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Seasonal variability of phytoplankton in the shallow waters of the southern Baltic Sea

Sezonowa zmienność fitoplanktonu w płytkich wodach południowego Bałtyku

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Abstract: The Baltic Sea is characterised by a seasonal variation of phytoplankton structure. These organisms are particularly sensitive to changes in various environmental parametres. Cyclic fluctuation of species composition that occurs annually, as well as abundance and biomass of phytoplankton is a consequence of these changes. Spatial and temporal variability of particular groups of phytoplankton is not the same in different areas of the Baltic Sea. The purpose of this work was to determine spatial and temporal distribution of phytoplankton in three chosen areas of the coastal zone of the southern Baltic Sea (Ustka, Poddąbie and Rowy) in the period of November 2014-September 2016. Mean values of abundance and biomass of phytoplankton for the surveyed areas were typical for this type of coastal waters. In each of the surveyed areas, the same dominant species in terms of abundance and biomass were observed. Growth of diatoms was recorded only in the area of Ustka, which could have been caused by the inflow of river waters. Seasonal surveys of phytoplankton indicated that in the case of studies regarding this parameter – taxonomic composition, abundance and biomass in the same surveyed area were similar at the three research stations (e.g. 75-80%), depending on the season of the year. On this basis, it was concluded that, whether carrying out the monitoring of phytoplankton or planned investments, the sample collection frequency was of greater significance than the number of research stations.

Keywords: Phytoplankton, seasonal variability, shallow water zone of the southern coast of the Baltic Sea

Streszczenie: W Morzu Bałtyckim obserwuje się sezonowe zmiany struktury fitoplanktonu. Organizmy te są szczególnie wrażliwe na zmiany różnych parametrów środowiska. Konsekwencją tych zmian jest cykliczna, powtarzająca się co roku, fluktuacja składu gatunkowego, liczebności oraz biomasy fitoplanktonu. Przestrzenna i czasowa zmienność poszczególnych grup fitoplanktonu nie jest taka sama w różnych rejonach Bałtyku. Celem pracy było określenie struktury czasowo-przestrzennej występowania fitoplanktonu w trzech wybranych rejonach strefy przybrzeżnej południowego Bałtyku (Ustka, Poddąbie, Rowy) w latach listopad 2014 – wrzesień 2016. Średnie wartości liczebności i biomasy fitoplanktonu dla badanych rejonów były typowe dla tego rodzaju wód przybrzeżnych. W każdych z trzech badanych rejonów można zaobserwować te same dominanty w liczebności i biomasie. Jedynie w rejonie Ustka odnotowano wzrost okrzemek, co może być spowodowane napływem wód rzecznych. Sezonowe badania fitoplanktonu wykazały, że w przypadku badań tego parametru skład, liczebność i biomasa z tego samego rejonu badanego na trzech stacjach badawczych w zależności od pory roku jest podobna (np. w 75-80%). Na tej podstawie stwierdzono, iż wykonując badania monitoringowe fitoplanktonu czy pod planowane inwestycje większe znaczenie ma częstotliwość pobieranych próbek niż liczba stacji badawczych.

Słowa kluczowe: Fitoplankton, zmienność sezonowa, strefa płytkowodna południowego wybrzeża Morza Bałtyckiego

INTRODUCTION

Phytoplankton is a primary producer in marine ecosystems and an important component of the trophic system. The Baltic Sea is characterised by seasonal changes in phytoplankton structure that depend significantly on environmental conditions, such as: light, temperature, salinity, pH, carbon dioxide and availability of biogenic substances [14], [15], [43]. In addition to temperature and insolation, the availability of nutrients is an important factor, affecting the growth of phytoplankton biomass. Phytoplankton is the main indicator of the trophic state of waters as it reacts to all changes in the concentration of biogenic compounds. Cyclical, fluctuation of species composition that occurs annually, as well as abundance and biomass of phytoplankton is a consequence of these changes [41].

There are two evident peaks of abundance and biomass observed in water bodies of the temperate zone - in the spring and in the autumn. During this time, there is domination of cryophilic diatoms (Diatomophyceae) in the plankton. Dinoflagellates (Dinophyceae) appear in late spring, i.e. when the water temperature is higher, but already contains significantly smaller quantity of nutrients [34]. After the spring bloom of diatoms and the early summer blooms of dinoflagellates and chlorophytes (Chlorophyta), concentration of biogenes in the water decreases (especially that of nitrogen and phosphorus), which further limits the growth of these groups of organisms. In these conditions, Cyanobacteria (Cyanophyceae) might develop in phytoplankton, if the pool of phosphates has not been completely depleted. In such a situation they become dominant over other groups of phytoplankton in biomass, as these organisms prefer higher water temperature and higher insolation [14], [41], [43]. Winter inhibition in primary production (lower insolation and water temperature) facilitates full regeneration of nutrient reserves in the euphotic zone [2], [16], [34], [42].

The list of phytoplankton species in the Baltic Sea contains over 2600 items [27], [33], including around 100 species occurring in the Polish waters [27]. Mechanisms of seasonal changes within the phytoplankton structure in the waters of the Baltic Sea are quite well known [19], [43], but special and temporal variability of particular phytoplankton groups is not the same in various areas of the Baltic Sea [36], [43]. Therefore, the purpose of this work was to determine the spatial and temporal distribution of phytoplankton in three selected areas of the coastal zone of the southern Baltic Sea (Ustka, Poddąbie, Rowy).

A comparison of seasonal variability of phytoplankton in three areas - a river mouth, a stony, and a sandy bottom - is going to be used for the analysis of significant differences between them. The only surveys (and available literature) of phytoplankton in these shallow water zones of the middle coast have been carried out by the IMWM (Institute of Meteorology and Water Management) as part of the Baltic Sea Monitoring HELCOM project at stations Ł7 and P16, which are located closest to the surveyed areas [18], [20-25], [28-30].

Tab. I. Geographic coordinates and depth of phytoplankton stations between 2014 and 2016.

