeberis mucronata (O. F. Müller)	–	–	1	–	–	–	–	1	–	–
Simocephalus sp.	–	–	–	–	–	–	–	1	–	–
Acroperus harpae (Baird)	1	–	2	–	1	–	3	3	2	2
Alona affinis (Leydig)	–	1	2	–	2	–	–	–	–	1
Alona guttata Sars	–	–	–	1	1	–	–	–	–	–
Alona intermedia Sars	–	1	–	–	–	–	3	2	–	–
Alona quadrangularis (O. F. Müller)	1	–	1	1	1	1	–	–	–	3
Alona rectangula Sars	2	2	–	–	–	–	–	–	–	–
Alona sp.	–	–	–	–	–	–	–	2	–	–
Alonella nana (Baird)	–	–	1	–	–	–	–	–	3	–
Chydorus sphaericus (O. F. Muller)	3	3	3	2	2	1	–	2	1	2
Graptoleberis testudinaria (Fischer)	–	2	1	2	–	–	–	1	1	–
Pleuroxus aduncus (Jurine)	2	–	2	1	1	–	–	–	–	–
Pleuroxus truncatus (O. F. Müller)	–	3	2	–	–	–	–	–	–	–
Eurycercus lamellatus (O. F. Müller)	1	–	–	–	–	–	–	–	–	–
Macrothrix hirsuticornis Norman et Brady	–	–	2	–	–	–	–	–	–	–
Macrothrix sp.	–	–	–	–	–	1	–	–	–	1
Ilyocryptus agilis Kürz	–	–	–	–	1	–	–	–	–	–
Ilyocryptus sp.	–	–	–	–	–	–	–	–	–	1
Bosmina cf. *coregoni* Baird	–	–	–	–	–	–	–	–	–	2
Bosmina cf. *crassicornis* Lilljeborg	1	–	–	3	2	–	–	–	1	–
Bosmina cf. *gibbera* Schoedler	2	–	1	–	–	–	1	1	1	2
Bosmina longirostris (O. F. Müller)	–	2	2	–	–	–	1	–	1	–
Diaphanosoma brachyurum (Lievin)	–	2	–	2	1	–	–	–	–	–
Sida crystallina (O. F. Müller)	–	–	–	–	–	–	–	–	1	1
Leptodora kindtii (Focke)	–	1	–	2	2	–	–	–	–	–
Copepoda										
Cyclops strenuus Fischer	–	1	–	–	–	1	–	–	–	–
Cyclops vicinus Uljanin	–	2	–	–	–	–	–	–	–	–
Cyclops sp.	2	2	–	–	1	1	3	3	2	2
Diacyclops bicuspidatus (Claus)	–	2	–	1	1	1	3	2	–	–
Eucyclops macruroides (Lilljeborg)	–	–	2	–	–	–	2	–	–	–
Eucyclops serrulatus (Fischer)	1	2	–	2	3	3	3	2	–	2
Mesocyclops leuckarti (Claus)	–	1	1	1	2	2	1	3	3	–
Paracyclops affinis (Sars)	3	2	3	2	3	3	2	3	1	1
Eudiaptomus gracilis (Sars)	1	1	–	–	2	–	1	–	1	1
Zoobenthos										
Hydroida										
Spp. indet	1	–	1	–	–	–	–	–	–	–
Turbellaria										
Spp. indet	1	–	1	–	–	–	–	–	–	1
