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Article

Assessing the ecological state of a small river in the urbanized area in terms of phytoplankton, zooplankton and zoobenthos characteristics (the Sodema River of Vologda Oblast as a case study)

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Abstract. During the studies (2021–2022) of the Sodema River (Vologda Oblast), a total of 125 species and forms of phytoplankton, 74 species of zooplankton and 70 species of zoobenthos were identified. Above the city of Vologda, the riverine phytoplankton was not abundant (0.2 mln cells/l, 0.3 g/m^3); diatoms dominated. Zooplankton and zoobenthos in the upper river reaches were most diverse. Zooplankton number was very high (7.1 thous. ind./m^3, 0.5 g/m^3). Upstream, the river was assessed as mesotrophic, clean and β-mesosaprobic. Within the city of Vologda, phytoplankton diversity and abundance of cyanobacteria, euglena and cryptophyte algae increased, while species richness of zooplankton and zoobenthos sharply declined. Zooplankton number was low (0.8 thous. ind./m^3, 10 mg/m^3). In zoobenthos, oligochaetes developed en masse. Low reaches of the Sodema were characterized as eutrophic, hypereutrophic and β-α-mesosaprobic. River pollution greatly affected zoobenthos because of pollutants accumulation in soil.

Keywords: Vologda city, bioindication, aquatic organisms, saprobity, water quality

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Научная статья

Оценка экологического состояния малой реки урбанизированной территории по характеристикам фитопланктона, зоопланктона и зообентоса на примере р. Содема (Вологодская область)

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Аннотация. По результатам исследований 2021 и 2022 гг. в р. Содеме (Вологодская область) зарегистрировано 125 видов и форм фитопланктона, 74 вида зоопланктона и 70 видов зообентоса. Выше по течению от г. Вологда фитопланктон реки немногочислен (0.2 млн кл./л и 0.3 г/м^3), доминируют диатомовые водоросли. Зоопланктон и зообентос в верховьях наиболее разнообразны. Зоопланктон характеризуется высоким обилием (7.1 тыс. экз./м^3, 0.5 г/м^3). Водоток в верхнем течении оценивается как мезотрофный, чистый, β-мезосапробной зоны. В черте г. Вологда увеличивается разнообразие фитопланктона и обилие цианобактерий, эвгленовых и криптофитовых водорослей. Видовое богатство зоопланктона и зообентоса резко снижается. Обилие зоопланктона становится низким (0.8 тыс. экз./м^3, 10 мг/м^3). В зообентосе массово развиваются олигохеты. Нижнее течение р. Содемы характеризуется как эвтрофное и гиперэвтрофное, β-α-мезосапробной зоны. Наибольшее влияние загрязнение реки оказывает на состояние зообентоса, что связано с накоплением загрязняющих веществ в грунтах.

Ключевые слова: город Вологда, биоиндикация, гидробионты, сапробность, качество воды

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Introduction

Numerous different-type small rivers of the taiga zone are the sources of water supply, transport routes, wastewater receivers, and recreation areas that makes them anthropogenically loaded with considerably transformed ecosystems.

The most dramatic anthropogenic transformation of rivers and streams is manifested in cities and near large industrial complexes, where watercourses receive waste effluents from enterprises and discharges of storm sewage. Therefore, their valleys often become completely transformed that inevitably affects the features of the emerging river communities (Grizzetti et al., 2017; Ivanova, 1976; Krylov, 2005).

Initially, the city of Vologda was founded as a river settlement. It was a background for a long-lasting multifactorial anthropogenic impact on the Vologda River and its tributaries (Ivicheva, 2019). Originating in the Vologda Oblast and running through the city of Vologda, the rivers Sodema and Shogrash are characterized by poor ecological state due to the lack of measures for their restoration (Ivicheva and Filonenko, 2013). On the other hand, the population need to use their valleys and channels for recreational purposes is increasing. This is especially true for the Sodema flowing in the central part of the city.

Until now, there are no comprehensive studies of different groups of the Sodema aquatic organisms, except for certain ones (Nikulina, 2019; Vilkova and Misheneva, 2015; Zyrina, 2013), and the river assessment is based on zoobenthos indicators (Ivicheva and Filonenko, 2019).

This work is aimed at assessing the ecological state of different sections of the Sodema River in terms of phytoplankton, zooplankton and zoobenthos characteristics.

Material and methods

Study area

The Sodema River, which belongs to the White Sea basin, is the right tributary of the Vologda River. Being of 19 km long, it is classified as “very small” (Vodogretsky, 1990). The river originates from wetlands of the Vologda-Gryazovets Upland. The Sodema is mostly located in the Prisukhonskaya Lowland. The position of the river at the boundary of a moraine upland and a lacustrine-glacial lowland determines the complexity of its valley structure and a relatively large gradient (Avdoshenko and Rassokhina, 1977).

In the upper and middle reaches, the river runs through a slightly hilly and heavily developed agricultural territory. The low reaches are located entirely within the city of Vologda. In the 16th century, before the construction of the Vologda Kremlin and the canal for a ditch watering, the Sodema flowed into another tributary of the Vologda River, i.e. the Shogrash. A significant river section was covered up with earth and the built canal for connecting the Sodema with the Vologda River was of great importance that time (Ornatsky, 1888). This river section of about 1.5 km long is called “Zolotukha” and flows along the terraces of the Vologda River. The Sodema River is crossed by the railway, the M-8 highway and numerous city streets with culverts and bridges. At the distance of 2.7 km above the river mouth, the dam for technical water supply operates. At the banks and in the riverbed, there are many water outlets (often not equipped with any treatment facilities) for discharge of storm sewage and industrial effluents. The river's catchment area has been significantly transformed throughout. Forests occupy only 6% of its area, whereas fields – 42% and settlements – 52% (Ivicheva and Filonenko, 2013).

In the low river reaches, the water level depends on discharged wastewaters. In low-water periods, the average width of the river here makes up 0.5–1.0 m, a flow velocity – 0.01–0.06 m/s, which may increase to 2.0–5.0 m and 0.1–0.5 m/s, respectively (Table 1). The highest flow velocity was recorded at the dam and mouth areas. The average depth of the river varies from 0.1 to 0.2 m, while the maximum reaches 1.5 m. During low-water periods, the Sodema water content is greatly reduced. In the upper reaches, the river dries up. In the city section, it almost does not freeze due to a constant flow of wastewaters.

Bottom sediments of the Sodema are predominantly sandy and sandy-clayey (Table 1). In the middle reaches, bottom siltation is strong. In the central part of the city and at the intersection of the M-8 highway, the river bottom and its banks are lined with reinforced concrete slabs and gabions. In some places, the river valley is heavily littered.

