Plankton community of the lower course of the Kama River in the late autumn period

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Abstract. The features of the plankton community structure and transformation have been investigated in the lower course of the Kama River in the late autumn 2020. The transformation of organic matter and seston composition of the Kama River was affected by the inflow of the largest tributary (the Vyatka River) and by the operating mode of the Nizhnekkamsk hydroelectric power station. Three structural groups of plankton have been defined: the Kama River community (upstream the confluence with the Vyatka River), the Vyatka River community, and the transformed community downstream of the Vyatka River confluence. The waters of the Vyatka River were characterized by the highest plankton biomass, which affected the quantitative indicators of the Kama River community downstream the tributary inflow. The transformation of the planktonic community under the influence of the Vyatka River inflow was manifested in the change of one dominant group (heterotrophic bacteria) to another (diatoms). In general, despite the lower volume of Vyatka runoff compared to the Kama River, 81% of the total organic carbon of plankton on weekends, and 61% on working days, was formed due to runoff from Vyatka. On the contrary, detritus mainly came directly from the Kama River waters (more than 97%). The influence of the Vyatka River on the Kama River ecosystem in its lower course and further on the Volga River was large, increasing even more on weekends as the amount of runoff through the hydroelectric power station reduced.

1. Introduction
Observations of the abiotic conditions and biotic components of the Kuibyshev Reservoir have been started by employees of the Kuibyshev Biological Station of the Institute of Biological Problems of the Academy of Sciences of the USSR from the very beginning of the Reservoir establishing; these observations were regular until the 1990s. The studies were performed at the grid of stations proposed by N A Dzyuban [1]; this scheme comprised only two sites have been monitored in the lower part of the Kamsky Reach of the Kuibyshev Reservoir, receiving the waters of the Kama River, the largest tributary of the Volga River. This does not allow us to assess the changes in the biotic component occurring along the longitudinal axis of the Kamsky Reach of the Kuibyshev Reservoir and to determine the impact of the Vyatka River, the second largest tributary of the Kama River, on the plankton community of the Kuibyshev Reservoir. After establishing of the Nizhnekkamsk and Cheboksary reservoirs in 1980, the Kamsky Reach, receiving the waters of the Vyatka River, became
the most productive area, instead of the Volzhsky Reach, which received the waters of the Oka River and was located upstream the dam of the Cheboksary hydroelectric power station [2].

The state of the plankton community in the upper part of the Kamsky Reach of the Kuibyshev Reservoir was studied by the employees of the Institute for Biology of Inland Waters of the Academy of Sciences of the USSR before the establishing of the Nizhnemaks Reservoir in 1975 [3]; of the Institute of the Ecology of the Volga Basin RAS (IEVB RAS) in 2009, 2012, 2014, and during the joint expedition of IEVB RAS and Institute for Biology of Inland Waters RAS in 2016 [4-6, etc.]. However, the number of stations performed in the Kamsky Reach of the Kuibyshev Reservoir was quite low. In general, the available information is far from sufficient to understand the processes of spatiotemporal variability, biodiversity of planktonic organisms and their role in the functioning of the ecosystem of this section of the reservoir.

The study aims to analyze the features of the development of particular components and structure of entire plankton community in the lower course of the Kama River in the late autumn, taking into account the influence of the Vyatka River.

2. Materials and Methods

The studies were carried out on October 17-19, 2020 at the lower course of the Kama River, which is the Kamsky Reach of the Kuibyshev Reservoir, namely, from the Bet'ki settlement to the station located downstream the confluence of the Sheshma River (figure 1). Station no. 6 was located directly at the Vyatka River estuary. The water was sampled from the surface layer. The quantitative indicators of bacterioplankton, detritus, and phototrophic picoplankton (by autofluorescence of chlorophyll a) were determined on the membrane filters [7, 8]. The phyto-, proto-, and metazooplankton were studied according to standard hydrobiological methods [9]. The species composition was identified using up-to-date taxonomic keys [10-16]. The carbon content in detrital particles, bacterioplankton, phytoplankton, metazooplankton, and planktonic ciliates was calculated using the standard equations [17]. The mean ± standard deviation are presented.

The indices of species diversity (Shannon, H) and evenness (Pielou, E) were used to assess the biodiversity of aquatic organisms. The dominant species were defined as exceeding 10% of the total abundance/biomass.