Gastropoda										
Viviparus viviparus (L.)	–	1	–	2	–	–	1	1	–	–
Viviparus ater (de Cristofori & Jan)	–	–	1	–	–	–	–	–	–	–
Cincinna sp. juv.	–	–	1	–	–	–	–	1	–	–
Bithynia decipiens (Mill.)	–	–	1	2	–	–	–	–	–	–
Bithynia tentaculata (L.)	1	1	1	1	–	1	2	1	1	–
Acroloxus rossicus Kruglov & Starobogatov*	–	–	1	–	–	–	–	–	–	–
Lymnaea sp.	1	–	–	–	–	1	–	1	2	2
Physidae sp.	–	–	1	–	–	–	–	–	–	1
Ancylus fluviatilis Müller	1	–	–	–	–	–	1	1	–	–
Anisus charteus (Held)*	–	–	1	–	–	–	–	–	–	–
Bathyomphalus sp.	–	–	1	–	–	–	–	–	–	–
Bivalvia										
Unio sp.	–	1	1	–	–	–	–	–	–	–
Anodonta sp.	–	1	1	–	–	–	–	–	–	–
Dreissena polymorpha (Pallas)	–	1	1	–	–	–	–	–	–	–
Musculium lacustre Müller	–	–	1	1	–	–	–	–	–	–
Amesoda solida (Normand)	–	–	–	1	–	–	–	–	–	–
Sphaerium westerlundi Clessin in Westerlund*	–	1	1	1	–	2	2	3	1	1
Cingulipisidium nitidum (Jenyns)	–	–	1	–	–	2	2	2	1	1
Pisidium amnicum Müller	–	1	2	2	–	–	1	1	2	1
Pisidium inflatum Megerle von Muhlfeld in Porro	–	–	1	–	–	–	–	1	–	–
Neopisidium moitessierianum (Paladilhe)	–	–	1	–	–	–	–	–	–	–
Euglesidae gen. sp	–	1	2	–	–	2	1	3	2	3
Tetragonocyclas milium (Held)	–	–	–	–	–	1	–	2	1	1
Henslowiana henslowana (Leach in Sheppard)	–	–	1	–	–	–	2	–	–	–
Henslowiana infirmicostata (Pirogov et Starobogatov)*	–	–	–	1	–	–	–	–	–	–
Henslowiana ostroumovi (Pirogov et Starobogatov)*	–	–	–	–	–	–	–	–	1	–
Henslowiana polonica (Anistratenko et Starobogatov)*	–	2	2	1	–	–	1	–	1	2
Pulchelleuglesa acuticostata (Starobogatov et Korniushin)*	–	–	–	–	–	–	1	–	1	–
Euglesa likharevi (Korniushin)*	–	–	1	–	–	–	–	1	–	1
Euglesa ponderosa (Stelfox)	–	–	1	–	–	–	–	–	–	–
Pseudeupera subtruncata (Malm)	–	–	1	1	–	1	1	1	2	1
Hiberneuglesa normalis (Stelfox)*	–	–	1	–	–	–	–	1	1	1
Hiberneuglesa parvula (Clessin in Westerlund)*	–	–	–	–	–	–	1	–	1	–
Oligochaeta										
Stylaria lacustris (L.)	2	–	1	1	–	–	–	–	–	–