Pollutant discharges affected the river hydrochemical regime making its water slightly alkaline and highly mineralized as compared to most other water bodies of the city (Table 1). In the middle and low reaches, the increased content of mineral forms of nitrogen and phosphorus, including petroleum products were recorded. In the low reaches, the concentration of ammonia nitrogen was higher than the

Table 1. Characteristics of sampling stations located in different sections of the Sodema River. Average values (for summer).

Station no.	Average depth, m	Average width, m	Average flow velocity, m/s	Soil type	Oxygen content, mg/l	Mineralization, mg/l
1	0.1	0.5–0.7	0	sand, clay, detritus	5.6	576
2	0.4	2.0–2.5	0.01	sand, detritus, stones	9.9	716
3	0.5	2.0–3.0	0.06	sand, stones	6.7	718
4	0.4	0.5–2.0	0.02	sand, silt, detritus	7.0	673
5	1.0	2.0–4.0	0	silt	5.8	941
6	1.2	3.0–4.0	0.1	silt	3.6	1251
7	1.5	2.5–3.0	0.5	sand, silt	5.6	1052
8	0.7	4.0–5.0	0.2	sand, stones	4.4	997
9	1.2	3.0–5.0	0.5	sand, stones	8.5	724

standards established for fishery reservoirs[1]. The content of nitrite nitrogen and phosphates exceeded the maximum permissible concentration throughout the river. Widespread and continuous water contamination with oil products was also noted there. In the river mouth, the decreased pollutant concentrations along with the increased dissolved oxygen content were observed due to dilution and reverse flow at high water levels.

In the majority of the river sections within the city, the average concentration of dissolved oxygen in 2021, 2022 was less than 6 mg/l. During low-water periods, in sites of intensive wastewater discharge (stations 5–7), the oxygen content in water dropped to 2 mg/l (Table 1).

Sample collection and processing

Field studies of aquatic organisms of the Sodema River were carried out in May–October 2021 and May–August 2022. Sampling was implemented at 9 river sections (Fig. 1). Stations 1 and 2 are located in the upper reaches of the river, where the anthropogenic impact on the watercourse is the least; st. 3 – on the border of Vologda city. Stations 4–9 are located within the city, in particular st. 7 – downstream from the technical water supply dam, st.9 – at the mouth of the Sodema River.

For analysis, phytoplankton was collected (June 2021) with a Patalas bathometer (1 l), fixed with the Lugol solution and formalin, concentrated through settling to a volume of 10 ml, and then quantitatively processed using a Nageotte counting chamber (0.01 ml) and a LOMO Mikmed 6 microscope. The names of algal taxa were given in accordance with the AlgaeBase system (Guiry and Guiry, 2023). The frequency of occurrence of a species was defined as the ratio of the number of samples, where it was present, to the total number of samples. Biomass was estimated by the volumetric calculation method and the specific weight of algae taken equal to 1 g/m^3 (Kuzmin, 1975). The species constituting ≥ 10% of the total number or biomass of phytoplankton were considered dominant. Trophic status was determined from phytoplankton biomass according to the I.S. Trifonova classification (1990). Based on the linear dimensions of single cells and colonies of algae, the following fractions were distinguished: less than 30, 30–70 and more than 70 μm.

Zooplankton samples were collected by filtering a fixed volume of water through a Judi net (75 μm mesh sieve) followed by fixation with a 4% formaldehyde. Laboratory processing of zooplankton samples was performed in accordance with the generally accepted methods (Metodicheskie rekomendatsii..., 1982) and the Key (Korovchinsky et al., 2021; Kutikova, 1970; Opredelitel’ zooplanktona..., 2010, etc.). Biomass of zooplankters was calculated using the formulas for the relationship between mass and body length of organisms (Balushkina and Vinberg, 1979; Metodicheskie rekomendatsii..., 1982; Ruttner-Kolisko, 1977). The species characterized by a relative number or biomass of more than 5% in each group of rotifers and crustaceans were considered dominant. Thus, we analyzed zooplankton collections for the years 2021 and 2022.

For zoobenthos collection (May and June of 2021), the GR-91 rod bottom grab with a bucket area of 0.007 m^2 and a hydrobiological scraper were used. First, macroinvertebrates were washed off the stones. In order to rinse the samples, we employed a 250 μm mesh sieve. Then the organisms were fixed with 4% formalin, identified (in the laboratory) to the lowest taxonomic levels probable and weighed on an electronic analytical balance. The species with number or biomass exceeding 10% were referred to dominant. Species richness, quantitative indicators, and calculated zoobenthos indices are given on average for two observation periods.

In total, 10 samples of phytoplankton, 99 of zooplankton, and 38 of zoobenthos were analyzed in this study.

To assess the ecological state of the river, we applied the Shannon–Weaver species diversity index (Shannon and Weaver, 1949), the Pantle and Buck saprobity index (Pantle and Buck, 1955) modified by Sladecek (1973) with the use of species lists (Barinova et al., 2006; Marvan et al., 2005; Sladecek, 1973, Wegl, 1983), and the Goodnight and Whitley index (Goodnight and Whitley, 1961). The quality class and contamination degree were determined by GOST 17.1.3.07-82[2]. For zooplankton, the trophy coefficient (Mäemets, 1980), the average individual biomass of zooplankter (Kryuchkova, 1987), and the

[1] Order of the Ministry of Agriculture of the Russian Federation dated December 13, 2016 No. 552 “On approval of water quality standards for water bodies of fishery importance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance”.

[2] GOST 17.1.3.07-82. Nature conservation. Hydrosphere. Rules for monitoring the water quality of reservoirs and watercourses: Interstate standard. Date of introduction: 01.01.1983.

