УДК 574.583

SPATIAL AND TEMPORAL ASPECTS OF TOXIC EFFECT OF HARMFUL ALGAE ON ZOOPLANKTON IN THE CURONIAN LAGOON (THE BALTIC SEA)

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Семенова А.С., Дмитриева О.А. Пространственно-временные аспекты влияния токсичных синезеленых водорослей на зоопланктон Куршского залива (Балтийское море) // Труды АтлантНИРО. 2017. Новая серия. Т.1, № 4. Калининград: АтлантНИРО. С. 56–69.

Куршский залив – крупнейшая пресноводная прибрежная лагуна Балтийского моря. Пробы фитопланктона и зоопланктона отбирали ежемесячно с апреля по октябрь на 6 станциях в 2007–2010 гг. в российской части залива. Для разделения зоопланктонных организмов на живую и мертвую фракции производили прижизненную окраску проб анилиновым голубым красителем. Мертвые организмы были обнаружены в популяциях всех доминирующих видов зоопланктона. В период массового развития токсичных цианобактерий и после него в июле–октябре 2008–2010 гг. доля мертвых особей от численности и биомассы зоопланктона возрастала в 5–13 раз (до 8,3–19,4%) по сравнению с долей мертвых особей в июле–октябре 2007 г. (1,5–1,8%), когда биомасса цианобактерий была на низком уровне. Чувствительность таксономических групп зоопланктона к «цветению» воды цианобактериями и влиянию токсинов (определяемая по возрастанию доли мертвых особей в период массового развития цианобактерий) возрастала в ряду: Cyclopoida→Calanoida→Rotifera→ Cladocera. Минимальная доля мертвых особей была отмечена на станции, на которой органическое загрязнение, эвтрофикация и биомасса токсикогенных цианобактерий (особенно *Microcystis* spp.) были на низком уровне. Одна из возможных причин возрастания доли мертвых особей в зоопланктоне – влияние токсинов *Microcystis* spp. Была обнаружена существенная корреляция между долей мертвых особей в зоопланктоне и биомассой токсикогенного *Microcystis* spp. (r=0,62–0,81). Зеленые водоросли, напротив, способны компенсировать негативный эффект влияния цианобактерий, корреляция между долей зеленых водорослей в биомассе фитопланктона и долей мертвых особей в зоопланктоне была отрицательной (r= –0,51-0,60). Таким образом, доля мертвых особей в зоопланктоне может быть чувствительным индикатором, отражающим влияние токсикогенных цианобактерий.

Ключевые слова: Куршский залив, токсичные водоросли, *Microcystis* spp., доля мертвых особей, токсический эффект, зоопланктон

Semenova A.S., Dmitrieva O.A. Spatial and temporal aspects of toxic effect of harmful algae on zooplankton in the Curonian Lagoon (the Baltic Sea) // Trudy AtlantNIRO. 2017. New series. Vol. 1, № 4. Kaliningrad: AtlantNIRO. P. 56–69.

The Curonian Lagoon is the largest freshwater coastal lagoon of the Baltic Sea. The phytoplankton and zooplankton samples were taken every month from April till October 2007–2010 at 6 stations in the Russian part of Lagoon. In order to distinguish between live and dead organisms, zooplankton samples underwent to intravital staining using aniline blue. Dead organisms have been found out in populations of all dominating zooplankton species. During the period of mass development harmful cyanobacteria and after it in July–October 2008–2010 the share of dead organisms from abundance and biomass of zooplankton increased in 5–13 times (up to 8.3–19.4%) compared with the share of dead organisms in July-October 2007 (1.5–1.8%), when biomass of cyanobacteria was very low. Sensitivity of zooplankton taxonomical groups to cyanobacteria bloom and influence of toxins (determined according to increasing share of dead organisms in the period of mass cyanobacteria development) increased in the line: Cyclopoida→Calanoida→Rotifera→Cladocera. Minimal share of dead organisms was observed at the station in which organic pollution, eutrophication and biomass of harmful cyanobacteria (especially *Microcystis* spp.) were at the lower level. One of the main possible reasons of increase in the share of dead organisms in zooplankton is the influence of *Microcystis* spp. toxins. We obtained a significant correlation between share of dead organisms in zooplankton and biomass of toxigenic *Microcystis* spp. (r=0.62-0.81). Green algae can presumably compensate negative effect of cyanobacteria, the correlation between share of Chlorophyta in the total phytoplankton biomass and share of dead organisms in zooplankton was negative (r= −0.51-0.60). Thus, the share of dead organisms in zooplankton may serve as a sensitive indicator reflecting the influence of harmful cyanobacteria bloom.

Key words: Curonian Lagoon, harmful algae, *Microcystis* spp., share of dead organisms, toxic effect, zooplankton

Introduction

The study of non-consumption mortality of zooplankton is currently very topical. Both abiotic and biotic factors may cause the rise of non-consumption mortality in zooplankton populations: physical (temperature, wind speed, turbidity, flow rate), chemical (oxygen, toxic substances), biological (diseases, parasites and epibionts) and trophic (quantity and quality of food) [Dubovskaya, 2009]. Cyanobacteria toxins also may increase the non-consumption mortality; however this possible influence is not fully investigated yet.

The Curonian Lagoon is a large shallow freshwater lagoon (water-surface area – 1584 km^2; water capacity – 6.2 km^3; average depth – 3.8 m) of the Baltic Sea which is strongly affected by anthropogenic pressure. The phenomenon of mass development of harmful algae (mostly cyanobacteria) is regularly observed in the lagoon; the biomass of these cyanobacteria in some years is considerably higher than the level that determines secondary pollution of the water body. During the last decades occurrence of the harmful algal blooms became to be more often. For instance, from the early 1980s, phytoplankton biomass in summer was always at the level 10–30 g/m^3. Intensive bloom of cyanobacteria (phytoplankton biomass over 100 g/m^3) was observed since the late 1980s to current period. It was observed that the phytoplankton biomass exceeded 100 g/m^3 annually during the summer period at some stations in 2002–2010, except 2007 [Dmitrieva, 2017].