LP.	STATION	LONGITUDE (WGS 84)	LATITUDE (WGS 84)	DEPTH [M]
1.	Pel_U1	16,8518500°E	54,5929333°N	6,4
2.	Pel_U2	16,8490667°E	54,5934000°N	7,7
3.	Pel_U3	16,8480500°E	54,5921500°N	7,1
4.	Pel_P1	16,9650333°E	54,6211833°N	2,7
5.	Pel_P2	16,9588333°E	54,6174000°N	3,4
6.	Pel_P3	16,9505333°E	54,6151167°N	2,8
7.	Pel_R1	17,0432667°E	54,6783833°N	8,7
8.	Pel_R2	17,0440500°E	54,6806667°N	5,2
9.	Pel_R3	17,0439500°E	54,6836000°N	9,6

STUDY AREA

The area of coastal waters of the southern Baltic Sea stretching from the town of Ustka to Rowy (Figure 1) was selected for the study. This area is located in the Ustka Bay, stretching to the west and east of the port of Ustka, between the 218th and 252nd kilometre of the sea coast. In the west, the bay begins at the level of Wicko Morskie, including Poddąbie Morskie located at the 224.2 km of the coast, and a headland (not easily distinguished) near the town of Rowy constitutes its eastern end [35]. The bay covers a 34-kilometre-long section of the coast. The depth of the bay reaches 20 m and the range of the surveyed area depth did not exceed 10 m (Table I).

Two rivers: Słupia and Łupawa flow into this area [3]. Phytoplankton surveys in the coastal zone of the middle coast in the area from the mouth of the river Słupia to the mouth of the river Łupawa were carried out in the period of November 2014 to September 2016. The surveys were carried out in three areas, in this paper conventionally called: Ustka, Poddąbie and Rowy (Figure 1).

METHODS

Samples were collected in the years 2014-2016 in three areas: Ustka, Poddąbie and Rowy, where within the area of each of them three sampling stations were located (Figure 1). Water samples for phytoplankton identification were collected and analysed in accordance with guidelines of the HELCOM COMBINE [10] and with the accepted methodology of field studies of phytoplankton in transitional and coastal waters of the Polish sea areas [26]. In accordance to this methodology, quantitative samples were collected with the use of a bathometer from 3 measurement levels: 0.5-1.0 m, 2.5-5.0 m and 7.5-10.0 m or 1.0 m above the bottom. This methodology is used when depth does not exceed 10 m, as in the case of the surveyed stations (Table I). Samples were preserved in Lugol's iodine (1.0 cm3 per 250 cm3 of collected water), then they were transported to a laboratory where they were kept in a temperature below 10° C. Ninety qualitative samples of phytoplankton were collected at 9 stations during the period of surveys be-

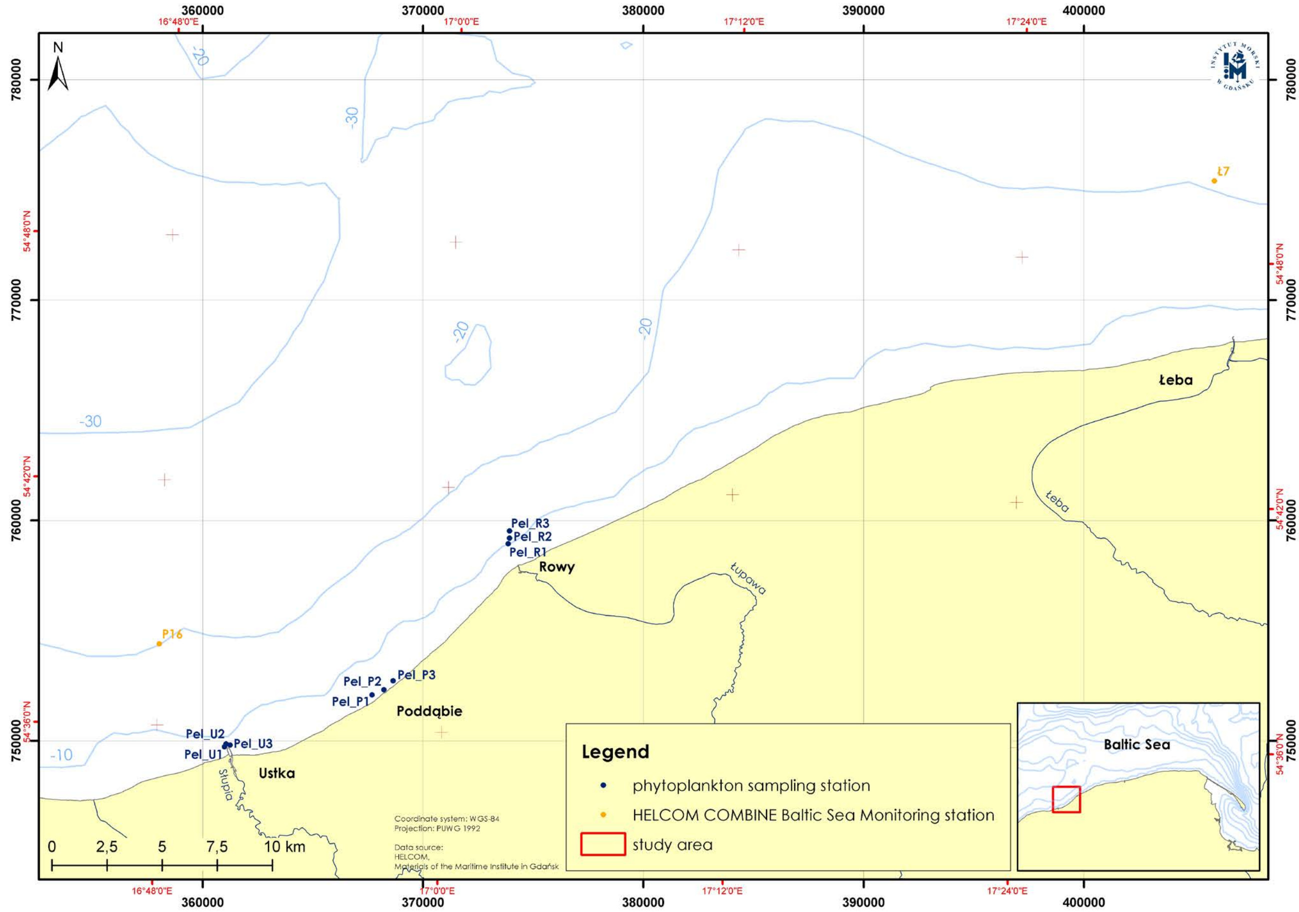

Fig 1. Distribution of pelagic stations surveyed in the years 2014-2016 in the coastal zone of the Baltic Sea between Rowy and Ustka and monitoring stations of the State Environmental Monitoring Program (HELCOM).

tween November 2014 and September 2016. For the purpose of laboratory analyses, an inverted microscope Olympus CK40 was used, comprising an ocular linear micrometre with a scale interval of 0.1 mm as well as basic lenses with magnitudes of 10x and 40x. The names used for individual taxa and groups were consistent with the current nomenclature of phytoplankton species accepted by the World Register of Marine Species, WoRMS (website 1). The quantitative analysis of phytoplankton (abundance and biomass) was carried out in accordance with the procedure by Edler [4] and according to recommendations of the Helsinki Commission [10].

