Distribution of picoplankton and detritus in the lower course of the Kama River

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Abstract. The distribution of picoplankton and detritus in the lower course of the Kama River in 2009, 2012, 2016 and 2020 was analyzed. The abundance (1.5-6.7 ×10^6 cells mL⁻¹) and biomass (25-173 μg C L⁻¹) of picoplankton corresponds to the mesotrophic level. The abundance and biomass of the heterotrophic picoplankton increases from spring to autumn, the autotrophic picoplankton has maximum in August. The amount (17-1367 ×10^3 particles mL⁻¹) and mass (0.1-62 μg С L⁻¹) of picodetritus varies greatly from station to station without clear patterns, but basically its mass is higher at coastal stations. Heterotrophic picoplankton prevails in picoseston structure; the average APP and picodetritis contributions are comparable, with little excess of picodetritus. The structure of the picoseston varies significantly depending on the season and the riverbed or the coastal location of the station. The amount of nanodetritus is very high (up to 229×10^3 particles mL⁻¹ and 662 μg C L⁻¹), and it varies slightly both in space and in time. Its mass is almost always several times higher than the biomass of picoseston. Most likely, nanodetritus is one of the main factors affecting the plankton of the lower course of the Kama River.

1. Introduction
In aquatic ecosystems, the size of organisms is of great importance for understanding the processes occurring in them. Traditionally, the picoplankton fraction includes all organisms whose size is <2 μm [1]. However, given the significant variability of microbial cells, especially colonial ones, many authors extend the size range of picoplankton to 3 μm or even 5 μm [2, 3]. The picoplankton is composed of heterotrophic bacteria (heterotrophic picoplankton, HPP), cyanobacteria (Prochlorococcus spp. and Synechococcus spp.) and small eukaryotic algae (autotrophic picoplankton, APP) [4, 5]. In addition to living organisms, suspended mineral particles and non-living organic particles (detritus) in the pico- and nano-size range (largest dimension 0.5 to 20 μm) are present in the water column [6]. Under certain environmental conditions and the type of water body, picoplankton and picodetritus together can make a significant contribution to the biomass of seston in freshwater ecosystems [5-7].

Although the ratio of heterotrophic and autotrophic picoplankton, their interdependence and the features of spatial distribution have not been studied in all reservoirs of the Volga-Kama cascade [5, 8-10], the available data indicate the important role of picoplankton in the ecosystems of reservoirs of the Volga and Kama rivers. Unfortunately, data on the distribution of pico- and nanodetrites and their role in the ecosystems of the Volga and Kama reservoirs are even more incomplete [10-12]. For the
lower Kama River section, from the dam of the Nizhnepinsk hydroelectric power station (HPS) to the confluence with Volga River, data on the spatial and temporal distribution of autotrophic and heterotrophic picoplankton and detritus are currently almost absent.

Here we report the distribution of autotrophic- and heterotrophic picoplankton (APP and HPP) and pico- and nanodetritus in the lower course of the Kama River at different periods of the year.

2. Materials and Methods

Heterotrophic and autotrophic picoplankton and detritus were studied in the lower course of the Kama River from the Nizhnepinsk HPS (Naberezhnye Chelny city) to its confluence with the Volga River (Kamske Ust’e settlement) in different periods (table 1). The study area was conditionally divided from upstream to downstream into 3 parts with different morphological and hydrological conditions: Part I (Nizhnepinsk HPS - Sokolka); Part II (Kamskie Polyany - Alekseyevskoe) and Part III (Sorochi Gory - Kamskoe Ustye). Water samples were taken with a Ruttner bottle from the surface and bottom horizons; in August 2016, an additional integral sample was taken by mixing subsamples from entire water column with 1 m step. The samples were fixed with a sterile formalin solution to a final concentration of 4% and then concentrated by filtering aliquots through membrane filters with a pore diameter of 0.2 µm. The abundance of HPP was determined with DAPI staining [13]. The abundance of APP was determined by the autofluorescence of chlorophyll a, counting all cells with size less than 3 µm. The cell sizes were estimated using the UTHSCSA Image Tools 3.00 image analysis software. The biomass of the picoplankton cells in units of organic carbon was calculated based on the data on the carbon content in cells [5, 14]. The number of pico- and nanodetritus particles and their mass (carbon content) were determined as in [6, 7].