In periods of harmful algal blooms from July to September, potentially toxic species become abundant in the phytoplankton and may achieve until 22–89% of the total phytoplankton biomass. A number of studies on cyanobacterial toxins in the waters of the Curonian Lagoon had confirmed the presence of toxigenic cyanobacteria in this water body [Karmaikl et al., 1993; Paldaviiene et al., 2009; Belykh et al., 2013]. The hepatotoxins, which are produced by toxigenic strains of cyanobacteria from genus *Microcystis*, were found in the Curonian Lagoon in 2006. The concentration of microcystins in water was in 26 times higher than the norm established by the WHO [Karmaikl et al., 1993; Paldaviĉiene et al., 2009; Belykh et al., 2013]. Mass development of harmful algae is one of the most unfavorable factors for aquatic organisms, animals and humans and has strong negative effects on whole ecosystem of the Curonian Lagoon. Large accumulations of cyanobacterial toxins have a depressing effect on zooplankton, leading to its mortality.

The purpose of this study is to analyze the seasonal and inter-annual dynamics, as well as the spatial distribution of relative mortality parameters in the zooplankton of the Curonian Lagoon in comparison with the development of harmful cyanobacteria.

Material and methods

Plankton samples were taken in 2007–2010 every month from April till October in the central part of the lagoon at six standard monitoring stations of the Atlantic Research Institute of Fisheries and Oceanography (Fig. 1) using a 6-liters Van Dorn water sampler from the depths of 0.5, 1.5, and 3.0 m.

Water for phytoplankton investigations was combined from different horizons to obtain an integral sample of 0.5 liters. The samples were fixed by the solution of Kuznecov and concentrated by the settling method. The counting of cells was carry out by the standard method in a Nageotte chamber. The dominant species were defined as being 10% of the total phytoplankton biomass and more [Method of …, 1975.]

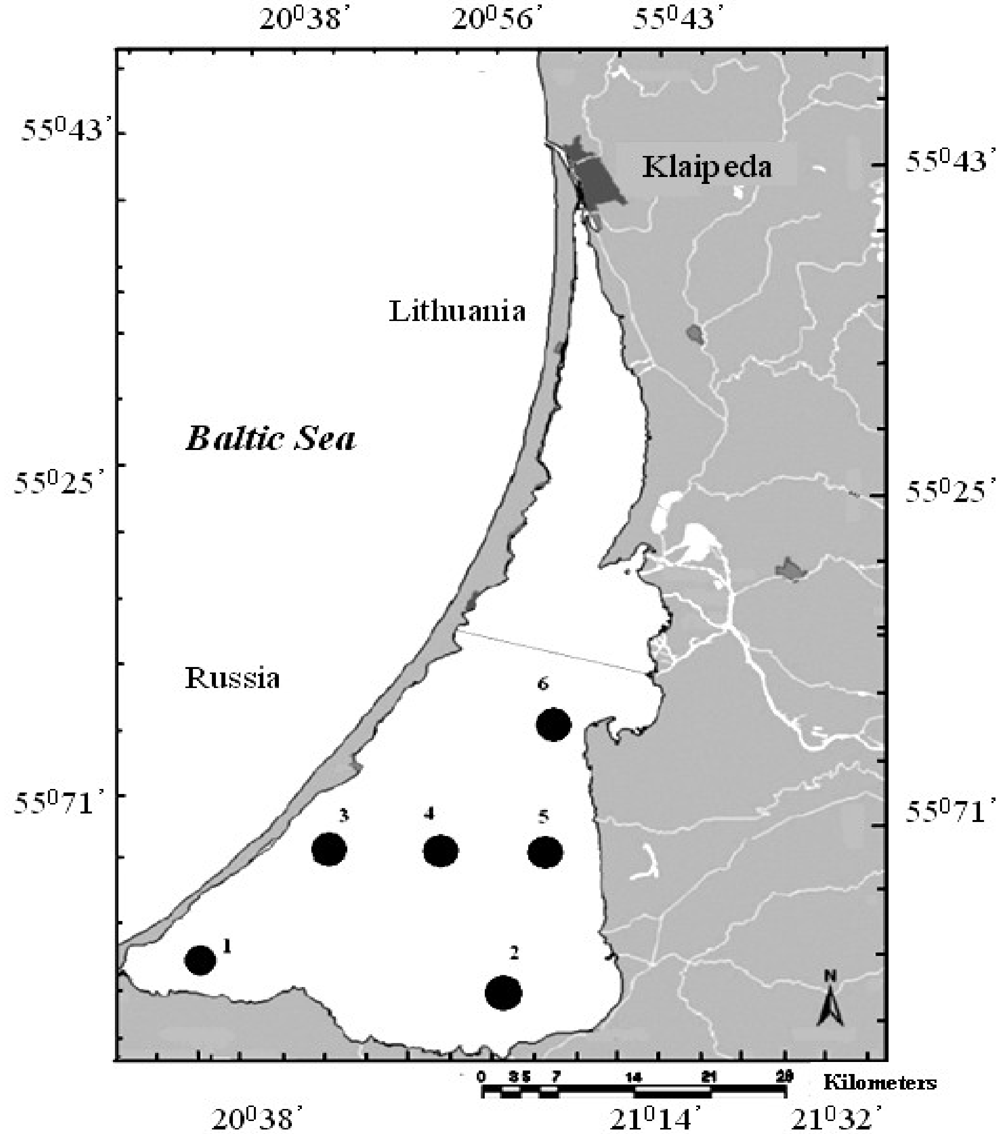


Fig. 1. Schematic map of the Curonian Lagoon (the Baltic Sea).
Numbers indicate sampling stations
Рис. 1. Схематическая карта Куршского залива (Балтийское море).
Цифрами указаны станции отбора проб

Zooplankton was filtered using a plankton net with a mesh size of 64 μm. For each zooplankton sample, 6 to 18 liters of water was filtered through the plankton net. Immediately after sampling, the zooplankton was stained with aniline blue to distinguish dead individuals from living ones [Seepersad and Crippen, 1978; Dubovskaya et al., 2003; Gladyshev et al., 2003; Bickel et al., 2008; Dubovskaya, 2008]. The staining was performed aboard the vessel, so as to exclude the additional mortality of zooplankters during the transport of samples. After staining, the zooplankton samples were washed with water and preserved in 4% formaldehyde with sucrose [Haney and Hall, 1973]. Laboratory processing was performed by the standard method [Kiselev, 1969; Methodological guidelines…, 1984], living (unstained and partially stained) and dead (entirely stained) zooplankters were calculated separately [Dubovskaya, 2008]. Biomass of zooplankton was calculated from size structure and abundance of species [Methodological guidelines…, 1984].

