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Species Composition, Seasonal Dynamics and Distribution of Phytoplankton of the Zaporizke Reservoir

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Abstract. Species composition, seasonal dynamics and distribution of phytoplankton were researched to characterize temporal dynamics and horizontal distribution of phytoplankton and to indicate the ecological status of the sites in the Zaporizke Reservoir. During 2015 - 2016 a seasonal dynamics of species composition and quantitative characteristics of phytoplankton have been studied near Monastyrsky island in upper part of the reservoir both in surface and bottom layers in conjunction with water temperature measurement. At early September 2016 phytoplankton sampling was performed at different sites of the Zaporizke Reservoir including the sites undergone to sewage impact. During phytoplankton seasonal dynamics diatom bloom was reported in March and early April and algae biomass was higher in the bottom layer with a gradual decrease in the direction of the surface layer. From July to October the apparent dominance of blue-green algae took place with a clear concentration in the surface layer. Domination of the species *Microcystis aeruginosa* determined phytoplankton distribution along the reservoir at the beginning of September. Despite the high resistance to the effects of toxic substances the level of *Microcystis aeruginosa (Kützing) Kützing* 1846 development decreased at the sites of direct sewage impact. At 100 m below the sewages sites degree of phytoplankton development increased mainly due to increase of blue-green algae abundance. Indexes of phytoplankton showed the best ecological state at the site «near Kodaki water draw-off» and the worst ecological state at the sites of direct sewage impact. The results obtained are important to indicate ecological state of the sites in the Zaporizke Reservoir.

1. Introduction

Under anthropogenic pressure in the Zaporizke Reservoir domestic and industrial sewage impact with ineffective system of sewage treatment cause transformation of algae biocenosis and may cause blue-green algae bloom [1]. In the Zaporizke Reservoir during the period of being within cascade of Dnieper reservoirs blue-green algae bloom was observed every year in July-September with average abundance 34 mln.cells/dm^3 and biomass 9.3 mg/dm^3 [2]. Blue-green algae of genera *Microcystis* and *Anabaena* were the agents of bloom similarly in all Dnieper reservoirs [3, 4]. Retrospective studies of the Zaporizke Reservoir phytoplankton showed that under sewage and eutrophication process at the sites of sewage impact abundance of saprobiontic populations increased while total biomass of phytoplankton especially green algae biomass decreased and some species from the group Chrysophyta disappeared [5]. A tendency of saprobity increasing has been observed in retrospective analysis [6]. While saprobiontic species indicating α-mesosaprobic conditions were not met in 30 years of 20th century then sporadic forms were observed in 60 years and in 90 years their percentage in total number of indicating saprobic species reached 14%. The problem of algae bloom in response to eutrophication is also a matter of great importance. Toxic compounds such as heavy metals, oil products and surface-active compounds flowing into the river inhibit reproduction of sensitive algae [7, 8]. Nowadays despite decreasing of industrial sewage volume in the Zaporizke Reservoir the concentration of toxic compound is growing due to accumulation by soil and subsequent raising to water column [9-11]. Species composition and abundance of phytoplankton are sensitive indicators of water pollution and eutrophication. Since the primary task is to assess the ecological status of the reservoir then investigation of such a sensitive component as phytoplankton is crucial to prevent irreversible changes in state of the reservoir hydrobiocenosis and to restore its steady state. First of all, it is important to study the transformations taking place in phytoplankton community at the sites of direct sewage discharge.

2. Materials and Methods

Based on the long-term data of Laboratory of hydrobiology, ichthyology and radiobiology of Research Institute of Biology, Oles Honchar DNU the upper part of the reservoir has been under intense technological pressure impact [1, 4, 9, 11]. Distribution of phytoplankton along the Zaporizke Reservoir has been studied in September 2016 by sampled at 8 sites of upper part of the reservoir within Dnipro city (Fig.1): 1) near Kaydaki water draw-off 2) Petrovsky plant sewage, 3) 100 m downstream from Petrovsky plant sewage, 4) River port of Dnipro city, 5) near discharge of urban sewage at the Festival pier, 6) 100 m downstream from discharge of urban sewage, 7) near Monastyrsky island, 8) near Voyskovoe village.

