EKOLOGIJA. 2011. Vol. 57. No. 3. P. 121–127

Structure and spatial distribution of winter phytoplankton of the Curonian Lagoon (Baltic Sea)

Evgenia K. Lange

Atlantic Branch of P. P. Shirshov, Institute of Oceanology of Russian Academy of Sciences, Prospekt Mira 1, 236022 Kaliningrad, Kaliningrad Region, Russia

The winter phytoplankton of the Russian part of the hyper-trophic Curonian Lagoon (Baltic Sea) was studied in 2010. Diatoms, cyanobacteria and cryptomonads prevailed in phytoplankton. Diatom *Aulacoseira islandica* was dominant and especially prevailing in the southern area of the lagoon, i. e. the area influenced by the Deyma River. Cyanobacteria *Planktothrix agardhii* was also a dominant species. The composition of the complex of dominant species and vertical distribution of phytoplankton differed compared to the results obtained 30 years ago in the same area. The study revealed the increase of the abundance of winter phytoplankton compared to the formerly recorded data.

Key words: winter phytoplankton, *Aulacoseira islandica*, *Planktothrix agardhii*, shallow lagoon

INTRODUCTION

The hyper-trophic Curonian Lagoon located in the south-eastern part of the Baltic Sea is a semi-enclosed shallow lagoon separated from the sea by a narrow sand spit and having the surface area of 1 584 km^2 (the Russian part constituting 1 171 km^2) and average depth of 3.8 m (Chervinskas, 1959).

The greatest part of the lagoon is a freshwater because of the Nemunas River runoff. On the average, 21.8 km^3 of river water flows into the Baltic Sea through the Curonian Lagoon yearly (Gailiušis et al., 2011).

The lowest water temperature of 0.1–0.2 °C is registered in January–February and the highest of 23–27 °C in July–August. The ice-cover forms annually during winter and lasts about 90 days from December till early March; the maximum thickness of ice is up to 80 cm (Gidrometeorologicheskie…, 1985; Krylova, 1985; Žaromskis, 1996).

Usually, most of hydrobiological studies are limited by the vegetation season. However, reliable predictions of ecosystem parameters, ecological modelling and aquatic system sustainable use must be based on the year-round data sets. The level of phytoplankton development during the vegetation season is sufficiently defined by its winter characteristics. In the Curonian Lagoon phytoplankton succession is studied mainly during the iceless period, from March to November (Uselite, 1959; Krylova, 1985; Olenina, 1991, 1998, 2001; Pilkaitytė, 2003; Semenova, Smyslov, 2005; Dmitrieva, 2007; Lange, 2007, etc.), whereas phytoplankton data from the winter seasons are limited.

The aim of the present paper is to describe the structure and spatial distribution of the winter phytoplankton communities in the Curonian Lagoon.

MATERIALS AND METHODS

Material was taken during the multidisciplinary winter field cruise of AB IO RAS in the second half of February 2010.

Ten phytoplankton samples were collected at 6 stations (st.) of the Russian part of the Curonian Lagoon: st. 13, 15 (central area), and st. 1, 24, 25, 28 (southern area) (Fig. 1). Depth varied from 3.6 to 5.3 m. Surface water temperature was not