Over 200 phytoplankton and 700 zooplankton samples were collected and processed during the study. The ratio (%) of the abundance/biomass of dead individuals in the total abundance/biomass of living and dead zooplankters was used as the parameters of zooplankton mortality [Dubovskaya, 1987; Dubovskaya et al., 1999].

The Spirmen coefficient was calculated for the correlation analysis. The mean of values of the indicators with the standard error (±M) were calculated while processing of data analyzing. The MS Excel electronic tables and the Statistica v. 6.1 were used for statistical analysis.

Results

Phytoplankton

During the study period, a total of 320 species and subspecies of phytoplankton have been found, the most abundant were Chlorophyta, Bacillariophyta and cyanobacteria.

In spring phytoplankton the diatoms dominated in biomass (67–86%). The species *Actinocyclus normanii* (Gregory) Hustedt, 1957*, Asterionella formosa* Hasall, 1980*, Cyclotella meneghiniana* Kutzing, 1844*, Stephanodiscus hantzschii* Grunow,1880*, Stephanodiscus astrea v. astrea* Ehrenderg,1845 and *Aulacoseira islandica* (O. Muller) Simonsen, 1979, formed the spring dominant complex. In early summer the diatoms, cryptophytes, green algae, filamentous and colonial cyanobacteria appeared. The phytoplankton community in summer and autumn mostly consisted of dominating diatoms *Actinocyclus normanii, Stephanodiscus astrea v. astrea* (50–62%) and potential toxigenic filamentous cyanobacteria (30–43%) *Aphanizomenon flos – aquae* Ralf ex Bornet and Flahault, 1886*, Planktothrix agardhii* (Gomont) Anagnostidis and Komarek 1988*, Anabaena sp., Microcystis wesenbergii* (Komarek) Komarek ex Komarek, 2006 *, Microcystis viridis* (A. Braun) Lemmermann, 1903 (Fig. 2).

The biomass of *Microcystis* spp., which is capable to produce hepatotoxins, in summer at some stations they reached 18 g/m^3 (Fig. 3). This species makes a significant contribution to the biomass in average over the study period, the maximum concentration of this species was observed in the northwestern part of the Curonian Lagoon (Fig 4 a).

Since cyanobacteria composed the main share of the total phytoplankton biomass in summer, the spatial distribution of their biomass repeated the pattern of spatial distribution of the total phytoplankton biomass. Maximum values were observed in the center of the southern part of the lagoon in area at the station 4, the minimum – at the station 6 (Fig. 4 b, d). Due to the fact that the spatial distribution of the cyanobacteria biomass depends on wind direction, significant concentrations of cyanobacteria have been observed in the southern part of the lagoon coast near the station 3, at the river Deima flow. The lowest share of cyanobacteria was observed in the area of the station 6 (Fig. 4 c).

Seasonal dynamics of phytoplankton biomass was characterized by a summer maximum in August and was caused by cyanobacteria bloom. Phytoplankton biomass varied from year to year, the lowest values were in 2007, the highest ones – in 2008 and 2010 (Fig. 5).

The average total biomass over the vegetation period was 27 g/m^3 in 2007, 58 g/m^3 in 2008, 40 g/m^3 in 2009 and 46 g/m^3 in 2010.

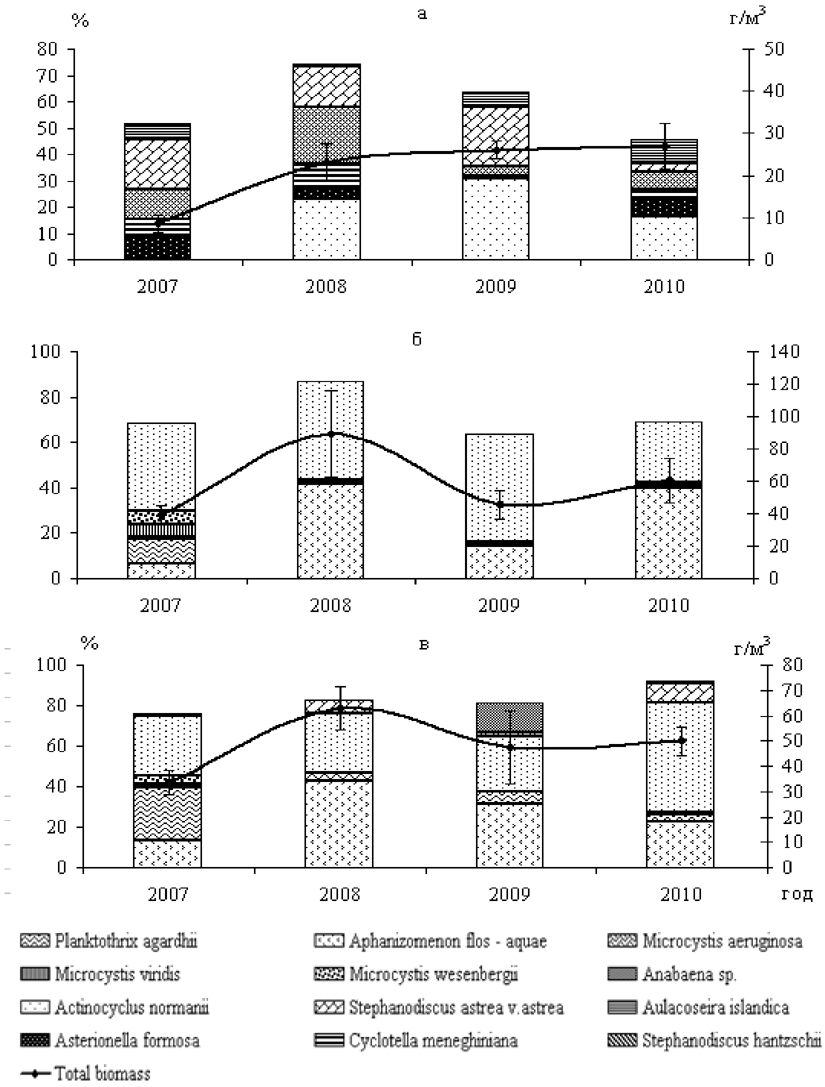


Fig. 2. Seasonal changes of dominant species complex of phytoplankton in 2007–2010: a – spring, b – summer, c – autumn. Total phytoplankton biomass (right y axis); percentage of dominant species (left y axis)
Рис. 2. Сезонные изменения доминирующего комплекса видов фитопланктона в 2007–2010 гг.: a – весна, b – лето, c – осень. Суммарная биомасса фитопланктона – правая ось, доля доминирующих видов – левая ось