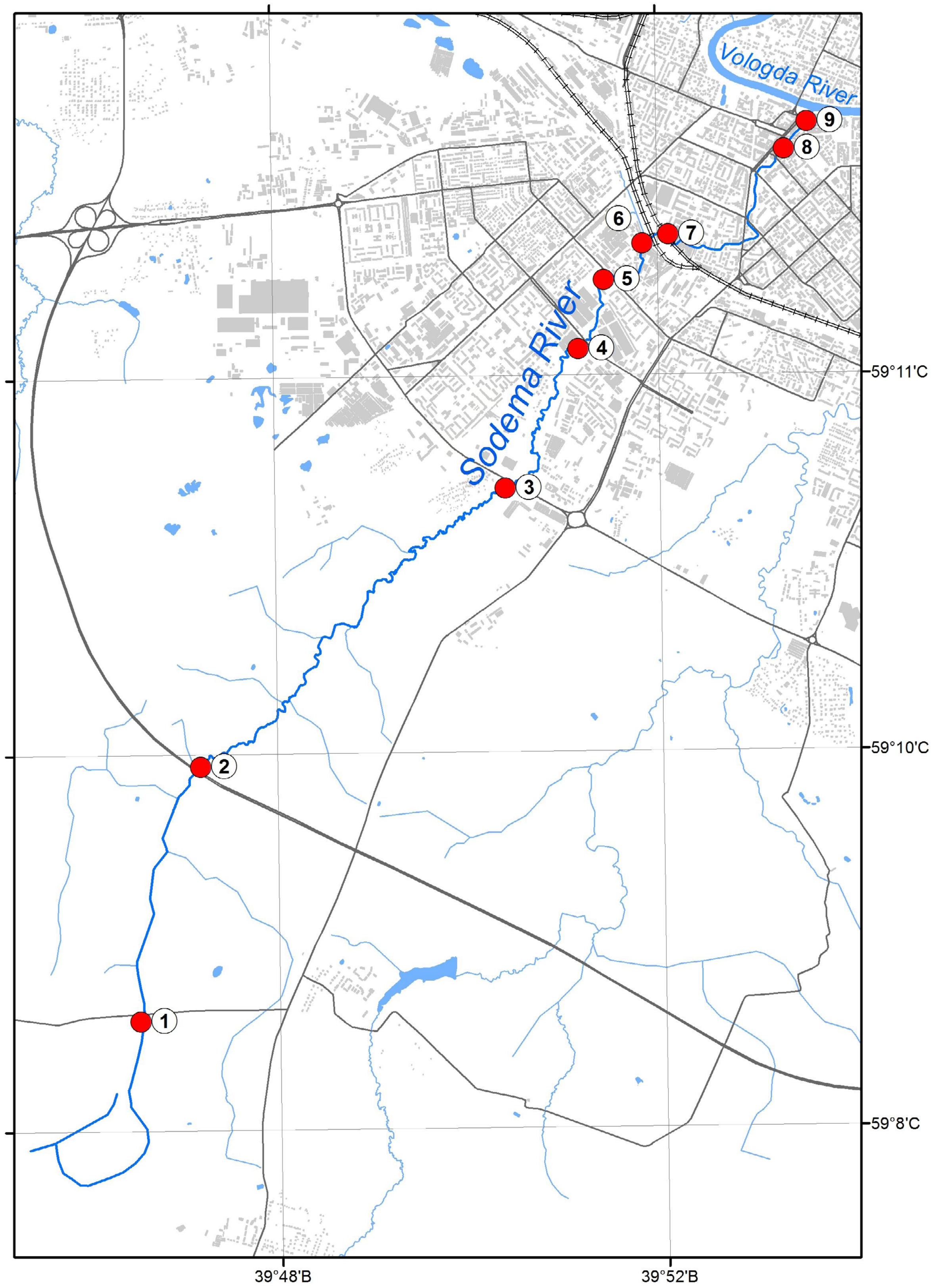


Fig. 1. Location of sampling stations on the Sodema River.

Table 2. Characteristics of structural indicators of phytoplankton at different sections of the Sodema River. $H_{N/B}$ – the Shannon–Weaver index by abundance/biomass; $S_{N/B}$ – the saprobic index by abundance/biomass; the saprobity zone: β – β-mesosaprobic zone.

Index	Station no.								
	1	2	3	4	5	6	7	8	9
Number of taxa	11	19	35	18	29	41	45	39	55
$H_{(N)}$, bit/cells	1.9	1.9	1.9	1.9	2.0	2.2	2.1	2.6	2.0
$H_{(B)}$, bit/g	1.9	2.0	2.1	1.7	1.7	2.6	2.1	2.0	2.1
S_N	2.2	1.9	2.0	2.2	2.1	2.2	2.2	1.9	1.9
S_B	2.1	1.9	2.1	2.3	2.1	2.2	2.2	2.1	1.6
Saprobity zone	β	β	β	β	β	β	β	β	β

ratios of quantitative indicators of major groups of zooplankton – N_{Crust}/N_{Rot}, $N_{Clad}/N_{Cop,}$ were calculated (Andronikova, 1996).

We made a visual assessment of a soil type of the river, measured a flow velocity with a hydrometric micro-turntable GMCM-1, and the oxygen concentration, active medium reaction and mineralization - with portable analyzers “SAMARA-2pH”, MARK-603, pH OHAUS STARTER 300. The data on the chemical composition of water were provided by the Department of Municipal Economy at the Vologda Administration obtained within the framework of the municipal project “Revitalization of the Sodema River through the riparian territories transformation.”

Mathematical data processing was implemented via using the standard statistical methods (Ivanter and Korosov, 2010) and MS Excel 2010 software (built-in functions, including the macros specially created for calculating individual parameters).

Research results

Phytoplankton

In phytoplankton of the Sodema River, we registered 125 species, varieties and forms of algae, among which diatoms prevailed (65 taxa). In terms of species richness, green algae took the second place (26). Euglena algae were represented by 14 taxa, cyanobacteria – by 9, cryptophytes – 7. Golden, dinophyte and yellow-green algae were distinguished by a small number of species (1–2). *Euglena viridis* (O.F. Müller) Ehrenberg, *Navicula cryptocephala* Kützing, *Ulnaria ulna* (Nitzsch) Compère were widespread species. *Nitzschia vermicularis* (Kützing) Hantzsch (89%), *Fragilaria capucina* Desmazières (78%), *Nitzschia acicularis* (Kützing) W. Smith (78%), *Surirella minuta* Brébisson ex Kützing (78%) were common in the river as well.

In general, the number of algal species, varieties and forms in the river increased within 11–55 from the source to the river mouth (Table 2). In the taxonomic structure, the importance of diatoms decreased (from 82% to 40%) and of euglenoids – increased (from 9 % up to 26% at st. 8). In the river mouth, algocenosis had the most complex structure. Diatoms and euglenids were less abundant in contrast to green and cryptophyte algae. Golden, dinophyte and yellow-green algae were present as well.

In the river mouth, the number and biomass of phytoplankton were the highest – 54.09 mln cells/l and 14.96 g/m^3, respectively (Fig. 2) that made this river section highly eutrophic. Cryptophytes (number: 38% and biomass: 46%), diatoms (22% and 36%, respectively) and green algae (number: 38%) dominated in the community. Algal number and biomass were growing, primarily, in the small-sized fraction (< 30 μm) (Table 3), represented by single cells and, to a lesser extent, small colonies.

In the upper reaches, the river was assessed as oligotrophic (0.24 mln cells/l, 0.25 g/m^3), where diatoms (80% and 84%) prevailed in the form of single cells of a medium size (30–70 μm). Phytoplankton (st. 2) was characterized by a larger share of green algae (number: 51% and biomass: 10%). Within the city, the algae amount increased. By biomass, the river waters corresponded to the mesotrophic type with a transition to the eutrophic below the dam (5.35 mln cells/l, 6.69 g/m^3). In this river section, the contribution of diatoms to phytoplankton number and biomass dropped with a growing share of blue-greens and euglena. As for a size structure, single cells of the medium and large (> 70 μm) fraction dominated. Below the dam, biomass mostly consisted of long filaments of *Oscillatoria limosa* C. Agardh ex Gomont. In the central city part (st. 8), the river phytoplankton again acquired oligotrophic features (0.92 mln cells/l, 0.77 g/m^3), but unlike upper reaches, euglena and blue-green algae played a larger role in the community.

