The effects of climate change on the development of phytoplankton in the Uchinsk Reservoir of the Moscow Canal

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Abstract. In the climate of European Russia, there are significant changes: before the year 2010, the tendency of warm period temperature to drop with a simultaneous increase in precipitation was dominated but nowadays it is dominated a reverse trend to increase average and maximum temperatures, decrease in precipitation, and increase in the number of sunny days. This creates the most favourable conditions for the development of phytoplankton and zooplankton consuming it. Our research exemplified by the Uchinsky Reservoir has established that since 2010 the number of phytoplankton has been increasing multiply with the development of blue-green algae at the end of the warm period, and it adversely affects the quality of water, leading to the development of eutrophication processes. The factors limiting the number of phytoplankton are the development of zooplankton and almost total consumption of ammonium nitrogen by phytoplankton. To manage the development of phytoplankton due to the most favourable climate conditions, a set of measures is required to reduce the intake of biogenic elements into the water of the Reservoir.

1. Introduction

The climate changes observed in recent decades have an impact on the natural environment, thereby changing the availability of natural resources for humans. One of the most important resources is clean water obtained from open water sources. So, the relationship between climate changes, aquatic biocenoses and water quality is a subject of constant scientific interest [1]. The entire ecosystem of the Reservoir reacts to changes [2]. For example, an increase in water temperature results in changes in the plankton composition and abundance [3, 4]. Climate changes, besides changes in temperature, lead to changes in the amount of precipitation, its distribution by season, and this changes the hydrological regime of reservoirs and can aggravate water erosion, and force the intake of nutrients into reservoirs [5]. As a result, the conditions for the development of planktonic organisms change significantly, that can lead to eutrophication of reservoirs and a decrease in water quality [1].

During the decade 2000–2009, the climate change trends expected a total increase in humidity, including the warm season, on the territory of Moscow and neighbouring regions, and also a gradual decrease in the air temperature of the summer months and the number of sunny days in the summer period was observed [6]. This tendency in climate-changing caused the development of water–logging processes in coastal areas of reservoirs, and the deterioration of conditions for the phytoplankton developing [7, 8]. From 2009 to 2010 in the climate of the European territory of Russia new trends have emerged, having a significant increase in temperatures during the warm period of the year with a
simultaneous decrease in precipitation during the year and especially in the summer period. These trends in climate change affect the hydrological regime of the rivers and reservoirs, which in turn changes the conditions for the development of aquatic organisms, in particular plankton. This paper attempts to trace the influence of climate-changing on the development of phytoplankton in the Uchinsky Reservoir of the Moscow Canal and its relationship with water quality indicators.

2. Materials and methods

Our research on the development of phyto and zooplankton, as well as the content of biogenic elements in water reservoirs, was conducted in the Uchinsky Reservoir of the Moscow Canal system [9, 10].

When studying the quantity and species diversity of phyto and zooplankton, their samples were taken using plankton nets. The collected samples were examined under a microscope to determine the species composition and abundance. The samples of water and phytoplankton were undergone to chemical analysis to determine the content of elements – biogens – the nitrogen compounds in the ammonium, nitrate and nitrite form, and the phosphorus and potassium compounds. The greatest attention was focused on detecting the content of ammonium nitrogen in different periods of the year in different parts of the water area, the main source of which is presumably agricultural activity, decomposition of organic residues in the water-collecting area of reservoirs and the entire Volga source. To identify changes in the abundance and species composition of planktonic organisms, changes in the chemical composition of reservoir water, the data obtained from the earlier studies were compared with the newly obtained data [9, 10].

3. Results and discussion

According to meteorological observations, in the European territory of Russia, the average temperature of the summer months for the period 1981–2010 was increased by an average of 0.5–1 degree compared to the period from 1961 to 1990 [6, 9]. At the same time, this increase was not constant. In the decade 2000–2009, there were trends of a gradual decrease in the temperature of the warm period with a simultaneous increase in the amount of precipitation, the number of cloudy days in the summer. The maximum temperatures in July decreased from 28 °C in 2002 to 22–23 °C in 2004–2009. In 2010 a sudden climate change was registered, the average temperature in July was 35 °C with a minimum of cloudy days and practically no precipitation during the warm period. Until 2019 the trend continued to increase summer temperatures and decrease the amount of precipitation in the summer period. If in the previous decade the number of clear days in July was 1–3, it became 8 or more since 2010. The exception was the years 2017 and 2019. The combination of warm water and clear days determined the most favourable conditions for the development of phytoplankton, the number of cells/ml, determined during the research in 2010 compared to 2005, increased several times, table 1.