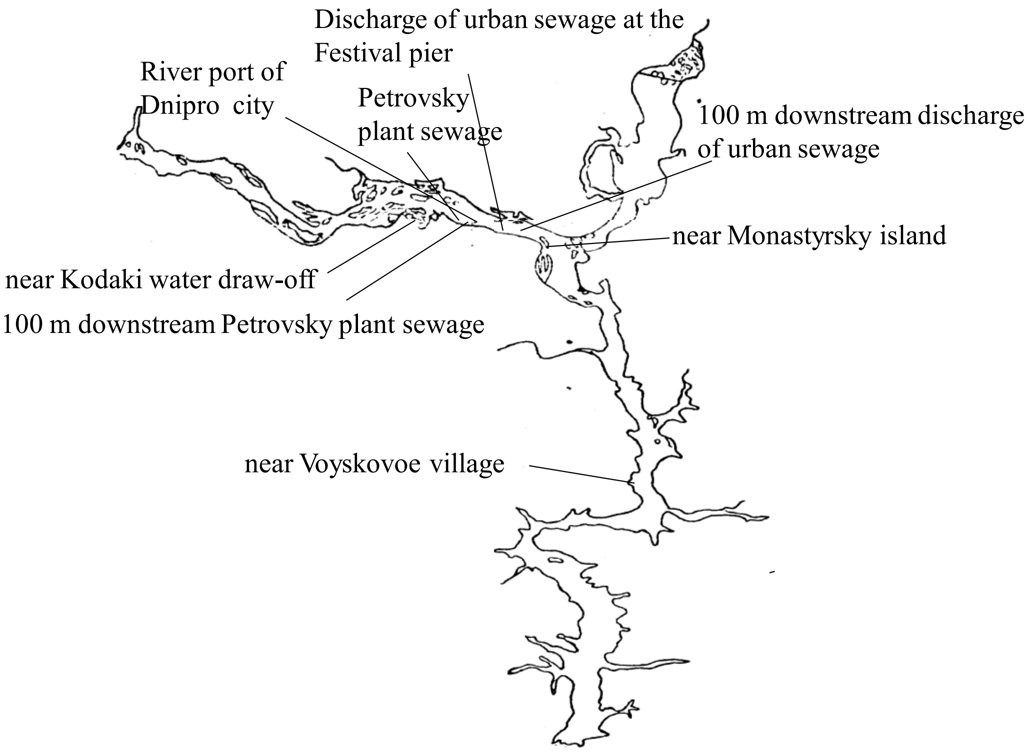

Figure 1. The sites of phytoplankton sampling along the Zaporizke Reservoir (47°57′36″N, 35°06′52″E).

At each site the samples were taken at the double replication accordingly to recommendations [12]. Seasonal dynamics and vertical distribution of phytoplankton has been studied in profundal at a distance of 25 m from the shore at a depth of 5 m near Monastyrsky island during 2015. Samples were taken at the surface and bottom layers of the water column during the hydrological year from 01.03.15 to 6.11.16 with an interval of 3-10 days. The total number of samples was equal to 52. Planktonic mesh sieve № 73 was used to take samples of phytoplankton for investigation of species composition. Molchanov bathometer was used to take samples of phytoplankton for quantitative investigation from surface and bottom layers according to standard technique [13]. Sampled material was conserved with several drops of 40%-formaldehyde up to 2%-concentration in the sample. After sedimentation in cylinder during 7–10 days the samples were processed using the Nazhotta's camera (0.02 cm^3) in the laboratory using Carl Zeiss Jenaval microscope. Numerical abundance of cells was counted for each species [12]. Phytoplankton biomass was determined for each species by cell volumes computing using simple geometric formulae for each cell form [14]. Species with biomass 10% and more of the total algae biomass considered dominating [12]. The degree of organic pollution (saprobity) of reservoir was evaluated by the saprobity index of Pantle and Bukk (in Sladecek modification) [15]. Species diversity was characterized using the Shannon index by phytoplankton abundance according to the formula:

$$H = -\sum_{i=1}^{n} \frac{n_i}{N} \bullet \log_2 \frac{n_i}{N},$$

where n_i is the number of individual species i, N – is the total number of individuals [12]. Water quality of the reservoir sites was estimated in accordance with the recommendations [16]. Data were analyzed statistically using the Microsoft Excel programs for Windows 2007.