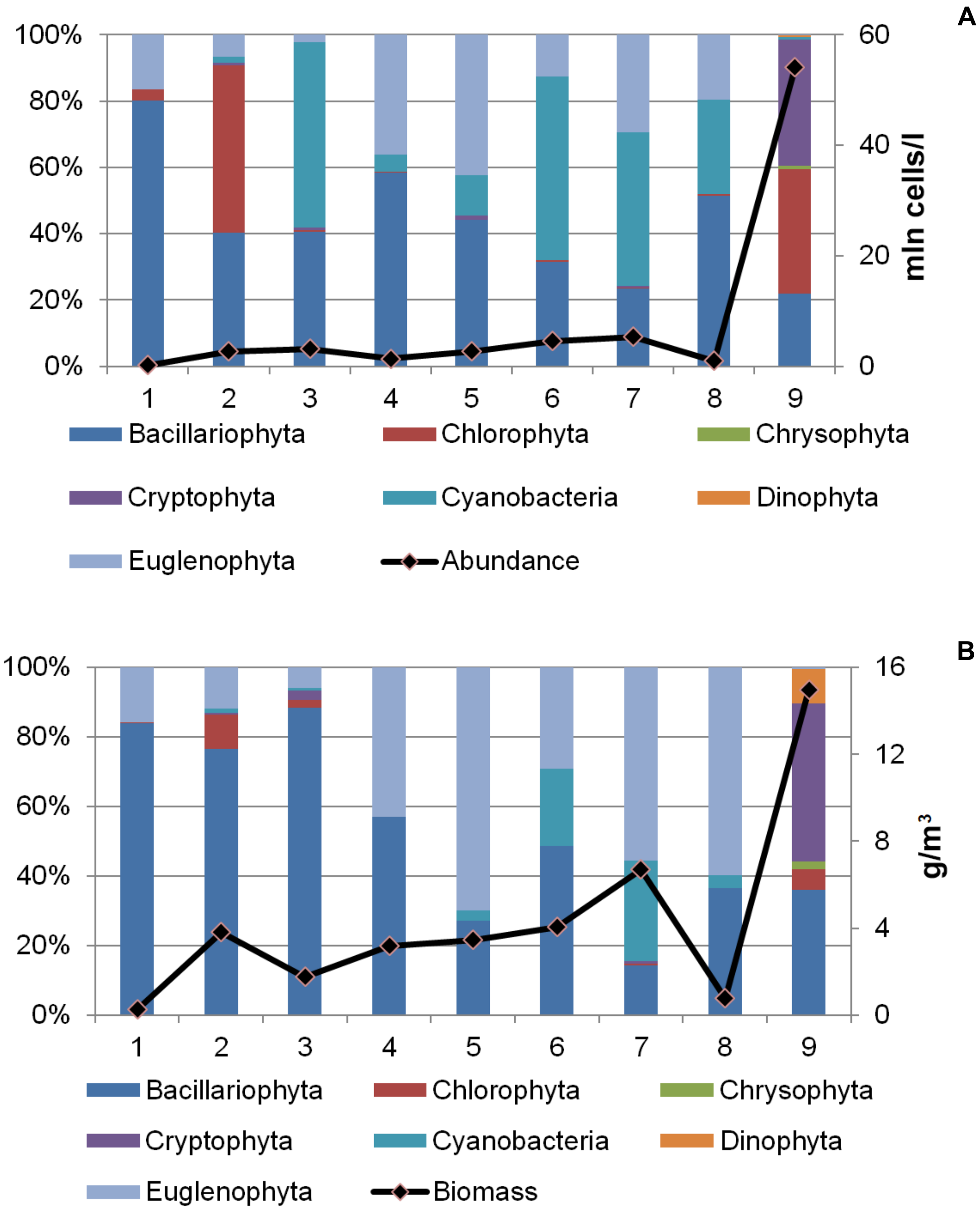


Fig. 2. Average number (**A**) and biomass (**B**), the ratio of major groups of phytoplankton from different sections of the Sodema River in June 2021.

Table 3. Phytoplankton number and biomass with regard to size classes at different sections of the Sodema River.

Size class, microns	Station no.								
	1	2	3	4	5	6	7	8	9
Number, mln ind./l									
< 30	0.10	0.36	0.53	0.16	0.35	0.70	1.19	0.28	35.26
30–70	0.14	0.62	0.84	0.92	1.88	1.21	1.62	0.35	3.85
> 70	0.01	0.24	0.11	0.22	0.09	0.15	0.10	0.04	1.03
Biomass, g/m^3									
< 30	0.06	0.38	0.23	0.07	0.31	0.50	1.97	0.15	8.26
30–70	0.13	1.51	0.85	2.06	2.41	1.57	2.57	0.50	5.60
> 70	0.06	1.92	0.68	1.04	0.72	1.97	2.15	0.12	1.10

Euglena viridis characterized by a higher number within the city was the most common dominant species in the river phytoplankton. In the upper reaches, the species of genus *Navicula* Bory, *Ulnaria ulna* prevailed. The species from the genus *Nitzschia* Hassall (Bacillariophyta) and cyanobacterium *Oscillatoria limosa* appeared in the dominant complex closer to the city center.

The Shannon species diversity index, calculated from phytoplankton number and its biomass varied insignificantly (1.9–2.6 bit/cells and 1.7–2.6 bit/g). A growing diversity of algocenosis was observed at the dam and in the low reaches of the river (Table 2). The saprobity index for phytoplankton varied as 1.9, 2.2, and for biomass – from 1.6 to 2.3, corresponding to β-mesosaprobic conditions and moderate pollution. A reduction in saprobity values was recorded in the river section near the M-8 highway and in the mouth area.

In the Sodema phytoplankton, the dominant indicator species (evident of a low organic pollution) had the greatest number in sites above the city and at the river mouth. The species indicating medium pollution (increasing from source to mouth) were widely represented as well. The number of indicators of severe organic contamination was maximal in the sections below the dam.

Zooplankton

In summer zooplankton of the Sodema River, we identified 74 species (Rotifera – 32, Cladocera – 18, Copepoda – 24), most of them were eurybionts. The number of zooplankter species in a single sample was low, i.e. in the upper reaches – on average 8, within the city – under 5. The most diverse (26–27 species) community was found in the upper reaches, at the periphery of the city and in the overgrown with macrophyte sites (stations 1, 4). In places with an artificial bottom cover and at a relatively high flow velocity (stations 2, 3, 8, 9), as well as near the outlets of untreated wastewater (st. 6), species richness of zooplankton dropped to 15–20 species. The largest number of cladoceran species was recorded in the upper reaches of the river (9). Within the city, diversity of rotifers was growing (26 species).