| Table 1. Brief characteristic of sampling conditions |
|-----------------------------------------------------|
| Period | 14-15 | 14-15 | 19-22 | 19-20 | 17-19 |
| Number of stations | 3 | 4 | 8 | 7 | 9 |
| Part of the river | coastal | coastal | riverbed | riverbed | riverbed |
| Depth (m) | 2.0 - 3.0 | 3.0 - 10.0 | 4.0 - 11.0 | 9.0 - 23.0 | 3.6 - 11.0 |
| Temperature (°C) | 21.3 | 22.48 | 23.58 | 25.0 | 10.43 |
| Transparency (m) | 0.9 - 1.2 | 1.0 - 2.7 | 0.5 - 1.7 | 0.9 - 1.4 | 0.9 - 2.1 |
| Dissolved oxygen (mg L⁻¹) | 7.07 - 13.1 | 6.46 - 10.40 | 7.28 - 14.46 | 5.74 - 10.22 | 6.7 - 13.4 |
| pH | 8.0 | 8.29 | 8.18 | 8.27 | 8.05 |
| Water discharge (m³ s⁻¹) | 3819 - 4508 | 2117 - 3856 | 1246 - 2390 | 987 - 2307 | 885 - 2634 |

| a | – number above the line is the mean value, below the line, variation limits |
| b | – according to data from hydrological post of the Nizhnepinsk HPS (http://gis.vodinfo.ru/) |
| c | – data from [15] |

3. Results and Discussion

In the lower course of the Kama River abundance and biomass of heterotrophic and autotrophic picoplankton varied significantly depending on the sampling time and distance from the Nizhnepinsk HPS dam (figure 1, table 2). No clear spatial patterns in the distribution of picoplankton were revealed, possibly due to the uneven distribution of stations over the study area on different dates (figure 1, table 2). On average, the abundance (but not biomass) of HPP increases slightly from...
upstream to downstream, no similar trend was found for APP. HPP biomass was usually slightly higher at riverbed stations and APP, at coastal stations (figure 2). HPP biomass increased more or less monotonously from June to October, but the difference between July and August was insignificant. On average, the highest APP development was registered in August, and the lowest in October (figures 1, 3, table 2).

Figure 1. Distribution of abundance and (bio)mass of heterotrophic picoplankton (a, b), autotrophic picoplankton (c, d), picodetritus (e, f) and nanodetritus in the lower course of the Kama River in different periods. Distance axis: 0 – near the dam of the Nizhnekamsk HPS; 62 – Sokolka settlement; 77 – Kamskie Polyany; 177 – Alekseevskoe; 228 Kamskoe Ustye.
The number, mass, and size of picodetrital particles in the lower course of Kama River are comparable to those in the Upper Volga and Kama reservoirs [10-12]. No explicit spatial or seasonal change was revealed in its distribution. However, it was noted that the number and mass of picodetritus in the coastal sites was 2-5 times higher than in the riverbed (table 2, figure 3). Apparently, this is a distinctive feature of the lower course, since in the Votkinsk and Nizhnekeamsk reservoirs, picodetritus was more abundant at the riverbed stations [10].

There are very few data on the presence and distribution of nanodetritus in freshwater ecosystems. In the lower course of the Kama River, the number of nanodetrital particles reached $229 \times 10^3$ particles mL$^{-1}$ at some stations (on average $82 \pm 55 \times 10^3$ particles mL$^{-1}$), which was 4-10 times more than in the Upper Volga and in the Verkhnevolzhsky Reservoir [11, 12]. During the studied period in the lower course of the Kama River the size range of nanodetrital particles was 2.1-15 μm. Their mass was quite stable throughout the studied water area (table 2, figure 3), except for some stations where it sharply reduced for unknown reasons (figure 1). Due to the large size variability of nanodetrital particles, the distribution of their mass and amount differs more significantly than it does for picodetritus. No significant differences in the quantity of nanodetritus between the riverbed and coastal stations were found (figure 2).

The number of nanodetritus was significantly less than the amount of picodetritus, but its mass was 5-200 times higher over the whole study period at almost all stations (figure 1 (e-h), table 2). The nanodetritus mass exceeded the picoplankton biomass (1.1-11.8 times) in 66% of the samples; it was comparable (accounting for 82-93% of the picoplankton biomass) in 11% of the samples, and was less than the picoplankton biomass (6-72%, on average 32% of the picoplankton biomass) in 24% of the samples (figure 1, table 2).

Table 2. Average abundance and (bio)mass of heterotrophic (HPP) and autotrophic (APP) picoplankton and detritus in different parts of the lower course of the Kama River

| Abundance                          | Bio)mass          |
|------------------------------------|-------------------|
| HPP (10$^3$ cells mL$^{-1}$) | HPP (µg C L$^{-1}$) |
| APP (10$^3$ particles mL$^{-1}$) | detritus          |
| picodetritus                       | nano              |
| detritus                           |                  |

**Part I** (Nizhnekeamsk HPS - Sokolka)

|   | HPP | APP | detritus | HPP | APP | detritus |
|---|-----|-----|----------|-----|-----|----------|
| June 2012 | 1540 | 8   | 26       | 31  | 24,5 | 0,6      |
| July 2016 | 2261 | 37  | 94       | 33  | 54,5 | 17,0     |
| August 2016 | 1815 | 164 | 96       | 79  | 50,4 | 34,8     |
| October 2020 | 3613 | 7   | 181      | 88  | 138,9| 2,2      |
| all period | 2761 | 41  | 129      | 66  | 90,5 | 11,6     |