* Corresponding author. E-mail: evlange@gmail.com

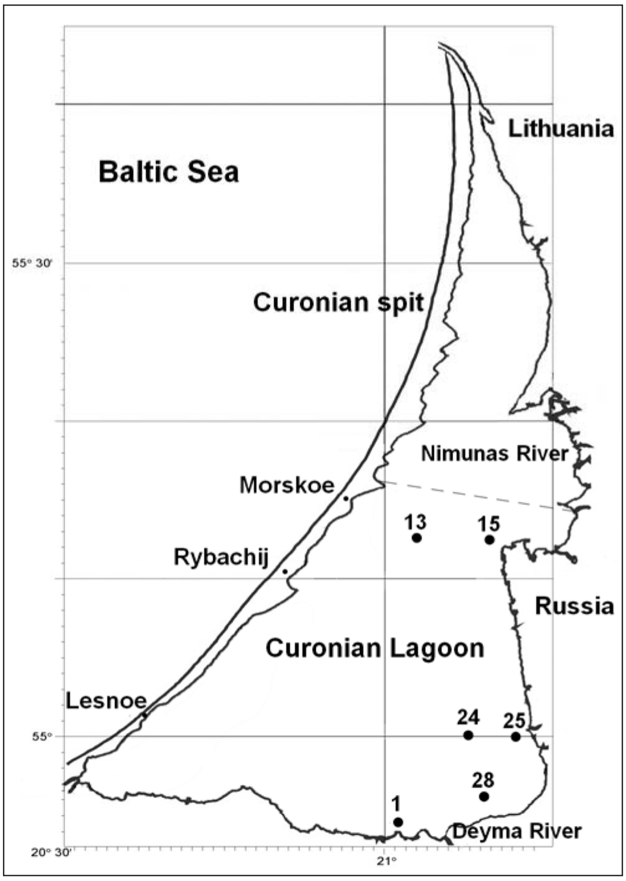

Fig. 1. Location of the sampling sites in the Curonian Lagoon, February 2010 (central area of the lagoon – st. 13, 15; southern area – st. 1, 24, 25, 28)

higher than 0.1–0.6 °C, and bottom temperature was below 2.3–4.0 °C. Ice thickness came up to 60 cm. The water samples for phytoplankton analyses (0.5 l volume) were collected in the surface and near-bottom layers, using a 1 l Frantsev bathometer. Phytoplankton was fixed in a modified Lugol's solution (Kuz'min, 1975) and concentrated to 5 ml volume.

The organisms were counted in the Nageotte chamber (0.02 ml volume) under the light microscope (Ergaval Karl Zeiss, Jena), magnification x256 and x640. Wet weight biomass of phytoplankton was assessed from cell geometry (HELCOM, 1988; Rukovodstvo…, 1992) and using a cell biovolume table (HELCOM, 2006). The algal species and groups that comprised more than 10% of phytoplankton biomass in a sample were considered dominant.

The Bray-Curtis index of similarity was used to evaluate the level of similarity between phytoplankton communities of sampling sites. Calculations were made with the use of mathematically transformed biomass values (taking the fourth root). The results of cluster analysis based on the weighted pair-group method were presented as a dendrogram. Cluster analysis was carried out in software PRIMER v.5.2.3.

RESULTS

Winter phytoplankton was represented by 58 taxa including the largest variety of different cyanobacteria (22 taxa). The following species were arranged in the descending order: green algae (15), diatoms (11), cryptophytes (6), dinophytes (3), euglenophytes (1), as well as unidentified flagellates forms ascribed as the Flagellata group.

The number of taxa ranged from 8 to 18 in different samples. Taxonomic diversity was lower in the surface layer than in the bottom layer (12 ± 3 to 16 ± 3 taxa, respectively). Cryptophytes were most diverse at the surface, while the diversity of other groups of phytoplankton increased in the layer close to the bottom (Fig. 2).

The widespread species with the frequency of occurrence of more than 50% were diatom *Aulacoseira islandica* (O. Müll.) Sim., cyanobacteria *Planktothrix agardhii* (Gom.) Anagn. et Kom., dinophytes *Gymnodinium* spp., small-size cryptomonads (smaller than 20 μm) and group Flagellata.

The total biomass of phytoplankton at an average of 43% was determined by *A. islandica*, the spatial distribution of which was uneven. This species reached the greatest development in the southern area, where its contribution to the total biomass was 40–99%. Abundance reached 262–1000 thous. cell $\cdot$ l^{-1} and biomass reached 0.45–1.59 g $\cdot$ m^{-3} in the upper layer, and 76 thous. cell $\cdot$ l^{-1} and 0.145 g $\cdot$ m^{-3} in the bottom layer, respectively. In the rest of the area of the Curonian Lagoon the amount of *A. islandica* was considerably lower and counted from 0 to 0.03 g $\cdot$ m^{-3}, although it continued to dominate.