3. Results and Discussions

Species composition of phytoplankton of the Zaporizke Reservoir

During the study period 74 species and intraspecific taxons has been recorded in species composition of phytoplankton of the Zaporizke Reservoir. The percentage of species between algal groups was as follows *Chlorophyta* (33%), *Bacillariophyta* (34%), *Cyanoprocaryota* (24%), *Euglenophyta* (6%), *Pyrrophyta* (3%).

The dominant species were *Cyclotella meneghiniana Kützing, 1844, Stephanodiscus hantzschii Grunow, 1880, Melosira islandica O.Müller, 1906, M. granulate (Ehrenberg) Ralfs, 1861, M. g. v. angustissima Müller, 1899, Pediastrum duplex Meyen 1829, Coelastrum microporum Nägeli in A. Braun, 1855, Dictyosphaerium pulchellum H.C.Wood, 1873, Ankistrodesmus angustus C.Bernard, 1908, Microcystis aeruginosa (Kützing) Kützing 1846, Aphanizomenon flos-aquae (L.) Ralf ex Bornet et Flahault, 1886, Anabaena flos-aquae Ralfs ex Bornet & Flahault 1886, Oscillatoria planctonica Woloszynska 1912*. Thus dominating species consisted of those which create mean part of food supply of upper trophic levels [17].

Most of the species has been found when investigating seasonal dynamics of phytoplankton at a stationary site near Monastyrsky island. Number of species at the sites varied from 3 to 21 and averaged 11.7 (Table 1). However, number of phytoplankton species beyond sewages equaled 14.3 and in the sewages equaled 4. The lowest number of species was recorded in discharge of urban sewage at the festival pier. This was due to pollution impact that suppressed life-sustaining activity of algae and decreased species diversity of phytoplankton.

Table 1. Number of phytoplankton species in the Zaporizke Reservoir in September, 2016.

Phytoplankton groups	1	2	3	4	5	6	7	8	Average
Cyanophyta	5	2	4	3	1	3	4	3	3.1
Bacillariophyta	8	1	3	6	0	3	7	4	4.0
Chlorophyta	6	1	1	4	0	2	5	4	2.9
Euglenophyta	0	1	1	1	2	2	1	1	1.1
Pyrrophyta	2	0	1	0	0	0	1	1	0.6
Total	21	5	10	14	3	10	18	13	11.7

1 – near Kodaki water draw-off, 2 – Petrovsky plant sewage, 3 – 100m downstream Petrovsky plant sewage, 4 – river port of Dnipro city, 5 – discharge of urban sewage at the Festival pier, 6 – 100m downstream discharge of urban sewage, 7 – near Monastyrsky island, 8 – near Voyskovoe village.

Seasonal dynamics of phytoplankton of the Zaporizke Reservoir

Blue-green algae were domination group over a large part of the vegetation period that is consistent with the data of the scientists who studied phytoplankton development in reservoirs of Dnieper cascade [3, 4]. Scientists explain the dominance of blue-green algae due to high percentage of phosphate compared to nitrate (concentration ratio of N to P is less than 29:1) [3, 6, 11]. It should be noted that in spring 2016 seasonal dynamics of phytoplankton was characterized by increased and prolonged (about a month) compared to the 2015 diatoms bloom of the species *Melosira islandica* and to a lesser degree *Melosira granulata* which biomass reached 23 mg/dm^3. Bloom of diatoms ended in early April. The association of diatom bloom with low temperatures was also marked by other authors [3, 18]. Upon studying of native algae samples during the spring bloom many ciliates, rotifers and filamentous fungi were met among abundance of *Melosira* filaments. This indicates the presence of significant amount of water dissolved organic matter excreted by *Melosira* during its vegetation [11, 19].

In late June 2016 bloom of blue-green algae began. At the beginning of the bloom the values marked varied from 0.1 to 3.7 mg/ dm^3 and a month later vegetation rate of the species *Microcystis aeruginosa* began to increase and algae *Microcystis aeruginosa* became the dominant species in mid-August. Maximal average biomass (31.5 mg/ dm^3) was observed in late August. Bloom of blue-green algae continued until early October. Upon studying of native algae samples at the beginning of summer bloom crustaceans from Chydoridae actively nourished *Microcystis* cells were frequent. This confirms the importance of blue-green algae as food for zooplankton that was noted by other authors [19, 20].