The species indicating oligotrophy in the riverine zooplankton were absent. Eutrophic indicators were found in all parts of the Sodema, the share of which in the total number of zooplankton increased within the city (Table 4) reaching its maximum (52%) at the dam. Next to the wastewater outlets, abundance of *Bosmina longirostris (*O.F. Müller, 1776) and *Brachionus quadridentatus* Hermann, 1783 (up to 20% and 80% of the total zooplankton, respectively) increased. In some sections of the river, rotifer was the only representative of zooplankton in the samples. Overall, zooplankton was characterized by low species diversity and, accordingly, high predominance (Table 4). In the central part of the city, the index of zooplankton species diversity reduced.

In different parts of the Sodema River, abundance of planktonic animals varied greatly. The highest number and biomass of zooplankton were recorded in the upper reaches and in the mouth of the river (Fig. 3). Here, the average number of organisms made up 8 thous. ind./m^3, biomass – 0.5 g/m^3. In the

Table 4. Characteristics of zooplankton at different sections of the Sodema River. $H_{(N/B)}$ – the Shannon–Weaver index by abundance/biomass; E – the trophy coefficient; W – the average individual mass of zooplankter; N_{Crust}/N_{Rot} – the ratio of crustaceans and rotifers; N_{Clad}/N_{Cop} – the ratio of cladocerans and copepods number; S – the saprobity index by number; RN – the relative number; the trophy level: m – mesotrophic, e – eutrophic, g – hypereutrophic; the saprobity zone: o – oligosaprobic, β – β-mesosaprobic; the water quality class: II – clean, III – moderately polluted.

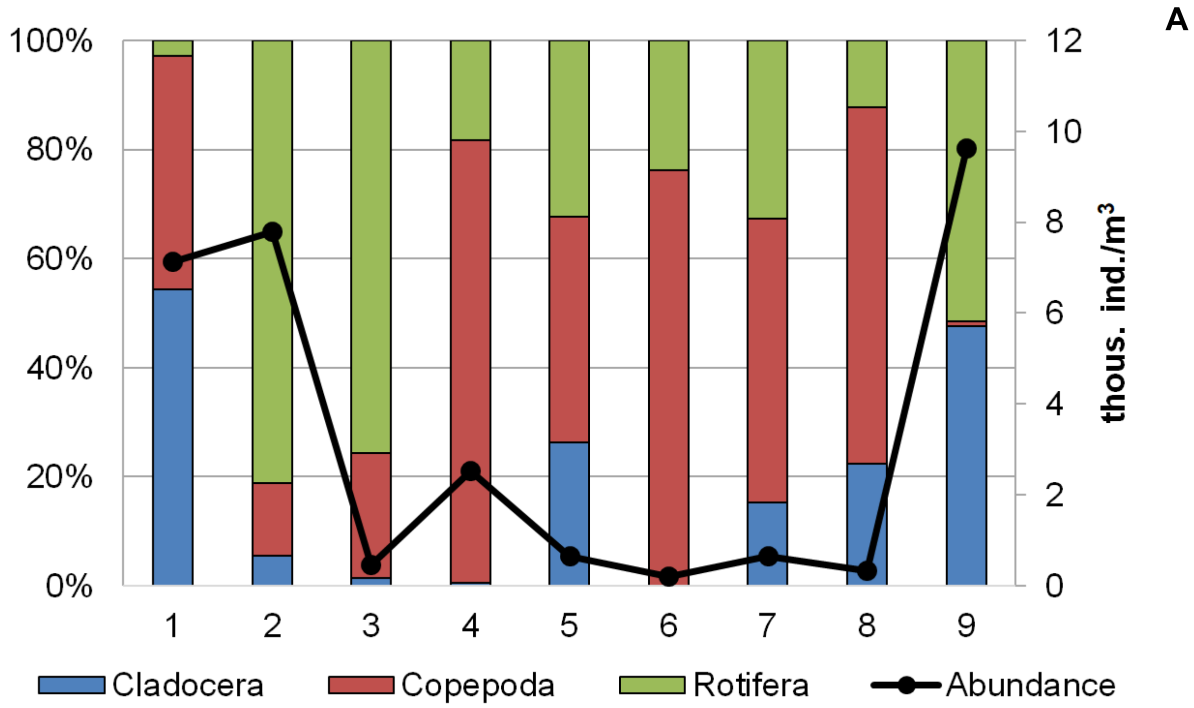
Characteristics	Station no.								
	1	2	3	4	5	6	7	8	9
Number of species	26	21	16	27	21	18	23	14	15
$H_{(N)}$, bit/ind.	1.9	2.0	1.4	2.2	2.1	1.8	1.6	2.3	1.7
$H_{(B)}$, bit/g	1.4	2.0	1.0	1.2	1.6	1.4	1.1	1.2	1.1
Trophy level by H	e	e	e	e	e	e	e	e	э
E	0.4	2.8	1.6	1.1	2.8	2.3	4.2	2.9	3.1
Trophy level by E	m	e	e	e	e	e	g	e	e
W, mg	0.047	0.009	0.004	0.009	0.011	0.009	0.015	0.017	0.024
N_{Crust}/N_{Rot}	6.0	15.2	4.2	3.7	0.8	5.1	4.2	6.7	5.0
N_{Clad}/N_{Cop}	2.0	0.4	0.1	0.01	0.6	6.5	0.7	0.3	1.2
S_N	1.5	1.4	1.4	1.6	2.0	2.0	1.8	1.7	1.5
Saprobity zone	o	o	o	β	β	β	β	β	o
Water quality class	II	II	II	III	III	III	III	III	II
RN of species-indicators of eutrophication, %	11.6	32.2	31.6	19.6	22.6	23.0	52.4	30.0	3.6

upper reaches, crustaceans *Moina brachiata* (Jurine, 1820), *Daphnia galeata* Sars, 1864, *Acanthocyclops vernalis* (Fischer, 1853), *Mesocyclops leuckarti* (Claus, 1857) formed the community base.

In the Sodema mouth, the spatial structure of zooplankton was heterogeneous. In the midstream, zooplankton number was low (0.4 thous. ind./m^3, 4 mg/m^3) and represented solely by *Daphnia galeata* and *Macrocyclops albidus (*Jurine, 1820), *Brachionus quadridentatus, Rotaria* sp., *Eucyclops serrulatus* (Fischer, 1851). In the river mouth, high number and biomass of zooplankton were noted at the beginning of summer in the shoaling with its slow flow, where *Daphnia galeata, Polyphemus pediculus (*L., 1761*), Scapholeberis mucronata* (O.F. Müller, 1776) and rotifers of the genera *Lecane* and *Synchaeta* developed en masse. At the end of summer, the shoaling was responsible for a low zooplankton density. The average number of zooplankton made up 28 thous. ind./m^3 and biomass – 1.5 g/m^3.