3. Results and Discussion

3.1. Environmental conditions in the Kamsky Reach in October 2020

During the study period, the weather was windy in the lower course of the Kama River. Considering that the depths in this area were small (6.5-11.0 m, table 1), strong waves contributed to the mixing of
the entire water column. Therefore, the data obtained during the processing of surface samples reflected the processes occurring in the entire water column.

The hydrological features of the upper section of the Kamsky Reach were highly preconditioned by the operating mode of the Nizhnekamsk hydroelectric power station (HPS), which operated on a weekly–daily basis. Our studies were carried out both on weekend, when both the discharge (Saturday, October 17, 2020) and water level (Saturday–Sunday, October 17–18, 2020) downstream the dam were minimal, and at the beginning of the working week (Monday, October 19, 2020), when these indicators increased again (figure 2), which naturally affected the water flow rate.

The physicochemical conditions influencing the development of the plankton community in the upper part of the Kamsky Reach of the Kuibyshev Reservoir are presented in table 1. The Vyatka River, which is the large tributary, has a noticeable effect on the transformation of the water masses of the Kama River. The water masses of the Vyatka River differ from that of the Kama River; the first are less transparent, they have lower oxygen concentration and oxygen saturation, slightly lower mineralization, and higher pH (table 1). The mixing of the water masses of the Vyatka and Kama rivers is likely taking place downstream of the confluence of these rivers (stations located nearby the Kamskie Polyany settlement and downstream the estuary of the Sheshma River), as evidenced by the change in the physicochemical characteristics of the Kama River.

![Figure 2](image-url)  
**Figure 2.** Hydrological conditions in the lower course of the Kama River of the Kuibyshev Reservoir in October 2020 according to data from hydrological posts (http://gis.vodinfo.ru): 1–4 – water level relative to the zero, 5 – water discharge. Designations of hydrological posts: 1 – Chistopol city, 2 – Sokol’i Gory (upstream of the confluence of the Sheshma River), 3 – Elabuga city, 4, 5 – downstream of the Nizhnekamsk HPS.

Picodetritus and the smallest fraction of nanodetritus were a significant source of organic matter and an important food source for microzooplankton and protozooplankton. Nanodetrital particles, due to its larger size, clogged the filter apparatus of rotifers and ciliates and, thereby, restricted the growth of the latter. The Kama River was characterized by the presence of a significant amount of detritus during both high water and summer low water [5]. According to our study, detritus remained an important component of the ecosystem of the lower reaches of the Kama River in the late autumn period.

In October 2020, detritus was presented by the particles of 0.5–15 μm (table 2). The abundance of pico- and nanodetritus was relatively stable and amounted to (0.043–0.20) × 10⁹ particles L⁻¹, except for station no. 3 (0.90×10⁹ particles L⁻¹). As expected, the content of organic carbon in detritus (the detritus “biomass”) depended strongly on the particle size and varied greatly between stations. Picodetritus accounted for 33–87% of the total detritus abundance and 2–29% of the detritus “biomass”.

![Table 2](table-url)
On average, picodetritus comprised 54% of the total number of detrital particles in both rivers, but it contributed to detritus organic carbon as 9% in the Kama River and 21% in the Vyatka River.

In general, the waters of the Kama River carried high amounts of detritus, compared to that of the Vyatka River (its tributary). This affected the development of plankton in the lower reaches of the Kama River along with the features of the hydrological regime.

Table 1. Characteristics of physicochemical conditions at sampling stations in the upper section of the Kamsky Reach on October 17-19, 2020.