Taxon	1a	1b	1c	1d	1e	2	3	4	5	6
Ripistes parasita (Schmidt)	–	–	–	1	–	–	–	–	–	–
Nais sp.	2	1	–	1	–	–	1	–	1	–
Specaria josinae (Veid.)	–	–	–	–	–	–	–	1	–	–
Piguetiella blanci (Piguet)	–	–	1	–	–	–	–	–	–	–
Ophidonais serpentina (Müll.)	2	–	–	1	–	–	–	–	–	–
Uncinais uncinata (Orst.)	–	–	–	1	–	–	–	–	–	–
Pristina biliobata (Bretscher)	–	–	–	1	–	–	–	–	–	–
Rhyacodrilus coccineus (Veid.)	–	–	–	2	–	–	–	–	–	–
Limnodrilus hoffmeisteri Clap.	1	3	3	3	3	3	3	3	3	1
Limnodrilus udekemianus Clap.	–	1	3	–	–	–	2	–	3	–
Psammoryctides barbatus (Grube)	–	–	3	–	–	–	–	–	–	–
Tubifex newaensis (Mich.)	–	1	1	2	–	–	–	–	–	1
Tubifex tubifex (Müll.)	1	1	1	2	2	3	2	–	2	1
Spirosperma ferox (Eisen)	1	–	–	–	–	1	–	1	1	–
Spirosperma velutinus (Grube)	–	–	–	–	–	–	–	–	–	1
Potamothrix hammoniensis (Mich.)	–	1	1	2	–	2	3	2	2	–
Enchytraeidae spp.	1	2	2	2	–	–	–	–	1	1
Lumbriculidae spp.	–	–	–	–	–	–	1	–	–	–
Lumbriculus variegatus (Müll.)	1	–	–	–	–	–	–	–	–	2
Eiseniella tetraedra (Savigny)	–	–	–	–	–	–	–	–	–	1
Hirudinea										
Glossiphonia complanata (L.)	1	–	–	1	–	2	2	2	1	1
Hemiclepsis marginata (Müll.)	–	–	–	1	–	–	–	–	–	–
Protoclepsis tessulata (Müll.)	–	–	–	1	–	–	–	–	1	1
Helobdella stagnalis (L.)	–	1	2	1	–	1	1	–	–	–
Haemopis sanguisuga (L.)	–	–	–	–	–	–	–	1	–	–
Erpobdella octoculata (L.)	–	–	–	–	–	–	1	–	–	–
Erpobdella sp.	1	1	–	1	1	2	2	2	2	1
Piscicola geometra (L.)	2	–	–	1	–	–	–	–	–	–
Isopoda										
Asellus aquaticus (L.)	–	–	1	–	–	2	1	2	2	–
Hydrachna										
Spp. indet	1	1	1	–	–	–	1	1	–	1
Insecta										
Ephemeroptera										
Baetidae spp.	2	–	1	1	–	1	2	1	1	1
Cloeon dipterum L.	2	–	–	–	–	–	–	–	–	–
Cloeon luteolum Müll.	3	–	–	–	–	1	3	3	–	2
Cloeon simile Etn	–	–	–	–	–	–	–	1	1	–
Baetis fuscatus L.	–	–	–	–	–	–	–	–	1	–
Baetis. rhodani Pict.	2	–	–	–	–	–	–	–	–	1
Baetis tricolor Tsch.	–	–	–	–	–	–	–	–	1	–
Baetis sp.	–	–	1	1	–	–	–	–	–	–
Heptagenia sulphurea Müll.	3	–	–	–	–	–	–	–	–	–
Habrophlebia fusca Curt.*	1	–	–	–	–	–	–	–	–	–
Leptophlebia cincta Retz.	1	–	–	–	–	–	–	–	–	1
Leptophlebia submarginata Steph.	–	–	–	–	–	–	–	–	3	–
Ephemerella ignita Poda	3	–	–	–	–	–	–	–	–	1
Ephemerella mucronata Bgtss.*	2	–	–	–	–	–	–	+	–	–
Ephemerella notata Eaton*	1	–	–	–	–	–	–	–	–	–
Eurylophella karelica Tiensuu*	1	–	–	–	–	–	–	–	–	–
Ephemera vulgata L.	2	2	2	–	–	–	3	2	3	2
Caenis horaria L.	2	1	2	–	1	–	1	–	–	–
Caenis lactea Burm.	–	–	1	–	–	–	–	–	–	–
Caenis macrura Steph.	1	–	–	–	1	–	1	–	–	–
Caenis spp.	–	1	–	–	–	–	–	–	–	–
Odonata										
Sympecma fusca (Linden)	–	–	–	–	–	–	1	1	–	–
Plathycnemis pennipes (Pallas)	–	1	–	–	–	–	–	–	–	–
Gomphus vulgatissimus (L.)	1	1	–	–	–	–	–	–	–	–
Onychogomphus forcipatus (L.)	2	–	–	–	–	–	–	–	–	–
Ophiogomphus serpentinus (Charp.)	1	–	–	–	–	–	–	–	–	–
Libellula fulva (Müll.)*	–	–	–	–	–	–	–	1	1	–
Plecoptera	–	–	–	–	–	–	–	–	–	–
Spp. indet	1	–	–	–	–	–	1	–	1	2
Megaloptera										
Sialis sp.	–	–	1	1	–	1	2	1	2	1
Heteroptera										
Nepa cinerea L.	–	–	–	–	–	–	1	–	–	–
Corixidae gen. sp.	–	–	–	1	–	1	–	–	–	–
Ilyocoris cimicoides (L.)	1	–	–	–	–	–	–	–	–	–
Aphelocheirus aestivalis (Fabr.)	1	–	–	–	–	–	–	–	–	2
Notonecta glauca L.	–	–	–	–	–	–	–	–	1	–
Coleoptera										
Dytiscus sp.	–	–	1	–	–	–	1	–	–	1
Elmidae gen. sp	3	1	1	1	–	–	1	1	–	2