Biomass of individual taxa was calculated on the basis of the accepted size classes of phytoplankton, developed and approved by the HELCOM PEG (the Phytoplankton Expert Group of the Baltic Environment Protection Commission) [8], [33]. Results regarding abundance and biomass of phytoplankton were calculated on the basis of the average value from the three sampling stations located in each of the three research areas (Ustka, Poddąbie, Rowy).

RESULTS

Dominance structure of individual groups of phytoplankton changed throughout the period of the surveys. The above analysis facilitated identification of the groups characterised by high abundance or biomass, which are widely recognised as modal values typical for a particular season of the year. This allowed to characterise seasonal variability of the individual groups of phytoplankton.

The surveys of seasonality of phytoplankton of the coastal waters in the southern Baltic Sea carried out in the years 2014-2016 indicated that in all three surveyed areas, diatoms (Bacillariophyceae) had a significant impact on both biomass and abundance of phytoplankton during the seasonal cycle. High biomass in a specific area was not always reflected in the abundance of phytoplankton, which is associated with the built and the size of individual taxa of phytoplankton. Differences in biomass and abundance were particularly discernible in the area of Rowy (Figure 4). Between January 2015 and July 2016, high abundance in this area was caused mainly by a bloom of diatoms and cyanobacteria (Table IV). Due to the bloom of cryophilic species of large-sized diatoms, high values of biomass were recorded in samples already in November 2014. At that time, the highest biomass value in November 2014 was equal to 1500 [mm3·m-3] in Ustka, then in the area of Poddąbie it was 820 [mm3·m-3], and the lowest biomass was recorded in the area of Rowy - 240 [mm3·m-3]. In January 2015, primary

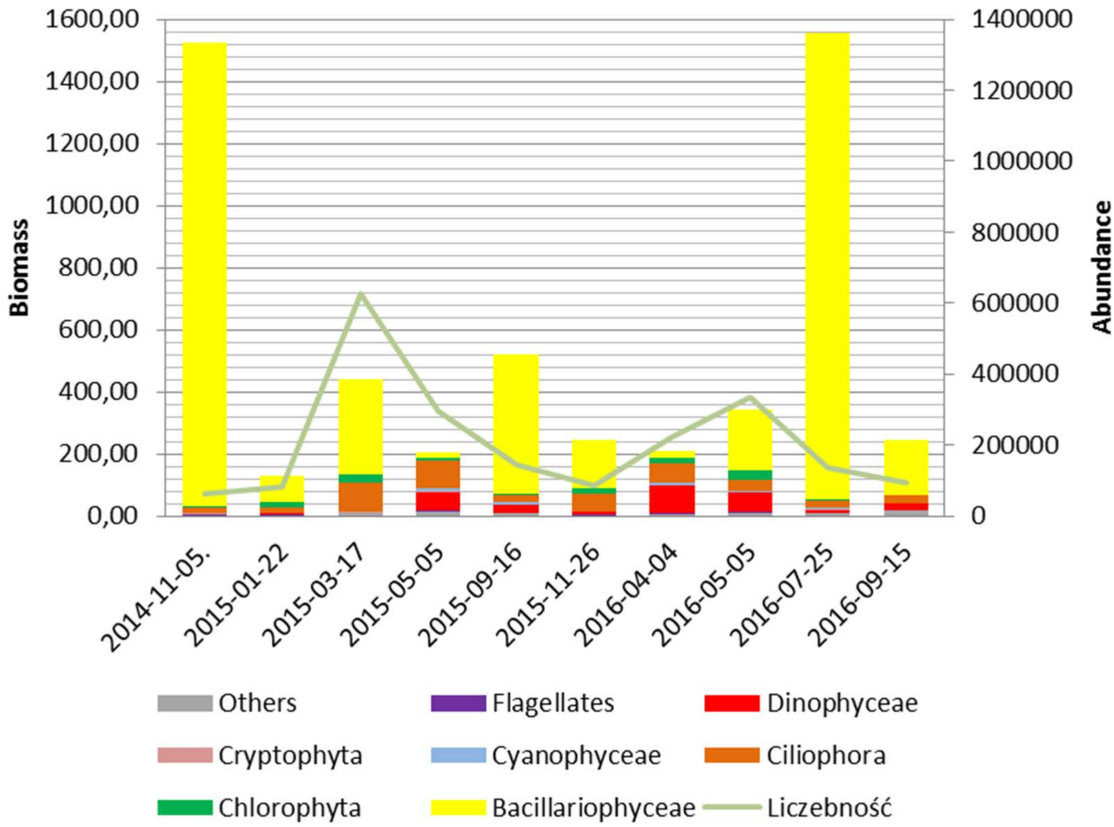

Fig 2. Average biomass and abundance of phytoplankton at successive stages of phytoplankton development, during period 2014 -2016 in Ustka area.