| Station                                | Station no. | Coordinates          | Sampling date in 2020 | Depth (m) | Transparency (m) | Temperature (°C) | pH | Dissolved oxygen (mg L⁻¹) | Dissolved oxygen (%) | Specific electrical conductivity (μSm cm⁻¹) |
|----------------------------------------|-------------|----------------------|-----------------------|-----------|-----------------|-----------------|----|--------------------------|----------------------|------------------------------------------|
| Downstream the Vyatka River confluence | 7           | 55°33'41'' N, 51°30'54'' E | Oct 17               | 4.3       | 1.2             | 8.9             | 8.2 | 8.9                      | 77                   | 433                                      |
| Vyatka River estuary                   | 6           | 55°36'35'' N, 51°28'48'' E | Oct 17               | 3.6       | 1.1             | 9.8             | 8.8 | 10.1                     | 87                   | 406                                      |
| Upstream the Vyatka River confluence   | 5           | 55°35'37'' N, 51°32'23'' E | Oct 17               | 8.5       | 0.9             | 10.4            | 8.4 | 10.5                     | 91                   | 444                                      |
| Kotlovka settlement                    | 4           | 55°38'13'' N, 51°41'36'' E | Oct 18               | 6.5       | 1.7             | 10.1            | 6.8 | 9.1                      | 82                   | 441                                      |
| Elabuga city                           | 3           | 55°44'17'' N, 52°01'11'' E | Oct 18               | 8.1       | 2.1             | 10.9            | 8.0 | 13.4                     | 120                  | 453                                      |
| Upstream Elabuga city                  | 2           | 55°43'12'' N, 52°02'40'' E | Oct 18               | 8.2       | 2.0             | 10.6            | 8.0 | 11.2                     | 110                  | 453                                      |
| Bet'ki settlement                      | 1           | 55°40'55'' N, 52°09'09'' E | Oct 18               | 7.7       | 1.9             | 10.6            | 7.9 | 12.2                     | 111                  | 445                                      |
| Downstream Kamskie Polyany settlement | 8           | 55°27'36'' N, 51°21'58'' E | Oct 19               | 11        | 1.3             | 11.9            | 8.5 | 9.5                      | 88                   | 449                                      |
| Downstream the Sheshma River confluence| 9           | 55°07'33'' N, 51°21'34'' E | Oct 19               | 10        | 1.5             | 11.5            | 8.0 | 8.6                      | 76                   | 452                                      |

Mean: Upstream the Vyatka River confluence: Stations nos. 1-5, Oct 17-18, 7.8, 1.72, 10.5, 7.82, 11.3, 103, 447
Vyatka River estuary: Station no. 6, Oct 17, 3.6, 1.1, 9.8, 8.8, 10.1, 87, 406
Upstream the Vyatka River confluence: Stations nos. 7-9, Oct 17, Oct 19, 8.4, 1.3, 10.8, 8.2, 9.0, 80, 445

Table 2. The amount of detrital particles and the content of organic carbon (biomass)

| Detritus     | Abundance (10⁵ particles L⁻¹) | Biomass (μg C L⁻¹) | Specific electrical conductivity (μSm cm⁻¹) |
|--------------|------------------------------|--------------------|------------------------------------------|
| Picodetritus | upstream the confluence      | Vyatka River       | downstream the confluence                | upstream the confluence | Vyatka River | downstream the confluence |
|              | 192,024                      | 22,725             | 122,607                                   | 15,03                     | 2,00          | 12,60                          |
|              | 17,044-787,791               | 90,699-147,712     | 2,76-51,45                               | 30,58-465,27              | 81,60-307,40  |
| Nanodetritus | 75,972                       | 88,138             | 192,76                                   | 7,45                      | 81,60-307,40  |
|              | 26,512-130,668               | 45,450-180,798     | 30,58-465,27                             |                           |               |
| Total        | 268,001                      | 210,205            | 207,79                                   | 9,48                      | 244,34        |

* - here and in the tables 3, 4: number above the line is the mean value, below the line, variation limits
3.2. Components of plankton community

3.2.1. Phytoplankton. In total, 108 taxa of algae were recorded (taxonomic rank below genus) in the phytoplankton community of the upper part of the Kamsky Reach of the Kuibyshev Reservoir. Meantime, the species richness varied greatly, from 8-9 species in the upper part of the reach to 73 species in the Vyatka River. The taxonomic structure of the algal community in these areas also differed. In the Kama River, upstream of the confluence of the Vyatka River, diatoms played the main role in total species richness of algae; in the Vyatka River, these were green algae. The influence of the Vyatka River on the taxonomic structure of the algal flora was tracked even downstream the confluence, where green algae still dominated. The similarity of the algal flora of the Vyatka River phytoplankton was significantly higher when comparing to that of the downstream section (55%) than of the upper part of the Kamsky Reach (15.6%).

During the study period, the species diversity index (by abundance) was significantly higher than that by biomass. This was due to the fact that large diatoms predominated in phytoplankton, making up 90% of the total biomass. Highest phytoplankton abundance was noted in the Vyatka River, highest biomass, in the upper sections of the Kamsky Reach. However, the phytoplankton community of the upper part of the Kamsky Reach was distinguished by a higher evenness.