The diatom *Actinocyclus normanii* (Greg.) Hust dominated in the surface layer, amounting to 12% of the total biomass. *Stephanodiscus rotula* (Kuitz.) Hendey (to 42%) was found in both layers. The abundance of these species did not exceed 1 thous. cell $\cdot$ l^{-1}. Different size cryptomonads played a definite role only in the surface layer

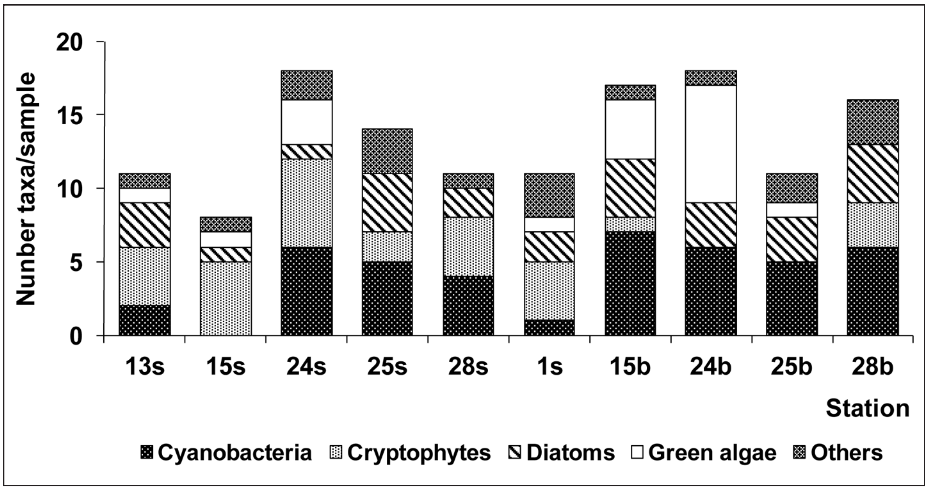

Fig. 2. Phytoplankton taxonomic composition in the Curonian Lagoon in February 2010 (s – surface layer, b – bottom layer)

(32% of total biomass on average): their abundance ranged from 70 to 139 thous. cell · $l^{-1}$and biomass from 0.01 to 0.02 g · m^{-3}. In the bottom layer their amount was reduced to 0–6 thous. cell · l^{-1} and biomass to 0–0.003 g · m^{-3}, respectively. In the south-eastern area (st. 24) cyanobacteria *Planktothrix agardhii* predominated with a maximum of 0.01 g · m^{-3} in the surface layer (st. 25). In general, the quantitative parameters of winter phytoplankton were determined by diatoms (66% of total biomass on average), cryptophytes (32% in the surface layer) and cyanobacteria (17% in the bottom layer) in both layers (Fig. 3).

The Bray-Curtis coefficient was used to assess the similarity of the phytoplankton communities of stations and the results are presented in Fig. 4. Phytoplankton communities with a low level of similarity (~20%) were divided into two clusters with pooled surface and bottom phytoplankton communities. Inside the cluster, the level of similarity was also low, especially comparing the assemblages taken from the layer near the bottom (similarity not higher than 45%). The structure of phytoplankton of the surface layer was also characterized by spatial heterogeneity, i. e. the stations merged into two subgroups: one included the data from the

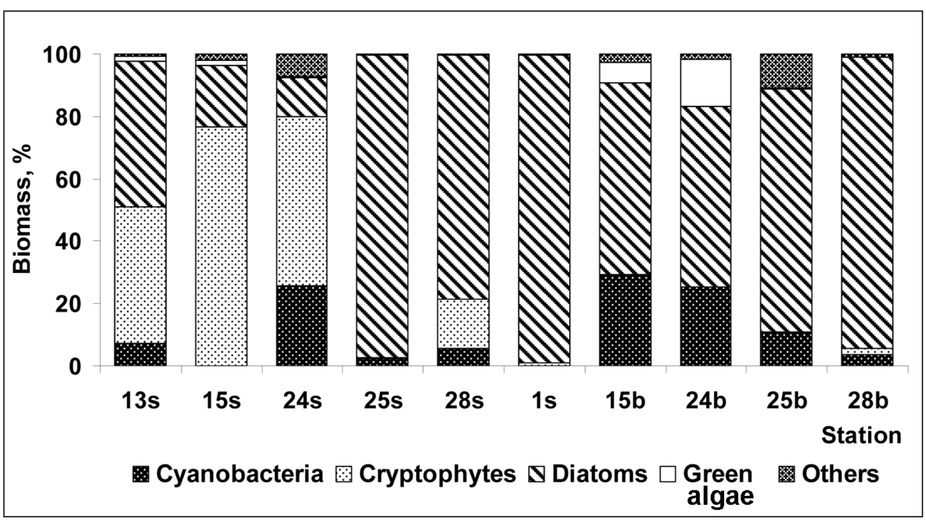

Fig. 3. Relative biomass of the main systematic groups of phytoplankton in the Curonian Lagoon in February 2010 (s – surface layer, b – bottom layer)