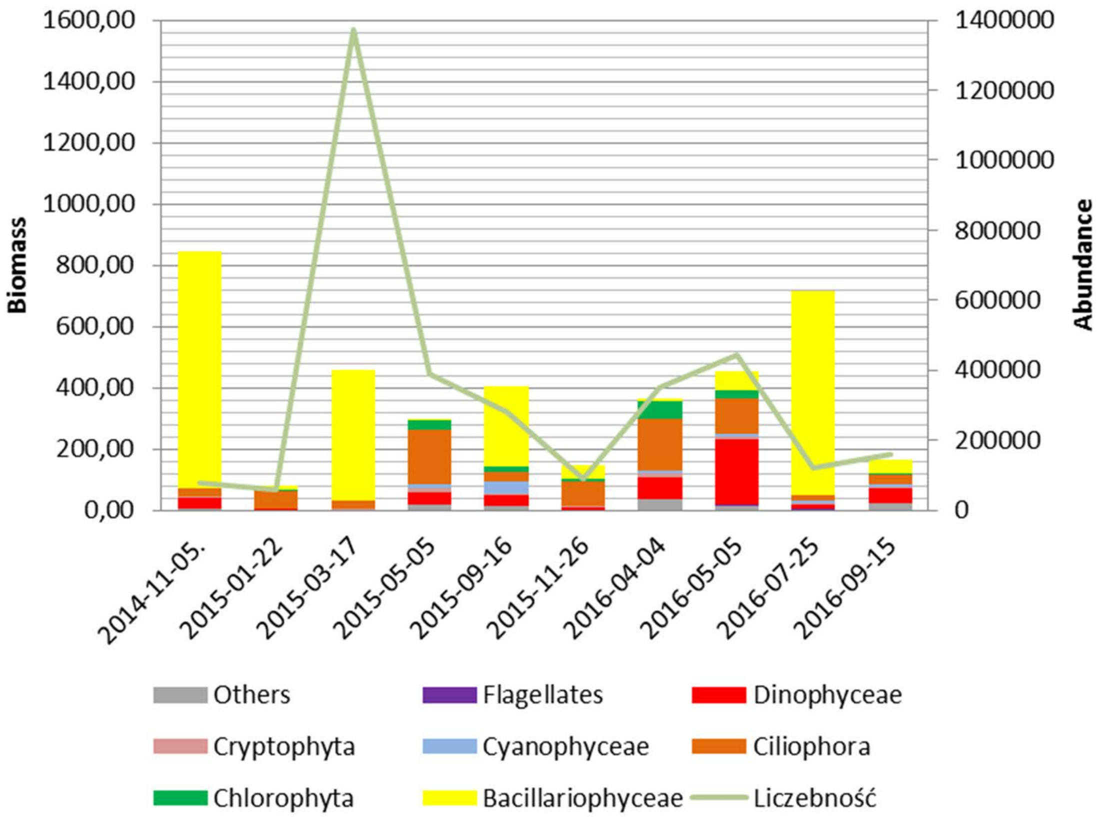

Fig 3. Average biomass and abundance of phytoplankton at successive stages of phytoplankton development, during period 2014 -2016 in the Poddąbie area.

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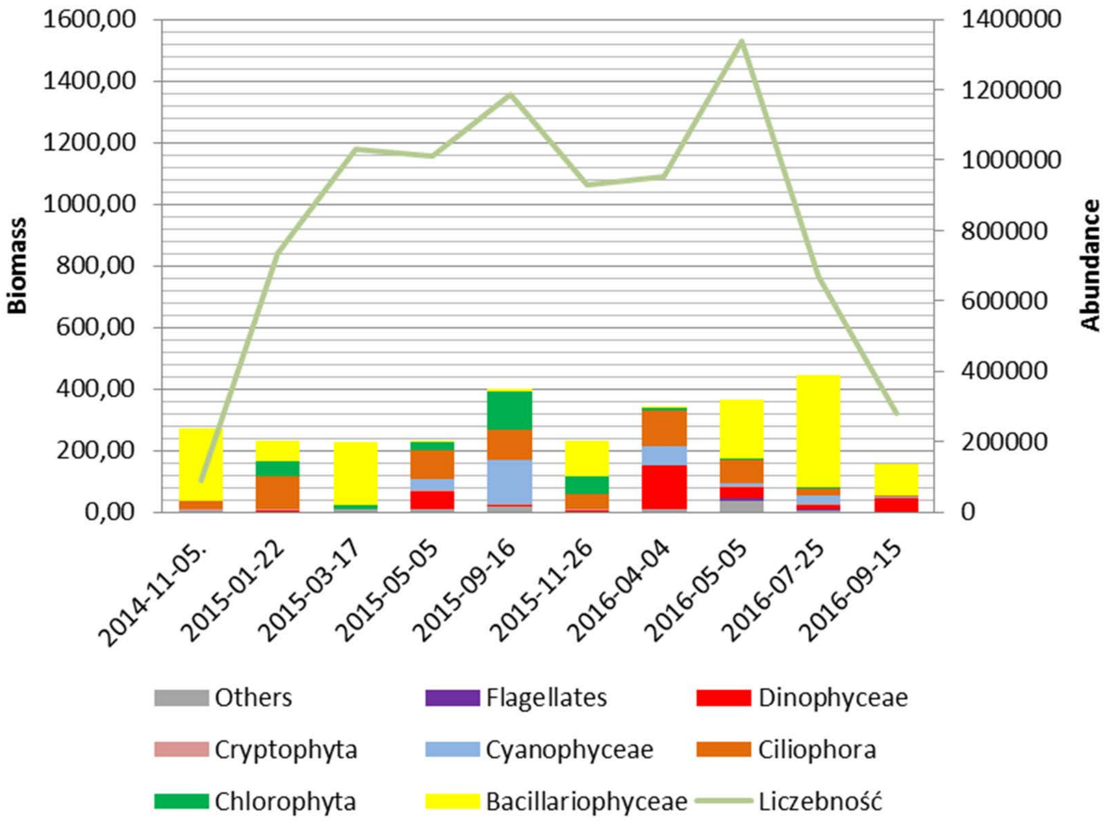

Fig 4. Average biomass and abundance of phytoplankton at successive stages of phytoplankton development, during period 2014 -2016 in the Rowy area.

production in the water was less intense which is evident in the graphs regarding biomass (Figure 2-3). Due to the bloom of diatoms, the highest volume in January 2015 occurred in the area of Rowy and was 700000 [N·dm-3] (Table IV). However, in March 2015 there was already a dramatic increase in the abundance and biomass of diatoms in the samples from each area, which is consistent with the seasonality described in literature. In May 2015 and in the period of April-May 2016 dinoflagelattes (Dinophyceae) constituted a high percentage of biomass, which had a significant impact on the biomass of phytoplankton in these months. Additionally, ciliates Mesodinium rubrum also constituted a high percentage in biomass in this period. Diatoms dominated in biomass at the stations of Poddąbie and Ustka in September 2015, and abundance there was relatively low (Table II-III). In September 2015,species distribution was different at the Rowy station, due to high abundance and biomass of chlorophytes and cyanobacteria. Total volume at this station in September 2015 was approximately 1200000 [N·dm-3]. Diatoms became predominant again in July 2016 (Figure 2-4). The highest biomass of phytoplankton in July 2016 was noted in Ustka - 1580 mm3·m-3, and the highest abundance between April - July 2016 - at stations located in the area of Rowy. Cyanobacteria contributed noticeably to the total abundance of phytoplankton in Ustka, Rowy and Poddąbie between May and September 2015 and between April and September 2016. Due to small sizes of nanoplankton species, they did not reach significant biomass during the studied period, except for September 2015 (Figure 2-4). During the whole period of the survey, cryptophytes (Cryptophyta) had a significant impact on abundance in all surveyed areas, as they constituted around 50% of the total abundance of phytoplankton. On the other hand, ciliates Mesodinium rubrum contributed noticeably to the total biomass in each studied period. It reached the highest biomass in the spring months (in May 2015 and during the period of April-May 2016). Other taxonomic groups that had a significant effect on biomass in the surveyed areas in warm months were chlorophytes (Chlorophyta) and dinoflagellates (Dinophyceaea).