Table 3. Abundance and biomass of components of plankton community

| Groups                        | Abundance (10³ cells L⁻¹) | Biomass (μg C L⁻¹) |
|-------------------------------|---------------------------|--------------------|
|                               | upstream the confluence   | Vyatka River       | downstream the confluence | upstream the confluence | Vyatka River       | downstream the confluence |
| Bacillariophyceae             | 72⁵                        | 3.724              | 1.131                   | 16.31                   | 1189.7             | 301.88                  |
| Other eukaryotic algae        | 39                        | 3120               | 583                     | 1.55                    | 62.71              | 15.53                   |
| Cyanobacteria, including picoc | 4377                      | 36-11 366          | 6.713                   | 0.37-4.32               | 8.26               | 3.35                    |
| Heterotrophic bacteria        | 3.506 964                 | 3 050 601-4 880    | 1 031 877               | 4 144 130-5 095        | 136.01             | 39.39                   |
| Ciliates                      | 441                       | 0.095              | 3.744                   | 0.104-3.504             | 0.25               | 5.95                    |
| Rotifera                      | 0.009                     | 0.020-0.248        | 0.100-0.034             | 0.02-0.55               | 0.00               | 0.90                    |
| Crustaceae                    | 0.26                      | 0.13-0.44          | 0.13-0.31               | 0.13-0.31               | 0.25               | 20.72                   |
| Plankton                      | 8 849                     | 19 238             | 20 839                  | 164.09                  | 1308.77            | 484.17                  |

The quantitative indicators of phytoplankton also varied within wide limits: in the Vyatka River, the phytoplankton abundance was 7.9 ×10⁶ cells L⁻¹, in the Kama River, upstream the confluence of the Vyatka River, only 0.14 ×10⁶ cells L⁻¹, and downstream the confluence, 1.9 ×10⁶ cells L⁻¹. The average biomass varied even more and amounted to 8.98, 0.13, and 0.96 mg L⁻¹, respectively (table 3). Cyanobacteria, including unidentifed picocyanobacteria, dominated by abundance, diatoms, by biomass (table 3). In the Vyatka River and in the Kama River (downstream the Vyatka River confluence), they accounted for 94% of the phytoplankton biomass, and upstream the confluence, for 83%. In the Vyatka River, picocyanobacteria formed 33% of the total cyanobacteria biomass (or 1% of the total biomass of phytoplankton), in the Kama River, 56% (or 6%), respectively.

The composition of the dominant complex of algal species also differed in the studied areas (table 4). In the Vyatka River, the diatom Stephanodiscus hantzschii Ehr. was the absolute dominant in phytoplankton both by abundance and biomass, accounting for 34% of the total abundance and 88% of the total biomass. This species was accompanied by Dictyosphaerium subsectorium von Goor.
(Chlorophyta), dominating at station no. 8. In the upper part of the Kamsky Reach of the Kuibyshev Reservoir, where low phytoplankton diversity was observed, "random" species of different algae divisions, which usually did not reach significant development, dominated by abundance. However, *Stephanodiscus hantzschii* prevailed in terms of biomass in the entire study area, with rare exceptions.

**Table 4.** Species richness, species diversity, and community structure of plankton in the lower reaches of the Kama River (by abundance)