Taxon	1a	1b	1c	1d	1e	2	3	4	5	6
Donacia sp.	–	1	–	1	–	1	–	2	1	1
Haliplus sp.	–	–	–	1	–	–	–	–	–	–
Gyrinus sp.	1	–	–	–	–	–	–	–	–	–
Trichoptera										
Lype phaeopa (Steph.)*	–	–	–	–	–	–	–	–	1	–
Cyrnus flavidus McL	–	–	1	1	–	–	–	–	–	–
Neureclipsis bimaculata (L.)	–	–	–	–	–	–	1	–	–	–
Polycentropus flavomaculatus Pictet	2	1	–	1	–	–	1	2	1	–
Plectrocnemia conspersa Curtis*	–	–	–	–	–	–	–	–	1	–
Hydropsyche nevae (Kolenati)	3	–	–	–	–	1	2	1	–	3
Hydropsyche pellucidula Curtis	–	–	–	–	–	–	2	–	–	–
Phryganea bipunctata Retz.	–	–	–	–	–	–	1	–	–	–
Semblis phalaenoides L.	–	–	–	–	–	–	–	–	–	1
Brachycentrus subnubilus Curtis	3	–	–	–	–	–	–	–	–	–
Lepidostoma hirtum Fabr.*	2	–	–	–	–	–	–	–	–	–
Nemotaulius punctatolineatus Retz.	1	–	–	–	–	–	–	–	–	–
Grammotaulius signatipennis McL.	–	–	–	–	–	–	–	–	1	–
Limnephilus rhombicus L.	1	–	–	–	–	1	1	–	–	1
Limnephilus politus McL.	–	–	–	–	–	–	1	2	–	–
Limnephilus sp.	1	–	–	–	–	1	1	–	2	–
Anabolia soror McL.	–	–	–	–	–	–	–	–	–	1
Potamophylax latipennis Curtis	1	–	–	–	–	–	–	–	–	–
Goera pilosa (Fabr.)*	1	–	–	–	–	–	–	–	–	–
Notidobia ciliaris L.*	3	–	1	–	–	–	–	–	–	–
Beraeodes minutus L.*	–	–	–	–	–	–	–	–	–	1
Molanna angustata Curtis	1	1	–	–	–	–	1	1	–	–
Athripsodes cinereus Curtis	1	–	–	–	–	–	–	–	1	1
Ceraclea annulicornis Steph.	1	–	–	–	–	–	–	–	–	–
Mystacides longicornis L.	–	–	1	–	–	–	–	–	–	–
Triaenodes bicolor (Curtis)	1	–	–	–	–	–	–	–	–	–
Setodes viridis (Fourcroy)	1	–	–	–	–	–	–	–	–	–
Ithytrichia lamellaris Eaton	2	–	–	–	–	–	–	–	–	–
Agraylea multipunctata Curtis	1	–	–	–	–	–	–	–	–	–
Hydroptila tineoides Dalm.	2	–	–	–	–	–	–	–	–	–
Orthotrichia costalis Curtis	1	–	–	–	–	–	–	–	–	–
Rhyacophila nubila Zett.	–	–	–	–	–	–	1	–	–	–
Lepidoptera										
Elophila nymphaeata L.	1	1	–	1	–	–	1	2	–	–
Diptera										
Anopheles sp.	–	–	–	–	–	–	–	1	–	–
Antocha sp.	–	–	–	–	–	–	–	–	–	2
Atherix ibis (Fabr.)	1	–	–	–	–	–	–	–	–	2
Atrichopogon sp.	–	–	–	–	–	–	–	–	–	1
Ceratopogonidae gen. sp.	1	2	2	2	–	2	2	1	2	2
Dicranota bimaculata Schumm.	–	–	–	–	–	–	–	–	–	1
Dixidae gen.sp.	–	–	–	–	–	–	–	–	–	1
Limnophora riparia (Fallen)	–	–	–	–	–	1	1	–	–	–
Limoniidae gen. sp.	1	–	–	–	–	–	–	–	–	1
Lispe sp.	–	1	–	–	–	–	–	–	–	–
Psychodidae gen. sp.	–	–	–	–	–	–	–	–	–	1
Simuliidae gen.sp.	3	–	–	–	–	–	3	1	1	2
Tabanus sp.	–	1	1	–	–	1	–	–	1	1
Clinotanypus nervosus Meig.	–	–	1	–	–	1	1	1	1	–
Procladius spp.	2	2	1	1	1	3	1	2	2	1
Chaetocladius gr. *vitellinus*	1	–	–	–	–	–	–	–	–	–
Corynoneura scutellata Winn.	1	1	1	1	–	–	2	1	–	1
Cricotopus spp.	2	2	1	3	1	–	–	1	–	2
Cricotopus gr. *bicinctus*	2	–	–	1	–	–	–	–	–	–
Cricotopus gr. *trifascia*	–	1	–	–	–	–	–	1	–	1
Diplocladius cultriger Kief.	–	–	–	–	–	3	2	–	1	1
Eukiefferiella gr. *claripennis*	–	–	–	–	–	–	–	–	–	2
Eukiefferiella gr. *coerulescens*	2	2	–	1	–	1	2	–	2	2
Eukiefferiella gr. *gracei*	2	1	–	–	–	1	1	1	1	2
Epoicocladius flavens Mall.*	2	–	–	–	–	–	1	–	2	–
Heterotrissocladius gr. *marcidus*	–	–	–	–	–	–	–	–	–	1
Metriocnemus gr. *hydropetricus*	–	–	–	–	–	–	–	–	–	1
Nanocladius bicolor (Zett.)	1	–	–	–	–	2	2	–	2	1
Orthocladius spp.	3	1	–	–	–	–	1	2	–	3
Paracladius conversus (Walk.)	–	–	–	–	–	–	–	–	–	1
Propsilocerus danubialis Botnariuc et Albu*	–	–	–	–	–	–	–	–	–	2
Psectrocladius spp.	2	–	1	1	–	–	1	–	–	1
Psectrocladius simulans (Johann.)	–	–	1	1	–	–	–	1	–	–
Psectrocladius fabricus Zelentzov	1	–	1	–	–	1	1	–	–	1
Psectrocladius sordidellus (Zett.)	1	–	2	–	–	–	–	2	–	–
Synorthocladius semivirens (Kief.)	2	–	–	–	–	1	1	–	1	1
Thienemanniella gr. *clavicornis*	2	–	–	–	–	–	1	–	–	2
Chironomus spp.	1	3	3	2	1	1	–	–	–	–