DISCUSSION

Surveys of species composition, abundance distribution and biomass of phytoplankton structures in the years 2014-2016 were carried out on the basis of the 90 samples collected from three areas: Ustka, Rowy and Poddąbie located in the shallow coastal zone of the southern Baltic Sea, showed similarities in terms of species composition in all surveyed areas and confirmed typical changes of phytoplankton depending on the season of the year.

Taxa noted in the areas of Ustka, Poddąbie and Rowy were typical of the coastal waters of the southern Baltic Sea [6], [8], [43]. Volume, biomass and abundance fluctuations are exceptionally difficult to interpret, because they are affected by various and numerous environmental factors. The study of the whole annual cycle leads to an observation that fluctuations

Tab. II. The mean abundance [N·dm-3] of main groups of Phytoplankton in Ustka area from 2014 to 2016.

DATE GRUP	2014-11-05	2015-01-22	2015-03-17	2015-05-05	2015-09-16	2015-11-26	2016-04-04	2016-05-05	2016-07-25	2016-09-15
Chlorophyta	1761	3882	32221	48823	21529	4268	44339	30331	13106	2079
Ciliophora	1853	1236	5114	4015	2059	3449	3333	2993	1668	5967
Cryptophyta	21745	31680	22569	35371	26028	31680	20242	13473	14159	21205
Cyanophyceae	1680	1330	5361	88499	6351	1330	63948	14386	59450	3586
Bacillariophyceae	11449	11078	516283	5508	32926	11593	14952	213255	37121	16841
Dinophyceae	1060	2399	0	18656	5199	2656	17385	9065	2110	9260
Flagellates	7001	14085	21141	18286	23475	14085	12479	4907	257	4478
Others	15186	15156	24381	77611	28252	15156	46596	46579	9293	28178

Tab. III. The mean abundance [N·dm-3] of main groups of Phytoplankton in Poddąbie area from 2014 to 2016.

DATE GRUP	2014-11-05	2015-01-22	2015-03-17	2015-05-05	2015-09-16	2015-11-26	2016-04-04	2016-05-05	2016-07-25	2016-09-15
Chlorophyta	1637	2450	20427	86578	65619	5519	51253	44556	4383	535
Ciliophora	1493	4435	154	10244	5045	6692	9472	5560	2543	12643
Cryptophyta	25452	30005	30613	133435	41843	38160	99829	42502	23557	18615
Cyanophyceae	788	376	1117	88545	64408	752	93775	69141	51080	13680
Bacillariophyceae	6301	3840	1291783	3130	33001	10584	6260	181162	17773	23351
Dinophyceae	26225	1534	432	20386	4849	3707	35706	40329	3583	15547
Flagellates	4942	7648	11806	12149	29378	10119	12149	19150	4060	0
Others	11336	9861	18389	33153	37989	12414	41863	40247	12849	74954

Tab. IV. The mean abundance [N·dm-3] of main groups of Phytoplankton in Rowy area from 2014 to 2016.

DATE GRUP	2014-11-05	2015-01-22	2015-03-17	2015-05-05	2015-09-16	2015-11-26	2016-04-04	2016-05-05	2016-07-25	2016-09-15
Chlorophyta	741	45230	7101	43799	64061	27418	59104	7297	44375	0
Ciliophora	2008	8340	0	5405	6624	4221	8288	5654	2080	4331
Cryptophyta	42481	46007	37752	28581	24216	46007	36077	57623	24957	19521
Cyanophyceae	1642	20573	5310	182894	219425	19276	112146	68162	109277	2756
Bacillariophyceae	3305	93930	258387	15492	29759	182698	2021	179068	12901	21748
Dinophyceae	2502	1400	0	18667	3501	1400	18612	3123	3521	3607
Flagellates	13838	15156	16473	11449	17915	15156	18903	13900	10340	10708
Others	24175	13838	19150	30548	29927	13838	62296	111891	15991	30146

of abundance do not coincide with biomass fluctuations. The maximum abundance of phytoplankton recorded in the annual cycle is often recorded in a different month/season of the year than the maximum biomass. This is associated with the sizes of phytoplankton species occurring in a particular season. Sall-sized species of phytoplankton (length does not exceed 10 μm), even if they occur in great quantities, when translated into small individual biomasses will have negligible share in the total biomass of phytoplankton. On the other hand, the presence of large-bodied species (e.g. with a diameter of 50-130 μm, or with a length of up to 300 μm), even in smaller quantities, can make the total biomass in a given research period considerable. Thus, the maximum abundance and biomass can be observed at various times throughout the annual phytoplankton development cycle. Phytoplankton in the surveyed areas throughout the research period showed strong fluctuations in terms of both biomass and abundance. Such a phenomenon is typical for the waters of the Baltic Sea and results from the changes in environmental conditions (particularly temperature, insolation, availability of biogenic compounds and preferences of organism groups, which is widely described in literature [5], [40], [42], [33], [48]. In the water bodies of the temperate zone, like the Baltic Sea, two distinct peaks of abundance and biomass are observed - in the spring and in the autumn [5], [19], [38], [41]. Diatoms are the most numerous groups in the marine phytoplankton [14], [15], which was also confirmed in the surveyed areas. Namely, during the current surveys, distinct peaks for biomass were observed - one in the autumn and a lower peak in the spring/summer. On the other hand, distinct peaks in terms of abundance were noted in early spring and spring, when cryophilic diatoms dominated in terms of abundance, including a small-sized species: Skeletonema marinoi.

Diatoms also dominated in biomass in the whole water column in the three surveyed areas (Ustka, Poddąbie, Rowy) during the autumn and winter seasons, this time mainly the ones of Coscinodiscus granii species. The intensity of blooms is determined mainly by the quantity of biogenic substances, nutrients accumulated in water during winter [14], [15], [43]. An autotrophic species of the ciliate - Mesodinium rubrum contributed significantly to the biomass throughout the whole period of surveys. Its presence in the seasons of winter, spring and autumn was widely noted in the waters of the Gulf of Gdańsk (especially during the spring blooms of dinoflagellates). As the latest studies indicate, the abundance and biomass of this organism have been increasing and it has become a significant element of the plankton community [1], [9], [17], [46]. Studies on abundance and biomass of ciliates Mesodinium rubrum in the coastal waters of the southern Baltic Sea in the years 2006-2008 in the area of Ustka [36] indicate that the abundance of ciliates has been changing irregularly, increasing from April until June – the highest abundance was noted in 2006. However, according to these studies, the average biomass estimated for Ustka is much lower than for the more eutrophic areas of the Baltic Sea, e.g. for the Gdańsk Basin or the Arkona Basin.