| Number of species | Shannon index | Pielou's index | Dominants and subdominants |
|-------------------|---------------|----------------|---------------------------|
| **Phytoplankton** |               |                |                           |
| Upstream the confluence with the Vyatka River | 11.8 | 2.33 | 0.83 | *Stephanodiscus hantzschii* Ehrl. (15.1%); *Chroomonas acuta* Uterm. (15.1%); *Microcystis aeruginosa* (Kütz.) Kütz. (14.0%); *Fragilaria virescens* Rafls (12.8%); *Cryptomonas caudata* Schiller (5.8%); *Stephanodiscus hantzschii* (34.8%); *Dictyosphaerium subsolitarius* von Goor (23.2%); *Pseudanabaena limnetica* (Lemmermann) Komárek (6.1%); *Aulacoseira alpigena* (Grun.) Krammer (5.0%)
| Vyatka River estuary | 73 | 2.56 | 0.59 |                               |
| Downstream the confluence with the Vyatka River | 40.3 | 2.59 | 0.67 | *Stephanodiscus hantzschii* (36.7%); *D.subsolitarius* (12.8%); *Aulacoseira alpigena* (Grun.) Krammer (6.2%); *Limnothrix planctonica* (Wolosz.) Meffert (4.9%)
| **Ciliates** |               |                |                           |
| Upstream the confluence with the Vyatka River | 8 | 2.44 | 0.87 | *Rimostrombidium hyalinum* (Mirabudalæv, 1985) (40.0%); small *Uroticha* spp. (10.0%); *Tintinnopsis cylindrata* Kof. & Cam., 1892 (6.7%); *Uroticha pelagica* Kahl, 1932 (5.8%)
| Vyatka River estuary | 29 | 2.09 | 0.71 | *R. hyalinum* (65.7%); *Uroticha* spp. (15.5%)
| Downstream the confluence with the Vyatka River | 18 | 2.89 | 0.72 | *R. hyalinum* (54.0%); *Uroticha* spp. (6.9%); *R. humile* (Penard, 1922) (5.7%); *T. cylindrata* (5.1%)
| **Metazooplankton** |               |                |                           |
| Upstream the confluence with the Vyatka River | 5 | 1.32 | 0.92 | Copepodes of Calanoida (39.3%), nauplii of Calanoida (22.1%), *Chydrorus sphaericus* (Müller, 1776) (10.3%), *Disparalona rostrata* (Koch, 1841) (3.5%)
| Vyatka River estuary | 8 | 1.16 | 0.84 | Copepodes of Calanoida (35.8%), nauplii of Calanoida (16.3%), *Keratella cochlearis cochlearis* (Gosse, 1851) (16.1%)
| Downstream the confluence with the Vyatka River | 10 | 1.44 | 0.57 | Copepodes of Calanoida (38.7%), nauplii of Calanoida (16.3%), *Keratella serrulata serrulata* (Ehrenberg, 1838) (6.3%), *Keratella quadrata quadrata* (Müller, 1876) (5.1%)

3.2.2. *Heterotrophic bacterioplankton*. In October 2020, in the lower reaches of the Kama River, the bacterioplankton abundance varied from 2.87 to 5.10 × 10^6 cells mL^-1 (on average, 3.88 ± 0.85 × 10^6 cells mL^-1), biomass, from 94.7 to 172.0 μg C L^-1 (on average, 137.2 ± 27.8 μg C L^-1). The lowest bacterioplankton abundance and biomass were observed in the Vyatka River (table 3). The spatial distribution of the abundance and biomass of bacterioplankton in October 2020 had an oscillatory character without a pronounced trend towards an increase or decrease along the stream.
The single-cell cocci and coccobacilli formed the basis of bacterioplankton in both the Kama and Vyatka rivers (78 ± 10% of the total abundance and 73 ± 10% of the total biomass). However, in the Vyatka River, the contribution of the smallest cells (< 1 μm) was higher. In addition, the share of cocci was about 40% of the abundance and biomass of bacteria in the Vyatka River, while in Kama it was about 30%. No significant influence of the tributary inflow was found on the abundance, biomass, and structure of bacterioplankton of the Kama River. The average volume of bacterial cells in the sample varied from 0.081 to 0.341 μm³, non-monotonic decrease of this parameter was noted toward downstream of the Kama River.

3.2.3. Ciliates. Ciliates are an important component of the planktonic community, despite their low abundance compared to other components (table 3). In the study area, 48 species of ciliates were identified. In the Vyatka River, ciliates were more diverse (36 species) than in the Kama River (32 species); the similarity of the species diversity was 62%. However, in the Vyatka River, the ciliate community was characterized by lower evenness; the Pielou’s index was 0.43 in the Vyatka River versus 0.87 and 0.72 in the Kama River, upstream and downstream the confluence of the Vyatka River, respectively. Therefore, in general, the species diversity in the Vyatka River community ($H = 2.09$) was lower than that in the Kama River communities upstream and downstream the confluence ($H = 2.44$ and $H = 2.89$, respectively) (table 4). Certain influence of the ciliate fauna of the Vyatka River on that of the Kama River was evidenced by higher similarity of ciliate community of the Kama River downstream the confluence to the ciliate fauna of the Vyatka River (66%) than with ciliate community of the Kama River upstream the confluence of the Vyatka River (52%).