Taxon	1a	1b	1c	1d	1e	2	3	4	5	6
Cladopelma lateralis (Goetgh.)	–	1	–	–	–	–	–	–	–	–
Cladopelma viridula (L.)	–	–	–	1	–	–	–	–	–	–
Cladotanytarsus gr. *mancus*	1	3	3	–	–	1	1	–	1	3
Constempellina brevicosta (Edw.)*	–	–	1	–	–	–	–	–	–	–
Cryptochironomus gr. *defectus*	–	1	1	2	–	–	–	–	–	1
Cryptotendipes nigronitens (Edw.)	–	–	–	–	–	–	1	–	–	–
Demicryptochironomus vulneratus (Zett.)	1	1	–	–	–	–	–	–	–	–
Dicrotendipes nervosus (Staeg.)	–	1	–	2	–	1	3	1	1	–
Endochironomus albipennis (Meig.)	1	3	2	2	–	–	–	1	1	–
Endochironomus impar (Walk.)	–	1	1	1	–	–	1	1	–	–
Endochironomus tendens (Fabr.)	–	1	–	–	–	–	1	1	–	–
Glyptotendipes gripekoveni (Kief.)	–	2	1	2	+	–	–	–	1	–
Glyptotendipes paripes (Edw.)	–	2	–	1	–	–	–	–	–	–
Harnischia curtilamellata (Mall.)	2	1	1	1	1	–	–	–	–	1
Microchironomus tener (Kief.)	–	1	–	1	1	–	–	–	–	–
Micropsectra gr. *praecox*	1	–	1	–	–	–	–	–	–	–
Microtendipes pedellus De Geer	2	2	1	1	–	2	1	3	2	1
Parachironomus arcuatus (Goetg.)	–	1	–	1	–	–	–	–	–	1
Parachironomus vitiosus (Goetgh.)	–	–	–	1	–	–	–	–	–	–
Paracladopelma camptolabis (Kief.)	–	–	1	1	1	–	–	–	–	1
Paralauterborniella nigrohalteralis Mall.	–	1	1	1	–	–	–	–	–	1
Paratanytarsus spp.	3	1	1	1	–	2	3	3	1	2
Paratendipes albimanus (Meig.)	1	2	–	2	–	2	3	–	1	1
Polypedilum bicrenatum Kief.	–	1	1	–	–	–	3	–	1	1
Polypedilum convictum (Walk.)	2	1	–	1	–	–	2	1	1	1
Polypedilum exectum (Kief.)	–	–	1	–	–	1	1	–	1	1
Polypedilum scalaenum (Schrank)	1	1	1	1	–	1	1	2	2	1
Polypedilum sordens V. d. Wulp	–	–	–	1	–	–	–	–	–	–
Polypedilum nubeculosum (Meig.)	–	2	1	1	1	–	–	–	–	–
Polypedilum pedestre (Meig.)	1	1	–	–	–	–	–	–	–	–
Stempellina bausei (Kief.)	–	–	–	–	–	–	–	–	–	2
Stempellinella minor (Edw.)	–	–	–	–	–	–	–	–	–	2
Stictochironomus gr. *histrio*	–	1	2	–	1	1	2	1	–	2
Tanytarsus spp.	2	2	2	1	–	3	1	2	1	3
Xenochironomus xenolabis Kief.	1	–	–	–	–	–	–	–	–	–
Zavrelia pentatoma Kief.	1	–	–	–	–	–	1	–	1	–
Monodiamesa bathyphila (Kief.)	–	–	–	–	–	–	1	–	–	2
Odontomesa fulva Kief.	–	–	–	–	–	–	–	–	–	2
Potthastia gaedii (Meig.)	1	1	–	–	–	–	–	–	–	2
Total number of invertebrates species	113	98	105	96	38	59	93	78	79	108