In the research period, mainly in the spring, blooms were also caused by dinoflagellates, mainly the species of Dinophysis acuminata, Heterocapsa triquetra. In terms of abundance, there were small cryptophites dominating in phytoplankton (Plagioselmis prolonga, Teleaulax acuta) in the whole water column of the three surveyed areas (Ustka, Poddąbie, Rowy), in the autumn and winter periods. If, during the spring blooms of diatoms and other groups of phytoplankton, the resources of phosphorus in the water were not used, this - combined with, e.g. a long period of warm, sunny weather in the summer and a large quantity of biogenic substances in water - often caused a cyanobacteria bloom during this season. Thus, during this period, in terms of abundance - cyanobacteria dominated in phytoplankton; they were mainly small, colony-producing species such as Lemmermanniella and Anathece, which is a natural phenomenon. The abundance of cyanobacteria in the summer months was high due to these nanoplankton species. The Aphanizomenon flos-aquae species constituted a significant proportion of biomass, and a toxic cyanobacteria species: Nodularia spumigena also played a significant role there. The dominance of cyanobacteria in the plankton in the summer supports reports that these organisms prefer higher water temperature and higher insolation [39].

Moreover, it was established that in many cases the dominance of cyanobacteria in the marine environment was associated with the higher optimum temperature, which was observed in these surveys in terms of the abundance of phytoplankton [40]. The results obtained during the current studies confirm typical changes of phytoplankton in the three surveyed areas, depending on the season of the year. They differed in terms of abundance and biomass in a given season between the areas, but there were no significant species differences noted between stations. A significant proportion of diatoms Coscinodiscus, Chaetoceros and diatoms Mesodinium rubrum noted in this survey is consistent with the generally observed trend regarding the increased proportion of these organisms in the waters of the Baltic Sea [1], [9], [12], [13], [43], [46]. An average total biomass of phytoplankton in the summer months (June-September) in the survey area was comparable to the data for station Ł7 and P16 in 2012 and significantly lower than a 10-year average for this area [31]. However, surveys carried out regularly in the same stations indicated that fluctuations of both abundance and biomass may vary in subsequent years of surveys [47]. Comparing results obtained in this survey to data from annual reports of the IMWM for the last decade, it may be noticed that values and fluctuations of total biomass and abundance of phytoplankton in the three surveyed areas are typical for areas of the coastal waters of the southern Baltic Sea [18], [20-25], [28-30].

The average values of abundance and biomass of phytoplankton in the surveyed areas were typical for this type of coastal waters. This is supported by annual surveys carried out as part of IMWM monitoring which in the last years 2016 and 2017 showed a species similarity among particular groups of phytoplankton which dominate in the coastal zone [49], [50]. Due to changeability of this parameter, fluctuations of both abundance and biomass may differ in subsequent years of surveys, depending on the place and time, and are typical for this parameter. In each of the surveyed areas, the same modal values in terms of abundance and biomass could be observed Growht of diatoms was recorded in the area of Ustka, which could have been caused by the inflow of waters of the river Słupia.

Enrichment of the Baltic Sea with nitrates and phosphates causes a general increase of the biomass of phytoplankton, including some species of diatoms or dinoflagellates, and consequently an increase of water turbidity, a decrease in the amount of oxygen in the benthic zone and changes in the taxonomic composition of algae [7], [37], [41]. Analyses of the seasonality of phytoplankton described in literature have showed changes in species composition and biodiversity of phytoplankton in the eastern Baltic Sea in the last decade [32]. Other sources state that an increase in the biomass of cyanobacteria may contribute to eutrophication of the sea, which may lead to far-reaching changes in the ecosystem. It seems that the biomass of cyanobacteria in the Baltic Sea has been increasing for at least 60 years [45]. Another group of phytoplankton appearing en masse in the Baltic Sea are diatoms. During the bloom, they quickly reach high biomass, because they intensely absorb the nutrients necessary for their growth. Due to their sedimentary properties, their quantity in a water column decreases quickly and they also constitute food for benthic organisms on the bottom [11]. Dinoflagelattes grow slower than diatoms and due to their ability of vertical migration in a water column, they can use nutrients from lower layers of water. The latest reports indicate that the ratio of the quantity of diatoms to dinoflagelattes reflects the state of the ecosystem and the quality of the phytoplankton system as food for other elements of the food chain which is evidence to the validity and necessity of studies on the seasonality of phytoplankton composition in the Baltic Sea [19], [44].

CONCLUSIONS

Comparing the seasonal variability of phytoplankton in the three considered areas - a river mouth, a stony, and a sandy bottom, leads to a conclusion that there are no significant differences between them. Occurrence of watercourses introducing freshwater species into the coastal waters of the Baltic Sea does not have a significant effect, as their contribution to the total abundance of phytoplankton is small. Furthermore, the influence of fresh waters on the brackish water species, which have high tolerance on the changes of abiotic factors, is negligible. A distinction of habitats in the research area: a river mouth for the area of Ustka, a sandy bottom habitat for the area of Poddąbie and a stony bottom habitat for the area of Rowy is not reflected in the spatial and temporal variability of phytoplankton.