The data according vertical distribution of phytoplankton showed its non-uniformity in water column during algae bloom in spring and during the summer-autumn period. At the beginning of bloom in spring high values of algae concentration were characteristic for bottom water and upon bloom development maximal algae concentration moved to surface layer of water column (Fig. 2). In summer distribution pattern of phytoplankton in bottom and surface layers changed considerably. Blue-green algae dominating in summer accumulated in surface layer whether at the beginning or at the end of its bloom. With the accumulation of phytoplankton biomass, the difference in concentration of blue-green alga between surface and bottom layers increased. In autumn phytoplankton biomass in bottom layer increased compared to the surface layer because the cooling of the bottom layer is slower that’s why algae in bottom layer aren’t subjected to depression usual for phytoplankton in surface layer.

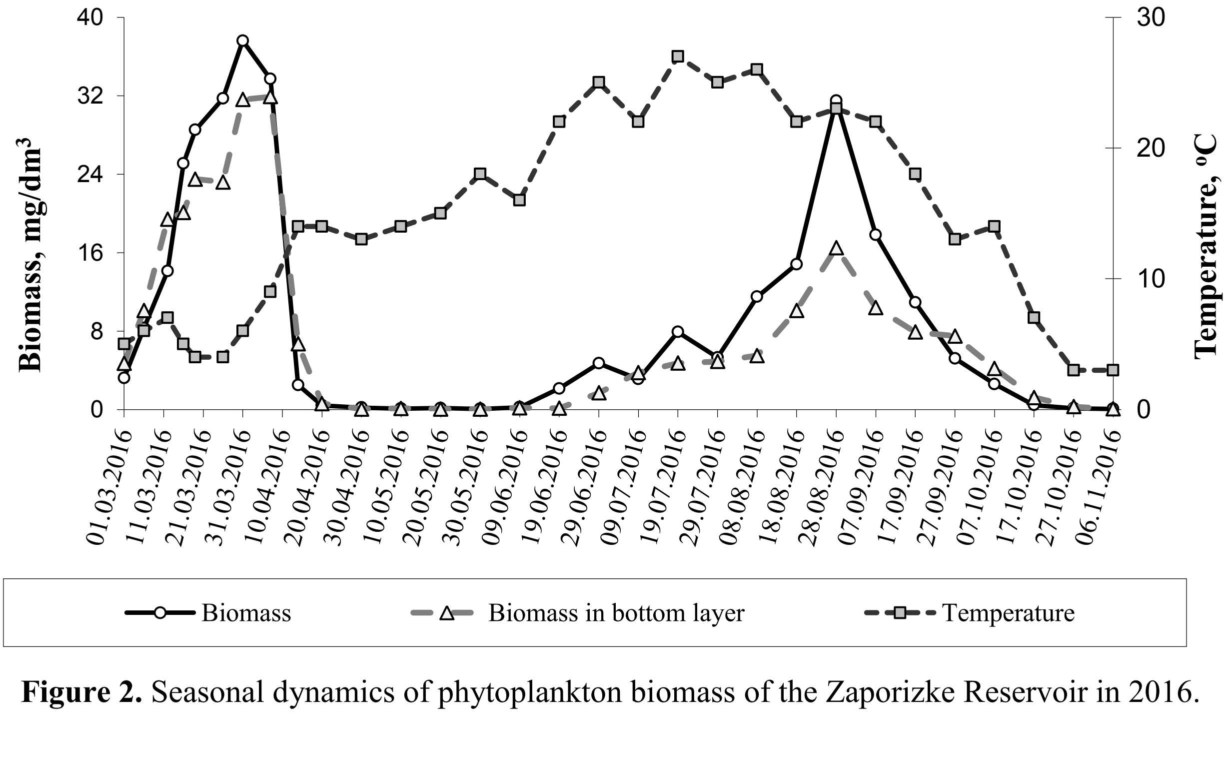

Figure 2. Seasonal dynamics of phytoplankton biomass of the Zaporizke Reservoir in 2016.