Note: rivers and sampling sites are listed in Table 1; asterisk (*) marks new species reported for the territory of the Vologda Region; numbers denote the abundance of species: 1 – sporadic, 2 – common, 3 – dominant.

Based on the results of a cluster analysis performed using phytoplankton abundance, three groups can be distinguished: 1) Vologda River sites; 2) Chernyj Shingar and Komya Rivers; 3) Losta, Lukhta and Belyj Shingar Rivers. Among the Vologda River sites, the similarity with the Upper Vologda River site and the city site (Fig. 2*b*) was noted. In the Upper Vologda River, a higher flow velocity affects the phytoplankton community; in the city center, phytoplankton experiences anthropogenic stress. These sites have similarity with the site downstream of the dam, where the pronounced flow is also present. The reservoir site is distinguished among other sites due to the most favourable conditions for phytoplankton. Among the small rivers, the first group includes the Chernyj Shingar and Komya Rivers with a relatively low level of anthropogenic load. The second group combines rivers with the most disturbed drainage basins (Losta and Lukhta Rivers), as well as the Belyj Shingar River with relatively high flow velocity.

Zooplankton. In total, 65 zooplankton species were found in the studied tributaries of the Upper Sukhona River (Table 3), the major part of which belongs to Cladocera (34 species); a smaller amount belongs to Rotifera (22 species), and 9 species belong to Copepoda.

The largest number of species (56) were registered in the Vologda River (20 – Rotifera, 27 – Cladocera, 9 – Copepoda). The smallest number of species (19) was recorded in the upper course, which has a swift flow. Only at this site, rotifers made up a little more than a quarter of the total species richness. Other sites are characterized by very slow flows, and as a result, the species composition is significantly richer there. The largest number of species (33) was recorded in the reservoir. Species richness in the reservoir was greater than that at the site downstream of the dam. At the city site, the species composition did not differ significantly, and no reduction in the number of species was observed. In the small rivers, the number of species varied from 14 to 19. The lowest species richness was observed in the Shernyj Shingar River, characterized by the least anthropogenically disturbed drainage basin. The greatest share of rotifers was witnessed in the Losta River, closest to the city of Vologda. The number of species in the Belyj Shingar River, having a rapid flow , was close to those found in rivers with low flow velocities.

Species diversity (Table 4) was higher at all sites of the Vologda River compared to those in the small rivers. The maximum values of the Shannon index were observed at the reservoir site.

Table 4
Number of species and values of Shannon Index calculated using abundance

Aquatic organisms	Rivers and sites									
	1a	1b	1c	1d	1e	2	3	4	5	6
Number of species										
Macrophyte	33	25	32	10	14	10	10	9	11	12
Phytoplankton	32	46	16	18	11	8	9	15	25	19
Zooplankton	19	33	27	28	25	15	15	19	14	19
Zoobenthos	94	65	78	68	13	44	78	59	65	89
Total number	178	169	153	124	63	77	112	102	115	139
Shannon index										
Phytoplankton	1.86 ± 0.68	2.67 ± 0.57	1.95 ± 0.63	1.98 ± 0.63	1.91 ± 0.53	1.54 ± 0.34	1.74 ± 0.39	0.99 ± 0.54	1.47 ± 0.45	2.90 ± 0.41
Zooplankton	1.09 ± 0.17	1.56 ± 0.47	1.37 ± 0.23	1.11 ± 0.16	1.28 ± 0.21	1.04 ± 0.16	0.90 ± 0.37	1.30 ± 0.26	0.96 ± 0.32	1.08 ± 0.25
Zoobenthos	2.14 ± 0.09	1.64 ± 0.12	1.78 ± 0.10	1.41 ± 0.25	0.26 ± 0.09	1.62 ± 0.12	1.91 ± 0.16	1.52 ± 0.17	1.85 ± 0.13	1.80 ± 0.22

Note: rivers and sampling sites are listed in Table 1; values of Shannon Index are given as mean ± standard error.

Cluster analysis (Fig. 2c) showed that all sites could be divided into two groups. All sites of the Vologda River, except for the upper course, made up one group; the second group included all the small rivers and the Upper Vologda River site. The greatest species similarity was seen between stations 1d and 1e experiencing the greatest anthropogenic load.

Zoobenthos. The fauna of benthic macroinvertebrates was represented by 215 species and taxa of supraspecific rank from 10 classes, 20 orders, and 70 families (Table 3). The most common were insects, representing 69% or 149 species belonging to Ephemeroptera (9.5% or 21 species), Trichoptera (14.9% or 32 species), and Diptera (35.8% or 77 species), among the latter, the most numerous were Chironomidae (29.3% or 64 species). The rest of the fauna was represented by Mollusca (15.8% or 33 species), Oligochaeta (9.9% or 21 species), and Hirudinea (3.6% or 8 species). For the first time in the Vologda Region, 24 species of benthic macroinvertebrates were registered: 10 species of molluscs (*Acroloxus rossicus*, *Anisus charteus*, *Euglesa likharevi*, *Henslowiana infirmicostata*, *H. ostroumovi*, *H. polonica*, *Hiberneuglesa normalis*, *H. parvula*, *Pulchelleuglesa acuticostata*, *Sphaerium westerlundi*) and 14 species of insects (*Ephemerella mucronata*, *E. notata*, *Eurylophella karelica*, *Habrophlebia fusca*, *Libellula fulva*, *Beraeodes minutus*, *Goera pilosa*, *Lepidostoma hirtum*, *Lype phaeopa*, *Notidobia ciliaris*, *Plectrocnemia conspersa*, *Constempellina brevicosta*, *Epoicocladius flavens*, *Propsilocerus danubialis*). Also, in the Belyj Shingar River, in August 2013, we found specimens of *Semblis phalaenoides* – a rare vulnerable species in the Vologda Region (category 3/VU) (Bolotova et al., 2010).