References:

[1] Ameryk A., Gromisz S. i in., (2012). Gdańsk Basin (Site 22). [in:] O'Brien T.D., Li W. i in. (Eds). ICES Phytoplankton and Microbial Plankton Status Report 2009/2010. ICES Cooperative Research Report No. 313: 48–49;

[2] Andrulewicz E., Szymelfening M., Urbański J., Węsławski J. M., (2008). Morze Bałtyckie – o tym warto wiedzieć. Wersja elektroniczna książki, Gdynia;

[3] Dobrzyński S., (1998). Współczesny rozwój brzegu morskiego w świetle badań litologicznych (na odcinku Jarosławiec – Czołpino), W S P w Słupsku, Słupsk;

[4] Edler L., (1979). Recommendations for marine biological studies in the Baltic Sea. Phytoplankton and chlorophyll. Baltic Mar. Biol. Pub. 5: 1-38;

[5] Fleming V., Kaitala S., (2006). Phytoplankton spring bloom intensity index for the Baltic Sea estimated for the years 1992 to 2004. Hydrobiologia 554: 57–65;

[6] Gasiūnaitė Z.R., Cardoso A.C., Heiskanen A.-S., Henriksen P., Kauppila P., Olenina I., Pilkaitytė R., Purina I., Razinkovas A., Sagert S., Schubert H., Wasmund N., (2005). Seasonality of coastal phytoplankton in the Baltic Sea: Influence of salinity and eutrophication. Estuarine, Coastal and Shelf Science 65: 239–252;

[7] Hajdu S., Höglander H., Larsson U., (2007). Phytoplankton vertical distributions and composition in Baltic Sea cyanobacterial blooms. Harmful Algae 6: 189–205;

[8] Hällfors G., (2004). Checklist of Baltic Sea Phytoplankton Species. Baltic Sea Environment Proceedings no. 95, 208;

[9] Hansen P.J., Fenchel T., (2006). The bloom-forming ciliate Mesodinium rubrum harbours a single permanent endosymbiont, Marine Biology Research 2:3, 169–177;

[10] HELCOM (2017). Manual for Marine Monitoring in the COMBINE Programme of HELCOM, Annex C-6: Guidelines concerning phytoplankton species composition, abundance and biomass. 1-17;

[11] Heiskanen A.S., (1998). Factors governing sedimentation and pelagic nutrient cycles in the northern Baltic Sea. Monographs of the Boreal Environmental Research 8: 1-80;

[12] Johansson M., Gorokohova E. et al., (2004). Annual variability in ciliate community structure, potential prey and predators in the open northern Baltic Sea proper. Journal of Plankton Research 26(1), 67–80;

[13] Klais R., (2012). Phytoplankton trends in the Baltic Sea. University of Tartu Press No 585. ISBN 978-9949-32-190-2 (pdf), 51 pp;

[14] Klais R., Tamminen T., Kremp A., Spilling K., Olli K., (2011). Decadal-Scale Changes of Dinoflagellates and Diatoms in the Anomalous. Baltic Sea Spring Bloom. PLoS ONE 6(6): e21567;

[15] Klais R., Norros V., Lehtinen S., Tamminen T., Olli K., (2017). Community assembly and drivers of phytoplankton functional structure. Functional Ecology 31: 760–767;

[16] Klais R., Tamminen T., Kremp A., Spilling K., An B.W., Hajdu S., Olli K., (2013). Spring phytoplankton communities shaped by interannual weather variability and dispersal limitation: Mechanisms of climate change effects on key coastal primary producers. Limnol. Oceanogr. 58: 753-762;

[17] Kobos J., Bełdowska M., (2016). Rtęć w fitoplanktonie Zatoki Puckiej. [w:] red. Falkowska L. Monografia Rtęć w środowisku. Identyfikacja zagrożeń dla życia człowieka. Wyd. Uniwersytetu Gdańskiego, Str. 83-90;

[18] Kordala I., (2016). Oznaczenie składu gatunkowego, liczebności oraz biomasy struktur fitoplanktonu, w oparciu o aktualną metodykę HELCOM COMBINE w 82 próbach dostarczonych przez Zamawiającego- Instytut Meteorologii i Gospodarki Wodnej- PIB w Gdyni. Wydawnictwa Wewnętrzne Instytutu Morskiego w GdańskuNr WW 7019;

[19] Kownacka J., (2017). Załącznik 12. Do sprawozdania z Etapu I „Testowanie i wyznaczenie wartości granicznej dla basenu gdańskiego oraz wykonanie oceny stanu dla wód morskich (tzw. threshold value) dla wskaźnika diatoms/dinoflagellates index przyjętego przez helcom w celu wykorzystania w opracowaniu aktualizacji wstępnej oceny stanu środowiska wód morskich", Morski Instytut Rybacki – Państwowy Instytut Badawczy;

[20] Kraśniewski W., Łysiak-Pastuszak E., (2011). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2011 roku. Wydawnictwo IMGW. ISBN 978-83-61102-73-1;

[21] Kraśniewski W., Łysiak-Pastuszak E., Koszuta V., (2013). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2012 roku. Wydawnictwo IMGW. ISBN 978-83-61102-90-8;

[22] Kraśniewski W., Łysiak-Pastuszak E., Piątkowska Z., (2005). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2004 roku. Wydawnictwo IMGW. ISBN 978-83-61102-23-6;

[23] Kraśniewski W., Łysiak-Pastuszak E., Piątkowska Z., (2006). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2005 roku. Wydawnictwo IMGW. ISBN 978-83-61102-30-4;

[24] Kraśniewski W., Łysiak-Pastuszak E., Piątkowska Z., (2007). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2006 roku. Wydawnictwo IMGW. ISBN 978-83-61102-38-0;

[25] Kraśniewski W., Łysiak-Pastuszak E., Piątkowska Z., (2008). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2007 roku. Wydawnictwo IMGW. ISBN 978-83-61102-47-2;

[26] Kruk-Dowgiałło L., Michałek-Pogorzelska M., Dubiński M., (2010). Fitoplankton [w:] Przewodniki metodyczne do badań terenowych i analiz laboratoryjnych elementów biologicznych wód przejściowych i przybrzeżnych. Biblioteka Monitoringu Środowiska ISBN 978-83-61227-36-6; 5-32;

[27] Krzymiński W. (red.), Burakowska B., Danowska B., Kamińska M., Łysiak-Pastuszak E., Neves S., Olszewska A., Śliwińska A., Woroń J., Zalewska T., Osowiecki A., Błeńska M., Michałek M., Brzeska P., Bubak I., Kalinowski M., Burchacz M., Piotrowicz J., Psuty I., Margoński P., Szlinder-Richert J., Usydus Z., Szymanek L., Luzeńczyk A., Pachur M., Lejk A., Celmer Z., Meissner W., Chodkiewicz T., Bzoma S., Brewka B., Woźniak B., Drgas N., (2014). Wstępna ocena stanu środowiska wód morskich polskiej strefy Morza Bałtyckiego – raport do Komisji Europejskiej, Ocenę przygotowano na podstawie opracowań wykonanych na zlecenie GIOŚ, finansowanych przez Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej.