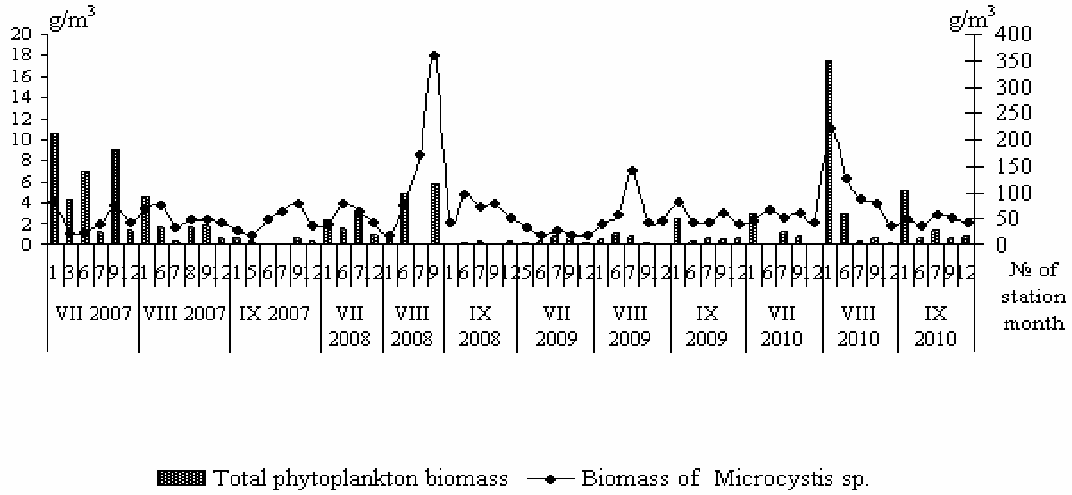


Fig. 3. Changes of total phytoplankton biomass *(right y axis*) and biomass of toxigenic *Microcystis* (*left y axis*) in July-September 2007–2010
Рис. 3. Изменения суммарной биомассы фитопланктона (правая ось)
и биомассы токсикогенного микроцистиса (левая ось) в июле–сентябре 2007–2010 гг.

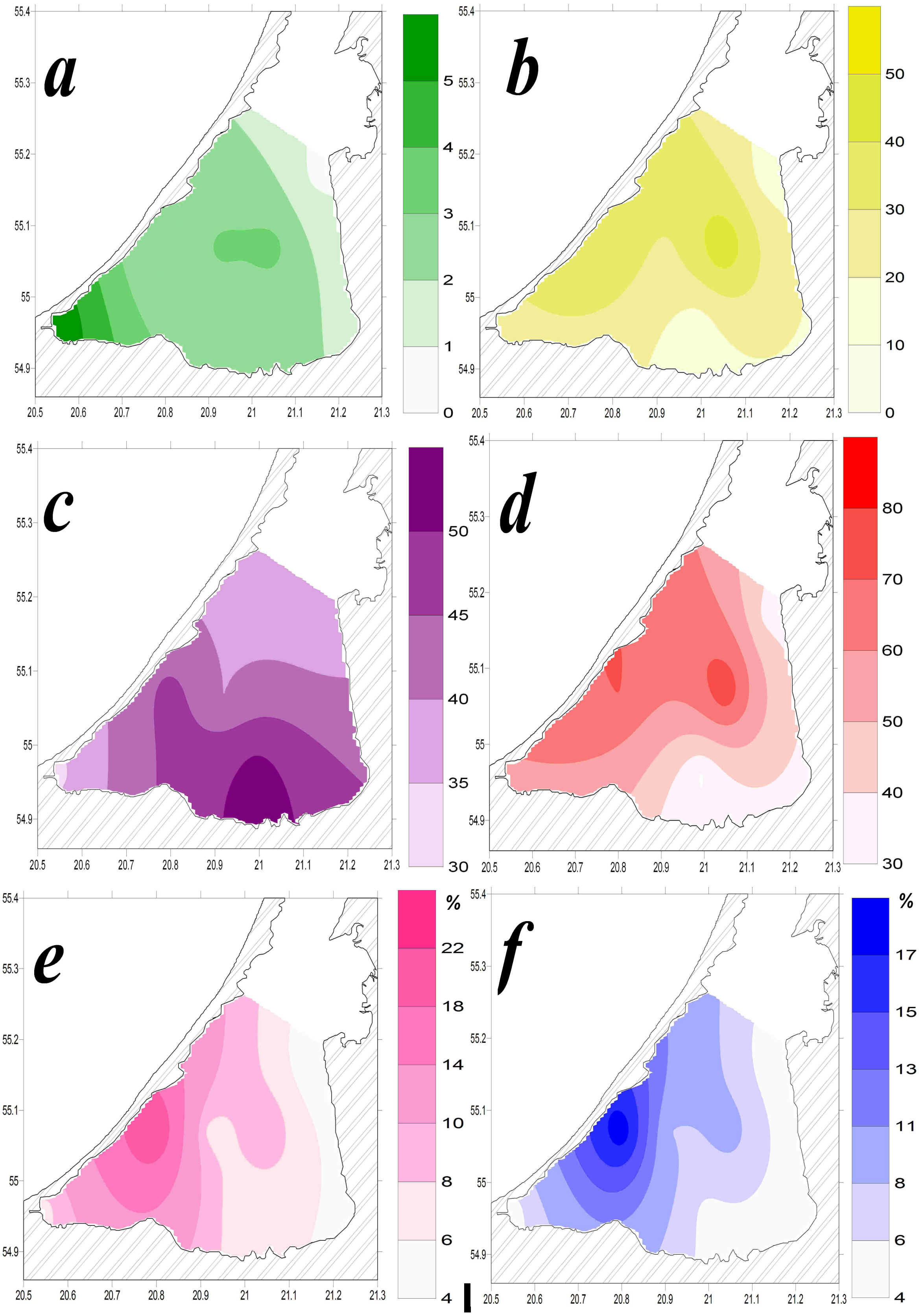


Fig. 4. Maps of spatial distribution: a – biomass of *Microcystis* spp., g/m^3; b – biomass of cyanobacteria, g/m^3; c – proportion of cyanobacteria in total biomass of phytoplankton, %; d – total biomass of phytoplankton, g/m^3; e – proportion of dead individuals in the total abundance of zooplankton, %; f – proportion of dead individuals in the total biomass of zooplankton, %