Within the city, the average number of zooplankton in the river reached 0.8 thous. ind./m^3 and biomass – 10 mg/m^3 (Fig. 3), whereas in sites with a higher flow velocity (stations 3, 8) and near water outlets (stations 5, 6), this indicator was the lowest. In the river sections with high anthropogenic loads, small-sized organisms dominated. The average individual mass of zooplankters within the city was 4 times less as compared to the sites upstream (Table 4). Copepods had the largest number and biomass (Fig. 3, Table 4). A low number of nauplii was typical for the riverine zooplankton. The increased cladoceran number was noted only in certain periods of observation due to *Moina brachiata*. Rotifers were characterized by a relatively high density (Fig. 3). In different observation periods, *Euchlanis meneta* Myers, 1930, *E. dilatata* Ehrenberg, 1832, *Keratella quadrata* (Müller, 1786*), Platyias quadricornis* (Ehrenberg, 1832*), Synchaeta* sp., *Rotaria* sp. prevailed.

In the river section within the city, the saprobity index, calculated from zooplankters number, corresponded to moderate pollution (β-mesosaprobic zone). In the central part of the city this indicator increased. The trophy coefficient in the dam area was 10 times higher than in the upper reaches of the river; the share of eutrophication indicators (in the total number) exceeded 50%. Hence, the river site within the city was eutrophic, and at the dam – hypereutrophic.



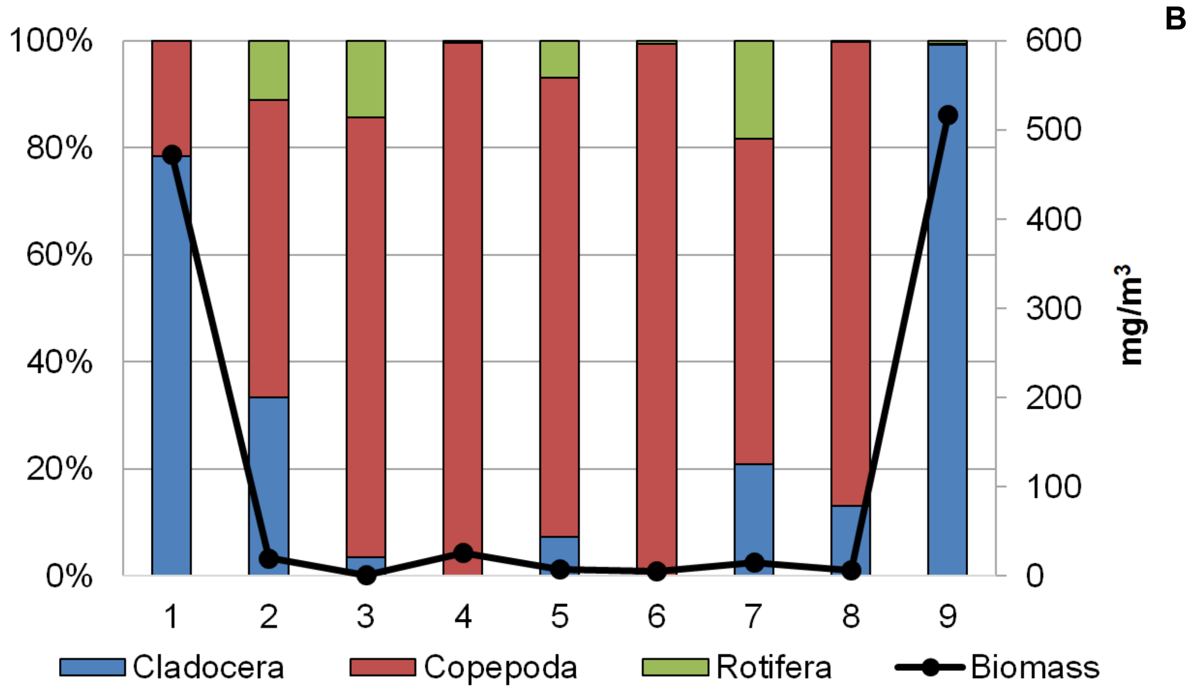


Fig. 3. Average number (**A**) and biomass (**B**), the ratio of major groups of phytoplankton from different sections of the Sodema River for 2021.

Zoobenthos

In April and June of 2021, the Sodema zoobenthos composition included 70 species and taxa of a higher rank. Amphibiotic insects were most numerous (48), 26 of which were representatives of Chironomidae. Oligochaete worms were represented by 11 species. The list of mollusks and leeches contained 5 species each. Of crustaceans, only *Asellus aquaticus* (L., 1758) were found. Hydracarina gen. sp. were sporadically noted in benthos samples.

In the upper reaches, besides the most common groups of zoobenthos (chironomids, oligochaetes and mollusks), we identified typical rheophilic groups of invertebrates (stoneflies, mayflies and midges) (Fig. 4), i.e. a total of 29 species of aquatic macroinvertebrates (Table 5). At st. 2, the oligochaetes dominance in benthic communities was apparently caused by fertilizers runoff from the fields. Benthic species richness in this section of the river was relatively high (24 species).

Downstream, the greatest species richness of zoobenthos (32 species) was observed at the city boundary, where more than 15% fell on Oligochaetes. The maximum number of species of caddis flies and mayflies (4 each), chironomids (13), as well the largest number and biomass of larvae of other dipterans (crane flies, horseflies, midges) were noted. Within the city, the structure of zoobenthos communities changed. In this section and at the dam (stations 4–6), abundabce and biomass of zoobenthos, as well as the share of oligochaetes increased. At the same time, the number of species dropped and reached its minimum (4) at the dam, where *Tubifex tubifex* (Müller, 1774) and *Limnodrilus hoffmeisteri* Claparède, 1862 dominated. Below the dam (st. 7), the recovery of benthic communities occurred. Note that *Asellus aquaticus* was recorded only in this site. In the city center (station 8), oligochaetes along with *Stylaria lacustris* (L., 1758) prevailed, in contrast to the section above the dam. In all sections of the river below the dam, leeches *Erpobdella* sp. constituted up to 50% of biomass. The highest species richness and species diversity of zoobenthos were recorded at st. 3, i.e. at the city boundary (Table 5). The reduction in species diversity of the community in the upper reaches was due to predominance of stoneflies, midges and bivalves. High species diversity along with low species richness were noted in the mouth section because of the evenness of zoobenthos communities. The dominant oligochaete *T. tubifex* provided the decreased species diversity at high species richness (st. 2). Probably, the reason was a local contamination induced by fertilizers runoff from agricultural fields. Downstream (st. 3), the recovery of bottom communities was obvious. In general, the reduced species richness and diversity (with minimal values above the dam and a subsequent increase below) were noted downstream.