| The sampling period | Number of phytoplankton by group, cells/ml | Total |
|---------------------|------------------------------------------|-------|
|                     | Diatomical algae | Green algae | Blue–green algae |       |
| July 2005           | 287            | 156         | 243              | 693   |
| August 2010         | 325            | 198         | 494              | 1,017 |
| July 2015           | 202            | 66          | 708              | 976   |
| August 2015         | 328            | 168         | 5,100            | 5,700 |
| July 2019           | 1,148          | 90          | 220              | 1,558 |
| August 2019         | 1,250          | 89          | 1,667            | 3,006 |
While in the cold period the phytoplankton is dominated by diatomic and green algae, in the late summer period there is an increase in the number of blue-green algae, the development of which has an obvious link with climatic indicators of the warm period, the highest temperature of the 2010 year corresponds to the maximum abundance of blue-green algae. Since 2002 the average annual number of phytoplankton was decreasing from 2200 cells/ml to 250 cells/ml in 2009. Since 2010 the average annual abundance has recovered at a slightly lower level, so we can establish a direct link between the changes in climate indicators and the development of phytoplankton, the increase in temperature with a decrease in precipitation is the most favourable and intensifies the eutrophication of the Reservoir. The species composition, the number of phytoplankton, and its change by the years are shown in table 2.

**Table 2.** The dynamics of the species composition and quantity of phytoplankton algae by seasons of 2015 in the water-consuming facility "Ucha".

| Name of phytoplankton algae genera | The algal groups | Number of cells in 1 ml of water | Percentage (%) of the total number of algae cells in 1 ml of water |
|-----------------------------------|----------------|---------------------------------|---------------------------------------------------------------|
|                                   |                | February | April | July | September | February | April | July | September |
| Amphora                           | Diatomic algae | –        | 16    | –    | –         | –        | 0.20  | –    | –         |
| Ankistodesmus                     | Green         | –        | –     | –    | 24        | –        | –    | –    | 0.60      |
| Aphanizomenon                     | Blue-green    | –        | –     | –    | 2.280     | –        | –    | –    | 57.0       |
| Asterionella                      | Green         | –        | –     | –    | –         | –        | –    | –    | –         |
| Aulocosira                        | Diatomic algae| 5        | –     | –    | –         | 7.05     | –    | –    | –         |
| Chrisococcus                      | Chrysophyta   | 14       | –     | –    | –         | 18.28    | –    | –    | –         |
| Chlamydomonas                     | Green         | –        | 16    | –    | –         | –        | 0.20  | –    | –         |
| Coelastrum                        | Green         | –        | –     | –    | 64        | –        | –    | –    | 1.60      |
| Didatios                          | Diatomic algae| –        | 16    | –    | –         | –        | 0.20  | –    | –         |
| Didimocystis                      | Green         | 5        | –     | –    | –         | 0.30     | –    | –    | –         |
| Gymnotheca                       | Diatomic algae| 1        | –     | –    | –         | 0.078    | –    | –    | –         |
| Gymnodinium                       | Periphyton algae | – | – | – | 8 | – | – | 0.20 | – |
| Fragilaria                        | Diatomic algae| 1        | 16    | 24   | –         | 0.078    | 0.20  | 0.9  | –         |
| Franceia                          | Green         | 1        | –     | –    | –         | 0.078    | –    | –    | –         |
| Mallomonas                        | Chrysophyta   | –        | 16    | –    | –         | –        | 0.20  | –    | –         |
| Microcystis                       | Blue-green    | –        | –     | 20   | 1,160     | –        | 0.75  | 29.0 | –         |
| Monoraphidum                     | Green         | 2        | 32    | 12   | –         | 2.61     | 0.40  | 0.45 | –         |
| Navicula                          | Diatomic algae| –        | 16    | 8    | –         | –        | 0.20  | 0.30 | –         |
| Nitzchia                         | Diatomic algae| 1       | 16    | 8    | 12        | 0.78     | 0.20  | 0.30 | 0.30      |
| Oscillariar                       | Blue-green    | –        | –     | –    | 80        | –        | –    | –    | 2.0       |
| Peridinium                       | Periphyton algae | – | – | – | 92 | – | – | 2.30 | – |
| Pediastrum                       | Green         | –        | –     | 64   | –         | –        | –    | 2.41 | –         |
| Phacotus                          | Green         | 1        | –     | –    | –         | 1.83     | –    | –    | –         |
| Pseudoephryon                     | Chrysophyta   | 1        | –     | –    | –         | 0.78     | –    | –    | –         |
| Scenedesmus                       | Green         | 13       | –     | –    | 64        | 17.49    | –    | –    | 1.60      |
| Stenokalyx                       | Chrysophyta   | 10       | –     | –    | –         | 13.05    | –    | –    | –         |
| Stephanodiscus                    | Diatomic algae| 3       | 6,976 | 988  | –         | 3.39     | 87.55 | 10.84 | –         |
| Tetrasporus                       | Green         | –        | –     | 16   | –         | –        | –    | 0.60 | –         |
| Ulothrix                         | Green         | 3        | –     | –    | 4         | 3.39     | –    | –    | –         |
| Chlorococcales (of small sizes)  | Green         | –        | –     | 4    | 8         | –        | –    | 0.15 | 0.20      |
| Flagellate algae (of small sizes) | Green         | –        | –     | 32   | –         | –        | –    | 0.40 | –         |