Рис. 4. Карты пространственного распределения: a – биомасса *Microcystis* spp, g /м^3; b – биомасса цианобактерий, г/м^3; c – доля цианобактерий в общей биомассе фитопланктона,%; d – общая биомасса фитопланктона, г/м³; е – доля мертвых особей в общей численности зоопланктона,%; f – доля мертвых особей в общей биомассе зоопланктона,%

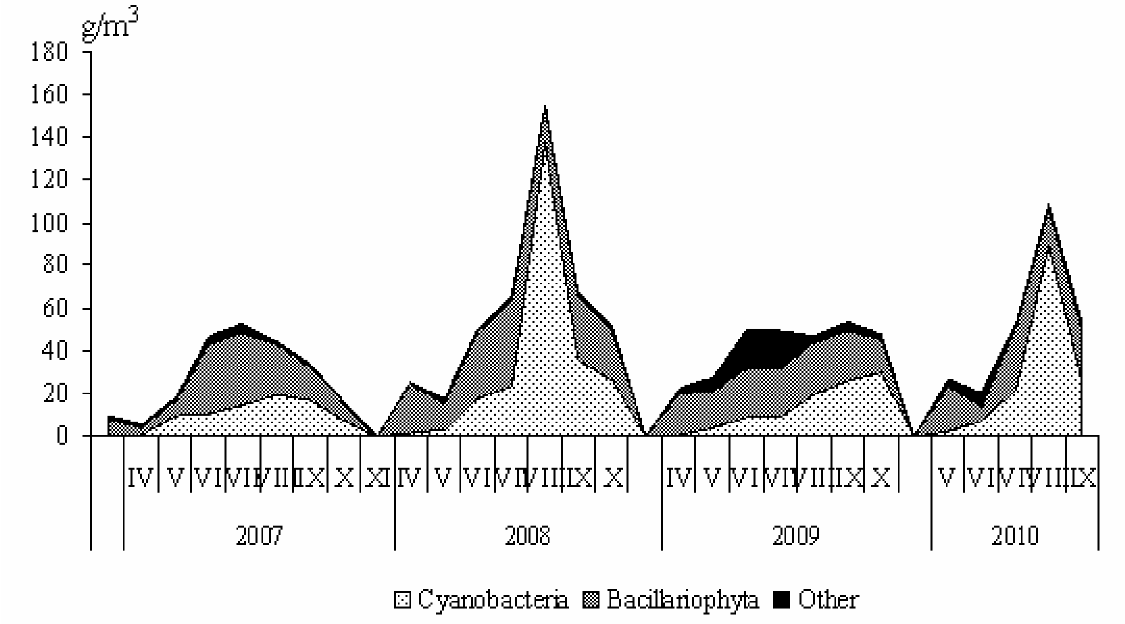


Fig. 5. Seasonal changes in the phytoplankton biomass in the Curonian Lagoon in 2007–2010
Рис. 5. Сезонные изменения биомассы фитопланктона Куршского залива в 2007–2010 гг.

Zooplankton

During the study period, a total of 90 species and subspecies of invertebrates have been found in the plankton of the Curonian Lagoon, including 45 of Rotifera, 27 of Cladocera, and 18 of Copepoda. The complex of dominant species, according to abundance, included *Keratella cochlearis* (Gosse, 1851), *K. quadrata* (O. F. Muller, 1786), *Chydorus sphaericus* (O. F. Mueller, 1785), *Eubosmina coregoni* (Baird, 1857), *Mesocyclops leuckarti* (Claus, 1857), and nauplial Copepoda. Rotifera were prevalent in zooplankton according to abundance. The highest total abundance of zooplankton was observed in May, when *Keratella quadrata* and *K. cochlearis* were dominant. The total abundance of zooplankters in different horizons differed visibly only in spring period, when the highest abundance was observed in the middle layer. The average values of the total zooplankton abundance were similar during vegetation seasons of 2007 and 2008 (433 ± 23 and 413 ± 43 thousand ind./m³, respectively) and during the vegetation seasons of 2009 and 2010 (190 ± 10 and 195 ± 17 thousand ind./m³, respectively).

In biomass, the zooplankton was dominated by *Asplanchna herricki* De Guerne, 1888, *Eubosmina coregoni*, *Chydorus sphaericus*, *Daphnia galeata* G. O. Sars, 1864, *Diaphanosoma mongolianum* Ueno, 1938, *Eudiaptomus graciloides* Lilljeborg, 1888 and *Mesocyclops leuckarti*. In all years of observations, Cladocera accounted for most of the total biomass (56–83%). The highest total biomass of zooplankton in 2007, 2008 and 2010 was observed in June: in 2007 and 2010 this was caused by increase in *Daphnia galeata*; in 2008 it was caused by increases in *Asplanchna herricki*, *Eubosmina coregoni*, and *Daphnia galeata*. In 2009 the highest total biomass of zooplankton was observed in May also due to increase in *Daphnia galeata*. In 2007, the average total biomass over the vegetation period was 2.5 ± 0.3 g/m³; in 2008 – 5.4 ± 0.6 g/m³, in 2009 – 4.0 ± 0.5 g/m³ and in 2010 – 2.1 ± 0.3 g/m³.