In 2015 bloom of diatoms algae was less intensive compared to 2016 due to long period of low temperature in March and further rapid increase of temperature. Bloom of *Melosira islandica* began March 19 and lasted for only a few days (Fig. 3).

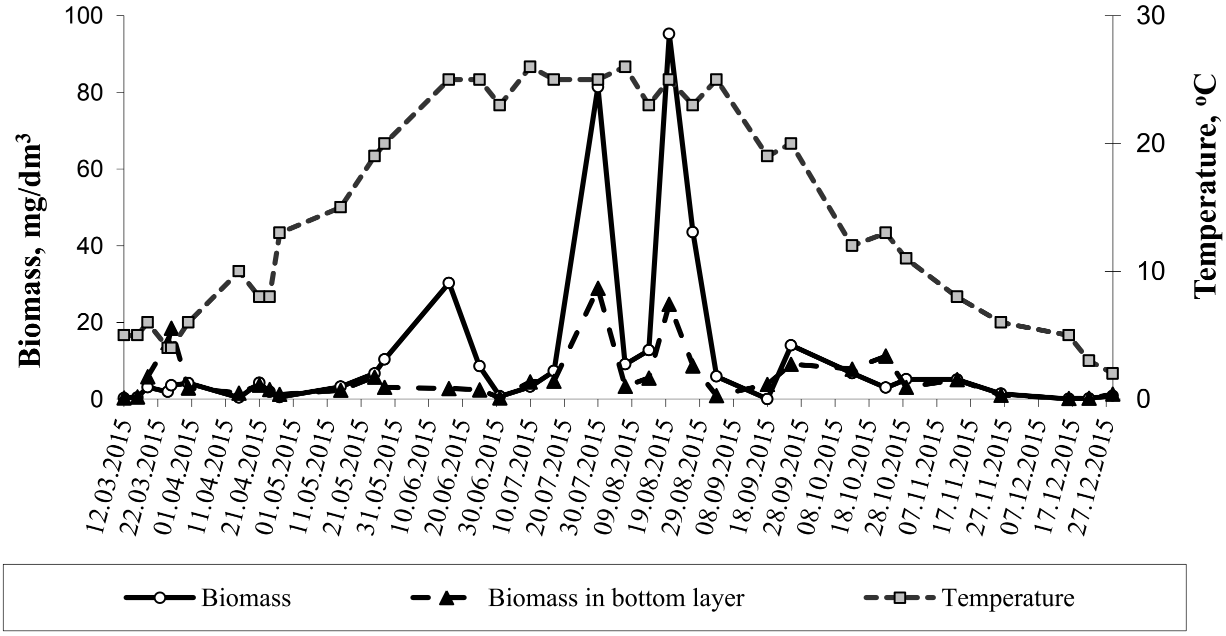

Figure 3. Seasonal dynamics of phytoplankton biomass of he Zaporizke Reservoir in 2015.

During *Melosira islandica* bloom biomass of diatoms in bottom layer amounted up to 18.5 mg / dm3 and exceeded diatoms biomass in surface layer. This is due to the fact that in winter spores and partly vegetative cells of diatoms and blue-green algae stored at the bottom and upon favorable conditions occurrence phytoplankton vegetation begins from the bottom [3]. Melosira islandica is a stenothermic algae which vegetation takes place in the temperature range from 4° C to 8° C [21]. In addition, reaching of water temperature 4° C promotes mixing of water column and raising algae from the bottom to the surface. Therefore, at the beginning of Melosira bloom maximum biomass was concentrated in the bottom layer but with rising of temperature up to 6° C mixing of water column took place that caused elevation of algae to the surface layer. Further depression of phytoplankton took place. After depression of phytoplankton a new growth of algae biomass lasted about a week. This phytoplankton vegetation was characterized by less intensive growth compared with *Melosira* bloom and was caused by large diversity of the species *Melosira granulata, Navicula gracilis, Stephanodiscus hantzschii, Chroomonas pulex, Pediastrum duplex, Chlamydomonas monadina, Dictyosphaerium pulchellum, Ankistrodesmus angustus, Scenedesmus acuminatus.* Therefore, it was polydominant community with great species diversity, similar biomass of the species as well as with frequent changes of dominants and small degree of dominance. During this period the vertical distribution of algae was uniform. In spring total biomass of phytoplankton in the surface layer of the reservoir varied from 0.28 to 10.35 mg / dm^3 and averaged 3.13 mg / dm^3. At the beginning of June, the species *Aphanizomenon* flos-aquae became a dominant and biomass of phytoplankton reached 30.3 mg / dm^3. Vertical distribution of phytoplankton was not uniform with concentration of algae in the surface layer. This phenomenon is typical for blue-green algae domination due to gas vacuole presence. Blue-green algae *Oscillatoria limnetica* and *Anabaena flos –aquae* together with *Aphanizomenon flos – aquae* were dominating species in spring.