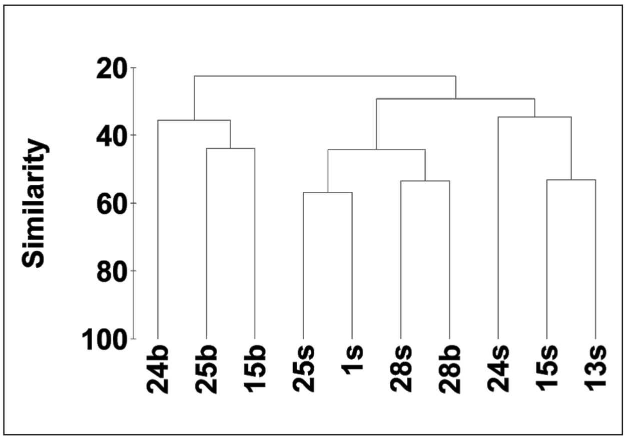

Fig. 4. Dendrogram of species similarity in winter phytoplankton communities based on the data of stations in the Russian part of the Curonian Lagoon in 2010, using the coefficient of Bray-Curtis similarity (%) (areas: centre – st. 13, 15, southern part – st. 1, 24, 25, 28)

southern part of the lagoon, the other from the central part. The specific structure of phytoplankton differed in st. 24 located in the southern part.

The average quantitative parameters of winter phytoplankton in the upper layer were 512 thous. cell · l^{-1} and 0.43 g · m^{-3} on average (Table 1). The total abundance in the bottom layer varied from 324 to 607 thous. cell · l^{-1} (447 thous. cell · l^{-1} on average), biomass from 0.03 to 0.16 g · m^{-3} (0.07 g · m^{-3} on average). Phytoplankton productivity was higher in the southern part of the lagoon.

DISCUSSION

The seasonal dynamics of phytoplankton communities typical of eutrophic freshwater of the temperate zone was observed in the Curonian Lagoon. Diatoms dominated in spring time, when water temperature reached 15–16 °C; cyanobacteria started dominating and occupied the second position in taxon diversity after green algae (Pilkaitytė, 2003; Dmitrieva, 2007). Water blooms were regularly observed in summer and autumn in the lagoon. It was caused by the development of potentially toxic phytoplankton species in this group: *Aphanizomenon flos-aquae* (L.) Ralfs ex Born. et Flah., species of the genus *Microcystis* (*M. aeruginosa* (Kütz.) Kütz., *M. wesenbergii* Kom., *M. viridis* (A. Br.) Lemm.), *Planktothrix agardhii*, *Woronichinia compacta* (Lemm.) Kom. et Hind. Toxic cyanobacteria blooms were observed, for example, in the summer–autumn period in 2010, when phytoplankton in water and microcystins were detected (Ezhova, Lange, 2011). Phytoplankton biomass in the lagoon can exceed 100 g · m^{-3} (Olenina, 1998; Semenova, Smyslov, 2005).

In 2010, cyanobacteria prevailed in the under-ice phytoplankton amounting to 38% of the total number of taxa. The highest diversity was recorded in the near-bottom layer (Fig. 2), where water temperature (2.3–4.0 °C) was higher than that in the surface layer (0.1–0.6 °C). Cyanobacteria became subdominant at the bottom, forming an average of 17% of the total biomass of phytoplankton. Cyanobacteria are characterized by the lowest demand to the light condition (solar radiation) compared with diatoms and green algae. Light conditions are not a limiting factor for cyanobacteria (Kuzmenko, 1981).