The abundance and biomass of ciliates was higher in the Vyatka River. The community of ciliates of this tributary has a significant impact on the community of ciliates of the Kama River downstream the confluence (table 3). Earlier (August 2016), a maximum abundance (4,980 cells L⁻¹) and biomass (124 mg m⁻³) was reported for this area [4]. In the downstream of the Nizhnekamsk HPS, the abundance and biomass of ciliates were minimal (table 3). In the Kama River, at different stations, the main structure-forming species were Balanion planctonicum Foissner et al., 1994 (10-20%), Pelagostrombidium mirabile (Penard, 1916) Krawler, 1991 (18%), Tintinnidium fluviatile Stein, 1863 (17%), Urotricha pelagica Kahl, 1932 (14-20%), small-size Urotricha (12%), Histioabalantium sp. (H. bodamicum Krainer & Muller, 1995) (7%), Mesodinium pulex (Clap.et L., 1859) (6%), etc., in addition to the main dominants (table 4). In the ciliate community of the Vyatka River, Pelagovorticella natans (Faure-Fremiet, 1924) Jankowski, 1985 (3.5%), Phascolodon vorticella Stein, 1859 (2.9%), and R. humile (Penard, 1922) (3.1%) were dominants in addition to those indicated in table 2.

In the trophic structure of ciliate community of the Vyatka River, the contribution of herbivorous was high (71% of the abundance) against 58% in the Kama River; on the contrary, the contribution of predators was low (21% and 31%, respectively). Mixotrophic ciliates, an important ecological group, played a greater role in the Kama River (11% of the abundance and 20% of the biomass) comparing with that in the Vyatka River (1% and 13%, respectively), which indicated indirectly lower trophic state of the Kama River.

3.2.4. Metazooplankton. This group includes drifting multicellular organisms, which are an integral component of the food chain in any water body. In total, 33 zooplankton species have been identified in the study area, including the estuary of the Vyatka River. Rotifera were represented by 16 species (48.4% of the total number of species), Crustacea, by 17 species (51.5%), of which Cladocera comprised 12 species (36.6%) and Copepoda, 5 species (15.1%). Species composition of zooplankton in the Vyatka River was less diverse (4 species versus 30 species in the Kama River), despite its high evenness (the Pielou’s index was 0.95 in the Vyatka River versus 0.78 and 0.79 in the Kama River, upstream and downstream the confluence of the Vyatka River, respectively). In general, the species diversity of the zooplankton community of the Vyatka River was lower ($H = 1.16$) than that of the Kama River upstream and downstream the confluence ($H = 1.32$ and $H = 1.44$) (table 4). Fauna of
metazooplankton of the Vyatka River was similar to that of the Kama River by 34%. The fauna of the Vyatka River affected the fauna of the Kama River, which evidenced by higher similarity of the zooplankton community of the Kama River downstream the confluence of the tributary with the fauna of the Vyatka River (44%) than with the fauna upstream the confluence of the Vyatka River (26%). Zooplankton community of the Vyatka River differed quantitatively (abundance of 346 ind. L⁻¹ and biomass of 0.01 g m⁻³) from the zooplankton community downstream the confluence (236 ind. L⁻¹ and 0.18 g m⁻³) and upstream the confluence with the Kama River (212 ind. L⁻¹ and 0.26 g m⁻³, respectively) (table 3). In general, copepodites of all ages and several adult females of the Caspian invader *Eurytemora caspica* (56% by the abundance), the rotifers *Keratella cochlearis cochlearis* (Gosse, 1851) (11%) and *Keratella quadrata quadrata* (O.F. Müller, 1786) (~5%) dominated in the Kama and Vyatka rivers (table 4).

3.3. **Structure of plankton community in the Kama and Vyatka rivers**

The absolute biomass of plankton in the Kama River upstream the confluence of the Vyatka River was relatively low, but increased almost threefold downstream the confluence (table 2, figure 3). This was due to the introduction of large-celled diatoms with the waters of the Vyatka River (table 2, figure 3, 5), which provided a high total biomass of plankton in this tributary. Differences in the phytoplankton abundance and biomass, and the content of suspended matter in the Kama and Vyatka rivers were clearly seen on satellite images (figure 4).