Zoogeographic analysis showed that the basis of the fauna was comprised by the transpalearctic species (40%). Molluscs and caddisflies represented European species (21%); chironomids mostly represented Holarctic species (23%); cosmopolite species (4%) were completely represented by annelids. Species with narrow natural habitat was not found.

The largest number of species (168) was recorded in the Vologda River. From upper course site to the site downstream of the city, a decrease in the number of species was witnessed. In the upper course of the Vologda River, where the most species were found (94 species), rheophilic species of zoobenthos were dominant. Downstream, where the flow rate decreases and sedimentation occurs, the number of species decreases. At the same time, in the reservoir, the species richness was lower than that registered at the site downstream of the dam (65 and 78 species, respectively). At these two sites, the invasive *Dreissena poly-*

morpha was found, forming druses in the reservoir. A decrease in the species composition was observed further down the river; 68 species were registered at the city site and 13 species downstream from the city, where *Limnodrilus hoffmeisteri* was an absolute dominant species with the most occurrence (in 85% of samples); other species were found sporadically.

Among the small rivers, the maximum species richness of zoobenthos was registered in the Belyj Shingar River (89 species), the only river where the flow is evident throughout the growing season. Of all the rivers analyzed, it was here that the greatest species richness of Insecta was observed (71% of all species), Diptera in particular (Chironomidae – 40%, other groups – 11%). In the Chernyj Shingar River, 65 species of benthic macroinvertebrates were found. In the Lukhta River, 78 species were registered, including the greatest number of Trichoptera (10 species). The smallest number of species (44) was found in the Losta River, closest to the city of Vologda.

The highest values of the Shannon Index showed samples from the Upper Vologda River (Table 4). In the middle course and downstream of the city, the indices of species diversity were lower. At the city site, a sharp decrease in the Shannon Index was observed. Among the small rivers, the lowest value of the species diversity index was registered in the Losta River, closest to the city.

Cluster analysis (Fig. 2*d*) showed significant differences between sites. The first group included all sites on the Vologda River except the upper course. Sites 1b, 1c, 1d, and 1e are located at a short distance from each other, and are affected by the dam. Within this group, the sites make up two sub-groups: upstream of the city (sites 1b, 1c), and within and downstream of the city (sites 1d, 1e). These differences are probably caused by an increasing anthropogenic load. The most specific fauna was observed in the Belyj Shingar River (sites 6). By the richness of fauna, Losta, Lukhta, Komya, and Chernyj Shingar Rivers (sites 2–5) as well as the Upper Vologda River (site 1a) made up the second group. The greatest similarity was witnessed between the faunas of the Losta River (site 2) and the Lukhta River (site 3). The drainage basins of these rivers are the most disturbed anthropogenically.

Discussion

In our study, the cluster analysis of fauna and flora showed slightly different results for different groups of aquatic organisms. In all studied groups, the sites on the Vologda River, within the city and downstream of the city, were distinguished among others. The closest results of cluster analysis were obtained for the zooplankton and zoobenthos which distinguished the fauna of the Vologda River.

The influence of river size and flow velocity. The largest number of species in all studied groups was registered in the Vologda River. At individual sites, the Vologda River generally has a greater number of species than on small rivers, even under similar hydrological conditions. Our results are in agreement with an observation on the dependence of the species richness and diversity (Shannon Index) on the size of the water object (Alimov et al., 2013; Vorste et al., 2017). Thus, an increase in the species richness and diversity of mosses and macroinvertebrates commensurate with with an increase in the sizes of rivers was studied in Finland (Heino et al., 2005). The association of drainage basin size with the number of algae species was shown in the Russian Far East (Bogatov & Nikulina, 2010). An increase of the diatoms' diversity and species richness along with river size was witnessed in Central Europe (Stenger-Kovács et al., 2014). According to the river continuum concept, from headwaters to mouth, the physical variables within a river system present a continuous gradient of physical conditions (Vannote et al., 1980). In headwaters, where the flow rate is significantly higher, benthic organisms play the main role; in the lower course, planktonic and benthic communities are equally developed (Alimov et al., 2013). In general, our results confirm this pattern. In our case, with the similarity of most abiotic conditions, the main difference between the sites is the flow velocity. Due to the lowland position of the river drainage basins, most sites are characterized by a very low flow velocity. Only in the upper course of the Vologda River (site 1a) and the Belyj Shingar River (site 6) is the flow pronounced, and, as a consequence, the large species richness of the rheophilic zoobenthos was evident. The work of Breuer et al. (2016) showed the negative relationships between the flow velocity and the species composition of diatoms. However, in our study, the association between the plankton species richness and the flow velocity was not witnessed.