[28] Łysiak-Pastuszak E., (2011). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2010 roku. Wydawnictwo IMGW. ISBN 978-83-61102-71-7;

[29] Łysiak-Pastuszak E., Kraśniewski W., (2009). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2008 roku. Wydawnictwo IMGW. ISBN 978-83-61102-48-9;

[30] Łysiak-Pastuszak E., Kraśniewski W., (2010). Fitoplankton, Chlorofil-a. [w]: Bałtyk Południowy. Charakterystyka wybranych elementów środowiska w 2009 roku. Wydawnictwo IMGW. ISBN 978-83-61102-61-8;

[31] Łysiak-Pastuszak E., Zalewska T., (2013). Ocena stanu środowiska morskiego polskiej strefy ekonomicznej Bałtyku na podstawie danych monitoringowych z roku 2012 na tle dziesięciolecia 2012-2011. Biblioteka Monitoringu Środowiska Warszawa. ISBN 978-83-61227-17-5, pp. 99;

[32] Ojaveer H., Jaanus A., MacKenzie B.R., Martin G., Olenin S., Radziejewska T, Telesh I, Zettler M.L., Zaiko A., (2010). Status of Biodiversity in the Baltic Sea. PlosOne; September 2010 .Vol. 5.: 9;

[33] Olenina I., Hajdu S., Andersson A., Edler L., Wasmund N., Busch S., Göbel J., Gromisz S., Huseby S., Huttunen M., Jaanus A., Kokkonen P., Ledaine I., Niemkiewicz E., (2006). Biovolumes and size-classes of phytoplankton in the Baltic Sea. Baltic Sea Environment Proceedings (Helsinki Commission, Helsinki) 106: 1-144;

[34] Pastuszak M., Zalewski M., Wodzinowski T., Pawlikowski K., (20160. Eutrofizacja w Morzu Bałtyckim – konieczność holistycznego podejścia do problemu [w:] I. Psuty (red.) 95-lecie Morskiego Instytutu Rybackiego. Tom II - Stan środowiska południowego Bałtyku, Morski Instytut Rybacki – Państwowy Instytut Badawczy, Gdynia, 2016, 1-100;

[35] Rudowski S., Wróblewski R., (2012). Potrzeba wzbogacenia toponomastyki brzegu i dna na przykładzie Zatoki Usteckiej. Geologia i geomorfologia nr 9, Słupsk, 57–59;

[36] Rychter K., Pączkowska M., (2012). Ciliate Mesodinium rubrum in the coastal zone of the southern Baltic Sea (central Pomerania). Baltic Coastal Zone – Journal of Ecology and Protection of the Coastline, 16: 97-102;

[37] Smayda, T.J., (1997). Harmful phytoplankton blooms: their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnol. Oceanogr. 42, 1137–1153;

[38] Sumann R., Hammer A., Görst S. Schubert H., (2005). Winter and spring phytoplankton composition and production in a shallow eutrophic Baltic lagoon. Estuarine, Coastal and Shelf Science 62: 169–181;

[39] Suikkanen S., Kaartokallio H., Hällf ors S., Huttunen M., Laamanen M., (2010). Life cycle strategies of bloom-forming, f ilamentous cyanobacteria in the Baltic Sea. Deep-Sea Research II 57: 199–209;

[40] Tilman D., Kiesling R., Stener R., Kihlman S.S., Jonson F.A., (1986). Green, bluegreen and diatom algae: diferences in competitive ability for phoshorus, silicon and nitrogen, Arch. Hydrobiol. 106: 473–485;

[41] Wasmund N., Nausch G., Matthäus W., (1998). Phytoplankton spring blooms in the southern Baltic Sea - spatio-temporal development and long-term trends. J. Plankton Research 20: 1099-1117;

[42] Wasmund N., Uhling S., (2003). Phytoplankton trends in the Baltic Sea. ICES Journal of Marine Science, 60: 177-186;

[43] Wasmund N., Tuimala J., Suikkanen S., Vandepitte L., Kraberg A., (2011). Long-term trends in phytoplankton composition in the western and central Baltic Sea. J. Mar. Syst. 87, 145-159;

[44] Wasmund N., (2017). The Diatom/Dinoflagellate Index as an Indicator of Ecosystem Changes in the Baltic Sea. 2. Historical Data for Use in Determination of Good Environmental Status. Frontiers in Marine Science 4: 153;

[45] Wasmund N., Busch S., Göbel J., Gromisz S., Höglander H., Jaanus A., Johansen M., Jurgensone I., Karlsson C., Kownacka J., Kraśniewski W., Lehtinen S., Olenina I., v. Weber M., (2015). Cyanobacteria biomass. HELCOM Baltic Sea Environment Fact Sheet 2015, Publikacjaq 288, sierpień 2017 r. http://helcom.fi/baltic-sea-trends/environment-fact-sheets/eutrophication/cyanobacteria-biomass/;

[46] Wasmund N., Nausch G. (2012): Eastern Gotland Basin (Site 23); Borbholm Sea (Site 24); Arkona Sea (Site 25); Meclenburg Bight (Site 26). [in:] O'Brien T.D., Li W. i in. (Eds). ICES Phytoplankton and Microbial Plankton Status Report 2009/2010. ICES Cooperative Research Report No. 313, 50–63;

[47] Witek B., (2010). Krótkookresowe fluktuacje fitoplanktonu w przybrzeżnej strefie Zatoki Gdańskiej, Wydawnictwo Uniwersytetu Gdańskiego, ISBN 978-83-7326-669-8, 108;

[48] Witek B., Pliński M., (2005). The occurrence of dinoflagellates in the phytoplankton of the Gulf of Gdańsk coastal zone in 1994-1997. Oceanological and Hydrobiological Studies 34(2): 6370;

[49] Zaboroś I., Mioskowska M., (2017). Oznaczenie składu gatunkowego, liczebności oraz biomasy struktur fitoplanktonu, w oparciu o aktualną metodykę HELCOM COMBINE w 83 próbach dostarczonych przez Zamawiającego - Instytut Meteorologii i Gospodarki Wodnej - PIB w Gdyni Wydawnictwa Wewnętrzne Instytutu Morskiego w Gdańsku Nr WW 7083;

[50] Zaboroś I., Mioskowska M., (2018). Oznaczenie składu gatunkowego, liczebności oraz biomasy struktur fitoplanktonu, w oparciu o aktualną metodykę HELCOM COMBINE w 82 próbach dostarczonych przez Zamawiającego - Instytut Meteorologii i Gospodarki Wodnej - PIB w Gdyni. Wydawnictwa Wewnętrzne Instytutu Morskiego w Gdańsku Nr WW 7182;

[51] Źródła internetowe: www.marinespecies.org (World Register of Marine Species, WoRMS).

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