Cyanobacteria *Aph. flos-aquae* was massively growing in the Curonian Lagoon in the summer–autumn season, but in winter it was found in only two samples and did not have any significance in plankton, although in 1975–1976 it was one of the dominant species with the frequency of occurrence year-round reaching over 70% (Krylova, 1985). In contrast, another summer dominant in recent years, non-N_2-fixing cyanobacteria *P. agardhii,* was widespread in the lagoon in February and prevailed in one of the southern stations. Earlier, these species had not been found in plankton (Krylova, 1985). *P. agardhii* can grow in mass over a wide temperature range from 6 to more than 20 °C, i. e. it refers to eurythermic organisms. As to another Oscillatoriales species, *P. agardhii,* it is with a low light-energy requirement for growth and is a 'turbulent' species (Stefaniak, 2005). This species was shown to occur in plankton in a hypertrophic fishpond (Central Moravia, Czech Republic) throughout the year; its winter population was concentrated at the bottom of the form hormogoniae and filaments, which begin to grow in March and reached the maximum length filaments in April and the greatest abundance in August (Poulickova et al., 2004). Such a scenario of the annual development of *P. agardhii* can be assumed for the lagoon.

Quantitative parameters of phytoplankton in February 2010 were mainly provided by diatom

Aulacoseira islandica, a freshwater species with cold temperature optimum between 5 and 10 °C. The turbulence of water masses plays an important role in its development and promotes an entry of resting fibers in the photic zone of diatoms and prevents their sedimentation (Trifonova, 1979). The highest development of this species observed in the southern part of the lagoon was subject to the influence of the Deyme River outflow. In the mid-1970s *A. islandica* also had a high priority in the winter plankton of the Curonian Lagoon (Krylova, 1985). In 2002–2004 this species together with the species of genus Stephanodiscus formed a spring dominant complex in the study area (Dmitrieva, 2007).

In the winter phytoplankton collected in the surface layer, our investigations revealed the dominant position of different size cryptomonads that had not been previously noted (Krylova, 1985). The representatives of cryptophytes may occur in plankton all year round and form a typical cold-water phytoplankton complex of ice-cover and early-spring periods in the temperate zone lakes (Trifonova, 1979), including a hypertrophic water body (Lepistö, 1999).

In the same season in the mid 1970s and early 1980s the average monthly biomass of phytoplankton lagoon consisted mainly of diatoms (60%), especially *A. islandica*, green algae and cyanobacteria (10–15%) (Krylova, 1985). In 2010, the amount of green algae decreased to an average of 3% and cryptophytes appeared as subdominants.

A cluster analysis revealed the spatial heterogeneity of phytoplankton distribution during the winter of 2010. The structure of taxonomic composition of phytoplankton in the study area highlighted the central and southern parts in the aspect of horizontal distribution, and surface and bottom horizons in the vertical distribution (Fig. 3). In the surface layer, the extreme values of the total abundance of winter phytoplankton differed by an order, while in the bottom layer only ca. 2 times. The total biomass varied in a wide range: up to 53 times in the surface layer, and up to 6 times at the bottom. Phytoplankton abundance varied at a lesser extent as largely determined by the biomass of the species of cyanobacteria and small-size cryptophytes (with the exception of st. 1, where *A. islandica* predominated); however, it mainly depended on the vegetation species with a great individual biovolume and the average was higher in the surface layer up to 6 times.

As in 2010, in the second half of 1970 the amount of phytoplankton in the southern part of the lagoon was higher than in the central deep zone: $1–5 \cdot 10^3$ thous. cell $\cdot$ l^{-1} (0.05–1.0 g $\cdot$ m^{-3}) and up to $0.1 \cdot 10^3$ thous. cell $\cdot$ l^{-1} (0.1 g $\cdot$ m^{-3}), respectively (Table). However, phytoplankton, different from the present situation, was concentrated in the bottom layers (Krylova, 1985).