Dead individuals were found in populations of 38 species. Species prevalent among them (on different dates and at different stations) included both dominant (*Asplanchna herricki*, *Keratella quadrata*, *Daphnia galeata*, *Chydorus sphaericus*, *Diaphanosoma mongolianum*, *Eubosmina coregoni*, *Mesocyclops leuckarti*, and *Eudiaptomus graciloides*) and relatively rare species (*Brachionus angularis* Gosse, 1851, *Conochilus unicornis* Rousselet, 1892, *Kellicottia* *longispina* (Kellicott, 1879), *Polyarthra vulgaris* Carlin, 1943, *Trichocerca capucina* (Wierzejski and Zacharias, 1893), and *Cyclops vicinus* Ulyanin, 1875).

The highest absolute abundance among dead individuals was recorded for *Keratella quadrata*, *Chydorus sphaericus*, *Mesocyclops leuckarti*, and nauplial Copepoda; the maximum biomass was found for *Asplanchna herricki*, *Daphnia galeata*, *Diaphanosoma mongolianum*, *Mesocyclops leuckarti*, and *Eudiaptomus graciloides*.

In populations of the dominant species of zooplankton, the share of dead individuals reached 14 and 18 % in abundance and biomass respectively (in *Mesocyclops leuckarti*) in 2007, 26 % (in *Keratella cochlearis*) in abundance and 49 % (in *Chydorus sphaericus*) in biomass in 2008; 23 % (in *Daphnia galeata*) in abundance and 48 % (in *Asplanchna herricki*) in biomass in 2009; 47 % and 51 % (both in nauplia Calanoida) in 2010.

Sensitivity of zooplankton taxonomical groups to bloom of cyanobacteria and influence of toxins (according to increasing share of dead organisms in the period of mass cyanobacteria development) increased in the line: Cyclopoida→Calanoida→Rotifera→Cladocera.

The share of dead individuals in the total abundance and biomass of zooplankton varied at different stations and horizons and over the vegetation period. During the vegetation period in 2007–2010, the highest share of dead individuals in the total abundance and biomass of zooplankton was recorded in different horizons, but usually their share was highest at the depth of 1.5 m, though the differences were not statistically significant.

In 2007, the share of dead individuals at different sampling stations from the total abundance and from 0.2 to 9.0% of the total biomass of zooplankton varied not so significant compared with 2008–2010, range of this variation was maximal in 2010 (Table 1).

Table 1

Share of dead individuals from the total abundance and biomass of zooplankton in Curonian Lagoon (Baltic Sea) in 2007–2010
Доля мертвых особей по численности и биомассе зоопланктона в Куршском заливе (Балтийское море) в 2007–2010 гг.

Year	Share of dead individuals					
	from abundance			from biomass		
	min	max	average (±M)	min	max	average (±M)
2007	0.4%	7.8%	1.6 ± 0.3	0.2%	9.0%	1.8 ± 0.3%
2008	0.2%	47.8%	6.1 ± 1.5%	0.1%	62.5%	6.9 ± 2.6%
2009	0.5%	24.2%	6.9 ± 1.5%	0.2%	28.5%	6.7 ± 2.6%
2010	4.4%	76.2%	16.1 ± 2.6%	0.3%	63.0%	12.8 ± 2.6%

The highest share of dead zooplankters in the total abundance and biomass were recorded in the western part of the lagoon (station 3), where the processes of pollution and eutrophication are more pronounced than at the other stations, and the lowest share was recorded in the northeastern part of the lagoon (station 6), which is strongly influenced by the river runoff. In the northeastern part of the lagoon (station 6) the minimum of biomass *Microcystis* spp., cyanobacteria biomass, total biomass of phytoplankton and minimal percentage of cyanobacteria in the total phytoplankton biomass were also observed (Fig. 4).

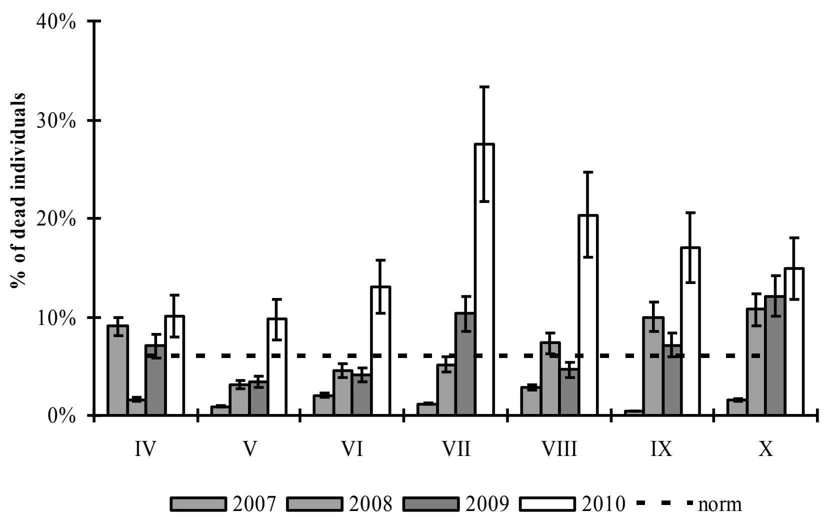
Thus, we note the coincidence of the minima of mortality indicators of zooplankton and the abundance of cyanobacteria (including toxigenic), which is due to the dilution effect of the Neman and Deima rivers. The maxima of these indicators are disunited in space; this is apparently associated with wind mixing and the system currents in the western and southwestern parts of the lagoon.

During the vegetation period of 2007, alterations in increase and decrease in share of dead zooplankters in the total abundance and biomass were observed. The highest share of dead organisms was recorded in April and August (Fig. 6). The average share of dead individuals in the total abundance and biomass of zooplankton (1.6 ± 0.3 and 1.8 ± 0.3 %, respectively) in the period of increased phytoplankton abundance and immediately after this period (from July to October) were close to those recorded during the vegetation period (2.6 ± 1.2 and 2.3 ± 0.7 %, respectively).

In 2008, the proportion of dead individuals in the total abundance of zooplankton continuously increased from April to September and then decreased (Fig. 6a). The share of dead zooplankters in the total biomass of zooplankton increased from April to October (Fig. 6 b). The average share of dead zooplankters in the total abundance and biomass of zooplankton (8.4 ± 3.5 and 8.2 ± 3.4 %, respectively) in the period of harmful algal blooms and immediately after this period from July to October were higher by a factor of 5 to 6 than in the same months of 2007. The average share of dead individuals over the vegetation period of 2008 was 6.1 ± 1.5 % by abundance and 6.9 ± 2.6 % by biomass, which was higher by a factor of 2 to 3 than in 2007.