**Part II** (Kamskie Polyany - Alekseevskoe)

|   | HPP | APP | detritus | HPP | APP | detritus |
|---|-----|-----|----------|-----|-----|----------|
| June 2012 | 2649 | 124  | 100      | 79  | 48,4 | 1,2      |
| July 2016 | 2454 | 129  | 925      | 143 | 43,3 | 24,9     |
| August 2016 | 2706 | 17   | 188      | 64  | 76,2 | 6,4      |
| October 2020 | 4685 | 323  | 222      | 132 | 103,4| 48,8     |
| all period | 3130 | 95   | 357      | 93  | 133,3| 1,5      |

**Part III** (Sorochi Gory - Kamskoe Ustyoe)

|   | HPP | APP | detritus | HPP | APP | detritus |
|---|-----|-----|----------|-----|-----|----------|
| July 2009 | 1763 | 94   | 432      | 101 | 32,6 | 14,1     |
| July 2016 | 4614 | 17   | 155      | 102 | 111,3| 3,1      |
| August 2016 | 3655 | 80   | 135      | 74  | 79,6 | 8,8      |
| all period | 3316 | 62   | 232      | 93  | 74,0 | 8,6      |

*a* – average value for all sampling dates
Like in other reservoirs of the Volga-Kama cascade [8-12], the basis of the picoseston biomass in the lower course of Kama River is formed by heterotrophic picoplankton, which determines the pattern of its seasonal dynamics (figures 1, 3, 4, table 2). The average contribution of HPP to the total picoseston biomass in the lower course of the Kama River was 73.4±20.7%. The contributions of APP and picodetritus varied in the range 0-50% of the total picoseston biomass depending on the station location and season. The average APP and picodetritus contributions are comparable, with some excess of the proportion of picodetritus (table 3). However, in July-August, at half of the riverbed stations the opposite situation was observed: the average APP share was 21.8%, and of picodetritus - 8.6%. During the entire observation period, the share of picodetritus in the total picoseston biomass remained relatively stable, with the exception of coastal stations in July (table 3). No significant differences were found between the average picoseston structure and the pattern of its seasonal changes from upstream to downstream of the Kama River lower course (figure 4, table 3).

Figure 2. Average (bio)mass (μg C L⁻¹) of HPP, APP, pico- and nanodetrital particles in riverbed and coastal stations in July

Figure 3. Seasonal dynamics of picoplankton biomass (μg C L⁻¹) and detritus mass (μg C L⁻¹) in the lower course of Kama River. Average data are calculated without taking into account the location of the station and the year of sampling. The error line - standard deviation of the value.
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Figure 4. Seasonal changes of picoseston biomass structure in the whole lower course (a) and in its upper (part I; b) and medium (part II; c) sites.

Table 3. The structure of picoseston biomass in the Kama River lower course: temporal and spatial variance

|                | HPP (%) | APP (%) | Picodetritus (%) |
|----------------|---------|---------|------------------|
| June           | 84.4±8.2 | 2.0±0.3 | 13.6±8.5         |
| July, riverbed | 79.0±13.3 | 9.8±10.9 | 11.2±7.3         |
| July, coastal  | 40.3±7.2 | 20.1±6.2 | 39.5±5.0         |
| August         | 71.9±18.7 | 19.0±19.8 | 9.1±3.5         |
| October        | 89.9±8.2 | 1.3±1.4 | 8.9±8.4         |
| Part I         | 80±17   | 11±15   | 9±7              |
| Part II        | 68±23   | 12±13   | 20±15            |
| Part III       | 73±21   | 10±10   | 18±13            |
| the lower course | 73±20 | 11±13 | 16±13 |

* mean ± standard deviation

4. Conclusions

Despite the significant differences in the location and number of sampling stations in different years, the presented data allow us to assess the distribution of picoplankton and detritus and to reveal some features of the picoseston structure in the studied parts of Kama River lower course:

- In general, the abundance and biomass of picoplankton corresponds to the mesotrophic level. The abundance and biomass of the heterotrophic picoplankton increases from spring to autumn, the autotrophic picoplankton has maximum in August.
- The amount and mass of picodetritus varies greatly from station to station without clear patterns, but basically its mass is higher at coastal stations.
- The structure of the picoseston (in terms of the contribution of individual components to the total organic carbon) varies significantly depending on the season and the riverbed or the coastal location of the station. No regular changes were found in the picoceston structure from upstream to downstream.
- The amount of nanodetritus is very high (up to $229 \times 10^3$ particles mL$^{-1}$ and 662 µg C L$^{-1}$), and it varies slightly both in space and in time. Its mass is almost always several times higher than the biomass of picoseston. Most likely, nanodetritus is one of the main factors affecting the plankton of the lower course of the Kama River.
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