![Figure 3. Spatial distribution of detritus amount and of plankton community structure at different stations of the lower course of the Kama River](image)

Plankton biomass decreased as the distance from the confluence increased (figure 3). The waters of the Kama River carried a large amount of detritus (43% of the seston biomass on average) (figure 5a) compared to the waters of its tributary, the Vyatka River, where the proportion of detritus did not exceed 1% (figure 5a). In addition, a larger fraction (3-15 μm) of nanodetritus was not found in the Vyatka River (figure 5a). Small rotifers and ciliates consumed picodetritus as a food [18]. In the studied period, in the Vyatka and Kama rivers, nanodetritus formed the basis of detritus biomass; therefore, the total detritus biomass negatively correlates with that of ciliates ($R = -0.23$) and rotifers ($R = -0.33$). In general, three main components prevailed in the seston in the study area: detritus, heterotrophic bacteria, and diatoms; their ratio varied in depending on the station (figures 3, 5). The contribution of plankton to the total seston biomass was 44-66% in the Kama River and 99% in the
Vyatka River (figure 5a). Upstream the confluence of the Vyatka River, mainly heterotrophic bacteria prevailed, but in the Vyatka River and downstream its confluence, diatoms prevailed (figure 5b).

Upstream the confluence of the Vyatka River, bacteria dominated in the plankton community of the Kama River, comprising 83% of the total biomass, followed by diatoms (10%) and crustaceans (4%). In the Vyatka River, diatoms (mainly *Stephanodiscus hantzschii*) dominated by biomass (91%). All other components played a minor role, and the share of bacteria was only 3%. Downstream the confluence of the Vyatka River, the plankton community of the Kama River transformed, manifested in a high contribution of diatoms (up to 63% of the total biomass), a decrease in share of bacteria (down to 29%) and crustaceans (down to 3%). Downstream the confluence of the Vyatka River, at different stations, the proportions of bacteria (17-51%) and *Stephanodiscus hantzschii* (26-68%) were comparable, although the contribution of the latter was higher on average (55% versus 29% of bacteria).

*Stephanodiscus hantzschii* is capable of heterotrophic feeding [19, 20] and develops en masse at a high content of dissolved organic matter. Its dominance in the plankton of both rivers (table 3) most likely indicates the regional features of the Kama River basin. In August 2009 and 2016, it was also abundant in this area and in the Nizhnekamsk and Votkinsk reservoirs located upstream [5]. The maximum development of this species in the Vyatka River indicates its higher trophic status, which also affects the plankton structure and the trophic state in the section of the Kama River downstream their confluence. Dredging in the area of the stations nos. 3, 5, and 6 had no effect on plankton and detritus.

Canonical analysis evidenced on a clear grouping of the structural components of plankton into three groups: the Kama River community upstream the confluence with the Vyatka River, the Vyatka River community, and the transformed community downstream of the Vyatka River confluence (figure 6). Plankton community at station no. 9 (downstream of the Sheshma River confluence), the most distant from the confluence of the Vyatka River, was most similar to the non-transformed
community of the Kama River; however, the leading role of diatoms brought in by the waters of the Vyatka River still remained. In addition, there was a specific community of organisms developing directly downstream the dam of the Nizhnekamsk HPS (station no. 1). A specific ratio of the components of the planktonic community and a reduced content of detritus were noted here (Fig. 3, 6), preconditioned by the operating mode of the Nizhnekamsk HPS.

![Graph showing share of different components of seston and plankton by biomass.](image)

**Figure 5.** Share of different components of seston (a) and plankton (b) by biomass.

![Graph showing CCA ordination of samples.](image)

**Figure 6.** CCA ordination of samples.

Cyan – Cyanobacteria, Bacil – Bacillariophyceae, Crypt – Cryptophyta, Chlor – Chlorophyta, B – heterotrophic bacteria, Cil – Ciliates, Rot – Rotifera, Clad – Cladocera, Cop – Copepoda; S – Secchi disk depth (m), Ox and Oxsat – oxygen content (mg L⁻¹) and oxygen saturation (5) Cond – specific electrical conductivity (μSm cm⁻¹), Dpico – biomass of detritus pico fraction (μg C L⁻¹), Dnano – biomass of detritus nanofraction (μg C L⁻¹).