CONCLUSIONS

The dominant species, vertical distribution in the water column and quantitative development of the winter phytoplankton community have undergone some changes in the Curonian Lagoon in 2010 compared with the situation 30 years ago. In the earlier period phytoplankton was mainly concentrated in the bottom layer, whereas in the present time the development level of phytoplankton both in the surface and bottom layers in the southern part of the lagoon was of the same order. Along with cyanobacteria, diatoms and cryptophytes

Table. **Quantitative parameters of winter phytoplankton in the Russian part of the Curonian Lagoon in different years (surface layer)**

Parameter	Lagoon		Central area		Southern area	
	1975, 1976, 1982[1)]	2010	1975, 1976, 1982	2010	1975, 1976, 1982	2010
Abundance, thous. cell $\cdot$ l^{-1}	40	512 (106–1240)[2)]	– (up to 100)	191 (106–275)	– (1000–5000)	739 (143–1240)
Biomass, g $\cdot$ m^{-3}	0.10	0.43 (0.02–1.76)	– (up to 0.10)	0,03 (0.02–0.03)	– (0.05–1.00)	0.81 (0.12–1.76)

[1] Krylova, 1985; [2] average (range)

(cryptomonads) became prevalent, and green algae have almost completely dropped out of the dominants. Cyanobacteria *Aph. flos-aquae* massively growing in the Curonian Lagoon in the summer season were found only twice in winter, thus were not really important. In contrast, another summer dominant cyanobacterium *P. agardhii* was found everywhere and prevailed in one of the stations. An increase of the quantitative development of phytoplankton was observed in the southern part and in all stations of the study area in general. At the same time, the diatom *A. islandica* remains the main dominant of winter phytoplankton, and the pattern of the horizontal distribution of the quantitative parameters of phytoplankton is also the same. The zone of influence of the Deyma River outflow is the most productive part of the southern part of the lagoon.

ACKNOWLEDGEMENTS

The author expresses thanks to the colleagues of the Atlantic branch of the Institute of Oceanology for participation in the field work and, in particular, Dr. E. E. Ezhova for the sampling of under-ice phytoplankton.

Received 17 September 2011
Accepted 09 November 2011

REFERENCES

1. Chervinskas Je. Osnovnye cherty gidrologichesko-go rezhima. Kurshju Mares. Vil'njus: Izd-vo AN LitSSR; 1959: 47–66.
2. Dmitrieva O. A. Potencial'no toksichnye vidy fitoplanktona rossijskoj chasti Kurshskogo i Vislinskogo zalivov Baltijskogo morja. Problemy izuchenija i ohrany prirodnogo i kul'turnogo nasledija nacional'nogo parka „Kurshskaja kosa". Sb. nauch. statej. Vyp. 5. Kaliningrad: RGU im I. Kanta; 2007: 102–118.
3. Ezhova E., Lange E. Cyanobacterian blooms and fish, invertebrate and bird kills in the Curonian Lagoon, Baltic Sea. ICES Annual Science Conference. Gdańsk, Poland, September 20–24, 2011. Gdańsk; 2011: 36–37.
4. Gailiušis B., Kriaučiūnienė J., Jakimavičius D., Šarauskienė D. 2011. The variability of long–term runoff series in the Baltic Sea drainage basin. BALTICA. Vol. 24(1): 45–54.
5. Gidrometeorologicheskie uslovija shel'fovoj zony morej SSSR. T. 1. Baltijskoe more. Vyp. 3. Kurshskij i Vislinskij zalivy. Pod red. T. A. Ivanovoj. L.: Gidrometeoizdat; 1985.
6. HELCOM, Baltic Marine Environmental Protection Commission – Helsinki Commission. Guidelines for the Baltic Monitoring Programme for the third stage. Part D. Biological Determinants. 27 D; 1988.
7. HELCOM, Biovolumes and size-classes of phytoplankton in the Baltic Sea. Balt. Sea Environ. Proc. N 106; 2006.
8. Krylova O. I. Funkcionirovanie planktona i bentosa Kurshskogo i Vislinskogo zalivov Baltijskogo morja v svjazi s ih ekologicheskimi otlichijami. Atlant. NIIryb. hoz-va i okeanografii. Kaliningrad; 1985. Dep. v CNIITEIRH 21.10.85 r. N 714-RH.
9. Kuz'menko M. I. Miksotrofizm sinezelenyh vodoroslej i ego jekologicheskoe znachenie. Kiev: Naukova Dumka; 1981.
10. Kuz'min G. V. Fitoplankton. Vidovoj sostav i obilie. Metodika izuchenija biogeocenozov vnutrennih vodoemov. M.; 1975: 73–87.
11. Lange E. K. Letnij fitoplankton Kurshskogo zaliva i ozera Lebed'. Problemy izuchenija i ohrany prirodnogo i kul'turnogo nasledija nacional'nogo parka „Kurshskaja kosa": Sb. nauch. statej. Vyp. 5. Kaliningrad: RGU im I. Kanta; 2007: 142–149.
12. Lepistö L. Phytoplankton assemblages reflecting the ecological status of lakes in Finland. Monograph of the Boreal Env. Res. N 16; 1999.
13. Olenina I. A. Issledovanie izmenenij chislennosti vidov fitoplanktona Kurshskogo zaliva v 1980–1987 gg. Issledovanie fitoplanktona v sisteme monitoringa Baltijskogo morja i drugih morej SSSR. M.; 1991: 191–201.
14. Olenina I. 1998. Long-term changes in the Kuršių Marios lagoon: Eutrophication and phytoplankton response. Ecologija. N 1: 56–64.
15. Olenina I. A. Potencial'no toksicheskie vidy fitoplanktona Kurshskogo zaliva i jugo-vostochnoj chasti Baltijskogo morja i ih sezonnaja dinamika. Tez. dokl. VIII s"ezda Gidrobiologicheskogo obshchestva RAN, T. 1 (16–23 sentjabrja 2001 g.). Kaliningrad; 2001: 197–198.
16. Pilkaitytė R. Phytoplankton seasonal succession and abundance in the eutrophic estuarine lagoons. Summary of doctoral dissertation. Klaipėda; 2003.
17. Poulickova A., Hasler P., Kitner M. 2004. Annual cycle of Planktothrix agardhii (GOM.) Anagn. & Kom. nature population. International Review of Hydrobiology. Vol. 89(3): 278–288.
18. Rukovodstvo po gidrobiologicheskomu monitoringu presnovodnyh ekosistem. Pod red. V. A. Abakumova. SPb.: Gidrometeoizdat; 1992.