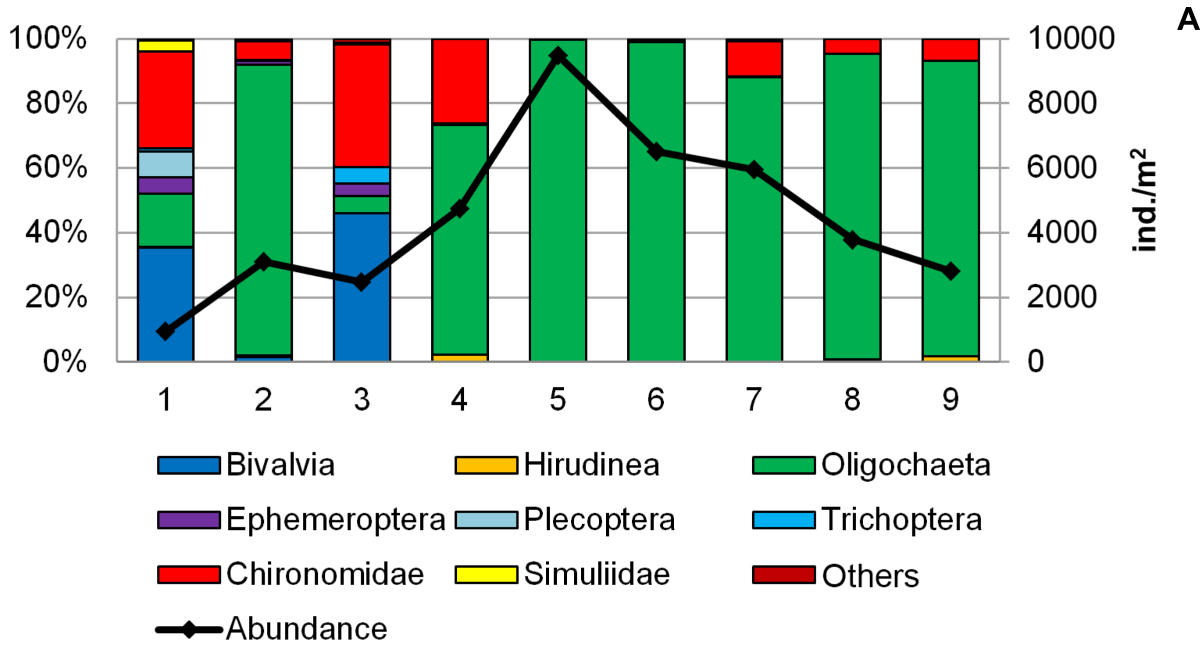
In terms of zoobenthos, only the upper reaches of the Sodema River were characterized as a β-mesosaprobic zone (Table 5). Stations 5 and 6 were referred to the polysaprobic zone. The river mostly belonged to the α-mesosaprobic zone. According to the Goodnight–Whitley index, the best water quality (characterizing this section as clean) was at stations 1 and 3. In other areas, despite significant or severe contamination, this index was high (stations 8 and 9) due to dominant oligochaetes of the family Naididae.

Discussion

As compared to other watercourses of the studied urbanized sites, phytoplankton of the Sodema River was chareacterized by great species richness and diversity (Ivicheva et al., 2018). In spring, phytoplankton diversity was usually higher in the rivers with complex anthropogenic impact (Turyanova, 2006). Unlike other heavily polluted rivers (Okhapkin, 1997), the saturation of microalgae genera with species in the Sodema river was high.

Табл. 5. Characteristics of zoobenthos at different sections of the Sodema River. $H_{(N)}$ – the Shannon–Weaver index by abundance; $S_{(N)}$ – the saprobity index by abundance; the water quality: h – polluted water, d – dirty (Balushkina, 1987); the saprobity zone: β – β-mesosaprobic zone, α – α-mesosaprobic zone, ρ – polysaprobic zone; the water quality class: I – very clean, V – dirty, VI – very dirty.

Characteristics	Station no.								
	1	2	3	4	5	6	7	8	9
Number of species	29	24	32	15	4	4	17	11	7
$H_{(N)}$, bit/ind.	1.4	0.8	1.7	1.3	0.01	0.2	0.9	0.9	1.5
Качество вод	h	d	h	h	d	d	d	d	h
$S_{(N)}$	1.9	3.5	2.8	3.3	3.7	3.7	3.4	3.0	3.4
Saprobity zone	β	α	α	α	ρ	ρ	α	α	α
Goodnight–Whitley index	10.1	89.2	13.7	71.1	99.8	98.9	79.9	94.5	91.5
Water quality class	I	VI	I	V	VI	VI	V	VI	VI



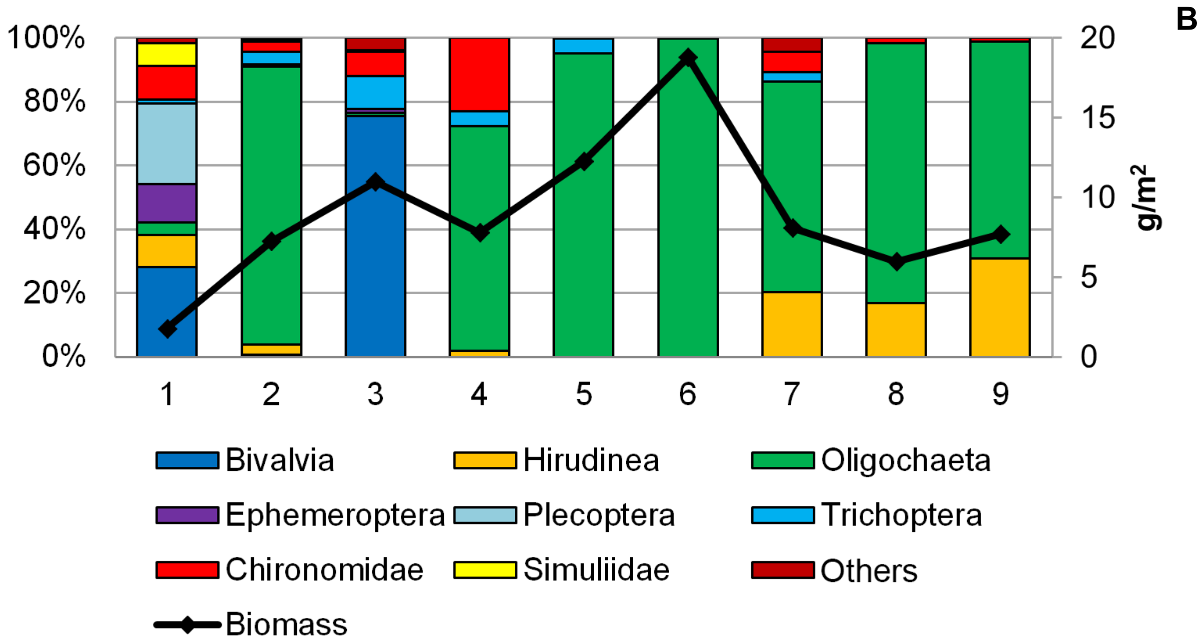


Fig. 4. Average number (**A**) and biomass (**B**), the ratio of major groups of phytoplankton from different sections of the Sodema River for April and June 2021.