According to the data of the Vyatskie Polyany hydrological post, the runoff of the Vyatka River during the study period was about 490 m³ s⁻¹ regardless of the day of the week (http://gis.vodinfo.ru/hydrographs/map/hydropost/76574). On the contrary, the runoff of the Kama
River was strongly influenced by the operating mode of the Nizhnekamsk HPS: on working days, it was about 2,500 m$^3$ s$^{-1}$, and on weekends, 900 m$^3$ s$^{-1}$ (figure 2) (hydrological post Nizhnekamsk HPS, http://gis.vodinfo.ru/hydrographs/map/hydropost/76965). Despite lower volume of runoff in the Vyatka River, the amount of organic carbon (g C s$^{-1}$) brought with its waters was comparable to that in the Kama River:

|                | total, g C s$^{-1}$ | including: detritus, g C s$^{-1}$ | plankton, g C s$^{-1}$ |
|----------------|---------------------|-----------------------------------|------------------------|
| Vyatka River   | 646                 | 4.6                               | 641.1                  |
| Kama River (working days) | 944.5 | 539.1                             | 405.4                  |
| Kama River (weekends)     | 340                 | 194.1                             | 146.0                  |

Therefore, the plankton of the Vyatka River is very important for the formation of the organic matter stock in the lower course of the Kama River, and its quantitative contribution is determined by the weekly operation of the HPS (figure 2). According to our calculations, 81% of the total organic carbon of plankton on weekends, and 61% on working days, are brought to this part of the Kama River with the waters of the Vyatka River. On the contrary, detritus mainly comes directly from the Kama River waters (more than 97%). In the late autumn period, the transport of plankton with the Vyatka River waters is quite significant and has a strong impact on the formation of downstream communities both in the Kama River and in the Volga River in the area of their confluence.

3.4. Assessment of the ecosystem state by biotic indices

The degree of organic pollution of the Kama and Vyatka rivers was mesosaprobic as estimated by the saprobity coefficients for different groups of plankton organisms [21]. According to a most of indicator species, the degree of saprobity in the Vyatka River was higher than that in the Kama River, but it was within the mesosaprobic range.

The trophic status, assessed by the water transparency, was eutrophic for both rivers. However, the estimates of the trophic status based on biotic parameters were somewhat lower. In particular, according to the phytoplankton biomass [19, 22] the Vyatka River was eutrophic, the section of the Kama River upstream the Vyatka River estuary was oligotrophic, downstream the confluence, mesotrophic. According to the ciliate abundance, the Kama River belonged to ultraoligotrophic type, the Vyatka River, to oligotrophic type [23]. According to the zooplankton biomass [22], the waters of the Kama River were mesotrophic, of the Vyatka River, ultraoligotrophic. According to our observations, low trophicity of water bodies, estimated by ciliate abundance and zooplankton biomass, was associated with a seasonal minimum in the consumers’ development and thus did not reflect real trophic state. An overestimation of the trophic level in terms of water transparency was due to the large amount of suspended mineral and organic matter in the Kama River. Therefore, we believe that the assessment of the trophicity of the water body is more indicative by the state of phytoplankton.

4. Conclusion

Our data make it possible to get new facts necessary for understanding the development and succession of the plankton community and the entire seston in the Kama River in the late autumn period and to assess the influence of a large tributary on these processes. The Kama River carry a large amount of detritus, but in the Vyatka River, plankton forms 99% of seston. Therefore, the influence of this tributary on the seston parameters in the Kama River (within the Kama Reach of the Kuibyshev Reservoir) is manifested in a decrease in the contribution of detritus brought by the Kama River waters, due to their "dilution" with the water masses of the Vyatka River.

The Vyatka River is characterized by higher biomass of plankton, which affects the quantitative indicators of the Kama River community downstream the confluence of this tributary. The transformation of the structure of the plankton community under the influence of the Vyatka River waters is manifested in the change of one leading group (heterotrophic bacteria) to another (diatoms). In general, despite the lower volume of the Vyatka River runoff compared to that of the Kama River, the share of plankton organic matter brought by the tributary is 81% on weekends, and 61% on
working days downstream the confluence of the two rivers. Thus, the influence of the Vyatka River waters on the Kama River ecosystem in its lower course and further on in the Volga River is quite pronounced and increases even more on weekends with a reduced amount of runoff through the hydroelectric power station. This largely affects the pattern of the trophicity level of the Kama River, from oligotrophic (upstream the confluence the Vyatka River) to mesotrophic (downstream the confluence).

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