In 2009, the highest share of dead individuals in the total abundance of zooplankton was in April, July and October, maximal share of dead individuals in biomass was in July (Fig. 6). The average share of dead zooplankters in the total abundance and biomass of zooplankton (8.1 ± 1.9 and 8.9 ± 1.9 %, respectively) from July to October were close in 2008 and 2009 and were also higher by a factor of 5 to 6 than in the same months of 2007. The average share of dead individuals over the vegetation period of 2009 was 6.9 ± 1.5 % by abundance and 6.7 ± 2.6 % by biomass, which was higher by a factor of 3 than in 2007.

a



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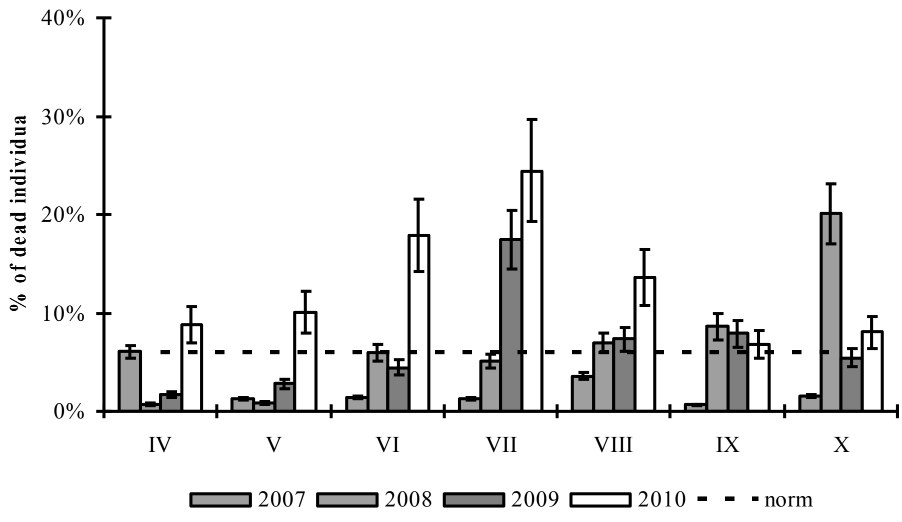

Fig. 6. Seasonal dynamics of dead specimens share (%) in the total abundance (a)

and total biomass (b) of zooplankton
Рис. 6. Сезонная динамика доли мертвых особей (%) в общей численности (а)
и общей биомассе (б) зоопланктона

In 2010, the share of dead individuals in the total abundance and in the total biomass of zooplankton increased from April to July and then decreased (Fig. 6). The average share of dead zooplankters in the total abundance and biomass of zooplankton (19.9 ± 5.1 and 13.2 ± 4.5 %, respectively) from July to October was higher by a factor of 7 to 13 than in the same months of 2007. The average share of dead individuals over the vegetation period of 2010 was 16.1 ± 2.6 % by abundance and 12.8 ± 2.6 % by biomass, which was higher by a factor of 5 to 6 than in 2007.

Thus, during the period of mass development of harmful cyanobacteria and after that in July–October 2008–2010 the share of dead organisms by abundance and biomass of zooplankton increased in 5–13 times (up to 8.1–19.9 %) when comparing with the share of dead organisms in July–October 2007 (1.6–1.8 %), when biomass of cyanobacteria was very low. Minimal share of dead organisms was observed at the station in which organic pollution, eutrophication and biomass of harmful cyanobacteria (especially *Microcystis* spp.) were at the lower level.

The significant correlations were obtained between share of dead organisms in zooplankton and biomass of toxigenic *Microcystis* spp. (r=0.62-0.81), and between share of Chlorophyta in the total biomass phytoplankton and share of dead organisms in zooplankton (r= –0.51-0.60).

Discussion

The Curonian Lagoon is the biggest lagoon in the Baltic Sea. The eutrophication processes here are strongly expressed due to the high concentration of nutrients, slow water change in the southern and central areas of the lagoon, shallow depths, and the silt accumulation in the bottom sediments. Cyanobacteria scum is common for the summer period since 2002 by the own data. The intensity and periods of these bloom exhibit strong interannual dynamics. The periods of maximal cyanobacteria bloom is controlling by the different biotic and abiotic factors. The blooms of cyanobacteria lead to a number of negative consequences, including the increase in the share of the dead individuals in zooplankton.

Dead individuals were recorded in all populations of all dominant zooplankton species; in some periods they reached a considerable share in their abundance and biomass, once again confirming the importance of taking into account the share of dead individuals in water bodies. Some invertebrate species were represented by only a few specimens, so that dead individuals of these species could not be found due to the small sample size.

The method of staining zooplankton with aniline blue used by different investigators in several water bodies and watercourses revealed different ranges of variation and average numbers of dead zooplankters in the total abundance of zooplankton. By our data fall within the average values of this variation, but the highest values recorded in the Curonian Lagoon in the years, when the higher cyanobacteria blooms were observed, are closer to those observed in unstable or disturbed ecosystems [Dubovskaya, 2009; Tang et al., 2014].

Different shares of dead individuals among zooplankters of different systematic groups probably reflects their different sensitivities both to factors related to eutrophication and to cyanobacterial toxins. Cladocera (especially large species of the genus *Daphnia*) are known to be sensitive to different pollutants and toxins, which is the reason for their wide usage as test objects in aquatic toxicology [Shcherban', 1982, 1992]. The influence of cyanobacterial toxins can be one of the causes of increased zooplankton mortality [Dubovskaya, 2009]. The toxic effect of cyanobacteria on zooplankton, especially *Daphnia*, is known and has been confirmed by a number of experiments in the laboratory and in the natural environment [Lampert, 1981; Fulton, Paerl, 1987; Nizan et al., 1986; Rohrlack et al., 2001; Moustaka-Gouni et al., 2006].

In July-September potentially toxigenic phytoplankton species abundantly develop in the phytoplankton of the Curonian Lagoon. A number of investigators [Karmaikl et al., 1993; Paldaviĉiene et al., 2009; Belykh et al., 2013] found cyanobacterial toxins in the waters of the Curonian Lagoon, thus confirming the presence of toxigenic cyanobacteria in this water body.