The influence of a dam. The influence of the dam on different ecologic groups of aquatic organisms was not manifested equally. The species richness and diversity of zooplankton and phytoplankton in the reservoir was much higher, which is in agreement with the results reported by Alhassan et al. (2015). Here, in backwater of the dam, the largest species richness and diversity of phytoplankton in our study was registered. An increase of phytoplankton and zooplankton species richness in backwater of the dam after its construction was seen in the Lancang-Mekong River (Fan et al., 2015). At the same time, organisms associated with the bottom (zoobenthos and macrophytes) were characterized by lower species richness in the reservoir in our study. This might be caused by the accumulation of pollutants in bottom sediments in the backwater area. However, the negative impact of dams on zoobenthos communities is not always evident (Mbaka & Mwaniki, 2015). Due to dam construction, changes in the species structure and an increase in the species richness can occur in homotopic zoobenthos. In our study, homotopic species also prevailed in the backwater area.

The influence of the city. In the Vologda River, downstream of the dam, with a gradual increase in the anthropogenic load, a decrease in the number of species of macrophytes and zoobenthos was witnessed, which corresponds with the results reported by Krylova (2010), Fominykh (2014), Karpova & Klepets (2014), and Philippov & Bobrov (2016). A decrease in the number of macrophyte species, especially typical aquatic plants, and simplification of their coenoses within the city and downstream of the city (sites 1c, 1d and 1e) may indicate an increasing anthropogenic load on the river ecosystem. This pattern can be caused by both the quality of the aquatic environment and the anthropogenic impact on the riverbed, banks and the adjacent areas of drainage basin. At the same time, the species richness and diversity of zooplankton, as well as the species diversity of phytoplankton within and downstream of the city remained at the same level. Apparently, the absence of a pronounced flow and high content of natural organic matter create favourable conditions for the development of these groups of aquatic organisms. For example, Breuer et al. (2016) showed that nutrients are the second limiting factor for phytoplankton development after temperature. Zoobenthos species diversity also decreased at the city site and reached its minimum values downstream of the city. Here, absolute dominance of Oligochaeta was witnessed, which indicates heavy organic pollution of the bottom substrate. A decrease in the species richness and diversity of zoobenthos with increasing organic pollution was also observed by Lock et al. (2011), Arimoro et al. (2015), and Wright et al. (2017).

In the small rivers, the lowest species richness and diversity was registered in the Losta River, which experiences the greatest anthropogenic load. A decrease (compared with the other small rivers) in the number of phytoplankton and zoobenthos species was evident there, apparently as a response to an increase in eutrophication (Mangadze et al., 2016). The drainage basins of the Lukhta and Komya Rivers are largely ploughed while the drainage basin of the Chernyj Shingar River is almost intact. Nevertheless, the species richness and species diversity in these rivers were close.

Aquatic organisms associated with substrate are considered well established indicators of the water quality in rivers (Semenchenko, 2004); which is in agreement with our results. The species richness of phytoplankton decreased with increasing anthropogenic load, while the species diversity remained at the same level. Thus, phytoplankton may also be considered as an indicator of water quality, as it was shown by Mangadze et al. (2016). Zooplankton is more dependent on physiographic factors, which was shown by Kurashov et al. (2017). The agricultural use of the drainage basins had a lesser effect on the species richness and diversity than the degree of urbanization.

Conclusion

The study of biodiversity in the tributaries of the Upper Sukhona River showed that the species richness of rivers with similar hydrological conditions was determined by the size of river. In rivers with a pronounced flow, the number of bottom associated species (zoobenthos and macrophytes) was greater than that in rivers where the flow velocity is low most of the year. The dam had a varying influence on the studied groups of aquatic organisms. A burst in the species richness of phytoplankton and zooplankton was witnessed upstream of the dam, in the reservoir; and by contrast, the bottom associated organisms, zoobenthos and macrophytes, showed lower species richness at this part of the river. Increasing anthropogenic load leads to a decrease in the number of macrophyte species, phytoplankton and zoobenthos and the dominance of certain species. In the small rivers, the lowest species richness was observed in the Losta River, closest to the city of Vologda. In the rivers with ploughed and almost intact drainage basins, the species richness remained at the same level. Aquatic organisms inhabiting the tributaries of the Upper Sukhona River are affected by both natural (flow velocity and size of a watercourse) and anthropogenic (proximity to a city and regulation of the river) factors.

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