In 2015 development of the species *Microcystis aeruginosa* began in July. During the period from 10.07.15 to 30.07.15 biomass of phytoplankton increased from 3.24 to 81.4 mg / dm^3 of which 97% was created by *Microcystis aeruginosa*. Maximum of phytoplankton biomass – 95.2 mg / dm^3 was observed at the end of August. Bloom of blue-green algae lasted until the middle of October. In autumn due to gradual die-away of blue-green algae proportion of Bacillariophyta species from genera *Nitzchia, Stephanodiscus, Cyclotella, Navicula* etc. was growing in phytoplankton species composition. The number of phytoplankton varied widely – from 1.99 to 34.0 mln. cells / dm^3 in the surface layer and from 0.55 to 8.0 mln. cells / dm^3 mln. cells / dm^3 in the bottom layer. Since the end of September until the end of October phytoplankton biomass in the bottom layer increased in comparison with the surface layer, and this difference was especially apparent in December. Higher level of phytoplankton biomass in the bottom layer in comparison with the surface was caused probably by less temperature fluctuations in the bottom layer in comparison with the surface layer in the cooling period of the reservoir. High stability of temperature in the bottom layer which seldom drops below 4°C, is the reason that algae fund is in the bottom layer from where with warming phytoplankton vegetation begins.

In summer and in September the total biomass of algae in the reservoir varied from 2.05 to 520 mg / dm^3, and averaged 87.3 mg / dm^3 in surface layer and 4.22 mg / dm^3 in bottom layer. Diatoms and blue-green algae were dominating groups occupying 19 – 34 %, and 36 – 84.0 % of total algal biomass, respectively while green algae 12-25 % and algal groups occupied 6 – 10 % of the total phytoplankton biomass.

In winter phytoplankton was represented mainly by cold-water or eurythermic diatoms. During this period the biomass of phytoplankton had the lowest annual values and varied from 0.07 to 0.9 mg / dm^3 in the surface layer and from 0.2 to 1.32 mg / dm^3 in the bottom layer and averaged 0.47 mg / dm^3.

Spacial distribution of phytoplankton of the Zaporizke Reservoir

On September 7, 2016 samples of phytoplankton were collected at different sites of the reservoir in order to study the distribution of phytoplankton in the reservoir and the impact of wastewater on the level and ratio of phytoplankton groups development as well as for ranking of the reservoir sites by contamination. Abundance of phytoplankton varied from 11.4 to 687.2 mln.cells /dm^3 and averaged 192.4 mln.cells / dm^3 (Table 2).

Table 2. Abundance of phytoplankton groups (mln.cells / dm^3) at littoral sites of the Zaporizke Reservoir in September 2016.

	1	2	3	4	5	6	7	8
Bacillariophyceae	1.71	0.13	0.25	0.63	0.07	0.21	1.15	1.6
Cyanophyceae	139.3	10.5	32.91	73.47	33.4	310.9	231.1	682.3
Clorophyceae	0.96	0.28	0.44	0.36	0	1.92	1.48	3.08
Euglenophyceae	0	0.52	1.34	0	5.12	3	0.72	0.25

1 – near Kodaki water draw-off, 2 – Petrovsky plant sewage, 3 – 100m downstream Petrovsky plant sewage, 4 – river port of Dnipro city, 5 – discharge of urban sewage at the Festival pier, 6 – 100 m downstream discharge of urban sewage, 7 – near Monastyrsky island, 8 – near Voyskovoe village.