In the period of mass development of harmful algae, the share of dead cladocerans in their total abundance and biomass in the Curonian Lagoon significantly increased by a factor of 5−13. It was probably the deterioration of conditions due to this period (possibly including increased toxicity) that cladocerans reacted to by increased mortality, which resulted in an increased share of dead animals. Since copepods, especially cyclopoids, are more tolerant to pollution of different kinds [Vinberg, 1979; Andronikova, Raspopov, 2007], the share of dead Cyclopoida did not increase significantly in the year of higher water bloom; however, the share of dead nauplial copepods considerably increased, which is probably explained by their increased sensitivity to cyanobacterial toxins.

One of the main possible reasons of share increasing of dead organisms in zooplankton is the influence of toxins *Microcystis* spp. We obtained a significant correlation between percentage of dead organisms in zooplankton and biomass of toxigenic *Microcystis* spp. (r=0.62–0.81). Green algae can presumably compensate negative effect of cyanobacteria, the correlation between percentage Chlorophyta in total biomass phytoplankton and share of dead organisms in zooplankton was negative (r= – 0.51-0.60).

According to the literature data, only impact of *Microcystis* spp. toxins was exactly proved on zooplankton [Nizan et al., 1986; Fulton, Paerl, 1987; Bernardi, Giussani, 1990; Rohrlack et al., 2001], which is confirmed by our data. On the other hand, in experiments [Hanazato et al, 1988; Chen, Xie, 2004] was shown that green algae can reduce the negative effect of blue-green algae, which confirms the dependence obtained by us.

Higher share of dead zooplankters was recorded in April and from July to October. The high share of dead individuals at the beginning of the vegetation period is probably related to hydrological factors: at this time of year, active wind induced mixing of the lagoon waters is observed, while the water temperature is low and food for zooplankton is deficient. Another factor explaining the high share of dead individuals in the spring may be mass development of harmful algae in the previous year [Aleksandrov, 2009].

Mass development of harmful algae is related to the abundant production of organic matter, which enters the water after phytoplankton destruction and leads to the secondary pollution of the water body [Aleksandrov, Dmitrieva, 2006]. The effect of this secondary pollution can probably still be observed the next year. The increased share of dead individuals in summer-autumn period is apparently related to the abundant development of phytoplankton, with a high share of potentially toxigenic species.

The possible negative impact of toxins is also confirmed by the fact that in July-October 2008-2010 the share of dead organisms from abundance and biomass of zooplankton increased in 5-13 times, when bloom of cyanobacteria was observed. The negative influence of the bloom of toxic cyanobacteria, leading to an increased share of dead zooplankters, was recorded earlier in the open part of the Baltic Sea [Shchuka, 2002].

It should be noted that in 2007, a complex of toxigenic species developed in summer and autumn, while in the same period of 2009 the complex of species not producing toxins developed. However, in these years, the negative effect on zooplankton was low with low share of dead individuals. The possible reason for this may be low quantitative development of cyanobacteria. When biomass of cyanobacteria is low, the zooplankton is well adapted and normally develops even in the presence of cyanotoxins in the water. It is known that with low biomass of toxigenic species, zooplankton organisms are resistant to the effects of cyanobacteria toxins and is able to accumulate them in their bodies [Hanazato, Yasuno, 1988].

In 2008 and 2010 non-toxigenic algae was dominated in the phytoplankton communities. In these years phytoplankton biomass was high. Nevertheless, the toxicogenic *Microcystis* presented in the composition of the communities, but in smaller abundance and biomass than the non-toxigenic *Aphanizomenon* sp. In these years, the negative effect on zooplankton as a whole and its mortality rates were most pronounced, while the mortality rates of zooplankton were maximal, and its quantitative development was at the low level. In July 2010, the maximum values of the dead individuals share were recorded for the entire study period. In the water area of the Curonian Lagoon, «dead zones» were formed – areas with a reduced abundance, biomass and production of zooplankton, at which the maximum mortality rates were recorded. The trigger mechanism for this phenomenon was the extremely high air temperature, which led to a significant increase in the temperature of the Curonian Lagoon. On average in July–August 2010 the water temperature of the Curonian Lagoon was the highest for more than 50 years of regular hydrometeorological observations on this reservoir [Semenova, 2013]. This, in turn, was the reason for the massive development of cyanobacteria, which leads to a hyperbloom of water. Toxins of algae and excess of organic substances in water, deterioration of the gas regime of the lagoon up to the complete absence of oxygen were observed with the massive development of cyanobacteria and their withering away. Thus, the cause of the mass death of zooplankton was, firstly, the deterioration of the oxygen regime and, secondly, the effect of toxins of cyanobacteria.

Conclusion

The Curonian Lagoon currently is a hypertrophy water body. The phenomenon of mass development of harmful algae (mostly cyanobacteria) is regularly observed in the lagoon; the biomass of these cyanobacteria in recent years is considerably higher than the level that determines secondary pollution of the water body.

During the period of mass development harmful cyanobacteria and after it in July-October 2008–2010 the share of dead organisms from abundance and biomass of zooplankton increased in 5-13 times (up to 8.3–19.4%) in comparison with the share of dead organisms in July–October 2007 (1.5–1.8%), when biomass of cyanobacteria was very low. Sensitivity of zooplankton's taxonomical groups to bloom of cyanobacteria and influence of toxins (according to increasing share of dead organisms in the period of mass cyanobacteria development) increased in the line: Cyclopoida→Calanoida→Rotifera→Cladocera.

Minimal share of dead organisms was observed at the station in which organic pollution, eutrophication and biomass of harmful cyanobacteria (especially *Microcystis* spp.) were at the lower level. One of the main possible reasons of dead organisms share increasing in zooplankton is the influence of toxins *Microcystis* spp. We obtained a significant correlation between share of dead organisms in zooplankton and biomass of toxigenic *Microcystis* spp. Green algae can presumably compensate negative effect of cyanobacteria, the correlation between percentage Chlorophyta in total biomass phytoplankton and share of dead organisms in zooplankton was negative. Thus, the share of dead organisms in zooplankton may serve as a sensitive indicator reflecting the influence of harmful algae.

Acknowledgements

This work was supported by Russian Foundation for Basic Research (grant 15-04-04030 A).

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