The Sodema phytoplankton was mostly represented by the green diatoms flora. The algal species number, biomass and abundance generally increased from the source to the river mouth. At the same time, the contribution of diatoms to these indicators decreased. Euglena, blue-green, cryptophyte and green algae made the structure of the algocenosis in the estuary more complex. Many cyanobacteria and euglena algae in the river served as indicators of water body eutrophication (Trifonova, 1990). Phytoplankton biomass corresponded to the conditions ranging from oligotrophic in the headwaters to highly eutrophic in the mouth. Many studies report about the increased trophicity in conditions of heavy and multifactorial anthropogenic loads on watercourses (Kadochnikova and Belyaeva, 2017; Umanskaya et al., 2018, etc.). Algae density in the Sodema varied widely. It is known that phytoplankton number and its biomass in streams of the urbanized areas are subject to significant fluctuations (Turyanova, 2006).

Similar to upper reaches, low quantitative parameters of the algal community were also noted in the city center characterized by a relatively diverse algocenosis. Here, we recorded the minimum oxygen content, increased mineralization and electrical conductivity. The increase in the alkaliphilic species number indicated a slightly alkaline medium reaction.

The most common dominant in the river phytoplankton was *Euglena viridis.* It is well-known that this species prefers rich-in-organic waters (Padisak et al., 2009) provided by agricultural runoff and effluents. The upper reaches of the river dominated in species dwelling in the highly mixed waters with low transparency. Above the dam and immediately below it, the dominant complex contained filamentous heterocystous cyanobacteria. In particular, often found in polluted water bodies a fresh- and brackish water species *Oscillatoria limosa* demonstrated the intensive development. Above the dam, *O. limosa* was represented solely by a large fraction with a maximum size up to 2.6 mm, while below the dam - fragmentation of filaments was observed.

Throughout, the river community consisted of dominant phytoplankters with a linear size not exceeding 70 µm. The share of the small-sized fraction (up to 30 µm) generally increased towards the mouth and decreased at the dam. The larger proportion of a fine fraction of phytoplankton along with high quantitative indicators were evidence of the growing water trophicity in the river mouth.

Zooplankton of the Sodema River was characterized by a relatively high species richness. At the same time, the composition and structure of the communities, characteristic of insignificantly transformed streams of this type (Krylov, 2005; own data), were observed only in the upper reaches of the river. In zooplankton composition, rotifers and copepods dominated. Diversity of cladocerans, among which filter feeders predominated, significantly declined in many river sections within the city (up to their extinction in certain periods) because of the wrong functioning of their filtration apparatus (Ivanova, 1976). In case of severe contamination, predatory species developed en masse, in particular, Cyclopoida – grabbers and gatherers (Chuikov, 1978).

Abundance and biomass of zooplankton in the Sodema upper reaches and its mouth were comparable to those in many small watercourses of the Sukhona River basin and Upper Volga (Krylov, 2005; Zaitseva et al., 2017; own data). Within the city, the riverine zooplankton was characterized by low abundance and predominance of copepods. Because of rise in water temperature induced by wastewater discharge to the river, zooplankton number could reach its maximum in spring in many sites. During low water, abundance of zooplankton declined with a decrease in water level and intensive development of phytoplankton.

In terms of zooplankton, the Sodema River was assessed as the β-mesosaprobic zone (moderately polluted, quality class III). At the same time, structural indicators of zooplankton (including the ratio of groups by number), average individual mass, trophy coefficients and the share of eutrophic species were evidence of a significant deterioration of the ecological state of the river section within the city, especially near the dam. Other authors (Semenova, 2014) also inform about similar differences in assessing water quality by different methods that confirms the need to use in bioindication a set of indicators and their overall analysis.

As for zoobenthos, the Sodema River was characterized by low species richness. Generally, it is typical for small rivers and comparable to other small watercourses of the Upper Sukhona basin (Ivicheva et al., 2018). From other previously studied small rivers, the Sodema differed by the completely transformed catchment, mostly located within the boundaries of the city of Vologda (Ivicheva and Filonenko, 2013). Downstream, the reduced species richness and species diversity of zoobenthos was noted. The most sensitive taxa (stoneflies, midges) were recorded only in the upper reaches. Similar to other watercourses, loss of all zoobenthos taxa, except for oligochaetes, took place in the city section (Bezmaternykh, 2008; Ekologicheskoe sostoyanie..., 2003; Ivicheva, 2019; Yanygina, 2013). At the dam, benthic communities were represented only by oligochaetes. Here, the river received a large amount of wastewaters that resulted in anthropogenic siltation. Recovery of benthic communities was observed below the dam. According to A. Martinez et al. (2013), the dam together with discharged treated industrial wastewaters generally had a positive effect on benthic communities at a relatively low water content. A local deterioration of the water quality (followed by self-purification) recorded above the city was previously observed in other rivers as well (Balushkina, 2003; Bakanov, 2003; Kononova, 2011).

Conclusion

The long-lasting heavy complex anthropogenic impact has greatly affected the state of the Sodema River. The natural community features, characteristic of small watercourses of the taiga zone, were noted only in the upper reaches of the study river. Here, at a relatively low abundance of microalgae, widespread in the region diatoms dominated. Zooplankton of the upper reaches was characterized by the greatest diversity and abundance. Cladocerans prevailed in zooplankton. In zoobenthos, typical rheophilic groups of invertebrates (stoneflies, mayflies and midges) were present only in the upper reaches.

The communities of phytoplankton, zooplankton and zoobenthos of the Sodema River section within the city of Vologda turned out to be transformed, and considerable changes in all elements of the river ecosystem were noted. In phytoplankton, the share of cyanobacteria, euglenoid and cryptophyte algae increased; the number and biomass showing the maximum in the mouth, as well as the role of a small-sized fraction of phytoplankton also increased. The city section demonstrated the depleted taxonomic composition of zooplankton and zoobenthos, including low species diversity. Only species able to adapt to high concentrations of suspended matter, organic substances, and nutrients survived. In plankton composition, these were active predators and euryphage gatherers. Zoobenthos number, its biomass and the share of oligochaetes were growing.

In terms of the riverine plankton, the Sodema River was assessed as β-mesosaprobic. At the same time, the structural and functional characteristics of phyto- and zooplankton indicated the eutrophic and hypereutrophic (at the dam) state of the river section within the city. Based on structural indicators of zoobenthos, the Sodema River can be predominantly assessed as α-mesosaprobic, water quality classes V–VI ("dirty" – "very dirty"). The characteristics of zoobenthos indicated the water quality deterioration in the locally polluted site at the intersection with the M-8 highway. The greatest pollution caused by contaminants accumulation in soil was recorded above the dam.

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