19. Semenova S. N., Smyslov V. A. Sostojanie fitocena Kurshskogo zaliva Baltijskogo morja na rubezhe HH–HHI vekov. Gidrobiologicheskie issledovanija v bassejne Baltijskogo morja, Atlanticheskom i Tihom okeanah na rubezhe tysjacheletij. Kaliningrad: AtlantNIRO; 2005: 17–64.
20. Stefaniak K., Kokociński M., Messyasz B. 2005. Dynamics of Planktothrix agardhii Agardhii (Gom.) Anagn. Et Kom. blooms in polimictic lake Laskownickie and Grylewskie (Wielkopolska Region) Poland. Oceanol. and Hydrobiol. Studies. Vol. XXXIV. Suppl*ement* 3: 125–136.
21. Trifonova I. S. Sostav i produktivnost' fitoplanktona raznotipnyh ozer Karel'skogo pereshejka. L.: Nauka; 1979.
22. Uselite S. I. Fitoplankton zaliva Kurshju Mares i ego sezonnaja dinamika. Kurshju-Mares. Itogi kompleksnogo issledovanija. Vil'njus: Izd-vo AN LitSSR; 1959: 139–163.
23. Žaromskis R. Ocean, Sea, Estuary. Vilnius: Debesija; 1996.

Evgenia K. Lange

KURŠIŲ MARIŲ (BALTIJOS JŪRA) ŽIEMOS FITOPLANKTONO STRUKTŪRA IR ERDVINIS PASISKIRSTYMAS

Santrauka

Straipsnyje pateikiami hipertrofinės Kuršių marių dalies (Rusijos) 2010 m. žiemos laikotarpio fitoplanktono tyrimų rezultatai. Fitoplanktone vyravo titnagdumbliai, melsvabakterės ir kriptofitainiai. Daugiausia rasta *Aulacoseria islandica* titnagdumblių, ypač pietinėje Kuršių marių dalyje, esančioje Deimos upės įtakos zonoje, taip pat *Planktothrix agardhii* melsvabakterių. Vyraujančių rūšių kompleksas ir vertikalus fitoplanktono pasiskirstymas, palyginti su pastarųjų trijų dešimtmečių fitoplanktono tyrimų rezultatais, skyrėsi, o žiemos fitoplanktono kiekybiniai rodikliai didėjo.

Raktažodžiai: žiemos fitoplanktonas, *Aulacoseira islandica*, *Planktothrix agardhii*, sekli įlanka