In the sampling period blue-green algae clearly dominated among phytoplankton groups that reflected on their percentage of total phytoplankton abundance at the different sites – from 86.5 to 99.3%, in average 95.7%. In early September 2016 at relatively clean station “Near Kodaki water draw-off” served as the site for comparison abundance of phytoplankton was 141.97 mln.cells / dm^3 and biomass was 8.77 mg / dm^3. Species diversity and uniformity of phytoplankton groups was highest at the site “Near Kodaki water draw-off” compared to other sites studied. The maximal abundance and biomass was observed at the site “Near Voyskovoe village” while minimal abundance and biomass were reported at the sites "Petrovsky plant sewage" and “discharge of urban sewage at the festival pier”. Degree of phytoplankton development increased at the sites 100 m downstream discharges but in different manner. While level of phytoplankton biomass increased slightly at the site “100 m downstream Petrovsky plant sewage” then at the site “100 m downstream discharge of urban sewage” biomass of phytoplankton rised sharply from 2.93 to 16.28 mg / dm^3 (Table 3).

Table 3. Biomass of phytoplankton groups (mg / dm^3) at the sites of open littoral of the Zaporizke Reservoir in September 2016.

	1	2	3	4	5	6	7	8
Bacillariophyceae	2.1	0.16	0.3	0.75	0.08	0.25	1.33	1.86
Cyanophyceae	6.43	0.5	1.55	3.47	1.57	14.8	11.1	32.4
Clorophyceae	0.24	0.07	0.11	0.09	0	0.48	0.37	0.77
Euglenophyceae	0	0.12	0.34	0	1.28	0.75	0.18	0.05

1 – near Kodaki water draw-off, 2 – Petrovsky plant sewage, 3 – 100m downstream Petrovsky plant sewage, 4 – river port of Dnipro city, 5 – discharge of urban sewage at the Festival pier, 6 – 100m downstream discharge of urban sewage, 7 – near Monastyrsky island, 8 – near Voyskovoe village.

It is obvious that decreasing in phytoplankton biomass at the sites of sewages discharge was caused by toxic effect of sewages compounds on degree of phytoplankton development. Thus despite tolerance of blue-green algae to the effects of sewages toxic compounds blue-green vegetation is inhibited in conditions of the Zaporizke Reservoir.

A significant increase in phytoplankton biomass at the site “100m downstream discharge of urban sewage” was caused by specifics of the sewage in which proportion of nutrients and organic matter was much higher compared to the site “100 m downstream Petrovsky plant sewage” due to high concentration of such compounds as heavy metals and oil products at the last site which inhibit phytoplankton vegetation [22]. Organic matter of the site "discharge of urban sewage at the festival pier" while decomposition to nutrients stimulates blue-green algae reproduction in the first place and as a result blue-green algae bloom had the greatest rates at the site “100m downstream discharge of urban sewage” of the studied area in reservoir upper part.

Decrease in degree of phytoplankton development at the site “river port of Dnipro city” was apparently caused by high oil product concentration that inhibits reproduction and growth of algae. At the site “near Monastyrsky island” at relatively high biomass species diversity and uniformity of phytoplankton groups increased compared to upstream sites. The greatest abundance and biomass of phytoplankton in lower part of the reservoir at the site “near Voyskovoe village” were explained on the one hand by farness of the site from the nearest major sewage and on the other hand by retardation of current speed that lead to the development and accumulation of phytoplankton.

Ranking of the sites studied by saprobity index

Under analyzing of water quality formation features and self-purification processes in the Zaporizke Reservoir it was found out that much part of phytoplankton species are indicators of water organic pollution as their percent of total phytoplankton species in this part of reservoir equaled 54%. Massive development of such α-mesosaprobiontic species as *Euglena acus, E. viridis, Trachelomonas hispida, Stephanodiscus hantzschii* at the areas of sewages impact indicates water quality impairment due to organic matter pollution especially in the upper part of the reservoir under the influence of Dnipro city sewages. At the investigated sites of the Zaporizke Reservoir saprobity index indicating organic pollution varied from 1.91 to 2.0 and averaged 2.26. Saprobity index had maximal value at the site “discharge of urban sewage at the festival pier” while at the site “Petrovsky plant sewage”. Saprobity index little decreased and the sites 100m downstream both studied sewages ranged in similar order (Table 4). At the sites ut of sewage influence β-mesosaprobic algae species with average saprobity index 2.05. The smallest saprobity index corresponding to the lowest level of organic pollution of the sites investigated was observed at the site "near Kodaki water draw-off" that is caused on one hand by situation of this site upstream of the main sewages and on the other hand by the most stream speed among studies sites as saprobiontic species are inhibited in conditions of high stream speeed.