When analyzing the reasons for the relatively low average number of phytoplankton under favourable climatic conditions, as possible causes were considered the following factors: since 2010,
when studying the water samples of the Reservoir it is observed the increase in several times of the average annual abundance of zooplankton, from 1,200–1,300 cells/ml in the period 2004–2009, which was characterized by a gradual decrease in temperature of the warm period and an increase in precipitation, to 12,500 cells/ml in 2010 with the average annual increase in the number to 35,000 cells/ml by 2015. In the composition of the zooplankton the species of Copepoda (80 %), Cladocera (15–20 %) and Nauplius (5 %) were dominated. These types of zooplankton are the natural consumers of phytoplankton and massively developing, they limit the number of phytoplankton. Another factor limiting the further growth of phytoplankton in water reservoirs, in our opinion, is the reduction in the concentrations of biogenic compounds required for phytoplankton growth – in the chemical composition of the water in the Reservoir throughout the year since 2015 it is observed the very low levels of ammonia nitrogen NH4 – 0.05 µg/l or less, and it can be assumed, that all ammonium nitrogen becomes assimilated by the phytoplankton and macrophytes in the Reservoir and the lack of their supply is limiting the number.

The data of Table 2 shows that during the cold season, diatomic algae predominate in the phytoplankton species composition, and the number of cells in 1 ml of water does not exceed 65. In the warm season, the number of cells in 1 ml increases by 2–4 orders of magnitude. The peak of phytoplankton developing is brought forward to August – September. At the beginning of the warm period, diatomic algae multiply massively, and in August – September there is an intensive developing of blue-green algae. Some species of blue–green algae (Aphanizomenon, Microcystis) multiply massively, which reduces the water quality indicators of reservoirs [10].

The change in the biocenosis of planktonic organisms in the reservoirs of the Moscow Canal, caused by climatic changes since 2010, has led to substantially more total assimilation of biogenic compounds entering the water from the Volga source and the flows of the small rivers and surface runoff from water-collecting reservoirs, in particular, ammonium nitrogen is consumed by planktonic organisms to the minimum content, so in 2014 in the Uchinsky Reservoir was practically no seasonal dynamics and its content was 0.02...0.04 mg/l. Other biogenic compounds were observed the seasonal dynamics of their content in the water, associated in particular with the increased surface runoff in the spring to ensure the intake of biogenic elements and decrease in the number of phytoplankton in the cold period of the year, which is typical for all water reservoirs of Central Russia. Taking into account the results obtained, it can be assumed that it is the content of ammonium nitrogen in the water of the reservoir that restricts the development of phytoplankton, thereby restraining the processes of eutrophication and improving the water quality of reservoirs.

4. Conclusion

The climate changes on the European territory of Russia occurring in the last decade and including the increase in the temperature of the warm period, the decrease in precipitation in the summer period, have had a favourable impact on the development of phytoplankton in the Uchinsky Reservoir, leading to a significant increase in the number of phytoplankton and the principal development of blue-green algae at the end of the warm period. Further increase in the population of phytoplankton in the water reservoir is controlled by two factors: 1) the increase in the number of zooplankton, that is a natural consumer of phytoplankton, the abundance of which has increased multiply over the last decade, as well as 2) the further growth of planktonic organisms being controlled by reducing the concentration of available biogenic compounds and the most consumed – ammonium nitrogen, which is almost completely assimilated by phytoplankton. This is important to maintain the current balance and, consequently, to contain the processes of eutrophication that negatively affect the quality of water. Since there has been no agricultural activity in the water-collection area of the Upper Volga in the last decade, the influence of industrial activity has been reducing, and the flows of small rivers and the surface runoff from reservoirs have become a significant source of biogenic compounds. To limit this influence, a set of measures is needed to reduce the intake of biogenic compounds, the sources of which are surface runoff, the flows of waters of small rivers, in the water-collection area of which residential development and agricultural activities are being actively conducted.
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