Table 4. Saprobity index by phytoplankton at the sites of open littoral of the Zaporizke Reservoir in September 2016.

The site of open littoral	Shannon index	Saprobity index
near Kodaki water draw-off	1.9	1.91
Petrovsky plant sewage	0.85	2.55
100m downstream Petrovsky plant sewage	1.13	2.26
river port of Dnipro city	1.57	2.20
discharge of urban sewage at the festival pier	0.43	2.74
100m downstream discharge of urban sewage	0.62	2.33
near Monastyrsky island	1.69	2.1
near Voyskovoe village	0.97	2.0

Shannon index by phytoplankton reflecting its species diversity at the sites investigated showed decreasing of species diversity at the sites of both sewages investigated. Shannon index low values were observed both at the sites of sewages and at the sites downstream sewages that is explained by not only low species numbers but also by unevenness of species development under absolute domination of *Microcystis aeruginosa*. The highest value of Shannon index was observed at the site "near Kodaki water draw-off" where uniformity of phytoplankton groups and species was maximal.

Under analyzing of phytoplankton development data obtained as well as saprobity and Shannon indexes by phytoplankton according to the water quality classification [16] the site "discharge of urban sewage at the festival pier" qualified as the 7 category "heavily polluted", the site "Petrovsky plant sewage" qualified as the 6 category "polluted", both sites 100m downstream the studied sewages as the 5 category "moderately polluted", the sites "near Monastyrsky island" and "near Voyskovoe village" as the 4 category "weakly polluted" and the site "near Kodaki water draw-off" as the 3 category "clean enough".

4. Conclusion

Thus during the study period in phytoplankton seasonal dynamics of the Zaporizke Reservoir 2 peaks of algae vegetation were determined. Diatom bloom was observed in March and early April and algae biomass was higher in the bottom layer with a gradual decrease in the direction of the surface layer. Diatom bloom in spring was caused both by temperature increase to 4^{o}C and by water column mixing in March and April. During the period of spring bloom abundance of phytoplankton averaged 34.0 mln. cells/dm^3 and biomass 37.0 mg/dm^3 respectively. From July to October the apparent dominance of blue-green algae took place with a clear concentration in the surface layer. Biomass of phytoplankton during 2015 -2016 years varied on a broad scale from 0.1 to 95.0 mg/dm^3. Degree of the species *Microcystis aeruginosa* development reached maximal values in July and bloom of blue-green algae continued until the beginning of October. Further development of phytoplankton was reduced and remained at a minimal level with abundance from 0.1 to 7.0 mln. cells /dm^3 and biomass from 0.01 to 0.35 mg/dm^3 until March. During the whole vegetative season from March to November biomass of phytoplankton averaged 11.8 mg/dm^3.

Decreasing of phytoplankton growth at the areas of sewages influence was caused by toxic effect of sewages compounds on the development of phytoplankton and at the site "river port of Dnipro city" by the influence of oil products. With distance enlarging from the sewages, degree of phytoplankton development increased and to a greater extent in the case of domestic sewage. The highest abundance and biomass of phytoplankton was reported at the site "near Voyskovoe village", that was caused by the site farness from the nearest major sewage as well as by retardation of current speed.

The ranking of the studied site by saprobity index and Shannon index of phytoplankton indicated water quality increasing from the sites of sewages to the site “near Kodaki water draw-off” that reflects organic pollution degree of the sites. Saprobity index varied from 1.91 to 2.0 and averaged 2.26 that corresponded to β-mesosaprobic level of organic pollution. Based on the results obtained phytoplankton monitoring of contaminated reservoirs is urgently needed as structural and functional phytoplankton parameters are sensitive indicator of pollution.

The results obtained are important for understanding of stability maintenance mechanisms in reservoir ecosystems in order to forecast pollution and purification processes as well as for planning and realization of sustainable development conception of natural and artificial ecosystems.

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